



AALBORG UNIVERSITY
DENMARK

Aalborg Universitet

Environmental impacts from Danish fish products

hot spots and environmental policies

Thrane, Mikkel

Publication date:
2004

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Thrane, M. (2004). *Environmental impacts from Danish fish products: hot spots and environmental policies*. Institut for Samfundsudvikling og Planlægning, Aalborg Universitet.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

This dissertation presents an assessment of the environmental impacts from Danish fish products in a life cycle perspective (from sea to table).

The assessment is carried out in three steps – and includes a MECO analysis, a quantitative LCA and a qualitative LCA. The results are used to discuss current environmental policies addressing the fishery, landing and auction, the fish processing industry, wholesale, transport, retail, and use.

It is concluded that considerable improvement potentials exist in the fishing stage, which also represents the largest environmental impact potential compared to other life cycle stages. The energy consumption is significant, particularly from some fishing methods, and it generates a considerable impact potential. In addition, other types of impacts such as seafloor damage and discard tend to be proportional to energy consumption per kg caught fish. It is suggested that passive and semi-active fishing methods such as Danish seine, purse seine, gillnet and long line represent a significant improvement potential compared to trawl. And it is shown that the energy consumption can be reduced with a factor 15 by substituting beam trawl with Danish seine in the Danish flatfish fishery.

Mikkel Thrane
Aalborg University
June 2004



Beam trawl: One of the most fuel consuming fishing practices, which also affects the seafloor.



Environmental Impacts from
Danish Fish Products

Mikkel Thrane
Aalborg University

Mikkel Thrane
**ENVIRONMENTAL IMPACTS
FROM DANISH FISH PRODUCTS**

Hot spots and environmental policies

PhD dissertation
Department of Development and Planning
Aalborg University, Denmark

Environmental Impacts from Danish Fish Product

Hot spots and environmental policies

Mikkel Thrane

Department of Development and Planning
Aalborg University, Denmark

Environmental Impacts from Danish Fish Product

- Hot spots and environmental policies

Printet at Center Trykkeriet, Aalborg University, Denmark

Cover photo: Foto af Flemming Gjedde, www.handyweb.dk

Distribution: Aalborg University, Department of Development and Planning, Fibigerstræede 13, DK-9220, Aalborg Oest.

List of contents

	Preface.....	I
	Summary	III
	Sammenfatning (summary in Danish).....	VII
	Terms and abbreviations.....	XV
PART I:	INTRODUCTION	
1	Introduction	1
1.1	<i>Product focus in environmental policies.....</i>	<i>1</i>
1.2	<i>Previous research.....</i>	<i>4</i>
1.3	<i>Problem definition, structure and framework.....</i>	<i>5</i>
2	The Fishery Sector (Sector Analysis).....	13
2.1	<i>Socio-economics, landings and trade.....</i>	<i>13</i>
2.2	<i>Product flow and interactions</i>	<i>24</i>
2.3	<i>Environmental aspects</i>	<i>35</i>
2.4	<i>Summary.....</i>	<i>37</i>
PART II:	MECO ANALYSIS	
3	Goal and Scope for MECO Analysis	41
3.1	<i>Introduction to life cycle assessment (LCA).....</i>	<i>42</i>
3.2	<i>Purpose of the MECO analysis</i>	<i>47</i>
3.3	<i>Product types and functional units.....</i>	<i>52</i>
3.4	<i>Scope</i>	<i>58</i>
3.5	<i>Data collection and treatment.....</i>	<i>69</i>
4	MECO Analysis – Fishing Stage	75
4.1	<i>Material exchanges</i>	<i>77</i>
4.2	<i>Energy exchanges.....</i>	<i>88</i>
4.3	<i>Chemical exchanges.....</i>	<i>100</i>
4.4	<i>Other exchanges.....</i>	<i>110</i>
4.5	<i>Summary.....</i>	<i>117</i>
5	MECO Analysis – Processing Stage.....	129
5.1	<i>Material exchanges</i>	<i>131</i>
5.2	<i>Energy exchanges.....</i>	<i>142</i>
5.3	<i>Chemical exchanges.....</i>	<i>151</i>
5.4	<i>Other exchanges.....</i>	<i>158</i>
5.5	<i>Summary.....</i>	<i>161</i>
6	MECO Analysis - Other Stages.....	171
6.1	<i>The landing and auction stage</i>	<i>172</i>
6.2	<i>The wholesale stage</i>	<i>177</i>
6.3	<i>Transport (distribution)</i>	<i>182</i>

6.4	<i>The retail stage</i>	189
6.5	<i>The use stage</i>	197
6.6	<i>Summary</i>	207
7	Conclusion on MECO Analysis	215

PART III: LIFE CYCLE ASSESSMENT

8	LCA of Flatfish (Characterization)	235
8.1	<i>Why LCA – potentials of LCA</i>	235
8.2	<i>Goal and scope</i>	241
8.3	<i>Inventory</i>	251
8.4	<i>Impact assessment (Characterization)</i>	254
8.5	<i>Summary</i>	274
9	LCA of Flatfish & Other Fish Products (Valuation & Interpretation)	277
9.1	<i>Normalization - LCAfood method (flatfish)</i>	278
9.2	<i>Weighting – EDIP 97 update (flatfish)</i>	285
9.3	<i>Generalization (LCA screenings of other fish)</i>	296
9.4	<i>Evaluation (Interpretation)</i>	307
9.5	<i>Conclusion (Interpretation)</i>	332
10	Qualitative LCA (Other Impacts)	341
10.1	<i>Selection of alternative impact categories</i>	342
10.2	<i>Impacts on the seabed</i>	346
10.3	<i>Land use</i>	351
10.4	<i>Waste</i>	355
10.5	<i>Depletion of non-renewable resources</i>	359
10.6	<i>Exploitation of fish stocks</i>	366
10.7	<i>By-catch and discard</i>	372
10.8	<i>Consumption of ground water</i>	375
10.9	<i>Human toxicity</i>	380
10.10	<i>Other types of impacts</i>	386
10.11	<i>Summary</i>	390

PART IV: REGULATION AND POLICIES

11	Regulation and Policies	403
11.1	<i>Conceptual framework</i>	404
11.2	<i>Implementation theory</i>	411
11.3	<i>Policies and Regulation - the Fishing Stage</i>	413
11.4	<i>Environmental Policies – Post landing</i>	424
11.5	<i>Policies Addressing the Whole Product Chain</i>	429
11.6	<i>Summary</i>	431
12	Barriers and Potentials	435
12.1	<i>About research perspectives</i>	435

12.2	<i>Natural Science Perspective</i>	437
12.3	<i>Social Science Perspective</i>	440
12.4	<i>Human science perspective</i>	445
12.5	<i>Policy instruments – what can we do?</i>	448
12.6	<i>Summary</i>	464
13	Conclusion and Perspectives	469
13.1	<i>Hot-spots and Improvement Potentials</i>	470
13.2	<i>Methodological Reflections</i>	478
13.3	<i>Environmental Policies and Regulation</i>	484
References		491
Appendix:		separate report

Preface

This Ph.D dissertation was carried out at the Department of Development and planning in the division of Technology, Environment and Society. The fields of research of the division are environment and energy planning as well as technology and planning.

The project is partly funded by “Direktoratet for FødevarerErhverv” [The Danish Directorate for Food, Fisheries and Agri Business] under the Danish Ministry of Food, Agriculture and Fishery and partly funded by the Department of Development and Planning at Aalborg University.

A special thanks goes to the Danish Research Institute of Food Economics and in particular Rasmus Nielsen from the Statistical Division, who has provided valuable data used for the calculation of fuel consumption in the Danish fishing fleet. In a number of cases, data and information has been obtained through interview and documents from companies. As the references has been kept anonymous, it is only possible to direct a general thanks – especially towards fishermen and fish industries that have been involved. Besides a great effort has been put into supervision by Professor Per Christensen from Department of Development and Planning and Dr. Bo Weidema from 2.-0 Consultants (www.lca.dk). A special thanks also goes to Anni Mathiesen and David Flynn – who has been involved in final editing.

For most matters the system of references follows the Chicago Manual of Style (CMS), thus mentioning the name of the author or reference and the year of publication in a bracket. If the reference is placed after a dot, it refers to the previous section. In other cases, it refers to the previous sentence. The references appear in alphabetic order after the conclusion in chapter 13.

Even though it is not common standard in English written reports, I have used punctuation (full stop) to separate numbers of thousands (example: 1.000 means one thousand), while a comma is used to separate numbers less than one (example: 0,5 means one half).

Figures, tables and footnotes are numbered from the beginning of each chapter. The appendix is available in a separate report and includes a CD with additional documents (word, excel) and databases used for the LCA.

Summary

As environmental policy becomes more product-oriented there is an increasing need for seeing environmental impacts in a life cycle perspective. Traditional environmental regulation mainly focuses on the companies and their (on site) emissions, but frequently larger environmental impacts are found elsewhere in the life cycle from cradle to grave or from Sea to table.

Methodological aspects

The dissertation “Environmental Impacts from Danish Fish Products” present a detailed analysis of the environmental impacts from Danish fish- and shellfish products in a regulation and policy perspective. The analysis represent state-of-the-art LCA methodology (that is consequential LCA), which is characterized by market based modeling of the product system, use of marginal data and the application of system expansion for handling of multi output processes.

Beside the quantitative LCA presented in chapter 8-9, two other approaches to environmental assessment are use, that is a separate MECO study in chapter 4-7 and a separate qualitative LCA, which cover the environmental impact categories that have not been sufficiently described in the “quantitative” LCA.

Overall results

The overall environmental assessment points towards the fishing stage as the overall most important life cycle stage in terms of environmental burden for most fish- and shellfish products. Similar conclusions are obtained in LCA studies of codfish products in Sweden and Island. Fishing activity is characterized by a significant fuel consumption (especially for some species and fishing methods), release of problematic biocides from anti fouling paint, overexploitation of certain fish stocks, a high frequency of injuries and accidents among fishermen (including fatal accidents), seabed impact inflicted by bottom dragged fishing gear (e.g. bottom- and beam trawl), by-catch of sea-mammals and discard of fish.

Key processes

In the present dissertation, it is argued that energy consumption plays one of the most important roles for the total environmental impacts from fish products from sea to table. Three types of processes are particularly energy consuming – that is fishing, transport, and cooling. The need for cooling is sig-

nificant for the retail- and use stage, while transport is most important at the use stage and for export of the fish products (termed transport stage).

Fuel consumption – an important variable

The analysis of fuel consumption at the fishing stage is comprehensive and unlike previous studies it models the fuel consumption as a function of the species which is primarily sought by a given fishery (target species), the vessel size, and fishing gear simultaneously (see chapter 4). As roughly all vessels catch several species at a time, system expansion has been applied to handle co-product allocation. The analysis is thereby the only of its kind, also internationally.

It is shown that there are great differences in the fuel consumption as function of the target species. The fuel consumption per kg caught fish is typically high for codfish, flatfish and shellfish (except mussels) while it is relative small for herring, mackerel and industrial fish such as sandeel.

The difference between the target species which represents the smallest and the largest fuel consumption is a factor 600 when system expansion is applied for co-product allocation. It only requires 0,01 liter diesel to catch one kg blue mussels, while it takes around 6 liter diesel per kg caught Norway lobster. These figures represent calculations where co-product allocation is handled by system expansion, and the differences are significantly smaller when co-product allocation is handled by mass or value considerations. This shows that the methodological assertions and assumptions are important.

Options for reduction of fuel consumption

For various reasons, it is probably difficult to change the output in terms of species composition from the fishing stage, but it is obvious to search for efficiency improvements among the most fuel consuming fisheries. In this respect, the results show that the fuel consumption per kilogram (kg) of caught fish varies considerably as a function of fishing gear, even considering the same target species. Thus, by addressing the “production method” it is indeed possible to obtain improvements for most species categories.

The fuel consumption in the flatfish fishery - which is one of the more energy consuming fisheries – can vary from 2,6 liter to 0,2 liter fuel per kg caught flatfish, where first represents beam trawl while the latter represents Danish seine. In this regard, it should be noticed that 2,6 liter per kg caught fish is around 8 liter fuel per kg consumed filet. If all flatfish were caught by Danish seine or passive fishing methods such as gillnet, it would theoretically be possible to save around 30.000 m³ fuel per year in the Danish fish-

ery alone. This is 15% of the total fuel consumption in one year. This figure is rather theoretical and probably overestimated, but improvement potential also exists for other species groups. Improvements can also be obtained by promoting the use of purse seine in the fisheries targeting herring and mackerel (and maybe other species), and by promoting the use of Danish seine, gillnet and long line in the fishery after codfish.

Environmental results from substituting fishing gear

An important conclusion is that improvements in fuel efficiency appears to be consistent with other objectives, such as reduced impacts on sea floor habitats, and reduced discards – that is fish which are caught but returned to the sea for various reasons. As an example, the fishery after Norway lobster represents the largest fuel consumption per kg caught fish (shellfish) as well as the largest discard of fish - that is more than 2/3 of the catch.

The life cycle assessment in chapter 9, shows that the aggregated weighted environmental impact potential for 1 kg consumed frozen flatfish filets, can be reduced with several factors just by substituting beam trawl with Danish seine. This assessment is based on the Danish EDIP 97 method in a updated version, and only five impact categories are included (global warming, ozone depletion, acidification, nutrient enrichment, and photochemical ozone formation). It is important to stress that beam trawl actually uses less anti fouling and has a better performance in the present scenario for ecotoxicity. On the other hand, future scenarios suggest that Danish seine will obtain the best performance for this impact category as well, due to the phasing out of the most problematic anti fouling agents such as TBT which has already been banned here in year 2004.

Hot-spots versus regulatory focus

Besides the fishing stage, the two last stages, use- and retail, also represents a significant impact potential. This particularly applies to the use stage – mainly due to shopping by car, as it frequently happens in Europe. Considerations about exposure are generally not included in the LCA, but as transport for shopping frequently happens in urban areas – it must be assumed that the exposure of air emissions and noise to humans is relatively high. This strengthens the conclusion that use stage is one of the most important stages.

An interesting conclusion is that the processing stage appears to represent a relatively small impact potential in most cases. This applies to the on-site emissions in particular, and even the contribution to nutrient enrichment from wastewater emissions is insignificant due to modern wastewater treat-

ment plants. The qualitative LCA suggest that the water consumption may represent an important impact potential in terms of resource consumption, but it is also argued that processing plants typically are localized in areas (Northern and Western Jutland) with relatively large amount of ground water.

Some segments of the fish processing industry consume large amounts of aluminum and glass packaging, and this represents a significant indirect impact. Still, using plastic packaging instead can significantly reduce the impact potential. Besides large improvements can be obtained by increasing the amount of filet/fish meat that is produced per kg raw material. The latter will also contribute to reductions of the impact potential in the fishery, and is truly a solution that promotes cleaner fish products.

The combination of small on-site impacts and relatively large regulatory focus on the fish processing industry represents is a paradox, which is likely to exist in other western countries as well. In terms of environmental regulation and policies, more attention should be given to the fishing stage – not only concerning overexploitation, but also in a wider sense where we consider the way in which the fish are caught – not only the quantity of the output. So far, the concept of cleaner production has mainly been applied in the industry, but the cleaner production practices are definitely also an issue in the fishing stage.

Recommendations

Apart from promotion of cleaner production at the fishing stage, recommendations are given to improve the implementations of existing regulations such as horsepower limitations – but also to develop new types of regulation that promotes market and self-regulation. This could be eco-labeling, demands to green accounts from large fishing vessels, taxes on fuel used by fishing vessels (there are presently no tax on fuel), economical incentives to return waste from the sea and fleet reduction programs which do not result in a further reduction in the capacity among the most energy efficient vessel segments.

Use of the results from the present study

Finally, it should be emphasized that the conclusions reached in this dissertation both with respect to environmental impacts and the more political aspects cannot be applied directly to other countries or other types of decision context. The results from an environmental assessment depend on the purpose of study, at least when consequential LCA is applied. The LCA in this project was carried out as part of a political decision context. If the purpose

had been to come up with suggestions to consumers, to whether they should buy fish or pork meat in a super market, the LCA results and therefore also the conclusions would have been completely different and probably not even involve wild fish.

Sammenfatning

Samtidig med, at miljøreguleringen bliver mere produktorienteret i Danmark og EU, øges behovet for at anskue miljøproblemer ud fra et livscyklusperspektiv. Historisk set har dansk miljøregulering hovedsageligt fokuseret på industrien og de lokale udledninger af eksempelvis spildevand, men ofte er der større og mere væsentlige miljøpåvirkninger i andre dele af produkternes livscyklus.

Metodiske aspekter

Nærværende afhandling "Miljøpåvirkning fra danske fiskeprodukter" præsenterer en detaljeret analyse af miljøpåvirkningerne fra danske fisk og skaldyrprodukter i et livscyklusperspektiv (fra hav til bord). Formålet er at vurdere, hvilke livscyklusfaser, der bidrager til den største miljøpåvirkning for fiskeprodukter og i dette lys diskutere, hvordan man fra politisk side kan fremme en gradvis reduktion af danske fiskeprodukters miljøbelastning.

Analysen er baseret på de nyeste metoder indenfor livscyklusvurdering (LCA), hvilket omfatter konsekvens LCA, der er karakteriseret ved en markedsbaseret tilgang til definerings og afgrænsning af produktsystemet, brug af marginale data og anvendelse af systemudvidelse ved allokering – se eksempelvis (Ekvall og Weidema 2004). Udover livscyklusvurderingen (kapitel 8-9), er der benyttet to andre tilgange til miljøvurdering: En MEKA analyse (kapitel 4-7) og en kvalitativ livscyklusvurdering (kapitel 10) af miljøpåvirkninger, der ikke er belyst i den "kvantitative" livscyklusvurdering.

Hovedresultater

Den samlede miljøvurdering peger på selve fiskeriet som den væsentligste livscyklusfase for danske fiske-, og skaldyrprodukter. Den samme konklusion er opnået i lignende studier af torskprodukter fra Sverige og Island (Eyjólfsson et al. 2003; Ziegler et al. 2003). Fiskeri indebærer et væsentligt brændstofforbrug (det er dog meget varierende for de enkelte fiskemetoder), udledning af biocider fra bundmaling, overudnyttelse af bestemte fiskebestande, et højt antal arbejdsulykker, som omfatter flere årlige dødsfald, fysiske påvirkninger af havbunden forårsaget af bundskrabende fiskemetoder, bi-fangst af havpattedyr og discard (altså udsmid af fisk).

Centrale processer

Det konkluderes, at energiforbruget har en central rolle for den samlede miljøpåvirkning fra fiskeprodukter fra hav til bord. Analysen peger på, at de væsentligste processer er fiskeri, transport og køling – set ud fra miljømæssige overvejelser. Kølebehovet er størst i supermarkedet og hos forbrugeren, mens transportbehovet hovedsageligt opstår i brugsfasen og for eksport af fisk (her kaldet transport fasen).

Brændstofforbrug – en central variable

Analysen af brændstofforbruget i fiskeriet er omfattende og belyser energiforbruget som en funktion af målart (den art som der fiskes efter i et givet fiskeri), fartøjsstørrelse og det anvendt fiskeredskab (se kapitel 4). Da stort set alle fiskefartøjer fanger flere arter på en gang har det været nødvendigt at fordele miljøpåvirkningerne mellem arterne, hvilket håndteres via systemudvidelse. På dette område er undersøgelsen den eneste af sin art, også internationalt. Det vises, at der er store forskelle i brændstofforbruget afhængigt af målarten. Brændstofforbruget per kg fanget fisk er typisk højt for torskefisk, fladfisk og skaldyr med undtagelse af muslinger, mens det er relativt lavt for sild, makrel og industrifisk eksempelvis Tobis. Den største forskel optræder mellem to typer af skaldyr, dybvandshummer og muslinger, hvor førstnævnte repræsenterer et brændstofforbrug på omkring 6 liter diesel per kg fangst, mens sidstnævnte kun kræver 0,01 liter diesel per kg fangst – en forskel der svarer til en faktor 600. Disse tal er baseret på systemudvidelse som anbefales ifølge standarden ISO 14040, men der er betydeligt mindre forskelle, hvis der masse- eller værdi benyttes som allokeringfaktor. Dette understreger væsentligheden af de metodiske antagelser og overvejelser.

Muligheder for reduktion i brændstofforbruget

Det er urealistisk, at ændre væsentligt på arts sammensætningen i fiskeriet, men det er oplagt at vurdere om en given art, der repræsenterer et stort energiforbrug, kan fanges på en mindre energiforbrugende måde. Her viser det sig, at energiforbruget af en given art varierer betydeligt som funktion af det anvendte fangstredskab. Ved at ændre på typen af fangstredskab kan man derfor opnå betydelige reduktioner i energiforbruget i mange tilfælde.

Som eksempel, varierer energiforbruget i fiskeriet efter fladfisk (hovedsageligt rødspætter) fra 2,6 liter til 0,2 liter brændstof per kg fanget fladfisk, hvor førstnævnte repræsenterer fiskeri med bomtrawl, mens sidstnævnte repræsenterer fiskeri med snurrevod. Her skal det bemærkes at 2,6 liter per kg fanget fladfisk svarer til omtrent 8 liter per kg fisk, der bliver spist i sidste ende. Hvis alle fladfisk blev fanget med snurrevod eller passive fiskemetoder som garn, ville det ”teoretisk set” være muligt at spare i omegnen af 30.000

m³ brændstof per år i det danske fiskeri alene. Det svarer til 15 % af fiskeriet samlede brændstofforbrug.

Dette tal er teoretisk og muligvis overvurderet, men der er også forbedringsmuligheder for fiskerier efter andre arter. Eksempelvis kan der antageligt opnås betydelige forbedringer ved at fremme brugen af not i fiskeriet efter sild og makrel (og måske andre arter), og ved fremme brugen af snurrevod, garn og langline i fiskeriet efter torskefisk.

Resultater der kan opnået ved at substituere fiskeredskaber

En central pointe er, at reduktioner i energiforbruget samtidig ser ud til at fremme typer af fiskeri, der også på andre områder er mere miljøvenlige. Her tænkes på påvirkningen af havbunden og udsmid. Som eksempel er udsmidet i fiskeriet efter dybvandshummer i størrelsesordenen 2/3 af fangsten samtidig med at dette fiskeri også har det største energiforbrug per kg fangst – blandt andet fordi mere energi skal tilskrives den resterende fangst, hvis 2/3 smides ud igen.

Livscyklusvurderingen i kapitel 9, viser at det samlede vægtede potentielle miljøpåvirkninger (fra hav til bord) for 1 kg frosne fladfiskefileter faktisk kan reduceres med en faktor 9 – ved at substituere bomtrawl med snurrevod i fiskeriet alene. Denne vurdering er baseret på den danske UMIP metode i en opdateret version af UMIP 97, og der indgår kun et begrænset antal miljøkategorier (drivhuseffekt, ozonlagsnedbrydning, forsuring, eutrofiering og ozondannelse). Det er dog vigtigt at understrege at forbruget af bundmaling og dermed udledning af biocider per kg fanget fladfish er betydeligt lavere for bomtrawl. Fladfish fanget med bomtrawl har derfor et mindre bidrag til øko-toksicitet i situationen som den tegnede sig omkring år 2000. Fremtidsscenerier viser dog, at snurrevod også vil opnå den bedste miljøprofil for økotoksicitet, hvis vi ser på situationen efter 2003 hvor TBT ikke må benyttes mere.

Hot-spots kontra det reguleringsmæssige fokus

De to sidste faser i livscyklus, supermarked og brusfasen, repræsenterer også store potentielle miljøpåvirkninger. Dette gælder særligt brugsfasen hvor transport med bil i forbindelse med indkøb er en væsentlig faktor. Eksponering er generelt ikke overvejet, men særligt i brugsfasen må det antages at menneskelig eksponering overfor støj og luftforurening fra transport er relativt høj idet den ofte forgår i bebyggede områder. Dette er med til at understrege betydningen af miljøpåvirkningen fra brugsfasen.

En af de centrale konklusioner i forhold til afhandlingens problemformulering er, at miljøbelastningerne fra fiskeindustrien er begrænsede. Dette gælder især de udledninger, der finder sted på selve virksomhederne som eksempelvis spildevand, der ikke længere udledes direkte i havet men i stedet behandles på effektive spildevandsrensningsanlæg. Det skal med i betragtningen at vandforbruget kan udgøre et ressourceproblem, men da fiskeindustrien typisk er placeret i Nord- og Vestjylland, hvor vandressourcerne ikke er overudnyttede set udfra en helhedsbetragtning, er det måske ikke et af de mest centrale problemer. Dette er nærmere diskuteret i den kvalitative LCA (kapitel 10).

Nogle dele af fiskeindustrien har dog et betydeligt forbrug af aluminium og glas der benyttes til emballage. Der kan opnås betydelige reduktioner i miljøbelastningen ved at erstatte dette med miljøvenlige plasttyper. Desuden er en af de store forbedringsmuligheder at øge filet udbyttet, altså den mængde fiskefilet der produceres per kg råvarer. Sidstnævnte er en af de typer af forbedringer, som også vil reducere miljøbelastningen i fiskeriet per kg consumeret fisk, og som derved kan siges at renere fiskeprodukter udfra et livscyklusperspektiv.

Myndighedernes regulering af miljøforhold har hidtidigt koncentreret sig om fiskeindustrien, mens fiskeriet stort set kun har været omfattet af traditionel fiskeriregulering med fokus på kvoter. Set udfra et livscyklusperspektiv eksisterer der således et paradoks da miljøpåvirkningerne netop ser ud til at afspejle den omvendte situation, altså store påvirkninger i fiskeriet og små påvirkninger i industrien. Hvis yderligere sub-optimering skal undgås kræver det, at miljødimensionen får en mere central placering i reguleringen af fiskeriet – ikke kun i forhold til resourcesituationen, men også og ikke mindst i forhold til den måde hvorpå fisken fanges. Indtil videre, er princippet om renere teknologi hovedsageligt blevet anvendt, i forhold til fiskeindustrien, men renere teknologi er i høj grad også relevant i forhold til fiskeriet og fiskemetoder.

Anbefalinger

Hvis vi ser på den traditionelle fiskeriregulering kan det anbefales, at der tages initiativer som sikrer at implementering generelt forbedres. Her tænkes også på særlige ordninger, som f.eks. hestekraftbegrænsninger, der skal sikre at store fartøjer ikke fisker i bestemte områder. Desuden er det centralt, at eksisterende flådereduktionsprogrammer, tilpasses så de i højere grad tager hensyn til ønsket om at fremme en mere bæredygtig og energieffektiv fiskeflåde.

I et bredere perspektiv handler det om at fremme nye former for regulering såsom selvregulering og markedsregulering – altså reguleringer, der skaber betingelserne for at aktørerne i sektoren i højere grad selv motiveres til at producere mere miljøvenlige fiskeprodukter. Erfaringer fra fiskeindustrien viser at der kan opnås betydelige resultater af denne vej.

Med hensyn til fremme af selvregulering kunne virkemidlerne være støtte til udvikling af renere teknologi, særligt i forhold til fiskeflåden, og krav til grønne regnskaber for visse fiskefartøjer

Eksempler på initiativer, der kunne fremme markedsregulering er udvikling af en mærkningsordning for fritfangede fiskeprodukter, afgifter på brændstof anvendt i fiskeriet (i øjeblikket er der ingen afgifter) og endelig økonomiske virkemidler, der kan bidrage til at affald ikke dumpes i havet men tages tilbage til land.

Brug af resultater fra nærværende undersøgelse

Som en afsluttende kommentar skal det fremhæves, at konklusionerne – både med hensyn til miljøpåvirkninger og det mere politiske, ikke kan benyttes direkte til at sige noget om forholdene i andre lande eller andre typer af beslutningssituationer. Resultaterne af en LCA afhænger grundlæggende af formålet med undersøgelse. Miljøvurderingen i nærværende afhandling reflekter en beslutningssituation, som knytter sig til hvad danske myndigheder kan gøre på det politiske plan for at fremme en udvikling mod renere fiskeprodukter. Hvis formålet drejer sig om anbefalinger til forbrugerne med hensyn til det mest miljøvenlige produktvalg f.eks. fisk eller grisekød, ville resultaterne og konklusionerne have været helt anderledes and antageligt ikke involveret vilde fisk.

Terms and abbreviations

Ancillary input: Material input that is used by the unit process producing the product, but does not constitute a part of the product

BAT: Best Available Technology

B_{lim} / F_{lim} : B_{lim} is the level of the spawning biomass under which the recruitment is in danger of being reduced. F_{lim} is the level of fishing mortality, which in short or long term exactly will keep the stock on the level of B_{lim} (The Nordic Council of Ministers, 2000a).

B_{pa} / F_{pa} : This is basically the same type of reference points as mentioned above, but here, a precautionary margin has been introduced to provide guidance on graduated action, when a stock is approaching the limit reference points (The Nordic Council of Ministers, 2000).

Benthos: The same as benthic fauna, which is organisms living on (epifauna) or in the bottom (infauna) of a the seabed sediment.

BOD: Biological Oxygen Demand.

By-catch: By-catch consists of fish, which are not primarily sought after in the given fishery. This is also termed incidental catch. It consist of non-target fish, invertebrates, birds and mammals but may also consist of undersized target fish and over quota target fish.

By-product: An example could be fish waste from the fish filet industry, which is used as animal feed. In LCA terminol-

ogy, the term “dependent product” is used instead.

Category endpoint: Attribute or aspect of natural environment, human health or resources, identifying an environmental issue of concern (Jerlang et al. 2000).

Characterization factor: Factor derived from a characterization model, which is applied to convert the assigned LCI results to the common unit of the category indicator e.g. CO₂ equivalents.

Cleaner production: Continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment (Definition adopted by UN)

Co- product: Any of two or more products from the same unit process.

COD: Chemical Oxygen Demand.

Codfish: A species group that include Atlantic cod, Saithe/Pollack, Coalfish, Haddock, Hake and Ling.

Co-product allocation: Partitioning of the environmental interventions of a unit process to one or more co-products (Jerlang et al. 2000).

DALY: Disability Adjusted Life Years.

Demersal fish: Demersal means sinking to or lying on the bottom. Demersal fish are fish living on or near the bottom e.g. cod and plaice.

Dependent product: A co-product that not determines the production volume of a given process. The term “by-product” is often used as well.

Determining product: A co-product that determines the production volume of a given process.

Discard: Catches, which are released back to the sea. Discard consists of unwanted by-catch and target fish e.g. undersized or low value fish, but it may also consist of marine mammals, birds and other species, which are not intended for commercial purposes (Nordic Council of Ministers, 2000a; Hall, 1999).

Discard ratio: Ratio of discarded weight to total catch weight.

Immediate exchange: This refers to inputs and outputs as well as non-flow related impacts that occur in the immediate products chain. This could be 1 MJ electricity used for fish processing. It is not a total inventory of all the affected processes, nor should it be confused with the “environmental exchange”.

IQF: Individually Quickly Frozen.

Edible fish: The term edible fish refers to fish that are sold for human consumption.

Elementary flow: Elementary flows are materials or energy entering or leaving the system, which has been drawn from or discarded to the environment, without previous or subsequent human transformation. An example of an elementary flow entering a product system providing electricity is coal in the ground. An example of an elementary flow leaving the same product system is CO₂ emitted to the atmosphere.

EMS: Environmental Management System – see also ISO 14001.

Final product: Product that requires no additional transformation prior to its use.

Environmental aspect: Element of an organization’s activities, products or services that can interact with the environment.

Environmental exchange: Environmental exchanges is “elementary flows” from or to the environment e.g. carbon dioxide that is released to the atmosphere or crude oil that is extracted from the earth.

Environmental mechanism: System of physical, chemical or biological processes for a given impact category, linking the LCI results to category indicators and to category endpoints (Jerlang et al. 2000).

ETWA: Eco-toxicity water acute.

ETWC: Eco-toxicity water chronic.

ETSC: Eco-toxicity soil chronic.

Exchange: The word exchange is used instead of “inputs and outputs” but includes “non-flow related impacts”, such as physical impacts to the seabed etc. in this report.

Farmed fish: The term farmed fish is used to describe fish whose origin is aquaculture farms, either fresh water ponds (inland) or salt water.

Fishing mortality: The fishing mortality is a measure of the proportion of the stock that is taken out by fishing every year (The Nordic Council of Ministers, 2000a).

Flatfish: A species group that include European Plaice, Flounder, Dab, Smear dab, Sole, Turbot, Brill and Halibut.

Functional Unit: Quantified performance of a product system for use as a reference unit in a life cycle assessment study (Jerlang et al. 2000).

GT: Gross Tonnage.

HDPE: High Density Polyethylene.

ICES: The International Atlantic Fisheries Organization. Gives scientific advice on the state of stocks and fisheries management (Nordic Council of Ministers, 2000a).

Indirect discard: Fish and invertebrates etc. which are not caught but instead damaged or killed in the trawl path (Nielsen and Møllgaard, 1999).

Life Cycle Inventory (LCI): Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle (Jerlang et al. 2000). In this report this also involves compilation and to some extent quantification of non-flow related impacts.

Industrial fish: Industrial fish refers to fish, which are caught with the intention of being used exclusively for processing of fishmeal and oil.

Input and output: Inputs are material or energy that enters a unit process. Outputs are material or energy that leaves a unit process (Jerlang et al. 2000). Input and outputs are often referred to as exchanges in this dissertation, but it should be noticed that exchanges might include non-flow related impacts as well.

Intermediate product: Input to or output from a unit process, which requires further transformation (Jerlang et al. 2000).

ISO: International Organization of Standardization.

ISO 14001: ISO standard for environmental management systems.

ISO 14040: ISO standard for LCA (principles and framework).

ISO 14041: ISO standard for LCA (goal and scope definition and inventory analysis).

ISO 14042: ISO standard for LCA (life cycle impact assessment).

ISO 14043: ISO standard for LCA (life cycle interpretation).

Landed fish. Fish, which are brought to harbour. For some species such as cod and flatfish the difference between caught and landed fish is that the latter is gutted and iced.

LDPE: Low Density Polyethylene.

HDPE: High density polyethylene.

Life cycle assessment (LCA): Compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system through its life cycle (Jerlang et al. 2000).

Life cycle impact assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (Jerlang et al. 2000).

Life Cycle interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined to reach conclusions and recommendations (Jerlang et al. 2000).

Life cycle phase: Life cycle phase refers to the phase in the life cycle assessment according to the ISO 14040 methodology for LCA.

Life cycle stage: Life cycle stage refers to the life cycle of a product or service, such as material extraction, processing, transport or the use stage.

MECO (-principle): MECO simply means Materials, Energy, Chemicals and other. In this dissertation, it is used to structure and systematize the analysis of immediate exchanges in chapter 4-6. Further applications of the MECO principle are described in Wenzel et al (1997)

Non-flow related impact/exchange: This is used to describe exchanges that imply an impact that is not related to a flow such as physical impacts, land use, animal welfare and some aspect of human health and safety.

PE: Person Equivalent - for instance used to describe the environmental burden for one average Danish citizen for one year.

Pelagic fish: Pelagic fish swims in shoals in the free water masses and often migrate over long distances. Examples are mackerel and herring (Muus et al. 1998).

Product system: Collection of materially or energetically connected unit processes which performs one or more defined functions (Jerlang et al. 2000).

Quota (fish-): A maximum allowable catch of a certain species within a defined area. In some cases a quota include other species, and the fishing area can be specified in various ways (Fiskeridirektoratet, 2001a).

Safe Biological Limits: A stock is beyond safe biological limits if the spawning stock mass is under a certain level (B_{lim}) and/or if the fishing mortality is over a certain level (F_{lim}). Applying the precautionary approach it may refer to B_{pa} and F_{pa} .

Sensitivity analysis: Systematic procedure for estimating the effects on the

outcome of a (LCA-) study of the chosen methods and data (Jerlang et al. 2000).

Shellfish: Aquatic animals with shells, e.g., crustaceans (prawns, lobsters) and mollusks (e.g., oysters, scallops, clams)

Target fish: Target fish are one or several fish species, which are primarily sought after in a given fishery (Hall, 1999).

Unit process: Smallest portion of a product system for which data are collected when performing a life cycle assessment (Jerlang et al. 2000).

Uncertainty analysis: Procedure to ascertain and quantify the uncertainty introduced into the results of a life cycle inventory analysis due to the cumulative effects of input uncertainty and data variability (Jerlang et al. 2000).

Introduction

The following introduction introduces the field of problem and presents the problem definition, related research questions, as well as a short introduction to the theoretical and methodological framework. Finally, an outline of the project structure is provided. A presentation of the fishery sector is given in chapter 2 and the introduction is therefore kept relatively short.

1.1 Product focus in environmental policies

Environmental policies in the UN and EU, as well as nationally, are currently being redirected from site-specific considerations and abatement solutions towards life-cycle-thinking and preventive solutions. The idea behind the product-oriented policies is to stimulate businesses to produce cleaner products and services, to avoid sub-optimization and to strive for long lasting solutions to environmental problems. (Miljø- og Energiministeriet, 1999).

The factor 4 debate

As suggested by Erhlich and Ehrlich (1991), the environmental burden from human activities roughly depends on three variables: The size of the population, the affluence, and the technology. This is often referred to as the IPAT equation¹. The United Nations suggest that the global population, as well as the average standard of living (the affluence), will increase considerably within the next 50-100 years (UNEP 2002; Lutz et al. 2001). As a result, if the technology factor remains constant, the environmental impact (I) may increase many-times. However, this does not have to be the case. Some envi-

¹ The IPAT equation suggests that environmental impact (I) is the product of population (P), per capita affluence (A) and technology (T) (Erhlich and Erhlich, 1991).

ronmental scientist argue that it is possible to produce the same products and services with less than one fourth of the environmental impacts typically generated today (Weizsaecker et al. 1998). This line of thinking is also reflected in the Danish debate about product-oriented policies.

Product oriented policies in Denmark

In the Danish statement about the product oriented environmental policies from 1998, it is stressed that Denmark must strive to reduce the resource consumption by a factor of four on the short- and medium term, and by a factor of ten in the longer term. The goal is to develop products that represents a smaller environmental impact compared to similar products with the same function. Among the measures are support for the development of cleaner products, establishment of green market incentives and stimulation of the industries' ability to compete on future markets. (Miljøstyrelsen, 1998a)

The importance of the food and fishery sector

In Denmark's national strategy for sustainable development, it is stressed that Denmark must seek the following goals (The Danish Government, 2002):

- 1) The welfare of society must be developed while economic growth is decoupled from environmental impacts².
- 2) There must be secured a high level of *bio-diversity, and ecosystems* must be protected.
- 3) Resources must be used more efficiently.
- 4) Environmental concerns must be taken into account *in all sectors*.
- 5) The market must support sustainable development.

Statements such as decoupling of economic growth and environmental impacts, efficient use of resources and a market that supports sustainable de-

² According to the Danish Energy Agency, the increase in economical activity measured in GNP, has been larger than the increase in energy consumption measured in Joules, in Denmark. Since 1980 the energy consumption per GNP has decreased by around 20% (Energistyrelsen, 2002). A decoupling has also been observed between GNP and key emissions such as nitrogen, phosphorus, SO₂, NO_x, CO₂, NMVOC and NH₃, in the period 1990-2001. This tendency has also characterized the development in groundwater consumption (Miljøstyrelsen, 2003)

velopment are in line with the product-oriented policies, as previously described. However, it is also stressed that all sectors must be involved. In this regard, the strategy specifically addresses food products from agriculture and fisheries. It is stated that: (The Danish Government, 2002):

“The Danish food producers must supply consumers with safe and healthy food. At the same time food producers must consider a viable production basis, animal welfare, the environment, profitability, and saleability”.

For fisheries, it is specifically stated that:

“Denmark must promote environmental considerations in the fisheries sector, nationally as well as internationally. New tools and technologies must be developed, the capacity of the fisheries fleet must be adjusted, and fish quotas must be administered to reduce the pressure on fish stocks. Improved fishing gear can reduce unintentional by-catches and reduce the pressure on the ocean bed and the ecosystem in general”.

Obviously, the fishery stage have a special environmental status because of the extraction of biological resources, but it is also important to consider other life cycle stages in the fishery³ sector in accordance with the intentions in the Danish product oriented policy.

The life cycle perspective

As environmental policy becomes more product-oriented, an increasing need for seeing environmental impacts in a life cycle perspective (from sea to table) is occurring. Traditional environmental regulation mainly focuses on the companies and their on site emissions, but frequently larger environmental impacts are found elsewhere in the life cycle (Wenzel et al. 1997).

According the OSPAR commission⁴ fisheries is one of the most important factors that influence the North Sea ecosystem. Historically, most focus has been given to overexploitation, but in recent years more focus has been di-

³ The word “fishery sector” is used to describe enterprises involved in fishing, landing and sale-, processing- and distribution of fish products.

⁴ The OSPAR Commission is an inter-ministerial co-operation, concerning prevention of sea pollution and measurement of the state of the environment in the North-east Atlantic. The participating countries are most European countries including Denmark.

rected towards by-catch, discard, emission of anti fouling agents and impacts on the seabed (OSPAR, 2000).

Life Cycle Assessment (LCA) is a useful tool to assess the type and importance of environmental impacts at different life cycle stages. Previous research concerning food and fish products is described in the next section.

1.2 Previous research

A study of the energy consumption in Danish households shows that the total energy consumption is equally distributed between transports, food consumption and housing. In other words, food consumption appears to constitute an important part of an average households environmental load. It is emphasized that meat products are a particular heavy burden on the environment partly due to the energy consumption in agriculture (primary production) and processing (I/S Økoanalyse, 1996).

LCA studies of fish products

So far, few LCA studies have addressed meat products, and especially fish. LCA screenings⁵ of specific fish products conducted by students at Aalborg University suggest that there are significant environmental impacts related to energy consumption and emissions of anti fouling agents in the fishery⁶, while relative small impacts are related to wastewater emissions from the fish processing industry, which have been the center of attention for the environmental authorities. Thus, indications exists that sub-optimization have occurred with respect to dealing with the environmental impacts from fish products (Ritter, 1997; Andersen et al, 2000; Madsen, 2001).

However, the studies have only been screenings and do not encompass a wider range of fish products. Hence, there is still a need for research that can provide a reliable picture of the environmental aspects from a wide range of

⁵ Prior to the present dissertation, three LCA screenings on fish products have been conducted at Aalborg University. The screenings concern canned mackerel in tomato paste, pickled herring (in jars), and frozen blue mussels (Christensen et al. 2001).

⁶ The term “fishery” is used throughout this report to convey three distinct meanings: 1) the fishing industry as a whole; 2) a sector of the fishing industry that targets a certain type of fish (i.e., the mackerel fishery) or uses a certain type of fishing gear (i.e., the Danish seine fishery); and 3) a particular fishing firm or establishment.

fish products (Jungbluth, 2001). This is essential knowledge for prioritization of governmental and corporate environmental policies. In this regard, some of the important questions are:

- Which products and product chains generates the largest impacts?
- How are these product chains interrelated?
- Which life cycle stages are hot-spots, in terms of environmental impacts?
- Are we currently applying the most effective measures to promote cleaner fish products?
- What are the options for process- or system improvements?

This illustrates the more pertinent questions. The problem definition and research questions are presented in the following.

1.3 Problem definition, structure and framework

The problem definition, the methodological and theoretical framework as well as the report structure is presented in the following. With respect to the theoretical framework, only a short presentation is presented here, while more thorough presentations are valuable in the respective chapters.

Problem definition

Based on the previous outline of the problem of interest, the following question is addressed

How can authorities and actors within the Danish fishery sector effectively promote cleaner⁷ fish products produced in Denmark?

The question is broken down into the following research questions.

⁷ Cleaner fish products are fish products that represents a smaller environmental impact compared to initial/ reference situation. In this dissertation, cleaner fish product does not mean fish products that are “cleaner” in terms of low content of heavy metals, chemicals or bacteria.

1) What characterizes the environmental impacts from different groups of Danish fish products in terms of environmental exchanges, types and magnitudes of impacts at different life cycle stages?

2) What characterizes the existing environmental regulation of fish products and what are the potentials and barriers for a development towards cleaner fish products?

The structure reflect that most attention is given the research question 1 – even though the fundamental purpose is to answer research question 2 and to provide recommendations to future regulations. This is not because the latter have proved to be simple nor irrelevant to analyze further, but merely a result of the workload that is related to conducting a full LCA on sector level.

Methodological and theoretical framework

The main elements of the methodological and theoretical framework are briefly explained in the following section.

Research question 1

Research question 1 is mainly analyzed via a natural science approach, involving literature reviews, empirical studies of material and energy flows as well as non-flow related impacts such as damage inflicted to the seabed.

From a methodological point of view, I follow the four phases of life cycle assessment according to the ISO 14040 standard as interpreted by Jerlang et al. (2001). This includes goal and scope definition, inventory, impact assessment and interpretation. I have used the MECO principle to structure both the inventory analysis of a wide range of fish products in part two and for inventory in the life cycle assessment of flatfish in part three.

The theoretical basis is mainly Life Cycle Impact Assessment (LCIA) – applied in part three - which enables an aggregation of data across life cycle stages as well as an impact assessment. The impact assessment is based on a multitude of scientific theories addressing environmental mechanisms. Chapters 3 and 8 contain a further description of the concept as well as its strengths and weaknesses. The key references are Udo de Haes et al. (2002), Wenzel et al. (1997) and Hauchild and Wenzel (1998).

Research question 2

Research question 2 is examined from a different perspective including a natural science perspective, a social science perspective, and a human science perspective. This is explicitly described in chapter 12. Chapter 11 is more descriptive in relation to existing planned regulations

The theoretical focus in chapter 11 is environmental regulation and implementation theory. The main references for regulation theory are Smink (2002) and Carter (2001) but background knowledge is also obtained from Remmen (2001b) and Nielsen & Remmen (2002). With respect to implementation theory, the main references are Winter (1994) and Winter (2003). With respect to actual descriptions of regulation and policies addressing the fishery sector, the main reference is Vedsmand (1998), but references are also made to a large number of other studies and reports including Thrane (2000a) and Thrane (2000b).

Besides referring to the theories presented in chapter 11, chapter 12 applies a methodological framework from Human Ecology that explicitly addresses five different research perspectives. This is applied in the analysis of barriers and potentials to obtain different views on possible actions, which could be used to reduce the environmental burden from Danish fish products. In a specific analysis of factors which influences the fuel consumption in the fishing stage, I have also applied theories within “system dynamics” to establish key variables and causal relationships. Here, the references are Senge (1990) and Anderson and Johnson (1997).

Structure

The report is divided in four parts of which parts one to three mainly address research question 1 while part four addresses research question 2:

- Part one contains an analysis of the fishery sector, the product flow from sea to table and a brief introduction to the types of environmental impacts at different life cycle stages.
- Part two presents an analysis of exchanges for a wide range of species groups from sea to table. The analysis serves as part of the inventory for the LCA in part three, but should mainly be considered as a separate data analysis, supplementing the LCA case study in part three. The MECO analysis includes descriptions of alternative production methods and cleaner technology.

- Part three contains a detailed life cycle assessment of two types of flatfish products as well as LCA screenings of a wider range of fish species/-products.
- Finally, part four focuses existing and planned regulations from sea to table as well as barriers and potentials for promotion of cleaner fish products.

The description of the fishery sector, the product flow and environmental impact types in part one, should be seen as an introduction to the sector and structural aspects that are relevant for the analysis in the following chapters. The detailed structure of the dissertation is illustrated in the figure below:

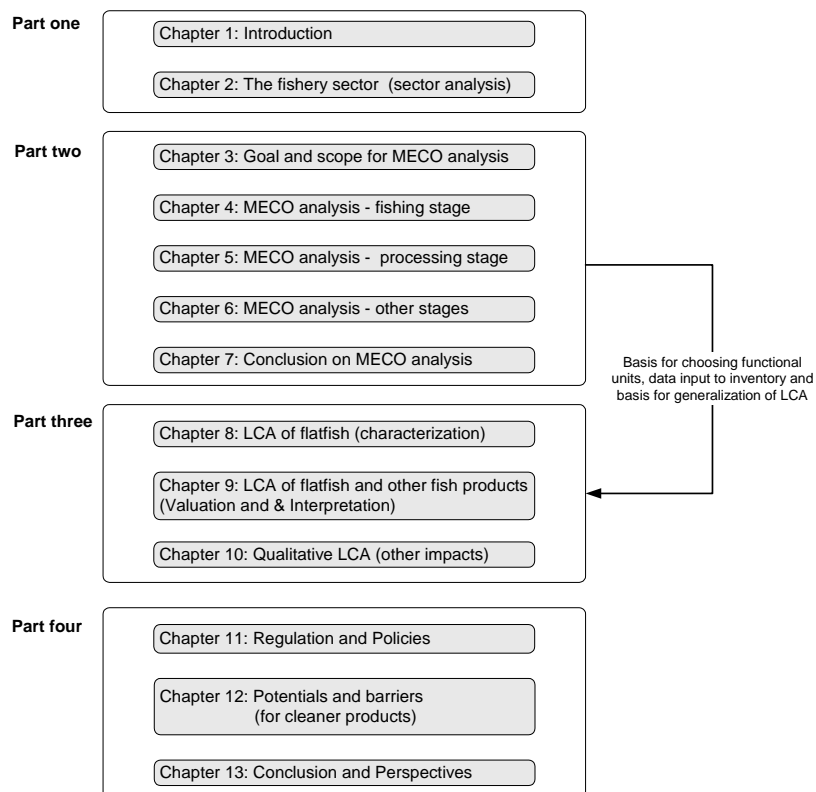


Figure 1. Structure of the present dissertation

The content of the different chapters in parts one to four are described in the following sections.

Part one

Part one is an introduction to the field of research and a description of the fishery sector, with focus on socio economic aspects, product flow from sea to table and environmental impact types.

Chapter 1. This is the present chapter with an introduction to life cycle thinking, problem formulation, methods, theory, and the structure of the report.

Chapter 2. This chapter contains an analysis of the employment, economic key figures, as well as the product flow from sea to table in the fishery sector. Finally, the chapter addresses the types of environmental impacts that occur at different stages of the life cycle.

Part two

Part two is a comprehensive analysis of the immediate exchanges from a wide range of Danish fish products that cover the whole Danish fishery. The analysis does not include an environmental impact assessment, nor does it include considerations of exchanges from related product chains. The MECO analysis will provide information about hot-spots for different types of exchanges, improvement potentials and environmental characteristics for different types of fish products. These aspects are important in themselves, but the analysis is also used to select a relevant product for the detailed LCA in part three.

Chapter 3. This chapter contains a short introduction to LCA, which is necessary as the MECO analysis is applied in a LCA context. Besides, it presents the goal and scope of the MECO analysis, which includes considerations about purpose of study, system delimitation, scope, co-product allocation, and cut-off criteria for the MECO analysis.

Chapter 4. With a focus on the fishing stage, this chapter provides a comprehensive analysis of the exchanges related impacts for nine groups of fish species that cover the entire Danish fishery. The analysis is structured after the MECO principle.

Chapter 5. Following the same structure and methodology as chapter 4, this chapter contains an environmental analysis of the fish processing stage.

Chapter 6. As with the two previous chapters, this chapter analyzes the exchanges related impacts during landing and auction, wholesale, retail and the use stage.

Chapter 7. This chapter is the conclusion of part two which concerns distribution of exchanges across life cycle stages as well as environmental characteristics and improvement potentials for different product types and product chains.

Part three

The analysis in part two will not answer questions such as: Does the emission of cooling agents in the fishery represent an important impact potential compared to energy consumption or emissions of anti fouling agents? Questions of this nature are therefore addressed in part three – the life cycle assessment.

Even though the concept of life cycle assessment has been introduced in chapter 3, this chapter provides a further description of LCA with a focus on the aspects analyzed in chapter 8-10 as well as the differences between the previous MECO analysis and the LCA in part three.

Chapter 8. Life Cycle Assessment of plain and breaded flatfish fillet. The chapter includes a short introduction to consequential LCA, the goal and scope of the LCA study, inventory and characterization results (the first step of LCIA). Data are mainly derived from the MECO analysis in part two but additional data has also been collected for the processing stage.

Chapter 9. Chapter 9 is a direct continuation of chapter 8, but includes the more value-based results from the LCIA, normalization and weighting. This chapter also contains a generalization, including LCA screenings of other fish products and the interpretation with uncertainty- and sensitivity analysis. The LCA screenings include six other fish products, and provides a basis for addressing all main groups of fish products based on wild fish in Denmark.

Chapter 10. The last chapter in part three contains a discussion and assessment of impact categories, which have not been previously assessed. The chapter includes the overall conclusion based on results derived in part three. Ultimately, key potentials for improvements and recommendations for future LCA studies are addressed.

Part four

Based on the findings in part two and three, as well as the structural and socioeconomic background from part one, part four deal with the political level and the different measures which could come into play to reduce the environmental burden from Danish fish products. While part two and three

mainly addressed research question one, part four focuses research question 2.

Chapter 11. This chapter analyzes existing, current and planned initiatives to reduce the environmental impacts, at different life cycle stages for Danish fish products.

Chapter 12. Chapter 12 provides an analysis of barriers and potentials for cleaner fish products as well as a detailed analysis of important variables influencing the fuel consumption at the fishing stage. The latter include specific recommendations for improvements

Chapter 13. The conclusion summarizes the most important results from the hot-spot analysis in part two and three, and discusses improvement potentials as well as relevant measures to promote cleaner fish products. It also provides a critical reflection on the results, the methodological approach, and its limitations. Finally, it addresses perspectives related to implementation, the probability for and the consequences of different development paths.

Appendix

It has only been chosen to print the following eight appendixes in the report.

(*) Include documents and excel files available on CD in the backcover:

- App. 1: Description of different fishing gears
- App. 2: Danish catches by vessel size and fishing gear
- App. 3: Product spillage along the life cycle
- App. 4: Basis for data quality assessments
- App. 5: Energy consumption in the fishery *
- App. 6: Anti-fouling emissions in the fishery *
- App. 7: Energy consumption for transport stage
- App. 8: Exchanges at the use stage *

Appendix 9-14 also contain word documents and excel files - mainly related to the LCA study chapter 8-9. These appendixes are only available on the CD.

- App. 9: Inventory data for the fishing stage (LCA of flatfish)
- App. 10: Inventory data for the processings stage (LCA of flatfish)
- App. 11: Inventory data for other stages (LCA of flatfish)
- App. 12: Data for related products and processes (LCA of flatfish)

- App. 13: Overview of data and results (MECO and LCA)⁸
- App. 14: Green account and a logical framework perspective.

⁸ Include Simapro files used for LCA calculations. Simapro is a PC tool used to conduct the calculations in the LCIA (Simapro 5.1, 2003).

The Fishery Sector (Sector Analysis)

This chapter introduces the fishery sector¹ and addresses aspects related to socio-economics, product flow, as well as the types of environmental impacts that occurs at different life cycle stages from sea to table.

Apart from an introduction to the fishery sector, the chapter provides a basis for the analysis of environmental impacts in part three and the analysis of environmental policies in part four.

2.1 Socio-economics, landings and trade

The following section presents the employment and turnover along the product chain and provides a detailed analysis of the landings and the export of fish products.

Employment and turnover

As table 1 points out, the fishery and the fish processing industry are the main employers in the sector (Table 1).

¹ That is enterprices involved in fishing, landing/sale-, processing-, and distribution of fish products

Tabel 1: Number of companies, turnover and employment in the fishery sector in the year 2000 (Fiskeridirektoratet, 2002a)

	Fish-farms	Fishery	Processing ²	Wholesale ³	Retail ⁴	Total
Firms	326	2.227	178	353	309	3.393
Turnover (million Dkr). ⁵	-	4.122	10.008	17.300	540	31.970
Employment 1 ⁶	499	3.041	5.560	2.153	419	11.672
Employment 2 ⁷	955	5.399	6.987	3.060	1.048	17.449

The number of firms is highest in the fishing stage, while the economical activity is highest in the wholesale and processing stage.

Regarding employment, the most important stage is fish processing - closely followed by the fishery. Wholesale is also quite important, while the employment in retail is relatively insignificant⁸. This indicates that occupational health and safety definitely should be considered in the first two life cycle stages.

The employment in the fishery sector is concentrated around the largest fishery harbours in Western and Northern Jutland as well as the Island of Bornholm in the Baltic Sea (Fiskeridirektoratet, 2002a). In some areas, such as

² For processing, it is only firms with 6 employees or more that are included. (Fiskeridirektoratet, 2002a)

³ Wholesale includes sale to non-private customers via auctions, middlemen etc. (Fiskeridirektoratet, 2002a)

⁴ Retail includes only sale to private customers in Denmark. (Fiskeridirektoratet, 2002a)

⁵ The turnover is based on the VAT registered business transactions from the Custom Authorities Business Register in combination with data from the accounts statements

made by the firms. These numbers are from 1999 because the Statistics Denmark no longer produces this table (Fiskeridirektoratet, 2002a)

⁶ Employment 1 is number of people in fulltime employment, where two people working 18 hours per week are basically counted as one fulltime job (Fiskeridirektoratet, 2002a)

⁷ Employment 2 is employees per 30/11 2000. The requirements for being adopted to this list are very small, and even one person working one hour a week is considered an employee.

⁸ It must be stressed that this is only retail in Denmark, which covers 5% of the sale of fish products (Fiskebranchen, 1999). If the remaining 95% were taken into account, retail may prove to be significant in terms of employment as well.

Skagen municipality, the employment related to fishery is responsible for more than 20% of the total employment. These areas are characterized by a relatively low economic activity in other areas apart from tourism, which is a seasonal activity. Hence, the fishery sector is of crucial importance to the economic activity and the employment in certain areas. (Vedsmand, 1998)

Development, opportunities and threats

There has been a significant decrease in employment in the fishing stage during the last 10-15 years. In the period from 1985 to 1995, the employment was reduced with about 35%, which can be explained by fewer and larger vessels as well as stocks showing a decline. (Vedsmand, 1998)

Regarding the fish processing industry, a large number of companies and jobs have been lost since the beginning of the 1990s. The reasons have been declining fish stocks and increasing competition from other countries (Vedsmand, 1998). According to Vedsmand, some of the threats to the Danish fishery sector are:

- 1) Opening of markets resulting in more competition from countries with relatively low labor costs
- 2) Price pressure from few but still more and more powerful supermarket chains in Europe
- 3) Depleted fish stocks (especially demersal fish) and
- 4) Demands to sustainable production methods/products.

The latter might be seen as a threat, but is obviously also an opportunity. Considering items three and four, it appears that the ability to handle environmental issues and save resources are among the most important factors influencing the competitiveness of the Danish fish sector in the future. This is confirmed by other studies such as Nordisk Ministerråd (1998a) and Pihl & Christensen (1998).

Landings in Danish harbours

This section analyzes the amount and type of fish landings from foreign and Danish vessels. The purpose is to elucidate the significance of different product types, and show for which product types, foreign fishermen are an important factor. The historical development is also analyzed to establish a better picture of the current situation, and what it represents.

In 2000, Denmark was the 14th largest fishery nation worldwide, measured in catch volume. The largest fishery nation the same year was China with a total catch volume of 17 million tons, which is 10 times the Danish catches. Denmark is the largest fishery nation within EU in terms of the quantity of landed fish, mainly due to the large catches of industrial fish (Fiskeridirektoratet, 2002a). The total amount of landings from Danish and foreign fishers in Danish harbours measured in value and volume is illustrated in table 2.

Table 2: *The value and volume of landings in Danish harbours in 2000 and the average for 1991-2000 (Fiskeridirektoratet 2001a).*

Vessels	Year 2000 [1000 tons]			Average for 1991-2000 [1000 tons]		
	DK	Foreign	All	DK	Foreign	All
Edible fish	363	227	590	406	185	591
Industrial fish	1.079	259	1.338	1.253	197	1.450
All species	1.442	486	1.928	1.659	382	2.041

Vessels	Year 2000 [billion D.Kr]			Aver. for 1991-2000 [billion D.Kr]		
	DK	Foreign	All	DK	Foreign	All
Edible fish	2.32	0.73	3.05	2.28	0.68	2.96
Industrial fish	0.72	0.16	0.88	0.82	0.14	0.96
All species	3.04	0.89	3.93	3.10	0.82	3.92

As the table infers, the total landings are around two million tons in Danish harbours, where nearly $\frac{3}{4}$ are industrial fish. Thus, industrial fish are the most important species considering the amount of bio-mass that is removed from the sea ecosystem.

The Danish landings, in the year 2000, represents a decrease in the landing volume of edible and industrial fish, compared to the previous decade. Foreign fishermen have increased their share of the landings, but not enough to compensate for the decrease in Danish landings.

Foreign fishermen contribute with considerable part of the landings of edible fish, but in terms of value, the contribution is less significant. The reason is

that foreign vessels mainly contribute with landings of herring and mackerel, which have a relatively low value per kg, compared to other edible fish (Fiskeridirektoratet, 2001a).

There were roughly 400 fish farms in Denmark in 2000 - principally fresh-water ponds. The total production amounted to 33.000 tons, mainly rainbow trout. This corresponds to around 6 % of the total amount of wild edible fish landed in Danish harbours the same year (Fiskeridirektoratet, 2001a).

Landings of edible fish in Danish harbours

The ten most important species of edible fish, considering landings in the year 2000, as well as the previous decade, are illustrated in table 3.

Table 3: *The total landings of edible fish in Danish harbours in terms of volume and value in the year 2000, and the average of 1992-2000. (Fiskeridirektoratet, 2001a)*

	Species	Landing volume [1000 ton]	Landing volume [1000 ton]	Deviation [pct.]
Nr		Year 2000	1992-2000	
1	Herring	288,4 (111 ⁹)	251,5	15
2	Blue mussels	110,6	111,4	-1
3	Atlantic Cod	58,7	80,8	-27
4	Mackerel	36,2	45,0	-20
5	European plaice	23,0	25,5	-10
6	Saithe	14,6	16,4	-11
7	Northern prawn	6,3	7,1	-11
8	Norway lobster	4,9	3,8	29
9	Flounder	4,5	4,4	2
10	Haddock	3,5	5,9	-41

⁹ Used to produce fishmeal and -oil

	Species	Landing value [Million Dkr.]	Landing value [Million Dkr.]	Deviation [pct.]
Nr		Year 2000	1992-2000	
1	Atlantic Cod	925,2	883,3	5
2	Herring	410,5 (85)	413,5	-1
3	Norway lobster	333,3	213,8	56
4	European plaice	278,6	295,1	-6
5	Mackerel	148,8	144,7	3
6	Blue mussels	120,9	79,5	52
7	Northern Prawn	106,5	106,2	0
8	Common sole	81,7	104,2	-22
9	Common shrimp	71,5	64,8	10
10	Angler/Monk	70,3	56,6	24

The data tells that herring, blue mussels, Atlantic cod, mackerel and European plaice are the five most important edible fish species. Together, they make up 88% of the total edible fish landings, measured in volume. In terms of value, Atlantic cod is by far the most important species, followed by herring and Norway lobster¹⁰.

Seven of the species appear among the ten most important species for both volume and value. This is *herring*, *mackerel*, *Atlantic cod*, *European plaice*, *blue mussels*, *Northern prawn* and *Norway lobster*. This suggests that these species are worth considering in the environmental assessment¹¹. It is worth noticing that a significant percentage of the herrings (38%) are used to produce fishmeal and oil (see the numbers in brackets in table 3)¹².

Except from herring, Norway lobster and flounder, the volume of all the landings has declined considerably, compared to the previous decade, especially codfish. Considered as an isolated phenomenon, it must be assumed that this will imply larger environmental impacts per kg caught fish in the

¹⁰ It is remarkable, that blue mussels changes position from a second place in terms of volume to a sixth place in terms of value. It should be stressed that these figures include the mussel shells.

¹¹ Considered isolated, a large volume suggests a large absolute impact, while a high value suggests a high relative impact e.g. for energy consumption.

¹² In this respect, it is surprising that the volume of herring that is used for human consumption decreases from 1999 to 2000, while the amount of herring used for other purposes increases more than 50% in volume. This surely indicates a problem concerning storing facilities on certain segments of the fishing vessels (Fiskeridirektoratet, 2001a).

year 2000 compared to the previous decade. This is especially the case for codfish, while the opposite may be the case for herring and Norway lobster.

“Danish” landings of edible fish in Danish harbours

This section only considers landings by Danish fishermen. The purpose is to further analyze the important flows and to establish for which products Danish fishermen are main responsible (Table 4).

Table 4: The Danish landings of edible fish in Danish harbours in terms of volume and value in 2000, compared to the average year in the period 1991-2000 (Fiskeridirektoratet, 2001a)

	Species	Landing volume [1000 ton]	Landing volume [1000 ton]	Deviation [pct.]
Nr.		2000	1991-2000	
1	Herring	117,6	129,1	-9 %
2	Blue mussels	110,6	112,9	-2 %
3	Atlantic cod	48,3	60,0	-20 %
4	European plaice	21,9	23,7	-8 %
5	Mackerel	18,6	27,2	-32 %
6	Norway lobster	4,7	3,6	+31 %
7	Flounder	4,4	4,0	+10 %
8	Saithe	2,9	3,8	-24 %
9	Northern prawn	3,6	5,0	-28 %
10	Common shrimp	2,3	2,2	+5 %

	Species	Landing value [Million Kr.]	Landing value [Million Kr.]	Deviation [pct.]
Nr.		Year 2000	1991-2000	
1	Atlantic cod	787,9	719,7	+9 %
2	Norway lobster	321,7	209,1	+54 %
3	European plaice	275,5	300,2	-8 %
4	Herring	146,6	210,9	-30 %
5	Blue mussels	120,9	79,7	+52 %
6	Mackerel	80,9	86,2	-6 %
7	Common sole	80,1	100,7	-20 %
8	Hangler/Monk	62,6	51,3	+22 %
9	Lemon sole	53,6	36,0	+49 %
10	Common shrimp	44,6	41,5	+7 %

The data shows that five of the species, herring, blue mussels, cod, European plaice and mackerel, represents a significant amount (87%) of the total Danish landings of edible fish in the year 2000. Seven species appear among the ten most important species with regard to both volume and value. This in-

cludes Atlantic cod, Norway lobster, European plaice, Herring, Blue mussels, mackerel and common shrimp. Thus, if we consider the importance of the total landings, with special emphasis on Danish landings, an environmental assessment should consider *Atlantic cod, Norway lobster, European plaice, Herring, Blue mussels, mackerel, common shrimp and Northern prawn*.

If the Danish landings are compared with the total landings, table 3, it appears that Danish fishermen have a high share of demersal landings (82% and 95% for cod and plaice). However, foreign fishermen contribute with roughly half of the landings of pelagic fish¹³. For shellfish, Danish fishermen contribute with a large proportion of Norway lobster and blue mussels, while foreign fishermen have a large share of the landings of Northern Prawn (~50%).

It is worth noticing that the volume of Danish landings has generally decreased compared to the previous decade. The decrease is roughly 25% for Atlantic cod, mackerel, Saithe and Northern prawn. It is only Norway lobster fishery that has experienced an increase.

Import and export

Denmark is the World's third largest fish exporter measured in value, just after Norway and China. In the year 2000, the Danish import of fish products was valued at Dkr 10.4 billion (thousand millions). Around 60 % of the import was unprocessed products (Fiskeridirektoratet, 2001a).

The same year, the total Danish exports of fish were Dkr 17.2 billion, and 40% was unprocessed (Fiskeridirektoratet, 2001a). Only a minor fraction of the fish products that is landed or processed in Denmark are sold on the domestic market, <5% (Fiskebranchen, 1999). This suggests that Danish consumers have limited opportunities to influence the producers of fish products, also in terms of environmental aspects.

¹³ The foreign nations, which contribute with the landings of herring, are mainly Norway, Sweden and United Kingdom, in this order. Regarding mackerel, it is especially UK, but also the Faeroe Islands and Sweden (Fiskeridirektoratet, 2001a).

The main importing countries of Danish fish products

The main importing countries of Danish processed and non-processed fish products are illustrated in table 5.

Table 5: *The main importing countries for Danish edible fish in 2000 (Fiskeridirektoratet, 2001a).*

	Unprocessed edible fish		Processed edible fish	
	[1000 ton]	[Million Dkr]	[1000 ton]	[Million Dkr]
1	Germany (73)	Germany (1.213)	Germany (106)	Germany (2.690)
2	Holland (39)	France (913)	France (27)	Italy (1.148)
3	France (33)	Holland (724)	UK (24)	UK (897)
4	Norway (43)	Italy (666)	Italy (21)	France (794)
5	Sweden (23)	Japan (544)	Sweden (19)	Sweden (602)
6	Spain/Port. (18)	Spain/Port. (512)	Holland (18)	Spain/Port. (349)
7	Japan (16)	Sweden (496)	Spain/Port. (9)	Swiss (304)
8	Italy (13)	UK (268)	Swiss (6)	Holland (282)
9	UK (12)	Norway (231)	Tjek. Rep. (5)	Norway (130)

Apart from edible fish, which appear in the table, a small amount of industrial fish is also exported, mainly to Norway. Furthermore, a considerable amount of fishmeal and -oil is exported to Norway, Italy, Holland, Spain and Portugal, in that order.

Germany is by far the most market – both in terms of value and volume. Other important export markets are Italy, France and the UK in that order, measured in value. Thus, southern Germany supposedly represent the average distance to the market for Danish fish products.

It is noteworthy that the UK mainly imports processed fish products, while the countries Japan and Holland primarily imports unprocessed products (Fiskeridirektoratet, 2001a).

Considerations about the types of end-products

Figure 1 illustrates the main categories of fish products that are exported from Denmark.

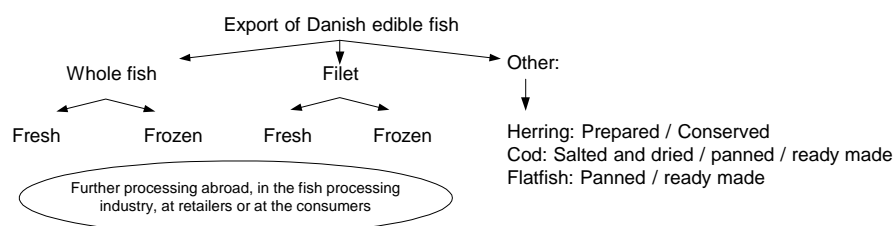


Figure 1: General view of the type of edible fish products that are exported from Denmark, inspired by Fiskeridirektoratet (2001a)

There is only little statistical material available on the precise types of end products that are exported. An analysis is further hindered by the fact that non-processed or semi-manufactured fish products in many cases are further processed abroad (Thrane, 2000b).

However, it has been possible to establish some figures for seven important species, see table 6.

Table 6. Type and amount of export products in the year 2000, based on seven species (Fiskeridirektoratet, 2001a)

	Cod fish	Flatfish	Norway Lobster	Shrimp	Mussels	Herring	Mack-erel
-----Un-processed [1000 ton]-----							
Whole fresh	25,6	27,6	6,8	70,0	26,5	43,3	13,6
Whole frozen	9,0	11,8				1,4	10,6
-----Processed [1000 ton]-----							
Filet fresh	12,2	-				27,9	-
Filet frozen	19,0	1,8				9,0	-
----- Further processed [1000 ton]-----							
Prep. / conserved				23,3	11,1	39,3	13,8
Salted or dried	6,2						
Breaded	13,2 (all fish)						
Ready made	6,3 (all fish)						

On the face of it, it appears that roughly one third of all edible fish (measured in volume) are sold as whole fresh fish; another third is exported as frozen fish (mainly filets), while the last third is exported as preserved or conserved fish.

Cod- and flatfish. As the data shows, cod- and flatfish are exported as whole fresh fish or as fresh or frozen filets including salted, dried, breaded and ready-made products. Further processed products constitutes a significant part of the export. For codfish, the largest meat volume is exported as filets. Here it should be noticed that the filet yield under 50% (see app. 3).

For flatfish, the largest meat volume is exported as whole fish, but filets, including the further processed, also constitutes a significant meat volume. The amount of breaded/ready made dinners is in the same order of magnitude as flatfish filets¹⁴ (Fiskeridirektoratet, 2001a).

Shellfish. The data for Norway lobster are indeed incomplete, but it appears that the largest proportion is exported as whole lobster (fresh and frozen). Whether this covers lobster tails and how many that are frozen, is difficult to tell. Data for shrimps is also rather incomplete. However, it can be established that in terms of meat contents there is probably exported an equal amount of whole shrimps and prepared shrimps. The latter is assumed to include frozen peeled shrimps (IQF) as well as canned shrimps. The meat content is roughly 30% - see app. 3. In terms of mussel meat, it is by far the largest proportion that is exported prepared or conserved. The latter is most likely frozen peeled shrimp (IQF).

Pelagic fish. For herring and mackerel a significant proportion, is exported as prepared or conserved products (mainly pickled herring¹⁵ and canned mackerel). Hence, it appears that pickled herring and canned mackerel con-

¹⁴ The production chief at a large producer of flatfish filets, suggests that around 15% of the 13.200 tons is panned flatfish filets. For ready-made dinners, the same company suggests that around 10 % is based on flatfish. In both cases the remaining is based on Cod, Alaska Pollack, shrimps, hoki, Saithe, Haddock (Company Flatfish, 2003).

¹⁵ For herring, a considerable proportion is packed abroad, especially in Germany (Thrane, 2000b).

stitute the largest volume in terms of meat content compared to the other product categories¹⁶.

Development tendencies

During the 1990s, Denmark experienced an increase in the export of unprocessed fish products of nearly 2 billion Dkr, while the export of processed products, measured in value, remained stable. Measured in volume, the export of unprocessed products increased as well, while the export of processed fish decreased. The export of fish filet, measured in volume, is responsible for the largest decrease – especially for frozen flatfish, which decreased nearly 70%. (Fiskeridirektoratet, 2001a)

The development shows that export of un-processed fish is significant and shows an increasing trend. Thus, an environmental assessment of fish products should ideally include unprocessed products. It also appears that a part of the processing, especially filleting of traditional fish products, has moved downstream in the product chain from the Danish processing firms to processing abroad. The latter may imply that fish offal¹⁷ ends up as waste, instead of being regarded as a by-product used to substitute other food or fodder products. To the extent that the fish are prepared in the kitchen at the use stage the by-products will probably not be used to substitute other products in general.

2.2 Product flow and interactions

The product flow from sea to table, the actors and the characteristics of the different product chains are analyzed in this section. Special attention is given to the interactions between the product chains.

¹⁶ Again, it should be considered that 50% or less of the unprocessed fish can be used as filets – see app. 3.

¹⁷ The term offal is used to describe fish spillage. If the offal is used to substitute other food products, it is considered a “by-product”. If the offal ends up as part of the waste stream, where it may substitute other energy sources, it is described as “waste”.

Product flow

The product flow, as well as main actors and related product chains in the fishery sector, are illustrated in figure 2.

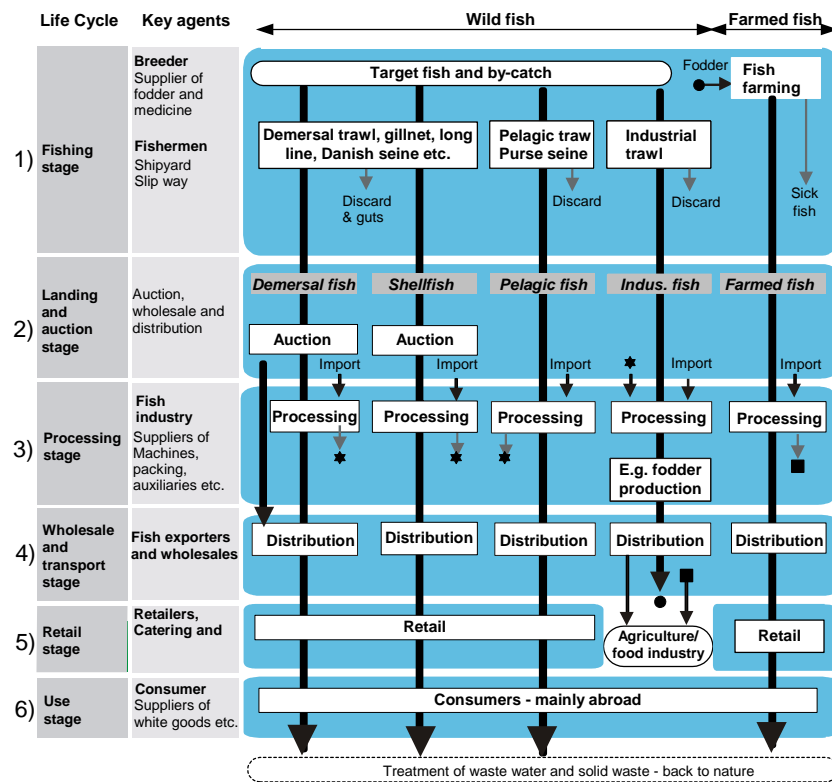


Figure 2: General view of the Danish fishery sector, the product flow and key agents¹⁸ and related production chains. Inspired by Fiskebranchen (1999).

An immediate point is that the fishery sector is a heterogeneous production complex. The sector is characterized by constantly shifting production conditions because the available fish resource depends on quotas, conditions of fish stocks, weather, etc. In addition, there are many actors involved - from

¹⁸ The key agents could also be seen as the agents of change which means that they have a key role in regard to technological change at the given stage of the life cycle

sea to table. In comparison, fewer agents are involved in the production and distribution of dairy products, where one big company "Arla foods" controls the market and several stages in the life cycle. It is reasonable to distinguish between at least five product chains: Demersal fish, shellfish, pelagic fish, industrial fish¹⁹ and farmed fish. The type of activities and the processes can obviously distinguish these product chains at different life cycle stages. However, they also have individual characteristics in relation to environmental aspects. This will be further elaborated in chapter 4-7, but first, something about the activities and the product flow in the five product chains.

The elements in figure 2 are explained further in the following. The numbers 1 to 6 refer to the numbers in the left side of the figure. Several types of fishing gear will be mentioned without further explanations, but appendix 1 contain a detailed description of fishing gear applied in Denmark.

- 1) Edible wild fish consist of demersal fish, shellfish and pelagic fish. Demersal fish and shellfish are **caught** with a wide range of fishing gear covering active/semi-active bottom tending fishing gear (trawl, demersal trawl and Danish seine) and passive fishing gear such as gill net and long line. Passive gear operates without being dragged over the seabed²⁰. Pelagic fish are caught with two types of non-bottom tending fishing gear (pelagic trawls or purse seine). Finally, industrial fish are mainly caught with small meshed trawls that have a light contact with the seabed (Fiskeridirektoratet, 2001b; Hansen, 2002). Some of the catches (both target fish and by-catch) are discarded. For demersal fisheries, this also applies to the fish guts. Farmed fish are not caught but bred in salt- or fresh water ponds. However, the fodder is mainly produced from industrial fish.

Related industries at this stage are shipyards, slipways and suppliers of fishing gear, anti-fouling paint, energy, fodder and medicine.

¹⁹ Industrial fish and farmed fish could be perceived as one product chain because industrial fish per definition is used for other purposes than human food, and because most of the fishmeal and -oil ends up like fodder for farmed fish. Still, I have chosen to distinguish between 5 product chains.

²⁰ Fishing gears may be divided into three categories: Passive fishing gears (such as gill net and long line), semi-active gears (such as Danish seine and purse seine) and active fishing gears such as trawls. Appendix 1 includes a description and illustration of different types of fishing gear.

- 2) When the vessels return to the harbour, the fish are **landed**. Demersal fish and shellfish are typically sorted on the assembly central and sold on fish auctions. Pelagic and industrial fish are often sold directly to the processing industries. This also applies to farmed fish. (Vedsmand, 1998). Related industries at this stage are suppliers of cooling equipment, energy etc.
- 3) The third life cycle stage is **processing**. Demersal fish are typically processed to finished goods (frozen, fresh and breaded filets) in Denmark, but a significant, and increasing part, is exported as un-processed fish. This also applies to shellfish, which is characterized by involving boiling, which is quite energy demanding, at the processing stage. Pelagic fish are also mainly processed in Denmark, but some are further processed abroad, such as pickled herring²¹. Industrial fish are processed into fishmeal and –oil, which is further processed into different fodder products for aquaculture and agriculture. A remaining part is used in the food industry as an ingredient in margarine, etc. Finally, processing of farmed fish only involves degutting. Related industries at the processing stage are suppliers of auxiliaries, chemicals, machines, water and energy as well as industries dealing with waste and wastewater treatment.
- 4) The fourth stage is **wholesale and transport**. As the main part of Danish fish products are exported (95%), transport is an important parameter at this stage, but transport should also be considered between harbour and fish processing industry²² as well as for shopping at the use stage (Fiskebranchen, 1999). Related industries at this stage are suppliers of cooling equipment and energy.
- 5) The fish products end up at **retailers** such as super-markets, local dealers and fresh fish markets. A part of the fish is sold to catering that covers restaurants, hotels, sea- and air traffic companies, etc. (Thrane, 2000 a).

²¹ On the input side, it is worth noticing that the Danish fish processing industry receives large quantities of unprocessed or semi-processed fish from other countries e.g. shrimps, salmon, trout, frozen and fresh cod, frozen flatfish and fresh herring (Fiskeridirektoratet, 2001a).

²² In this regard, it should be noticed that some fish products e.g. codfish caught in Norway are frozen and transported to china where they are filleted, frozen once more and subsequently exported back to the European market (Møller, 2003). However, this is not considered in figure 2, where the focus is the Danish fishermen and the Danish fish processing industry.

Related industries at this stage are suppliers of cooling equipment and energy.

- 6) Finally, the products are bought and **consumed** in the use stage. This mainly involve foreign consumers, which implies that Danish consumers have a limited opportunity to influence the production. Related industries are suppliers of stoves, white goods, water and energy as well as industries dealing with waste and wastewater treatment. Suppliers of private cars and public transportation could also be seen as a related product chain at this stage.

The complexity of the sector and the shifting production conditions, especially in the fishery, makes it difficult to plan the production and to balance the supply and demand. In terms of fishery management, remote fishing activities are basically difficult to control. In addition, the auctions represent a barrier for tracing the history of the fish, that is; who caught them, when, where and how? This is a hindrance for producers and consumers; to place demands to the immaterial product quality²³ and a barrier for product oriented regulation such as eco-labeling. (Lassen, 1996).

Interactions

The product chains described above are not isolated in terms of material flow. Neither is the fishery sector isolated from other sectors. For instance, there is an important flow of fishmeal and -oil, fish silage and offal from the fishery sector to the agricultural sector, where it is used as fodder. The interactions between the production chains are illustrated below - see Figure 3.

²³ According to Lassen (1996) the immaterial product quality is used to describe quality properties that cannot be derived from the product itself. Moreover, it is related to the method or the circumstances by which it has been produced.

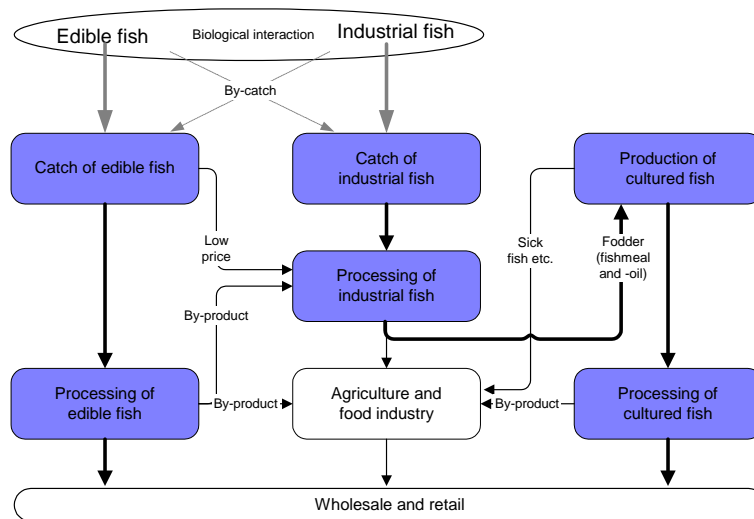


Figure 3: Detailed product flow with focus on interactions between product chains. “Low price” means fish sold below a certain minimum price. Inspired by the Nordic Council of Ministers (2000a) and the Ministry of Food, Agriculture and Fisheries (2001)

As illustrated, there are several links between the different product chains in the fishery sector.

Interactions in the fishery

In the sea, individual fish species do not live in a vacuum. They eat each other and compete for food and space. This is called biological interactions. The biological interactions exist in the relationship between edible fish and industrial fish, but also among edible and industrial fish (Nordic Council of Ministers, 2000a).

Fisheries targeting edible fish also catch industrial fish and vice versa. This is called by-catch or technical interactions (Nordic Council of Ministers, 2000a). As explained, considerable amounts of herring are caught in industrial fisheries.

Interactions in fish processing

Further down the product chain, there are several links as well. Edible fish, which doesn’t obtain the minimum price, is used as raw material in fishmeal production. Herring nearly constitutes 100% of this flow (Fiskeridirektoratet,

2001a). By-products from the processing of edible fish should also be considered. Approximately half of the fish products (in terms of raw material input) that are processed in Denmark end up as by-products. Around 90% of the by-products are used to substitute other food products, while roughly 10% is used for other purposes. (Miljøstyrelsen, 1998b)

Interactions between farmed fish and wild fish

Considering fish farming, the fish that is unfit for human consumption - as well as offal from the processing stage - is used as fodder in mink farming. The waste stream has to be separated from the production of fishmeal and -oil because it may re-circulate pathogen bacteria and virus (Nielsen, 2002a).

Fishmeal and -oil is mainly used as a fodder component in aquaculture. A bold arrow, which symbolizes a large volume, illustrates this²⁴. Fishmeal and -oil is also used as a protein supplement²⁵ in fodder for animal husbandry such as poultry, piglets, cattle, sheep, and furred animals. Furthermore, fish oil is used in the food industry, for example as a component in margarine production²⁶. Finally, a small proportion is used within medical-, paint- and lacquer industries. (Ministry of Food, Agriculture and Fisheries, 2001)

Implications of interactions

Political measures aimed at reducing the environmental burdens such as eco-labeling, should consider these interactions to avoid sub-optimizations.

Interaction in fish processing and Eco-labeling

As an example, it would be irrelevant if an eco-label for farmed fish restricted the use of fishmeal and -oil, based on industrial fish, and instead suggested the use of by-products from the fish processing industry. Such a regulation would hardly reduce the industrial fishery. First off all, there is an increasing demand for fishmeal and -oil because of the growth in aquaculture that depend on fish oil with omega 3 fat acids. Secondly, the industrial

²⁴ The large volume implies that foreign fish farmers are included.

²⁵ Fishmeal as a protein supplement competes openly with other protein sources such as skimmed milk powder, soybean meal, rapeseed meal etc. (Ministry of Food, Agriculture and Fisheries, 2001).

²⁶ In the production of margarine, fish oil competes openly with other oil products such as soy-, rapeseed- and palm oils. In the production of aquaculture fodder, there is currently no alternative to fish oil (Ministry of Food, Agriculture and Fisheries, 2001).

fishery is restricted through quota as the situation is today. Thus, nothing suggests that the demand for fishmeal and -oil is the determining parameter for the production volume (Nielsen, 2002a). Thirdly, nearly all the by-products from fish processing in Denmark are already used to substitute other food products or protein sources. Finally, the production of by-products would hardly increase as a result of increased demand unless the price becomes higher than the price on fish, which is unrealistic.

The result of restricting the fodder for farmed fish to originate from by-products would therefore probably be an increasing demand for plant-based protein sources in other parts of the food sector.

Hence, from a system perspective, such a regulation would be irrelevant, unless the eco-label suggested that the by-products should be imported from countries where the alternative use is waste. In this case it may be a good solution if the extra transport needed to import these products not erode the environmental benefits²⁷

Interactions in fishery

As illustrated in figure 3, there are also interactions between different stocks in the sea ecosystem (that is biological interaction). In this regard, the NGO “The Danish Society for A Living Sea” argue that the industrial fishery results in significant reductions in the catch potentials in demersal fisheries²⁸.

Yet, leading Danish scientists and research institutions suggest that there are no significant potentials by increasing the production of edible fish by reducing the fishery targeting industrial fish, nor vice versa. (Gislason and Kirkegaard, 1999; Nielsen, 2003b). It is not mpossible to verify any of the statements, but it shows one example of the conflict between so-called expert knowledge and “real life” experiences – a common problem in fishery regulation.

It is most likely that species interactions among edible fish are more important as these stocks generally are more exploited. Hall (1999) suggests that the importance of interactions among demersal fish most likely will increase as the ecosystem is pushed towards its limits by overfishing.

²⁷ In this regard, it should be considered that the by-products have a low value to weight ratio. Thus, from an economical point of view, this would also be a questionable solution.

²⁸ <http://www.levendehav.dk/politik/enkeltsager/Industrifiskeri/industrifiskeri.htm>

A large stock of mature cod may be considered desirable in order to sustain the cod population, but as the cod stock impose a predation pressure on other stocks, such as herring and other round fish, it may increase the overall protein output from fisheries if the cod-stock is reduced (Nordic Council of Ministers, 2000a p. 25).

Apart from optimizing the overall output, such a strategy may contribute to a reduction of the environmental exchanges per kg fish protein. The reason is that it increases the abundance of fish, and in the example above, it specifically increases the abundance of pelagic species, which causes relatively small environmental impacts compared to other species – see chapter 4.

Even though this type of strategy sounds persuasive, the truth of the matter is that scientists still find it difficult to predict these dynamics. In fact, modern fishery management is still based on single species assessments, to a large degree, thus ignoring biological interactions (Hall, 1999 p. 224).

Production restrictions

Production restrictions is yet an important factor influencing the flow from sea to table.

Restrictions for the total output from the Danish fishery

As mentioned, each country gets a share of the total quota for all EU countries. It is up to each country to manage their own fisheries. The management goal is to catch as much as possible within the given quota, but considerations also have to be made concerning quality, economy, fish resources, social aspects and market aspects etc.

In the year 2000, Denmark had 63 quotas covering 26 species and 22 fishing areas. With a few exceptions, all fishermen can participate in all fisheries (Løkkegaard et al. 2001).

Production restrictions at vessel level (quota regulation)

Traditional quota regulation. Until recently (year 2003), the production restrictions on vessel level have mainly been related to fish quotas in Denmark (Frost and Jensen, 2001).

This traditional quota system is also called “ration based” quota regulation because the quotas for specific stocks and areas are subdivided in rations for months or weeks. Each vessel gets a quota proportional to the vessel length, and one vessel typically gets several quotas - in some cases up till 30. In the industrial and pelagic fisheries, the number of quota are smaller²⁹ (Frost and Jensen, 2001).

If a vessel catch more than allowed, it will either face an economical penalty or reduced quotas in the following period, depending on the given fishery³⁰ (Frost and Jensen, 2001).

Other types of quota regulation. Since 2003 the quota has become transferable in the Danish herring fishery. This means that quota can be transferred from one vessel to another. Ideally, this would ensure that quota will accumulate in the fisheries that are most efficient (Fiskeridirektoratet, 2004b).

Yet, another type of quota regulation is quota that are given to individual vessels for longer periods, typically for one year at a type. This is called Individual quota (IQ) and has been used in the mackerel fishery (Førby, 2004).

Production restrictions at vessel level (seaday regulation)

Since 2003, the traditional quota regulation in the demersal fishery has been combined with a seaday regulation. This has been introduced as a part of the plans for rebuilding the stocks of cod and it affects most fisheries that have a significant catch or by-catch of cod. The seaday regulation is based on a maximum allowable number days at sea (seadays) allocated to different vessels segments (Fiskeridirektoratet, 2004a). This could be regarded as “input” regulation, but as the fishing vessels still are limited by quota – we actually have a combined input and output regulation. According to Førby (2004) the fishermen have to stop the fishery if they use up the quota, before the number of seadays are fully utilized. Opposite, the fishermen also have to stop

²⁹ In the pelagic fisheries it is possible to conduct pool fishery, where up to 7 vessels share a common quota (Ministeriet for Fødevarer, Landbrug og Fiskeri, 1998).

³⁰ The general rule is that it is not allowed to start fishing on next period's ration, even if the ration for the current period has been caught, until the start of the next period. A vessel can shift between fisheries if the ration for the current fishery has not been caught (Ministeriet for Fødevarer, Landbrug og Fiskeri, 1998).

the fishery if they meet the limit for seadays, before the quota. Thus, in fact the fishermen are faced with two types of production restrictions³¹.

The purpose and result of the production restriction

In the long run, the regulations (quota and seadays) are supposed to reflect the status of the stocks – or the production capacity of the sea. Nearly all the quota that the Danish fishermen have access to, are presently fully exploited³². In cases where the quota has not been fully exploited, the reason is typically that the condition of the stocks has prevented further exploitation. (Ministeriet for Fødevarer, Landbrug og Fiskeri, 1998).

Even though, seaday regulation has been introduced as an “extra layer” of regulation, the quota regulation is still in force. Furthermore, it must also be expected that the number of seadays, allocated to the different vessels, will be continuously adjusted to reflect the catch composition and to meet the overall quota for the whole fishing fleet. This means that by-catch of a certain fish species, let's say cod, in one fishery will reduce the cod quota in fisheries targeting cod – over time. This is important to have in mind with respect to the handling of co-product allocation in the fishing stage, in chapter 4. Another point is that a comparative environmental assessments that compares fish A with fish B hardly would be relevant for consumer recommendations because the demand hardly is an important factor that influences the fishery after different species. Moreover it is the quota which decides the output from fisheries³³.

³¹ The reason for changing towards effort regulation in terms of seadays has been an ineffective quota regulation. The seaday regulation represents a significant change for the fishermen, but the goal remains the same – to keep the exploitation of different fish stocks on a certain “sustainable” level.

³² The European fishing fleet is estimated to have an overcapacity of around 40% (European Commission, 2001a).

³³ If the scale of change is large, let's say all Europeans stops buying cod, there might be a change in prices. But still cod is an attractive product all over the world and we really need a big scale of change to avoid fishermen catching codfish. On the other hand, it is possible to imagine a increase in demand. In this situation, we are stuck with a system that already is providing everything it can. Thus, the system cannot respond to an increase in demand and will ultimately collapse if it tries. Both situations considered (decrease and increase in demand), it is most likely that the affected product system should be found in the agriculture sector or in aquaculture, where it is possible to adjust to consumer demand – at least in some areas (e.g. fish farming in Norway, chicken production or minced pork etc).

2.3 Environmental aspects

This section provides a short description of the types of environmental aspects that are relevant to consider for fish products. The purpose is to establish an overview of the impact types and to provide some indications of their importance. It is not an environmental assessment, but is used as a basis for the delimitation of the analysis of environmental exchanges in part two.

Types of environmental impacts

Fishery faces nature on two fronts: As a production condition and as a consequence area (Lassen, 2000). The external environment is a production condition for the sea-ecosystem, which constitutes a production condition for the fish stocks.

Considering the fishery, it is obvious that fishing has a direct impact on the fish stocks, which influences the sea ecosystem. However, the fishery also has a direct impact on the sea ecosystem through damage inflicted to the seabed (via bottom-dragged fishing gear) and the external environment through the emission of green house gases etc. The impact relationships from sea to table are illustrated in figure 4:

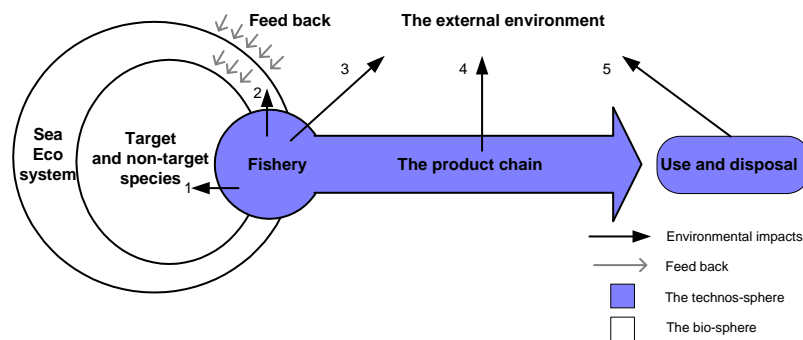


Figure 4: Aspects of environmental impact from fish products. Inspired by the Nordic Council of Ministers (2000b) and Lassen (2000).

The figure is further elaborated in the following.

1) Fishery - fish resource

The fishery has an impact on the fish stocks and other biological resources through catch of fish and by-catch of fish, marine mammals, birds etc. This

is mainly a biodiversity issue, but it also an issue concerning food production. In a wider perspective the exploitation of the fish resources will influence the whole sea ecosystem. The concentric circles in figure 4 illustrate this. (Nordic Council of Ministers, 2000b; Hall, 1999 p. 204).

2) Fishery - sea ecosystem

Apart from the direct impact on target and non-target species, fisheries using bottom-tending fishing gear inflict damage to the seabed. This is a direct impact on the sea ecosystem (see figure 4). Another direct impact on the sea ecosystem is the release of biocides³⁴ from anti-fouling paint that prevents algae and other organisms from growing on the hull of the vessels. Other considerations are lost fishing gear that may continue to catch (ghost netting), solid waste, fish waste, wastewater from tanks etc. (Nordic Council of Ministers, 2000a). Even though the main contributing factor to release of anti-fouling agents is commercial shipping, it is also worth considering fishing vessels, especially because they depend directly on sound fish resources (Foverskov et al. 1999).

3) Fishery - external environment

Regarding the other parts of the external environment, the impacts of fishery are mainly related to the combustion of diesel. Additional factors, which might be considered, are waste brought on land and environmental effects from the slipway, where the vessels are maintained (Thrane, 2000a).

4) Product chain - external environment

The product chain from fishery to use involves the fish processing industry, wholesale and transport. The environmental impacts are related to consumption of energy, chemicals, water and other resources as well as emissions of wastewater and solid waste.

5) Use (consumer) - external environment

Finally, the products are sold to and consumed by the consumers. The environmental aspects are related to transport, storing, freezing, heating, prepara-

³⁴ Biocides are a component in anti-fouling paints being used to prevent algae and other organisms to attach to the surface of the hull (OSPAR 2000, p.1). Biocidal products are defined as: "Active substances and preparations containing one or more substances, put up in the form in which they are supplied to the user, intended to destroy, deter, render harmless, prevent the action of, or otherwise exert a controlling effect on any harmful organism by chemical or biological means" (Lassen et al. 2001)

tion and disposal. This involves energy consumption and emission of wastewater and solid waste. Particular for the use stage, health aspects in relation to consuming the fish is also an issue.

It is important to emphasize that the description above only includes examples of impact types. Occupational health and safety is obviously an issue at practically all life cycle stages as well as land use etc.

Parallel and serial impacts

There are several environmental aspects to consider in the different lifecycle stages. It is obvious that there are many types of parallel environmental impacts like in the fishery, but serial effects should also be considered. For instance, the greenhouse effect and seabed impacts may change production conditions in the sea ecosystem, which in turn may change the abundance and composition of species in a given area³⁵ (Hall, 1999).

2.4 Summary & final comments

The Danish fishery sector (fishermen, auctions, processing industries, wholesalers and retailers) employs a total of about 12-18.000 people, depending on how it is calculated. Most of the employment is concentrated in geographical areas that otherwise have limited economic activities. Employment-wise, the fishery and processing stages are the most important life cycle stages. Occupational health and safety issues are therefore important to consider at these stages.

The employment in fishery and processing has been reduced considerably during the 1990s due to decreasing stocks and increasing competition. The future threats are even further depletion of stocks, competition from other countries, price pressure and demands for sustainable fish products.

³⁵ The latter could be one among several reasons behind the reduction in the cod stocks in the Northeast Atlantic during the last years (Hall, 1999, p. 156). Recent studies suggests that the effect on Atlantic cod as well as other specie such as European plaice and Sandeel may be worse than previously expected - as a result of global warming (Skov- og Naturstyrelsen, 2004).

Landings

The analysis of landings shows that industrial fish, by far, are most important in terms of volume, while edible fish are most important in terms of value. Considering both landing volume and value, it is suggested that the most important edible fish species are Atlantic cod, European plaice, Norway lobster, Common shrimp, Northern prawn, blue mussels, herring and mackerel. Together with industrial fish, these species are therefore worth considering in the environmental assessment in part two and three.

Foreign vessels contribute with a considerable landings of edible fish (roughly 50% of the volume), especially for herring and mackerel. This would suggest that the possibilities to influence these fisheries are relatively limited, as seen from a Danish regulation perspective.

The Danish landings of edible fish (especially demersal fish) have decreased compared to the previous decade. Seen as an isolated phenomenon, this suggests that the environmental impacts per kg caught fish are increasing, compared to the previous decade.

Markets - aspects

The main part of the fish products are exported to other European countries such as Germany, Italy, France Holland and the UK. This implies that Danish consumers have a limited potential to influence the sector. It also suggests that environmental impacts in the use stage should reflect the behavior and technology used in the importing countries.

Another type of market aspects that has been described, is the quota regulation – or the combined quota and seaday regulation, after 2003. Basically, this type of regulation is intended to reflect the natural production capacity of the sea ecosystem which is limited. The special characteristics of fisheries production systems are well defined by the Nordic Council of Ministers (2000a):

“Fisheries rely on living natural resources. These resources are produced through natural processes within aquatic ecosystems without any inducement or control by man. The resource of fisheries are thus limited by natural production processes and subject to the natural variability of the resource system. Contrary to agriculture or forestry, it is not possible to increase or stabilize fisheries production by developing the basic production system”

As all quota can be perceived as fully exploited in the Danish fishery, it is reasonable to assume that by-catch of a given species (e.g. cod) in one spe-

cific fishery is subtracted from the cod quota in another fishery targeting cod. This “logic” is used to handle co-product allocation in chapter 4.

A second point is that a change in demand for fish (as an end-product, and ingredient or as fodder for farmed fish etc). wouldn't influence the production of wild fish. The production mainly reflect the quota or the production potential of the sea (over time). Thus, a comparison of the environmental impacts from lets say “codfish” and “flatfish” is somewhat irrelevant if it is used to regulate the demand. Actually, it will hardly be relevant to compare wild fish with any food products. For instance it is unrealistic to increase the production of cod on the expense of chicken, due to the same production limitations.

Flow from sea to table and interactions

The analysis of the physical flow from sea to table suggests that it is reasonable to sub-divide the fishery sector in at least five distinct product chains characterized by different material flow, processes and environmental impacts.

It is an important point that there are several fishing gear involved in the catch of demersal fish, shellfish and pelagic fish. This shows a potential for substitution of production methods that may enhance the environmental performance.

Another point is that demersal and shellfish are sold at auctions, where they are mixed with other fish. This constitutes a barrier for tracing and consequently also eco-labeling.

Interactions between product chains

Finally, I have addressed the interactions between the five product chains, thus applying “system thinking” in the flow analysis. The analysis of interactions in the fishery not only also suggests that there may be a potential in reconsidering the balances between fish species in the ecosystem in the attempt to maximize the total protein output, but also to reduce the environmental impacts per product volume or protein output.

Further down the product chain, the analysis shows that organic offal to a large extent used for animal feed and even directly as human food products e.g. mince. Hence, an eco-label for farmed fish that promotes the use of fish offal to produce fish fodder will have a very limited effect in Denmark, as the production of protein sources such as soy in other parts of the food sector would have to increase.

Environmental aspects

The chapter has also presented a framework for understanding the different types of environmental impacts. The large biological resource extraction is one of the most obvious aspects that distinguish fish products from many other products. However, there are wide ranges of other exchanges that are characteristic for fish products. This includes impacts on the seabed, emissions of biocides and animal welfare. The latter is much similar to agriculture, but in the fishery it is not applied on the products themselves, but instead on the vessel's hulls to prevent algae to settle. Thus, the impact types are not only centered on the exploitation of the fish stocks themselves, but equally on the way the fish are caught. In this respect, there is also energy consumption, which is an issue at almost all life cycle stages. Also wastewater, packaging, and occupational health and safety are among the environmental impact types that occur in the rest of the product chain.

3

Goal and Scope for MECO Analysis

Part two includes chapter 3-7 which focus on the immediate exchanges³⁶ in the life cycle of Danish fish products. This provides a broad picture of the exchanges in the Danish fishery sector. Each chapter is structured after the MECO-principle, where immediate exchanges are analyzed in relation to four categories: Materials, Energy, Chemicals and Other aspects.

A MECO analysis is typically developed as the initial basis for a life cycle assessment, where it serves as a structured way to organize the data collection. However, in accordance with suggestions in the ISO 14040 standard for LCA, I would argue that separate conclusions can be established from the MECO study as well. Thus, it has been chosen to treat the MECO analysis as a separate analysis with a separate conclusion in chapter 7. As the analysis presents a large number of data, which can be difficult to interpret separately, the reader can choose to read chapter 7 first and subsequently look for more specific data and discussion in the chapters 4 to 6.

The MECO analysis is carried out in a LCA context, and it is necessary for the reader to be familiar with the concept of life cycle assessment. Therefore, this chapter initially provides a short introduction to life cycle assessment according to the ISO standard. The chapter also presents the purpose of the MECO analysis, the products which are analyzed, the scope and the procedure for data collection.

³⁶ An example of an immediate exchange is the consumption of 1 MJ electricity. This does not include considerations of exchanges related to the production of energy as well as the extraction and transport of coal to the power plant. Obviously, this would imply that we used significantly more than 1 MJ electricity. In an LCA, the goal is to include all indirect exchanges as elementary flows.

3.1 Introduction to life cycle assessment (LCA)

The definition of LCA according to the ISO 14040 standard is a compilation and evaluation of the input, outputs and the potential environmental impacts of a product system³⁷ throughout its life cycle (Jerlang et al. 2001).

Definition of LCA

The standard also provides a more detailed descriptions, which explains the phases in an LCA. Here LCA is defined as (Jerlang et al. 2001):

"..a technique for assessing the environmental aspects³⁸ and potential impact associated with a product by:

- *Compiling an inventory of relevant inputs and outputs of a product system;*
- *Evaluating the potential environmental impacts associated with those inputs and outputs;*
- *Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.*

It is emphasized that the environmental impacts needing consideration include resource use, human health, and ecological consequences (Jerlang et al. 2001). LCA studies cannot measure the "real" impacts and it is therefore only the "potential" impacts that are assessed.

The inventory implies a compilation of exchanges from the unit process, which is the smallest portion of a product system for which data are collected. Inputs are material or energy that enters a unit process. Outputs are material or energy that leaves a unit process (Jerlang et al. 2000). Input and outputs (that is exchanges) include non-flow related impacts such as land use, seabed effects or occupational health and safety effects³⁹. All inputs and

³⁷ Collection of materially or energetically connected unit processes which performs one or more defined functions (Jerlang et al. 2000).

³⁸ Element of an organization's activities, products or services that can interact with the environment (Jerlang et al. 2000 p.6).

³⁹ Some research institutions have chosen to use the term "interventions" instead of "exchanges" to stress that non-flow related impact are included, but this is not chosen here

outputs must “eventually” be described in terms of environmental exchanges i.e. elementary flows to or from the environment.

The ISO 14040 framework

The different phases in a life cycle assessment according to the ISO 14040 standard appears in figure 1 (Jerlang et al. 2001).

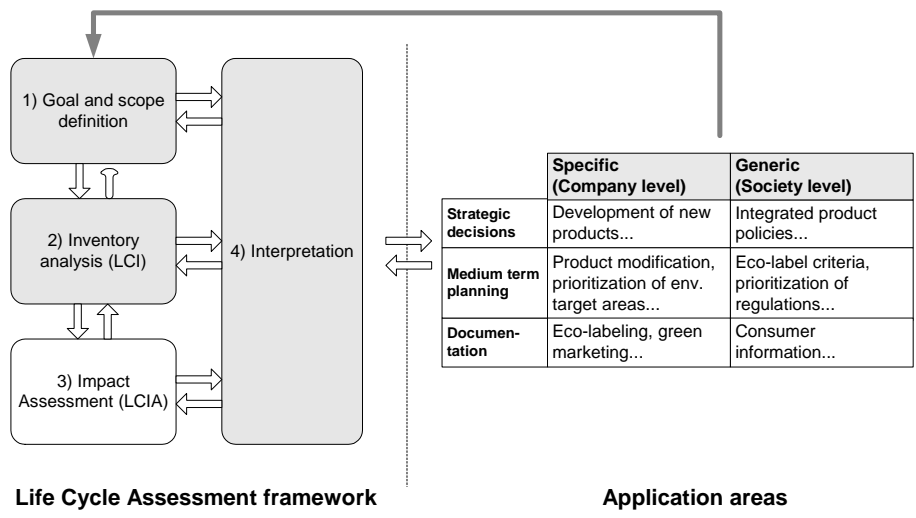


Figure 1: Phases in an LCA and examples of application areas. Inspired by Jerlang et al (2001). Phase three (LCIA) is blank to illustrate that the MECO analysis in chapter 3-7 do not include this phase.

The double arrows emphasizes that it is an iterative process, where changes in all phases may appear continuously as the performer gradually becomes wiser and more focused. Secondly, the application area, the right side of figure 1, is not a part of the LCA method as such. Still, the application areas should be carefully considered as part of the goal and scope definition. For example, studies with a strategic purpose must reflect future situations rather than older data with historical interest, according to Jerlang et al. (2001).

Contents of the four phases

Goal and scope. The first phase includes definition of the goal and scope. Here the practitioner must formulate and concretise the goal and object of the study. The object of study should be described in terms of a functional

unit. The goal and scope definition also description of relevant processes and the methodology applied in the study. The design of the LCA and therefore also the results strongly depends on the purpose of study.

Inventory: The second phase includes data collection for relevant processes, documentation and verification of data. The data must be related to the functional unit defined in the goal and scope definition. Interpretations or conclusions can be drawn from these data alone, but the data can also be used as input for the impact assessment.

Impact assessment: The third phase involves the calculation of relative contributions to different impacts categories such as global warming, ozone depletion etc. If necessary, a valuation is carried out, which can include normalization and/or weighting. Normalization provides a basis for comparing different types of environmental impacts and the weighting step is an evaluation of the importance of each impact category.

Interpretation: The fourth and last phase is basically the conclusion on the study, but besides a presentation of the key results it must include a critical reflection about the study, uncertainty, sensitivity and methodological choices.

A more detailed table of the main content of the different phases is provided in table 1:

Table 1: The main contents of the four phases of an LCA - Inspired by Jerlang et al. (2001). Phase tree is not a part of the MECO analysis illustrated with blank cells.

Phase one: Goal and scope definition	
<i>Purpose of the study:</i> <ul style="list-style-type: none"> • Intended application • Target audience • Functional unit • Product alternatives <i>Scope:</i> <ul style="list-style-type: none"> • Scope definition • Procedure for co-product allocation • Cut-off criteria 	<i>Methodology (not necessary for part two):</i> <ul style="list-style-type: none"> • Impact categories • Method for impact assessment • Key assumptions and exceptions <i>Data collection and treatment:</i> <ul style="list-style-type: none"> • Data types • Demands to data quality • Strategy for data collection • Plans for verification of results
Phase two: Life Cycle Inventory analysis (LCI)	
<i>Data collection:</i> <ul style="list-style-type: none"> • Process description • Collection of quantitative and qualitative data for relevant exchanges associated with the system 	<i>Treatment and description of data:</i> <ul style="list-style-type: none"> • Data treatment (relate to functional unit) • Data quality assessment • Maybe, separate presentation and discussion of results
Phase three: Life Cycle Impact Assessment (LCIA) – only included in chapter 8-10	
<i>Characterization:</i> <ul style="list-style-type: none"> • Classification (Assignment of LCI results to impact categories) • Characterization (Conversion of LCI results to common units and the aggregation within the impact category) 	<i>Valuation:</i> <ul style="list-style-type: none"> • Normalization (Calculation of the magnitude of indicator results relative to reference information). • Weighting (The normalized values are multiplied with a weighting factor)
Part four: Interpretation	
<i>Evaluation:</i> <ul style="list-style-type: none"> • Completeness check • Consistency analysis • Sensitivity analysis 	<i>Results and conclusion:</i> <ul style="list-style-type: none"> • Conclusion and recommendation based on results as well as uncertainty related to data and methodology.

With reference to these terms, the MECO analysis mainly address the two first phases, namely goal and scope (this chapter) and inventory (the following chapters). Still, the conclusion in chapter 7 includes most the elements typically included in an interpretation.

Differences and similarities between MECO and LCA

The MECO analysis mainly distinguishes itself from the LCA, with respect to the depth of environmental mechanism. The MECO study only address immediate exchanges, while the LCA calculates the environmental exchanges (elementary flows), as well as the resulting impact potentials – see figure 2.

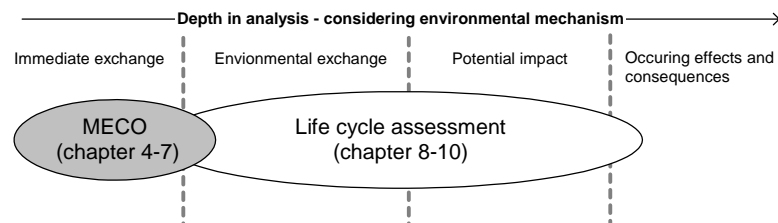


Figure 2. Illustration of the main differences with respect to the environmental mechanism between the MECO analysis in part two and the LCA carried out in part three.

The MECO study only deals with immediate exchanges, while the LCA in part three deals with environmental exchanges and potential impacts (mid-point in the environmental mechanism). The LCA in part three even discuss the chance for the impacts to occur and the consequences of this occurrence in some cases (end-point in the environmental mechanism)⁴⁰.

For the goal and scope as well as the inventory many similarities exist between the MECO analysis and the life cycle assessment – see table 2.

Table 2: Key differences between the MECO analysis in part two and the LCA in part three.

	MECO	LCA
Product types	Wide range (sector perspective)	Focus on flatfish, but the generalization includes screenings of other products.
Exchanges types	Only immediate exchanges	Elementary flows (exchanges with the environment) related to the immediate product chain as well as related product chains
Scope	Exchanges in the immediate product chain are included	Exchanges in related product systems are included.
Impact assessment	No	Yes, in chapter 8 to 10
Comparison across life cycle stages	Yes, mainly in chapter 7	Yes, in chapter 8 to 10
Comparison across impact categories	No	Yes, in chapter 9 and 10

⁴⁰ This is the case when site-specific aspects are discussed and when the consequences of seabed impacts and overexploitation of fish are discussed in chapter 10.

3.2 Purpose of the MECO analysis

The purpose of the MECO analysis is to establish a picture of the environmental exchanges from a wide range of Danish fish products from sea to table. As mentioned in chapter 1, the analysis will serve as a basis for data input to the LCA in part three, but it will also represent a separate analysis which seeks to answer questions such as:

- What are the environmental characteristics for various types of fish products?
- Which life-cycle-stages are environmental hotspots for different types of exchanges such as energy and water consumption?
- What are the improvement potentials considering alternative production methods of cleaner technology?
- What are the development tendencies with respect to technologies and exchanges for different life cycle stages?

Answers to these questions are also the basis for the choice of a relevant product for the life cycle assessment in part three.

The intended applications

The intended application of the MECO analysis (as well as the LCA study) is to provide a basis for a debate about strategic decisions on societal level such as:

- Change and re-focusing of existing types of policies and regulation.
- Introduction of new and more actor- and market-driven forms of regulation

Still, attention will also be given to initiatives at company level, where self regulation by means of environmental management systems is discussed as well.

The target audience

The target audience for the MECO analysis (as well as the LCA), includes authorities, research institutions and companies in the product chain (see table 3).

Table 3: Target audience and application examples for the MECO analysis and the LCA.

Target audience	Examples of application
Generally	Basis for discussion of the concept of sustainable fishery and sustainable fish products.
Authorities	Basis for political and regulatory decisions and measures. Basis for prioritizing measures to reduce environmental impacts from fish products.
Research institutions	Basis for further research in environmental impacts from fish products as well as improvement potentials (e.g. cleaner production methods).
Firms	Eye openers for environmental impacts in other parts of the product chain and for environmental assessment of suppliers.

As the analysis focuses on Danish fish products the target audience is mainly Danish organizations, but the results are also relevant for actors in other countries and international institutions such the European Commission.

The dissertation has been prepared in a neutral research environment (Aalborg University), without being sponsored by specific companies or organizations. However, there are some actors that may be influenced by the results and therefore have real and concrete interests in the project. In the following, I have mentioned some of the most obvious stakeholders and their key objectives. The purpose is also to provide background knowledge for the discussion of regulation in part four.

Professional associations

Important stakeholders among the professional associations include:

- The Danish Fishermens Association (DFA)
- The General Workers Union in Denmark (GWUD)
- The Association of Danish Fish Processing Industries and Exporters (ADFIE)

One of the most important stakeholders in the product chain is DFA, which represents 80% or the total number of fishermen in Denmark. The purpose of the organization is to promote fishery in Denmark and to promote a fishery regulation that meets the interests of the members. DFA works as a consultant for members, and participates in committees and in lobby activities. They have a considerable influence on the national fishery regulation (quota and structural policies etc) through participation in the committees for fishery regulation. (Vedsmand, 1998; Nielsen, 2000).

Another important stakeholder is GWUD, which represent around 2.000 crew-members from all kind of fishing vessels. The principle objectives are to represent the wage earner's interests and that socio-economic factors are considered in the fisheries' policies. (Nielsen, 2000)

Finally, there is ADFIE. The members here are processing firms and exporters mainly dealing with codfish, flatfish, pelagic fish, shellfish and smoking of salmon. There are 100 members representing 80% of the turnover and 85% of the employment in the sector. The principal task of the organization is to carry out market functions related to information services for the members and to represent the interest of the firms on the political level. (Nielsen, 2000).

Companies in the product chain (business network)

It is assumed that the most important stakeholders in the product chain include the following three actors:

- Fishermen
- Processing firms
- Retail

Based on experiences from interviews with fishermen and fish industries in a previous project (the POET project), it must be assumed that the fish processing industry is interested in a continuous raw material supply of sufficient quality at a reasonable price on one hand, and a demand and price structure that enables a sufficient profit on the other hand. This is basically also in the interest of the fishermen, but here it is also important to distinguish between the interests of the small and the large vessels and between different segments of the fishery. It appears that large vessels and the industry have the most similar interests because large vessels are most likely to fulfill the objectives of the fish processing industry – at least short term. (Thrane, 2000b).

The supply from the small vessels will vary more, as their fishery is more dependent on weather, stock fluctuations and other seasonal changes. Consequently, these vessels tend to focus more upon issues related to a sustainable fishery with a larger abundance of fish being the precondition for survival of smaller coastal vessels (Thrane, 2000a).

It must be assumed that the retail's main interests are closely related to the interests of the consumers. However, there are some Danish retail chains,

such as Coop Denmark, that also strive for a green profile⁴¹. Coop Denmark, the former FDB, has launched campaigns to promote organic products and is obviously perceiving itself as having an educational role towards the customers. On a European scale, there are a few large retail chains that are responsible for a significant proportion of the purchase decisions in Europe. Some of these retail chains focuses on the environmental aspects of the products, and in some cases the fish processing industry can expect to obtain a higher price for their products if they have certified environmental and quality management⁴² (Thrane, 2000b).

Actors in the regulatory and political system (regulatory network)

The stakeholders in the regulation network include a wide range of institutions on different levels.

At the local level, municipalities are interested in maintaining economic activity but there is probably also a focus on protecting the local environment against degradation. At the national level, the main stakeholder are:

- The Danish Environmental Protection Agency (EPA)
- The Ministry of Food, Agriculture and Fisheries.

The Danish EPA represent the environmental interests and as explained in chapter 1, the goals are to integrate the environmental dimension in all sector and to obtain a factor 4 reduction in the environmental burden for products in the short and medium term and a factor 10 in longer term. Avoidance of sub optimization and an efficient environmental policy that address the most important environmental problems in a cost-effective manner is among the goals of the Danish EPA (Regeringen, 2003).

the Ministry of Food, Agriculture and Fisheries has the overall responsibility for the regulation of food production in Denmark. However, the Ministry has 10 directorates, each responsible for different aspects of the food production. Concerning the fishery sector, the most important are:

⁴¹ During the last 5-10 years, there have also emerged a number of niche retail chains specializing in organic or eco-friendly products such as the retail chain “Årstiderne”.

⁴² There is also a German retail chain where the exporter signs a paper, guaranteeing that the fish are from sustainable fisheries (Fiskebranchen, 1999).

- The Fishery Directorate
- The Danish Veterinary and Food administration
- The Danish Directorate for Food, Fisheries and Agri Business

The Fishery Directorate is responsible for ensuring sustainable use of the fish resources as well as control of sanitary conditions when the fish are sold, which involves hygiene inspections at sea and where the fish is landed, at auctions, collection centers etc.

The Danish Veterinary and Food administration has the goal to ensure healthy stockbreeding, good standards for animal welfare, and to maintain high veterinary standards in Denmark.

Finally, the Danish Directorate for Food, Fisheries and Agri Business administers EU agricultural policy and EU subsidy schemes for agriculture and fishery. The schemes include subsidies for the modernization of fishing vessels.

Besides, there are two important research institutions, namely:

- Danish Institute for Fisheries Research
- Danish Institute for Food Economics

The first deals with research in relation to fishery, but it also deals with the rest of the product chain. Research includes the impact of fishing and natural changes on fish production and also catch handling, processing and improvement of fish products as well as quality management in the fishing industry.

The Danish Institute of Food Economics concentrates on researching economic aspects of the production, consumption and marketing of food. The institute conducts economical statistics related to both the fishery and the agriculture sector, but also assessment of economical consequences of new policies, rules and regulation.

Research Institutions (knowledge network)

The most important stakeholders among the research institutions are probably:

- The Danish Institute for Fishery Research
- The Institute for Fisheries Management and Coastal Community Development (IFM).

The Danish Institute for Fishery Research is described above. IFM conduct research on socio-economic and institutional aspects of fisheries management, and provides advisory services in Denmark and world-wide.

Other stakeholders

Finally, one of the most important stakeholders is the consumers that influence the sector directly through their purchase behavior. The consumers are represented by the Consumers' Council that participates in the policy process and express the views of the consumers in the political arena. The consumers' council has not elaborated a particular strategy on fisheries and has no detailed knowledge about fisheries' questions. (Nielsen, 1998)

Studies so far do not indicate that the consumers are very conscious about fish products and their environmental impacts in a life cycle perspective. However, overexploitation and discard are issues, which some consumers are familiar with, and some degree of environmental concern can be detected. (Grunert, 1995; Nordisk Ministerråd, 1998a; Nielsen et al. 2001)

The fishery sector is an area with many opposite interests. History has shown that conflicts occur between fishermen, especially large versus small vessels, but also between fishermen and authorities involved in the regulation of fishery. However, fishery has also been involved in conflicts with other "users" of the sea, such as off-shore activities, oil-extraction, waste dumping etc. Considering other actors in the product chain, it is worth considering the fish processing industry which is a strong player and which is interested in a stable supply - as well as the consumers that probably are most interested in fish products that are safe to eat. Still, there is evidence that other aspects related to the way the fish are produced are getting more and more attention amongst the consumers. Examples are overexploitation, by-catch, and discard (Thrane, 2000a; Nordisk Ministerråd, 1998a).

3.3 Product types and functional units

As illustrated in chapter 2, the fishery sector can be divided in at least five distinctive product chains: Demersal, shell-, pelagic, industrial and farmed fish. As these product chains each make up a significant part of the sector either in terms of volume or value, and as they each have individual envi-

ronmental characteristics, it has been chosen to include all in the MECO analysis - except farmed fish⁴³.

Product and process distinctions

In the fishing stage, it has been possible to include average data (mix of different fishing methods) for the catch of nine different species groups: Two demersal species, four shellfish, two pelagic species as well as industrial fish. However, it has also been possible to include data for specific fishing methods and different vessel types for selected species, which elucidates improvement potentials.

At the processing stage, I distinguish between a slightly smaller number of species, but still enough to represent demersal, shell- and pelagic fish separately. Industrial fish are left out because the life cycle becomes a part of the life cycle for farmed fish – see chapter 2. The data collection focuses on typical processes, but data has also been gathered for additional processes, such as smoking and drying.

For the landing and auction stages, I have only distinguished between pelagic/industrial fish and other fish. The reason is that pelagic and industrial fish typically are sold directly from the fishing vessel, while the other species are sold at the auction. At the landing and auction stage, it is assumed that the exchanges are proportional with the weight of the fish and as a consequence, further species' distinction has not been relevant. For all storing processes, that mainly involve energy for cooling, I have only differentiated between:

- Individual quickly frozen fish (IQF)
- Block frozen fish
- Fresh fish and
- Perishables (conserved products that need cooling e.g. pickled herring)

This distinction is made for storing at the wholesale-, retail- and the use stage. The four product categories are chosen because they represent products that typically have a different volume and thus differences in energy

⁴³ Data for the life cycle of farmed fish are available in the LCA food database (www.lcafood.dk).

consumption. Obviously, there are also non-perishables, which are conserved products such as canned mackerel. These products can be stored in room temperature and are assumed to be insignificant in terms of exchanges.

The same distinctions are also applied for transport except that no distinction has been made between IQF and block frozen fish. The reason is that the exchanges related to transport depend on the mass, and there is hardly a weight difference between IQF and block frozen fish.

For shopping in the use stage, no species distinction has been made. For food preparation, data have been gathered for different preparation methods of cod- and flatfish (demersal fish). These data may also be used for shellfish and pelagic fish if served hot, but only in the absence of better data. For dish washing, no species or product distinctions have been made, but the analysis include two types of dishwashing – dishwashing by hand and by machine. All the product and process differentiations made in the MECO analysis are illustrated in figure 3. Obviously, it is possible to make many more distinctions such as in the fishery, where only a few of the possible alternative fishing methods have been included.

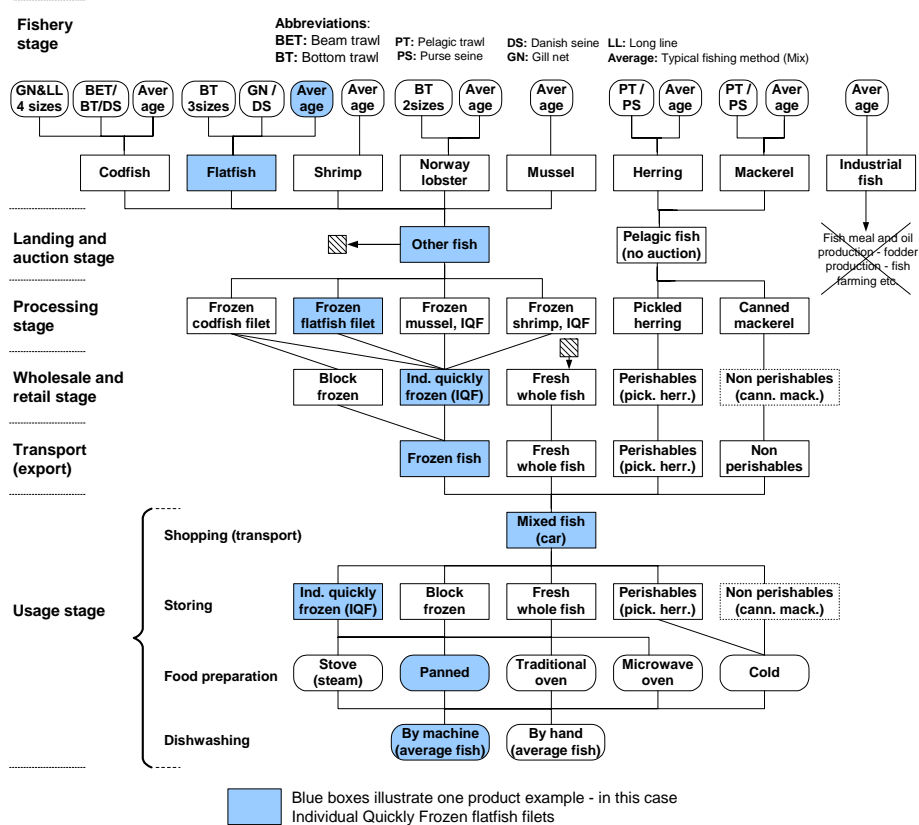


Figure 3. Illustration of different processes (round box) and product distinctions (square box) made in the MECO analysis. The connections show potential scenarios. Dash and dot lines illustrate processes that are considered insignificant in terms of exchanges.

The links between the boxes illustrates different ways of combining the life-cycle stages. In this regard, it is possible to connect storing of pickled herring (in the use stage) to cold food preparation, but not to stove and oven, because pickled herring is consumed cold and never hot.

In the conclusion of part two (chapter 7), eight different scenarios are made, but it is possible to make more. Especially if we consider different fishing methods, different types of anti fouling agents, cleaner technology in the processing stage and special processes such as drying and smoking of fish. The blue boxes illustrate one of the eight scenarios representing consumption of IQF flatfish filets.

Reference flows and functional unit

In the MECO analysis, exchanges are analyzed relatively to one kg output at each life cycle stage except fishery, where it is one kg input in terms of catch. As described in app. 3, it requires an input of more than 3 kg caught fish to provide one kg consumed fish, depending on the species. It has therefore been necessary to include considerations of material loss in the conclusion (chapter 7) where the eight scenarios are described per kg consumed fish. The scenarios are one kg of consumed:

- Codfish (block frozen filet in cardboard box)
- Flatfish (IQF filet in cardboard box) – see figure 3 (blue boxes)
- Prawn (boiled, peeled IQF in cardboard box)
- Shrimp (boiled and peeled IQF in cardboard box)
- Mussel (boiled and peeled IQF in cardboard box)
- Herring (pickled in jar)
- Mackerel (filet and canned)

The scenarios can be interpreted as the functional units. However, it is not what we normally understand as a functional unit such as the consumption of fish for one person in one year. Moreover, it is a series of production scenarios that provide a picture of the environmental exchanges for different product chains in the fishery sector. The basis for choosing exactly these end-products is the analysis of typical end-products in chapter 2 (table 6).

Product alternatives

Often the purpose of a MECO or LCA analysis is to compare the environmental impacts from two or several products. An example of this type of “comparative” analysis would be an assessment of the environmental consequences of choosing codfish (A) instead of flatfish (B) in the supermarket. In this case the object of study must be carefully described in terms of a functional unit⁴⁴. It should be assessed if 1 kg of fish A actually can be compared to one kg of fish B or if other properties than the weight should be considered. This could be the protein content, energy content, the content of omega 3 fat-acids combined with other qualitative factors such as taste. In certain cases it can also be relevant to consider if the two products are comparable with respect to market segments and non-market relevant product properties. If a large price difference exists between the two functional units, the ideal

⁴⁴ A functional unit is defined as a quantified performance of a product system used as a reference unit (Jerlang et al. 2001)

analysis would also require considerations of marginal spending and rebound effects (Weidema, 2001a).

As described in chapter 2.4 it is not relevant to compare different fish species or even fish species compared to other food products – at least not if the purpose is consumer recommendations or regulation of the demand after different fish species in other ways. A traditional comparative assessment between different species is therefore irrelevant and the functional units can be defined in a simpler way. The purpose of this dissertation is to elucidate hot-spots⁴⁵ and improvement potentials, but the latter is analyzed through different production scenarios⁴⁶ for a given species, rather than adjustments of the output of different species.

Production alternatives

As argued, it is more interesting to focus on alternative production methods, especially in the fishery where previous studies suggest that there are substantial differences in the environmental burden as a function of the applied fishing gear.

Product alternatives come into the picture by the back door. As an example codfish may have different properties concerning quality and price, depending on the catch method. Furthermore, some fishing methods may depend more on weather conditions and therefore only deliver fresh fish when the weather allows. However, these aspects are not further elaborated but instead taken into consideration in the conclusion of part two.

⁴⁵ It is still relevant to elucidate the environmental burden related to different fish species, because the hot spots may change from one product chain to the other, depending on species.

⁴⁶ Obviously, this can also be understood as product alternatives, and in a future situation with eco-labeling of fish products, the consumer might be able to choose between codfish produced in different ways.

3.4 Scope

The scope of study as well as methods for co-product allocation and cut-off criteria are described in the following.

Temporal scope

As mentioned in chapter 1, the intended use of the MECO analysis is as a basis for debate and considerations about the future policies and regulation of the fishery sector. This is mainly related to the political level but also strategic decisions and concrete measures at the company level. According to Jerlang et al. (2001) it is important that there is a correlation between the temporal scope of the study and the intended application, as illustrated in the table below:

Table 4: Illustration of different types of intended application area and the demand for validity of the environmental analysis, based on Jerlang et al. (2001).

Demand for validity	Focus: Actor oriented	Focus: Society oriented
Long perspective (Future estimates are essential)	(*) Strategic product development or strategic environmental management	(**) Strategic planning – e.g. environmental and fishery policies
Five years ahead	(*) Development of cleaner products and prioritization of environmental target areas	(*) Development of criteria for eco-labeling fish products
Historical	Documentation of and compliance with criteria for eco-labeling	Consumer information

The main purpose is strategic planning on the societal level (see **), but I will also discuss strategic initiatives and development of cleaner products at company level as well as development of eco-label criteria at the societal level (see *). As it appears, the validity needs to have a long time perspective for studies of this character, as the implications of strategic planning typically reach well into the future.

Forecasting

Hence, the analysis should include future estimates that reach 10-15 years ahead. It is not necessary to make future forecasts for all parameters and processes. It is most important to focus on processes or products that are

expected to have an atypical development tendency⁴⁷. However, it is initially necessary to know at least something about all processes and products to be able to conclude where these atypical development tendencies will appear. Therefore, chapters 4 to 6 include future estimates of all involved processes, while the conclusion of the MECO analysis (chapter 7) will concentrate on the processes and products for which the development is believed to be both atypical and significant.

The reason is that the goal of the study is to establish a part of the knowledge basis for policies and regulatory measures that may be implemented gradually over the next decade and which may stay in effect for another decade. Hence, although they are somewhat uncertain⁴⁸, future estimates have been developed as a basis for the best possible recommendations of strategic character, i.e. product oriented policies.

Methods for future estimates

On the practical level, future estimates are based on different methods and different levels of detail. In most cases, the estimates are based on simple prediction. According to Pesonen et al. (2000), this is defined as estimates based on general development tendencies and assumptions. These types of estimates are not based on thorough assessments.

For energy consumption and consumption and emissions of anti fouling agents at the fishing stage, the estimates are based on more thorough assessments. For energy consumption in the fishery the estimates are based on considerations of historical trend as well as future regulation

For anti fouling agents, two scenarios are developed based on information from one of the largest producers of anti fouling agents (Hempel) as well as anticipated future regulations.

As described by Pesonen et al. (2000) this type of estimates are more advanced and are therefore expected to have a higher certainty.

⁴⁷ These also include indirect processes such as energy production, but this will be discussed in part three.

⁴⁸ The uncertainty is partly related to changes in the market situation, which may influence which processes are being affected, but obviously also the assumptions about technology development (Weidema, 2001a).

Geographical and technological scope

The following sections presents the geographical and technological scope, but also touch upon theories about market based system delimitation according to Weidema (2001a).

Geographical scope in the “main” product chain

The problem formulation poses the question: How may Danish authorities and actors within the Danish fishery sector effectively promote cleaner Danish fish products?

Thus, in this study, we deal with possible measures taken by the Danish authorities or Danish companies addressing Danish suppliers, which limits the scope to Danish fishing vessels, Danish fish industries, Danish auctions and Danish wholesale and transport.

Whether Danish retail and consumers should be included in the scope can be discussed, as it is only about 5-10% of the products, which are sold in Denmark. I have chosen to focus on foreign retailers and consumers because this represents the largest market volume⁴⁹.

Technological scope in the “main” product chain

For other technological factors, it is the intention to establish data for the average Danish technology, representing average Danish enterprises, processes and materials used. One of the reasons for choosing an average situation is that the purpose of the hot-spot analysis is to provide information about the typical situation concerning distribution of exchanges among the life cycle stages. In other words, the scope is limited to ordinary companies and average technology at all stages in the attempt to reflect a sector average. However, it is important to stress that descriptions of alternative production methods and cleaner technology are included in nearly all stages with the purpose of elucidating improvement potentials.

Market based system delimitation and related product systems

It has been argued that the relevant processes in the “main” product chain are fixed geographically and technologically. However, it is also necessary to

⁴⁹ It may be debated how much Danish authorities and companies can affect foreign consumers, but they may be influenced by the way products are designed (e.g. the volume of marinade in pickled herring) and preparation suggestions (e.g. concerning preparation in microwave).

consider system delimitation in relation to interactions with other product systems. The affected suppliers cannot in advance be fixed geographically or technologically. Weidema (2001a) suggests that market based system delimitation should be applied to isolate the suppliers or at least the most probable suppliers⁵⁰. In this context, the geographical and technological scope becomes secondary - or at least it becomes a function of the analysis of the affected suppliers.

Weidema (2001a) presents a detailed method to assess the processes affected by a change in demand for a product or intermediate product at any stage of the life cycle. The method involves considerations about scale and time horizon for the investigated change, market delimitation, market trends, and production limitations.

The method is not further described here except at the first point, where it can be established that we are focusing on a relatively small or marginal change over a medium to long time horizon. In other words, the study does not suggest or imply large-scale changes that may change market trends and the technological infrastructure.

The system delimitations in relation to handling systems with more products are further elaborated in the following.

Systems with more products

Market based system delimitation is also used to avoid co-product allocation by means of system expansion. Product systems often deliver more than one product. In other words, we typically have one (or several) determining products and one or several dependent products (by-products) leaving a unit process or a product system⁵¹. An example of a determining product is cod-

⁵⁰ In this regard, Weidema argues that traditional delimitation of the scope to all processes within a specific country and a specific level of technology is arbitrary. In other words, it does not reflect what really happens in a socio-economic context (Weidema, 2001a).

⁵¹ According to Weidema (2001b) the determining product is the product that determines the production volume of a process. That a product is determining for the production volume of a process is the same as saying that this process will be affected by a change in demand for this product. The determining product often re-

fish from a fishery targeting codfish. Other fish species caught at the same time (by-catch) could be considered as dependent product, in this situation. Obviously, it could be argued that no-products are determining in the fishery, because an increase in demand hardly will affect the production of any products, as the system is limited by quota – see chapter 2. However, in praxis the fishermen will often target certain species, that will be determining for the fishing gear applied as well as the fishing ground etc.(see app. 1 and 2)

The ISO 14040 standard suggests that co-product allocation should be avoided (item 1 and 2), while underlying physical relationship should be applied if this is not possible (item 3). Mentioned as the last option is co-product allocation according to economical value (item 4). Thus, the standard suggests the following methods to handle systems with more functions:

- 1) Divide the unit process to be allocated into two or more sub-processes and collect the input and output data related to these sub-processes (co-product allocation is avoided)
- 2) Expand the product system to include the additional functions related to the co-products, taking into account the requirements of functional unit (co-product allocation is avoided)
- 3) Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationship.
- 4) Where physical relationships alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way, which reflects other relationships between them, e.g. based on considerations of value. (Jerlang et al. 2001).

The following sections describe the methods applied at different stages of the life cycle in the MECO analysis.

flects the largest revenue of the co-products. A more detailed procedure for identification of determining and dependent co-products is available in Weidema (2001a)

Handling of co-products in fishery

Many fishing vessels have a considerable amount of dependent products in the form of by-catch. Thus, co-product allocation is definitely an issue at this stage. To avoid co-product allocation, I have applied a combination of subdivision of processes (item one) and system expansion (item two) for energy consumption as well as consumption and emission of anti fouling agents⁵². For other exchanges, co-product allocation has been handled by considering the underlying physical relationship, which has been mass in all cases.

System expansion can be understood in the context of market based system delimitation. First, we ask : Which processes or products are affected by a change in the production of each of the dependent products (the by-products). These products or processes can be identified by the same procedure as described for system delimitation according to Weidema (2001a). In chapter 2.2 it was established that the production restriction represented by the quota system, theoretically result in a situation where the bycatch in one fishery would displace the target fish quota in another fishery. This is further elaborated in the following.

The principle is the following: Given a fishery A, defined by targeting fish A (the determining product) and having fish B as by-catch (dependent product), and given fishery B, defined by targeting fish B and having fish A as a by-catch, the following is true under certain circumstances. Considering a long period of time, by-catch of fish B in fishery A substitutes a proportional quota of fish B in fishery B. Likewise the by-catch of fish A in fishery B substitutes a proportional quota of fish A in fishery A. The result is a regression where certain products or quota displace other products/quota. Preconditions for this to be true are the following:

- 1) At a sector level – all quota must be fully exploited though not over-exploited over a longer time perspective

⁵² In the present dissertation, it has been chosen to estimate the exchanges in the fishery based on both system expansion, mass allocation and economical allocation. There are two reasons: First of all, mass and value is still used for co-product allocation in other studies such as Ziegler (2003) and Tyedmers (2001), and comparisons with other studies are therefore only possible if the same method is applied. Secondly, system expansion is also based on assumptions that may not be true in all cases (this is discussed in the following paragraphs). However, it should be stressed that the results based on system expansion is believed to reflect reality most accurately.

- 2) At vessel segment level - overfishing must be punished by subtraction of a proportional quota in the following period or equivalent measures with the same effect, such as fines.
- 3) At vessel segment level - underutilization of the quota will result in increased quota in the following period – typically allocated to other vessels segments

Ad 1) According to the Ministeriet for Fødevarer, Landbrug og Fiskeri (1998), nearly all the access quota of the Danish fishermen are presently fully exploited. In situations where this is not the case, the reason is related to the availability of the stocks. Therefore hypothesis 1 can be regarded as being partly fulfilled – bearing in mind that it will never be possible to hit the quota limit exactly. Further details about quota restrictions are available in chapter 2.2.

Ad 2) If a vessel, a group of vessels or the whole fishing fleet catches more than the allowed quota, there are various restrictions. The fishery is either stopped for a period of time, the quota is reduced in the following period, or a fine is given (Frost and Jensen, 2001). The purpose of these restrictions is to reduce the fishery or to compensate for overexploitation. For further details, also about seaday regulation, see “production restrictions” in chapter 2.2.

Ad 3) If the opposite is the case (quotas are not fully utilized), the regulation respond will typically be adjusting (increasing) the quotas for other vessels⁵³, targeting the same species in the following periods (Frost & Jensen, 2001). In the long run, it is therefore reasonable to assume that assumption 3 is fulfilled as well. If we consider the situation around year 2000, the preconditions are therefore almost 100% fulfilled⁵⁴.

⁵³ This may be other Danish vessels or vessels in other countries. In this regard, it is also worth mentioning that the countries swap and trade quota between themselves with the purpose of maximizing the economical output. If Denmark fishes more herring than the quota suggests, we have the opportunity to swap a part of another fish quota with a herring quota from another country (Frost & Jensen, 2001).

⁵⁴ There may be situations where this is not the case. For instance, some quota may not be fully utilized in some years, and marginal changes may not cause proportional changes in quotas in other fisheries, but considering a long time perspective, it is assumed that the preconditions are generally met.

One aspect that has not been discussed is to which extent a reduction in quota for a given vessel / -segment will reduce the fuel consumption proportionally. In the short term, this is probably not the case because of structural conditions such as investments in fishing gear etc. However, it is reasonable to believe that it results in a proportional reduction in fishery intensity and therefore also energy consumption in the longer term because the overcapacity will be reduced gradually over time. All in all, it is assumed that the assumptions to a large extent are fulfilled.

Matrix inversion

At first glance, to conduct a co-product allocation in fishery by means of system expansion seems an overwhelming task of regression. There are multiple product systems (fishing vessels or categories of vessels) with multiple outputs (target fish and by-catch). However, the problem can easily be solved by linear algebra (matrix inversion).

The procedure can be explained by an example with two fisheries and two types of output (one target fish and one type of by-catch). If we want to establish the fuel consumption for fish species A (according to previous definitions), a data matrix can be established with information about catch volumes and fuel consumption:

Table 5. Example of a data matrix with information about fuel consumption, total catch and catch composition

	Fishery A	Fishery B
Total fuel consumption	50 liter	100 liter
Total catch	100 kg	100 kg
Catch of fish A	80 kg	20 kg
Catch of fish B	20 kg	80 kg

If we are interested in knowing the relative fuel consumption for one kg fish A, we simply solve two equations with two unknowns that looks like this:

$$80X + 20Y = 1 \text{ (kg fish A)}$$

$$20X + 80Y = 0 \text{ (kg fish B)}$$

X is the necessary output from fishery A, and Y is the necessary output of fishery B, needed to provide a total output (considering both fisheries) of one kg fish A.

Solving the second equation is relatively easy, and the result is obviously:

$y = -1/4x$. Insert this result as Y in the first equation and the first equation becomes: $80x + 20(-1/4x) = 1$. Result: $x = 1/75$ and $y = -1/300$.

In other words, we need $1/75 \cdot 50$ liter fuel from fishery A and $1/300 \cdot 100$ liter from fishery B. The total is $2/3$ liter – $1/3$ liter = 0,33 liter diesel per kg fish A. Using the same calculation principle, the fuel consumption is 1,167 liter per kg fish B. The result can be verified by multiplying the total catch of fish A with 0,33 liter and the total catch of fish B with 1,167 liter. The result is 150 liter, which is the correct figure for the total energy consumption.

Obviously, fuel consumption would have been 0,5 liter per kg fish A and 1,0 liter per kg fish B if the calculation had been based on mass allocation. The results of different allocation methods is illustrated below:

Table 6. Results based on system expansion and mass allocation

	System expansion	Mass allocation
Fish A	0,33 liter per kg	0,50 liter per kg
Fish B	1,16 liter per kg	1,00 liter per kg
Verification (total fuel consumption)	0,33 liter per kg * 100 kg + 1,16 liter per kg * 100 kg = 150 liter	0,50 liter per kg * 100 kg + 1,00 liter per kg * 100 kg = 150 liter

In the MECO analysis, I have divided all of Danish fishery in nine fishing categories and nine species groups. Hence, the matrix is not a 2x2 matrix but a 9x9 matrix. When operating with such large matrixes, it is convenient to use matrix calculation (linear algebra), where excel can be used to solve the system of linear equations in a few seconds. However, the logic is still the same as shown above – see chapter 4 and app. 5 and 6.

Co-products at the processing stage

At the processing stage, there is also a number of co-products. For processing of demersal fish, the products include fish filets (the determining product) as well as “dependent products” such as mince⁵⁵ and fish offal. The latter is used for mink fodder and production of fish meal and oil. These products substitute other protein sources and ideally the avoided environmental exchange should be taken into consideration. However, this has not been

⁵⁵ Mince is fish meat from white fish e.g. flatfish or codfish that is not a part of the filet, but derive from between the fish bones. Mince is typically produced on special mince machines based on vacuum and is used to produce meatballs or fish fingers etc. Mince is typically frozen down at the factory before being dispatched.

done in the MECO analysis, where all the exchanges have been allocated to the determining product instead. The result is that all the exchanges are somewhat overestimated. Avoided exchanges are included in the LCA study in part three (chapter 8-9).

Co-products during the landing and transport stage

At the “landing and auction” stage, as well as for transport, co-product allocation has been dealt with by considering the underlying physical relationship, which has been mass in both cases. For the landing and auction stages, processes such as grading and selection are proportional with the mass of the products, and the same applies to ice consumption. Volume considerations may also reflect the exchanges for some processes, but as the volume and the mass are quite similar at this stage, mass has been chosen as the variable that reflects the physical relationship best.

Information provided by one of the largest fish exporters in Denmark suggests that mass is determining the maximal load on each truck (Therkelsen, 2003). Therefore, mass has been chosen as the variable for co-allocation for all transport processes, except for transport related to shopping at the use stage (explained later).

Co-products during storage (wholesale and use stage)

Co-product allocation for storing during wholesale and the use stage is based on volume. The reason is that the products are already frozen⁵⁶ when they enter the storing process and that the volume will be the determining parameter for the size of the storing room, even if it is a household freezer. Further argumentation is presented in the respective chapters. This is also an example of co-product allocation according to the physical relationship.

Co-products for other processes at the use stage

At the use stage, a number of allocation methods have been applied. As mentioned, volume is used in relation to storage. For transport during shopping, co-product allocation is based on economical considerations. Alternative methods for allocation could be mass, volume, energy content or durability. In this regard, value, has been assessed to be the best alternative⁵⁷.

⁵⁶ There may be some heating of the product during transport but this has been disregarded here.

⁵⁷ We need to isolate the key parameters that influence the marginal shopping frequency and the marginal shopping distance. I would argue that it is not possible to isolate one variable that always is determining for all products. When distinguishing

Co-product allocation for food preparation is handled by system expansion. Allocation has been necessary because recipes contain other ingredients than fish, which are considered the determining product⁵⁸. In this regard, the avoided exchanges have been estimated by the exchanges typically needed to prepare the other ingredients separately⁵⁹.

For dishwashing, the exchanges have been handled by allocation after the energy content. In this regard, it is assumed that the number of servings are proportional with the energy content and therefore also the number of dishes that have to be washed. The result would have been roughly the same if mass allocation had been used – see app. 8. It could be argued that detailed considerations of the underlying causal relationship would include considerations of fat content in the dinner (especially for dishwashing by hand). It could also be argued that the meat content of the dinner varies considerably according to the chosen recipe and that considerations of the average energy

between fresh and frozen fish, it is presumably the durability, which is the most relevant parameter, but it has not been able to develop a method, which can be used in praxis. In this regard, it is worth to note that the consumers buy a lot of other things, where durability could turn out as an irrelevant allocation parameter.

It is also difficult to argue that mass or volume should be the key important parameters when we consider transport with car – at least it would hardly be the general case. Thus, it is chosen to use value as the default allocation parameter. It can be argued that expensive food products often influence the composition of meals. Fish products are relative expensive and therefore the most important parameter for the purchase decision, the choice of supermarket etc. Accessories are typically cheaper and therefore represent a smaller impact potential according to this method, which seems plausible. It is also worth to note that the turnover in supermarkets increases each month around pay day (Klüwer, 2004). This suggest that economical aspects, is an important factor for the amount of groceries purchased per shopping trip – supporting that value based allocation is plausible. Finally, I would argue that the consumer tend to buy small and relatively inexpensive things in the local kiosk while more expensive items tend to initiate shopping in larger malls and supermarkets, which generally require longer traveling distance. This suggests that there is a proportionality between the traveling distance and the money spend, which is an important argument for value allocation.

⁵⁸ I would argue that the fish is the most important parameter for the type of recipe that is used. Thus, it is the fish, which affects the choice of other ingredients as well as the preparation method (not vise versa).

⁵⁹ In this regard, I have considered the avoided exchanges from the preparation of these vegetables separately on a stove (the typical method for preparation of vegetables separately).

content are somewhat inaccurate. However, the allocation based on energy content has been chosen as the best default solution in this case.

Cut-off criteria

It has been the goal to include material flows of more than 0,1% of one kg fish product dispatched from the processing stage. In this regard, it should be noted that exchanges in the fishery should be multiplied with a factor that reflects the loss of mass from the catch to the processed fish products. For emissions, exchanges below this level have been included, but this is mainly due to some inputs being split up into emissions to different compartments. Besides this, exchanges under 0,1% are included in a few cases where the consumption or emission have been considered to have a significant impact potential. This is the case of anti-fouling agents and lead used in the fishery as well as HFC based cooling agents used in the fishery in retail and at the use stages.

The cut-off criteria for energy consumption have been 0,1 MJ per kg frozen fish dispatched from the processing stage. It is most likely that energy consumptions over this limit, as well as flows over the limit of 0,1%, has been incidentally disregarded, but considering the wide range of processes that are described, it must be considered inevitable.

3.5 Data collection and treatment

The following described key elements of the data collection and treatment, including data types, data quality goals, strategy for data collection and plan for verification of data.

Data types / -categories

As mentioned in chapter 2, there is a broad spectrum of environmental impacts that should be considered in the fishery sector, especially in the fishing stage. In the MECO analysis, it has therefore been sought to include a wide range of exchanges including sea floor impacts and occupational health and safety. The data categories and immediate exchanges that is included in the MECO analysis is listed below with an indication whether they are described quantitatively or qualitatively or both.

Materials

The analyzed material related exchanges are illustrated below. It is important to emphasize that some exchanges are mainly described qualitatively – which is indicated in brackets.

- Impact on fish stocks (mainly qualitatively)
- Discard and guts, discard of fish
- Consumption and emission of packaging
- Consumption of water and emission wastewater
- Consumption of ancillaries
- Production / emission of waste
- Production / emission of co-products
- Consumption of ice
- Consumption and loss of fishing gear (effects such as ghost netting are only considered qualitatively)

As shown, there are a long series of data categories. However, it is important to stress that the MECO analysis only consider immediate exchanges and that some data categories are disregarded at various life cycle stages because they are estimated to be below the cut-off criteria.

Energy

The energy consumption included at all life cycle stages. The MECO analysis specifies whether the energy consumption is electricity or heat energy, which may be generated by oil, gas or co-generated with electricity. The energy analysis include data for the following processes:

- Energy consumption for fishery - as a function of fish species (nine different species), vessel size and fishing gear.
- Energy for different types of fish processing, considering five types of end-products representing six different species.
- Energy consumption for cooling processes at landing and auction, wholesale, retail and use stage.
- Energy consumption for transport processes – with focus on distribution and shopping.
- Energy consumption for food preparation and dishwashing.

All energy exchanges are measured in MJ (primary energy) to make comparison easier. As for other exchanges, it is important to consider material loss when comparing exchanges at different life cycle stages. Data about material loss are available in app. 3. Chapter 7 includes a comparison for

selected exchanges such as energy and water per kg consumed product covering all the life cycle stages.

Chemicals

The analysis of chemicals includes the following types of exchanges:

- Consumption and emission of anti-fouling agents
- Consumption and emission of cooling agents
- Consumption and emission of cleaning agents
- Consumption and emission of process chemicals
- Hazardous waste
- Waste water (organic and chemical effluent)

As it will appear in the MECO analysis, several of the chemical exchanges are included even though they are below the cut-off criteria. The reason for this is that these chemicals are considered to be especially important in terms of potential environmental impacts. Chemicals such as cleaning agents are considered as one group of chemicals instead of individual brands of cleaning agents.

Other

Finally, there are a series of data categories that doesn't belong to some of the previous categories. This includes the following exchanges:

- Human health and safety
- Impact on the sea floor (mainly qualitative)

Additional aspects are discussed in the qualitative LCA in chapter 10 – this includes land use and animal welfare.

Data quality goals

The following section contains a description of the data quality goals for the direct⁶⁰ exchanges in the MECO analysis. According to Weidema (1998), the

⁶⁰ It is important to emphasize that demands to data quality only concern the immediate exchanges. Thus, the quality demands obviously address Danish fishermen and processing companies but not Danish producers of diesel oil and ancillaries such a soy protein. Data quality demands including indirect exchanges of this character will be further described in part three.

data quality goals can be reduced to five key parameters, namely temporal scope, geographical scope, technological scope as well as reliability and completeness. The method is further described in app. 4.

Demands to scope

As mentioned, it has been the goal to describe the present situation (status quo) as well as assessments of future developments – reaching 10-15 years ahead.

As mentioned, the geographical scope is limited to fish products caught by Danish fishermen, landed in Danish harbors and produced in Denmark. Thus, the geographical scope is the national boundaries of Denmark. However, as most of the products are exported and consumed in other countries, the data must reflect this. In regard to the technology factor, it is the intention to establish data for average Danish technology, representing average Danish enterprises, processes and materials used.

Demands to reliability and completeness

As the analysis will encompass a large number of processes and materials, it has been necessary to accept data with a relatively low degree of reliability and completeness in some cases. However, demands to reliability and completeness in fishery and processing stage have remained on a relatively high level as previous LCA-screenings suggest that these stages are particularly important (Ritter, 1997; Christensen et al. 2001; Ziegler, 2003). This is also the reason why two appendices are used to describe the exchanges of energy and anti-fouling agents in fishery.

In most cases, data periods of one year has been sufficient to even out normal fluctuations. However, the resource situation in the fishery implies that there may be significant fluctuations from year to year at this stage. Also, the fast technological development for anti-fouling agents in the fishery should be considered.

Strategy for data collection

The data collection has been based on literature studies, empirical research and databases. Chapters 4 to 6 include further information about the exact data references for each life cycle stage.

All exchanges are related to one kg dispatched fish from each life cycle stage – except the fishery where exchanges are related to the catch - and the use stage, where the exchanges are related to one kg consumed fish. A comparison across life stages must include considerations of material loss along the life cycle.

The data collection for the energy consumption and anti-fouling emissions in the fishing stage has involved numerous sources and thorough modeling. Appendix 4 and 5 specifically deals with data for these exchanges in the fishery.

The chapters 4 to 6 include further information about the methods of data treatment at the different stages.

Plans for verification of data

The following sections contain information about the methods used for validation for different data sets at different life cycle stages. It should be emphasized that each of the following chapters in part two includes an assessment of the data quality with respect to scope as well as reliability and completeness.

Data for the fishery

It has been sought to perform a thorough validation of data sets that are considered especially important. This is the case for energy consumption and consumption/emission of anti fouling agents in the fishery. As the total energy consumption of the whole Danish fishing fleet is known, it has been possible to validate the data for energy consumption through mass balances. Furthermore, I have compared with other studies for the species-specific energy consumption. This has also been the case for some of the data for species- and fishing-gear-specific energy consumptions. In this regard, I have conducted a number of interviews with Danish fishermen as a basis for validation. For validation see app. 5 and 6.

For anti-fouling agents, it has not been possible to check the data via mass balances, as the total consumption has not been known. However, there have been a few data available from other studies that serve to validate selected data sets. However, the data as such has not been thoroughly validated.

Apart from data for energy consumption, data at the processing stage have generally speaking not been validated. However, it is worth to emphasize that the wide scope of product types analyzed serves as validation in itself because it is possible to compare and see if some data sets are unrealistically small or large.

For other data sets, it has been the intention to apply validation in cases where the data are based on estimates while data based on measurements are used without further validation in a number of cases.

4

MECO Analysis – Fishing Stage

This chapter presents an analysis of immediate exchanges at the fishing stage (figure 1) according to the MECO principle, where exchanges are described separately according to the themes Material, Energy, Chemicals and Other aspects.

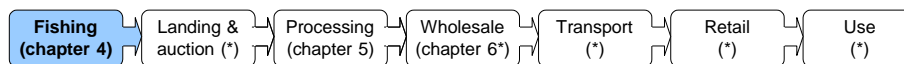


Figure 1: Illustration of the focus of this chapter, which is the fishing stage.

It has been sought to obtain quantitative data, but a non-quantitative approach has been applied in some cases, especially for the non-flow related impacts (e.g. damage to seafloor).

Development tendencies and future estimates are described at the end of each section. The summary (section 4.5) includes an overview of the various exchanges and development tendencies as well as a discussion of the limitations of the MECO analysis.

Description of processes

The included processes are steaming to and from the fishing ground, the catch phase and additional processes such as cooling and hauling etc.



Figure 2. Steaming to fishing ground, catch phase, storing and cooling of fish and steaming back to the harbour– with permission from Webmaster at www.hvidesande.net

The focus has been on consumption of energy and anti-fouling agents since previous LCA screenings suggest that these two factors are among the most important in the fishery (Christensen et al. 2001). Rough estimates are also established for consumption of ice, fishing gear, cleaning agents and fish boxes – see figure 3.

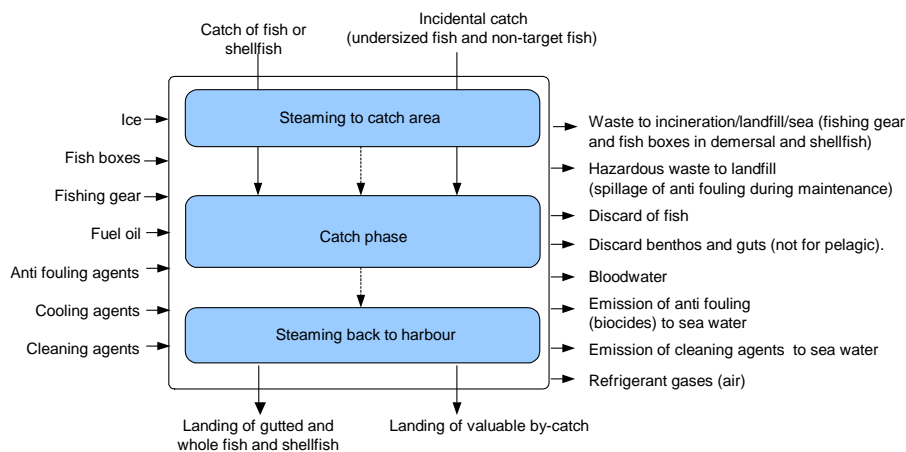


Figure 3. Product flow, inputs and outputs in the fishing stage. The illustration does not include non-flow related impacts.

As the figure illustrates, the fishery is characterized by targeting a certain species e.g. flatfish, but there will always be a certain amount of incidental catch consisting of undersized fish, non-target fish, benthos etc. Part of the incidental catches, and sometimes part of the target fish, may be discarded together with benthos and guts from the degutting process. If the target fish is demersal or shellfish, the typical output is landed gutted fish/shellfish, but if the target fish is pelagic or industrial fish, the output is whole fish.

Data collection and treatment

The data for immediate exchanges in the fishery are based on a combination of literature studies, empirical studies and data extracted from databases at the Danish Research Institute of Food Economics. Exchanges for energy and anti-fouling agents have required a significant amount of data processing, which is separately described in app. 5 and 6. All exchanges are related to one kg of caught fish, down to the level species or species groups, and cover steaming to and from the fishing ground, fishing operation and energy for cooling, hauling equipment etc. General descriptions of data quality requirements, data treatment and methods for co-product allocation and cut-off

criteria are available in chapter 3.2. Descriptions of the limitations of the MECO analysis at this stage and the obtained data quality are given in the summary (section 6.6).

4.1 Material exchanges

The following sections focuses on inputs and outputs of materials including renewable and non-renewable resources. The first three sections will focus on renewable biological resources.

Exploitation of fish stocks

As described in chapter 2.1, industrial fish made up 3/4 of the measured Danish landings volume in the year 2000, which is quite typical for the Danish fishery. From a resource depletion perspective, industrial fish therefore appears to be important, but up 'till this point, the stocks of industrial fish have not shown any signs of depletion. This illustrates that it makes little sense to assess the biological resource depletion in terms of absolute catch volume as described in chapter 2.1, especially when the exchanges are measured per kg caught fish. The focus is therefore the status of the fish stocks in this section. This is closely related to aspects of impact assessment which is included in part three (specifically chapter 10.6 for exploitation of fish).

The status of the stocks

There has been a focus on decreasing fishing stocks at least since the 1970s. (Nordic Council of Ministers 2000a, p.61). In the start of the new millennium, the situation seems to be worse than ever. FAO assess over 80% of the fish stocks in the North East Atlantic are “fully exploited, over-exploited, depleted, or are recovering from depletion” (FAO, 2000). In “The state of the world’s fisheries and aquaculture”, FAO writes (FAO, 2000):

“The Northeast Atlantic has followed a trend of declining catches together with a shift towards landings of fish from lower levels in the food web, which may indicate an underlying ecological change”

Over-exploitation of the fish resources, as well as increasing sea temperatures, pollution and off-shore activities are mentioned among the causes of reduced stocks (Nordic Council of Ministers, 2000a).

A problem related to over-exploitation is discard⁶¹. In 1994, it was estimated that the global amount of discard was app. 27 million ton, in comparison with the annual landed catches of around 77 million tones. Both over-exploitation and discard can be seen as a wasteful practice, where huge food resources are lost.

Demersal species

The resource situation for demersal species appears to be the most problematic in the North East Atlantic. Concerning the EU waters as a whole, the quantities of mature demersal fish have declined significantly over the last 25 years. The EU Green Paper “The future of the Common Fisheries Policy” states that the quantities of mature demersal fish were 90 % greater in the early 1970s than in the late 1990s. For some stocks such as cod, even more drastic reductions in mature fish have occurred. The Commission states (European Commission, 2001a):

“From a biological point of view, the sustainability of a high number of stocks will be threatened if the current levels of exploitation are maintained and, at present, this risk is highest for demersal round fish stocks, which are of high commercial value. Recent scientific advice has indicated the very poor state of cod stocks in the North Sea to the West of Scotland and in the Irish Sea, and for the northern hake stock, which inhabits the geographical area from the Skagerrak to the Bay of Biscay”

The situation for other demersal species such as flatfish, plaice and sole is considerably better than for round demersal species (European Commission, 2001a).

Other species

The resource situation is also better for pelagic fish. Stocks of small pelagic species, such as herring and mackerel and species that support industrial fisheries⁶² (Norway pout, sand-eel), have generally not deteriorated over the

⁶¹ Catches, which are released back to the sea. Discard consists of unwanted by-catch and target fish e.g. undersized or low value fish, but it may also consist of marine mammals, birds and other species, which are not intended for commercial purposes (Nordic Council of Ministers, 2000a; Hall, 1999).

⁶² As mentioned in chapter 2, The Danish Society for A Living Sea argue that the industrial fishery is a problem in terms of changes to the food web (because of the large quantity of catches, which are food for other species) and by-catches of edible fish. Some researchers appear to argue for the opposite because the fishing mortality

last twenty years, and especially not over the last ten years (European Commission, 2001a). It has not been possible to establish any general information about the resource situation for shellfish except on the national level described in the following.

The resource situation for Danish waters

Concerning the Danish waters, the situation is not much different from the general situation in EU. For certain stocks, such as herring, it is assessed that the stocks are presently beyond safe biological limits, but the situation is far more serious for round demersal species, especially cod. For shellfish, such as prawn and Norway lobster, the resource situation is sustainable or close to sustainable. No information has been available for shrimps specifically. Further descriptions are available in appendix 5 (Petersen, 2001, 2002).

Indirect exploitation through aquaculture

The Danish production of farmed fish is approximately 33.000 ton per year in the year 2000. It is reasonable to assume that 3-5 kg of industrial fish is used to produce one kg of farmed fish. This means that 33.000 ton of farmed fish corresponds to 100.000 - 165.000 ton industrial fish, which is less than 1/6 of the total Danish industrial fishery (Ministry of Food, Agriculture and Fisheries, 2001; Fiskeridirektoratet, 2001a). Thus, it is reasonable to say that Danish production of farmed fish is relatively insignificant, considering the depletion of wild fish stocks.

By-catch

By-catch is unavoidable and not necessarily a problem. In flatfish fisheries, it is typically not a problem to have a by-catch of various codfish and shellfish. However, by-catch may also consist of marine mammals or birds, thus the situation is different.

is very low, and the amount of by-catch is insignificant. These researchers argue that the industrial fishery does not have any important impact on the resources of edible fish and visa-versa as the situation is today (Gislason and Kirkegaard, 1998; Nielsen, 2003b). Thus, it is very difficult to make conclusions. However, it should be mentioned that a comprehensive system with at least one sample per 1,000 ton of landed industrial fish ensures that the Directorate of Fisheries is able to make a relatively good estimates of the by-catches in this fishery (Ministry of Food, Agriculture and Fisheries, 2001). However, this does not mean that there are no problems in the industrial fishery, especially concerning by-catch of herring.

By-catch of Sea Porpoises has been the cause of a heated debate in Denmark in the last decade. Some experts have claimed that the total number of entangled Sea Porpoises was around 7.000 individuals per year – especially due to certain gillnet fisheries targeting demersal fish. By-catch or entanglement of seals is typically not a significant demersal problem, because the seals navigate with their eyes and easier avoid entanglement than Sea Porpoises. (Danmarks Naturfredningsforening, 2003). This type of by-catch is further described and assessed in chapter 10, but it can be established here that gillnet fisheries is the main concern in this respect.

Discard of guts and fish

Fish appear as an input when it is caught, but fish also appear as an output considering guts and discard. Discard typically consists of fish that are undersized or have low value (Nordic Council of Ministers, 2000a).

Discard of guts

Discard of guts is only considered in relation to fisheries targeting demersal fish and shellfish. The amount of discarded guts may vary considerably, depending on the exact type of fishery. For flatfish, the amount of guts is typically approximately 5% of the caught flatfish (w/w), while Norway lobster may produce 70% guts per kg caught lobster when landed as tails. The amount of guts for other species groups is further described in Fiskeridirektoratet (2001a) – see also app. 3.

Discard of fish (global assessment)

According to Alverson et al. (1994) the discard is around 27.0 million ton with a range from 17.9 to 39.5 million ton – on global level. This is nearly one third of the total global fisheries. Shrimp and prawn fisheries, particularly for tropical species, were found to generate more discard than any other fishery type. Some examples of fisheries with highest and lowest discard ratio are mentioned below:

- Shrimp/prawn: 0,84
- Crabs: 0,71
- Flounder, halibut and sole: 0,43
- Herring, sardines and anchovies: 0,1
- Mackerel, Snooks, cutlassfishes: 0,03

It is assessed that the lowest discard ratios are in pelagic trawls, purse seines targeting small pelagic fish and some of the high seas driftnet fisheries. (Alverson et al. 1994)

The study also investigates the discard as a function of the fishing gear. This shows the following order with the first mentioned representing the gears with the highest discard ratio (Alverson et al. 1994).

- Shrimp trawl (highest discard ratio)
- Non pelagic fish trawl
- Pots and traps
- Long line
- Danish seine
- Purse seine
- Pelagic fish trawl (lowest discard ratio)

As illustrated, shrimp and non-pelagic trawl have the highest discard ratio while the lowest ratio is for Danish seine, purse seine and pelagic fish trawl. It should be mentioned that this represents general worldwide tendencies and that it may vary from area to area.

Discard of fish in Denmark

The average discard in Danish vessel segments targeting demersal fish in the northern North Sea *is assessed to be approximately 25% of the catches* (Nordic Council of Ministers, 2000a p. 91).

Danish Fisheries Research Institute recently published a study with an overview of the discard in Danish fisheries in the period 1995 to 2000. The study confirms that the most important reasons to discard is undersized fish (especially cod) or fish of a low value such as whiting and common dab. Quota and rations are more seldom the reason behind discard. The study shows that discard is largest in fisheries with small mesh size such as fishery for Norway lobster. (Danmarks Fiskeriundersøgelser, 2001)

The Danish discard-study deals with fisheries targeting Atlantic cod, European plaice, Norway lobster, Northern prawn, common sole, and turbot. The study covers a wide range of fishing gears but only in a few cases, different gears have covered fisheries targeting the same species in the same area. An obvious conclusion is that fisheries targeting Norway lobster have the largest

discard ratio⁶³. These fisheries employ bottom trawl, and more than half of the catch is thrown into the sea again. The discard mainly consists of under-sized Norway lobster and other valuable fish such as cod and flatfish. (Danmarks Fiskeriundersøgelser, 2001). According to Kuula and From (2004) the discard is around 2/3 of the catches in the Norway lobster fisheries.

Gillnet fisheries generally have a very low discard ratio. Gillnet fisheries targeting Atlantic cod in the North Sea has a discard ratio of 1,6%. This can be compared to demersal trawl, which has a discard ratio of 12% targeting the same target species in the same area. Gillnet fisheries targeting European plaice in the North Sea has a discard ratio of 6%. This can be compared to Danish seine which has a discard ratio of 8,4% or beam trawl, where the ratio is 14% targeting the same species in the same area. (Danmarks Fiskeriundersøgelser, 2001).

Another interesting conclusion is that fisheries targeting Northern prawn has a low or moderate discard ratio at 12% in the North Sea, which is lower than one should expect from the FAO study, mentioned earlier (Danmarks Fiskeriundersøgelser, 2001).

Other aspects and types of discard

Despite previous study of discard provides a good insight in the discard ratios, there are several factors, which also should be considered. Firstly, the mortality rate of the discard is probably not the same for different fishing gears. A Dutch study termed IMPACT II from 1999 concludes that mortality rate of discarded fish in trawl fisheries is 50-100% for flatfish and 80-100 % for round fish (Lindeboom and de Groot, 1999). It is reasonable to believe that gears that inflict little damage to the catch, such as Danish seine, have a lower mortality rate of discard. However, it has not been possible to find any studies supporting this hypothesis.

Secondly, the discard of invertebrates should be considered as well. The Dutch IMPACT II study provides examples of catch and discard for two sizes of beam trawl:

⁶³ Discard ratio is the ratio of discarded weight to total catch weight.

Table 2: Catch composition and discard from 4 and 12 meter beam trawl (BET) and bottom trawl (BOT) in the North Sea and the German Bay (Nielsen og Møllergaard, 1999 p. 8 -15)

	Southern North Sea [kg per hectare]		German Bay [kg per hectare]		
	12m BET	4m BET	12m BET	4m BET	BOT
Total catch of fish (kg)	15	12	56	70	3
- marketable fish (kg)	5	4	28	18	1
- marketable sole (kg)	2	1	3	8	<0,1
- discard of fish (kg)	10	8	28	52	2
Total discarded of invertebrates (kg)	16	25	128	26	1
- total discard of dead invertebrates (kg)	2	3	na	na	na
Discard of fish per kg marketable fish	2	2	1	3	1,5
Discard of inver. per kg marketable fish	3	6	5	1,5	1
Disc. of dead inver. per kg market. fish	0,4	0,8	na	na	na

BET: Beam trawl, BOT: Bottom trawl (Otter trawl), na: not assessed

As illustrated, the amount of discarded invertebrates is considerable. In addition, there is all the animals, which are damaged in the trawl path. This is not included in table 2. The study suggests that the discard of fish only makes up 1/3 of the total amount of damaged/destroyed benthos in the trawl path (Nielsen & Møllergaard, 1999 p. 3).

The study also shows that beam trawl inflicts considerably more damage to benthos than ordinary bottom trawl (otter trawl). The reason is that otter trawl has a smaller penetration depth (lower friction) and therefore only damages plants and animals in the top sediment. The study also suggests that small beam trawl (4-m) generates more damage than large beam trawl (12-m). This appears contradictory but is due to the difference in towing speed. The 4-m beam trawl is towed with max. 5 knots while the 12-m beam trawl is towed with up to 8 knots. (Nielsen & Møllergaard, 1999 p. 11). Other studies support that the friction on the seabed decreases when the towing speed increases e.g. Fonteyne (2000).

There is no reason to believe that passive fishing gear, such as gillnet and long line, will cause any significant discard of invertebrates, nor damage to benthos. For semi-active fishing gear such as Danish seine, there may be some discard and some damage to the benthos, especially when heavy ropes are applied, but this has not been investigated further.

Water and ice consumption

The consumption of water and ice is discussed in the following, but few data have been available.

Water consumption

Some fisheries, such as pelagic and industrial fisheries, uses seawater to cool down the fish in Refrigerated Sea Water (RSW) tanks. However, salt water is not considered a limited resource.

The direct consumption of drinking water is probably mainly related to cleaning of the fishing vessel. It has not been possible to establish data for this, but it is assumed that the consumption is insignificant.

Ice consumption

Considerable amounts of ice are used in demersal fishery. The ice is typically produced in ice factories on the harbour and loaded on the fish vessels before each fishing trip. The amount of ice is roughly *0,5-1,0 kg per kg demersal fish*. (Ziegler, 2002; Andersen, 1998; Danish seine 1, 2001).

Fishing gear and fish boxes (I/O)

The following section deals with the consumption of fishing gear and fish boxes as well as their disposal/loss.

Consumption of fishing gear

Detailed data about material consumption as a function of species group and fishing gear have not been obtained. Still, a few data have been available. Fishing gears are typically made of LDPE, Nylon, iron and/or lead. A Swedish study concludes that the amount of materials used in gillnetting per kg landed are *2,8 gram LDPE, 13 gram nylon and 5,8 gram lead per kg landed cod*. For trawling, the same study estimates that the material consumption is *0,38 gram LDPE and 0,63 gram iron per kg landed cod*. Thus, gillnetting clearly imply the largest material consumption in this case. (Ziegler, 2002).

From an environmental point of view, the lead consumption is probably the most important. Additional data have therefore been obtained. According to Lassen et al. (2003), the total consumption of lead in the Danish fishery was 550 ton in year 2000. Roughly, half was used in gill and pound net fisheries, while the other half was used in a other fishing gears including trawl, both for sinks and in wires. As described in app. 2, gill and pound-net fisheries

caught around 19.000 ton fish in 1999, while other fishing gear caught 1443.000 ton fish. This suggests that the average lead consumption in *gill and pound-net fisheries was 12 gram per kg caught fish*, while *other fishing gears used 0,16 gram per kg caught fish*. For gillnet, this is somewhat higher than suggested by Ziegler (2002), but it is still in the same order of magnitude.

Loss of fishing gear

Lost fishing gear may cause an environmental burden in two ways. First of all, the fishing gear may continue to fish. This is called ghost netting and is a special concern for gillnet fisheries. Only few studies of this phenomenon exist, but it appears that the size of the problem varies considerably as a function of the location, the fishing practices, and other activities in the area. (Jennings et al. 2001).

Secondly, it is worth paying attention to lead pollution. According to Lassen et al. (2003), roughly 13 % of the lead consumption can be regarded as lost to the sea, while roughly 57% goes to incineration or landfill: Of this, it is assumed that 80% goes to incineration while 20% ends up as landfill.

The remaining lead is reused. Based on the data for lead consumption from Lassen et al. (2003), this would suggest the following emissions of lead from gillnet:

- *1,6 gram lead to the sea per kg caught fish (gillnet)*
- *5,5 gram lead per kg caught fish to incineration (gillnet)*
- *1,4 gram lead per kg caught fish to landfill (gillnet)*

For other fishing methods, the emissions are considerable less:

- *0,02 gram lead to the sea per kg caught fish (other)*
- *0,07 gram lead per kg caught flatfish to incineration (other)*
- *0,02 gram lead per kg caught flatfish to landfill (other)*

Apart from lead, loss of fishing gear also contributes with non-organic waste from different types of plastic, nylon and iron/steel that is used. It is assumed that these material flows roughly follow the material flows of lead. This is not calculated here, but it can easily be derived from the material consumption suggested by Ziegler (2002), and is included in the LCA in part three.

Consumption of fish boxes

The demersal fishery use fish boxes for storing and transportation of the fish after landing. The fish boxes are typically made of HDPE and reused until they break (Christensen, 2003).

An LCA study of similar boxes used for vegetables suggests that they are reused 50 times (DOR Århus A/S, 2000b). The producer organizations typically provide the fish boxes that include collection and wash of used boxes. Many types of boxes and sizes exist. The smallest boxes are used at Bornholm, medium sized boxes are used in the inner Danish waters, and the largest are used on the West Coast. Data have only been available for the largest boxes, which weigh 3,4 kg each. They have a volume of 50 liter, and typically contain 25 kg landed fish per box (Christensen, 2003). If it is assumed that the boxes are re-used 50 times as suggested, the material consumption would be roughly *3 gram HDPE per kg landed fish*.

Waste from fish boxes

It is assumed that the waste from fish boxes is equal to the consumption, namely *3 gram HDPE per kg landed fish*.

Development tendencies

The future development tendencies with respect to material exchanges are discussed in the following.

Over-exploitation

Concerning the development in over-exploitation, fishing stocks have decreased since the 1970s, as mentioned earlier. FAO concludes that the Northeast Atlantic has followed a trend of declining catches and that catches changes towards fish from lower levels in the food chain (FAO, 2000).

On the EU level, there are plans for a major reduction in the fleet capacity as it is estimated that the over-capacity is between 30-60%, depending on the fleet segment. Denmark has already implemented large reductions in the gross tonnage, but Denmark still have to reduce the fleet capacity considerably because technological improvements and larger vessels have eroded the reduction in gross tonnage, thus increasing the effectiveness of the fleet. (Institute of European Environmental Policy, 2002; European Commission 2001a). This speaks for a future reduction in the over-exploitation. However, the lesson from previous attempts to reduce the fishing fleet in EU and Denmark has shown that political interests may become a barrier for effec-

tive fleet reductions (Vedsmand, 1998). Therefore, it is assumed that the level of over-exploitation will remain constant in the following years⁶⁴.

Discard and guts

Research focusing on improving the selectivity of fishing gear, especially trawl, is taking place in many parts of the world (Hansen, 2002). This may have a positive effect on discard ratios, but it is not likely to change the ratio significantly – in my opinion. Historically, fishermen have proven to be able and willing to circumvent the selectivity devices. More precisely, discard depends on several factors other than the fishing gear itself. One of them is the quota regulation (Vedsmand, 1998)⁶⁵.

Thus, it is assessed that no development tendencies or technological innovations suggest a significant change in the amount of discard⁶⁶. The same applies to guts.

Ice, fishing gear and fish boxes

It is also assumed that the consumption of ice, fishing gear and fish boxes will remain stable within the next 10-15 years. However, this is not the case for lead. According to a new Danish Departmental order, import and sale of lead in fishing gear will be illegal after September 1, 2002. Lead will probably be substituted by iron. However, it will still be legal to use old nets, for some years to come (Miljø- og Planlægningsudvalget, 2000; Fiskeritidende, 2002). I have assumed that roughly 80% of the lead is phased out by the years 2010-15.

⁶⁴ To prevent ghost netting, gillnets attached with biodegradable plastic materials are being developed, which should ensure that the nets fall to the sea bottom after a certain period – see. app. 1. Thus, it must be assumed that problems of overexploitation related to ghostnetting will decrease, but this is a specific problem related to specific fishing methods in certain areas.

⁶⁵ Currently, Danish fishermen are faced with reduced quota on codfish, which can lead to high grading, where only the largest or most valuable fish are landed.

⁶⁶ In Norway, there are currently research projects aiming at reducing the amount of fish waste from sea to table. Also large factory vessels have been developed, which produce mince and fishmeal from the guts (Ellingsen, 2001). Still, it is not possible to predict whether this production will be introduced in Denmark.

4.2 Energy exchanges

Energy consumption in Danish fishery was 197 million liters of diesel⁶⁷ in 2000. This covers 1528 firms⁶⁸ that contributed to more than 99% of the total turnover in the sector (Fødevareøkonomisk Institut, 2001b).

The total catches (that is whole caught fish) and landings (that is landed and gutted fish) from Danish fishermen in Danish harbours were respectively 1.534 and 1.442 million kg in 2000. However, the 197 million liters cover only these 1528 concerns, which correspond to 1.519 million ton of caught fish and 1.427 million kg landed fish (Fiskeridirektoratet, 2001a; Fødevareøkonomisk Institut, 2001b).

In terms of direct fuel consumption in the Danish fishing fleet, this gives an average of *0,13 liter per kg caught mixed fish or 0,14 liter per kg landed mixed fish*⁶⁹. These figures cover large differences between species and vessel segments, as it will appear in the following sections.

⁶⁷ The Danish Statistical Institute provides data suggesting that the total energy consumption in the fishery is $9,451 \cdot 10^9$ MJ in the year 2000 within the Danish fishery (Energistyrelsen, 2002). This is approximately 263 million liters of diesel oil, if it is assumed that the energy content in diesel is 36 MJ per liter. The Danish Statistical Institute finds it difficult to explain why this difference occurs. Basically, it is because the statistical institute uses other sources and because the statistics are less detailed. A researcher at the Danish Institute for Food Economics argues that the estimate on 197 million liters ($7,1 \cdot 10^9$ MJ) is the most precise estimate (Nielsen, 2003a). It can be mentioned that Denmark's total energy consumption was $630 \cdot 10^9$ MJ in the year 2000. The fuel consumption in fishery is therefore around 1,1% of the total energy consumption in Denmark in the year 2000. This is also the same as the total energy consumption used for domestic transportation at sea and rail, or one third of the energy consumption for air-traffic (Energistyrelsen, 2002).

⁶⁸ One firm may own several vessels or a percentage of a vessel (Fødevareøkonomisk Institut, 2001b).

⁶⁹ In 1999 the total fuel consumption in the Danish fishing fleet was 208 million liter and the relative fuel consumption nearly 0,15 liter diesel per kg caught fish. However, the reason is not that fishery suddenly has become more efficient in 2000. The reason is probably more landings of industrial fish in 2000 compared to 1999 (Fødevareøkonomisk Institut, 2001a, 2001b).

Fuel consumption for species groups

To provide a more detailed picture of the variation in fuel consumption for different species groups, this section analyzes the fuel consumption for nine species groups covering almost the entire Danish fishery. The nine species reflect the nine species groups that are assessed to be the most important in terms of volume and value, considering landings from Danish and foreign fishermen – see section 2.1. The data as well as data treatment, results, validation and representative assessment are reported in app. 5.

Considerations of all species – divided into nine groups

To obtain data for nine species groups, it has been necessary to allocate the energy consumption of the joint fisheries which all have significant amounts of by-catch. As it appears in app. 5, three different methods have been applied: Mass allocation, economical allocation and system expansion. System expansion is considered the most accurate⁷⁰ way of dealing with co-product allocation, but it is chosen to show the results for all three allocation methods in table 3.

Table 3: *The absolute and relative fuel consumption for nine species, based on three different allocation methods. For further details, see app.5. The main references are Fødevarerøkonomisk Institut (2001b) and (2002b).*

	Demersal fish		Shellfish				Pelagic		Indus.
Allocation method	Codfish	Flatfish	Prawn	Shrimp	NL.	Mus-sels	Herring	Mack-erel	Sand-eel etc.
	Total catch volume (1000 ton)								
	67,80	40,74	5,72	2,58	5,04	109,4	134,96	34,27	1.117,71
	Relative fuel consumption - per caught fish (liter per kg)								
Mass	0,47	0,56	0,54	1,02	1,16	0,01	0,14	0,08	0,10
Value	0,86	0,92	0,89	1,22	3,95	0,08	0,07	0,27	0,04
Sys. Exp.	0,36	0,97	0,76	1,03	6,05	0,01	0,18	0,06	0,06
	Absolute fuel consumption per caught fish (1000 liter)								
Mass	31.780	22.754	3.115	2.629	5.864	1.378	19.009	2.891	107.692
Value	58.245	37.565	5.068	3.149	19.929	8.233	9.791	9.263	45.870
Sys. Exp.	24.460	39.630	4.354	2.664	30.539	1.365	24.253	1.916	67.930

⁷⁰ The ISO 14040-43 standard recommends a technical subdivision of the product system as the highest priority for co-product allocation. If this can't be done, it is recommended to apply system expansion, economical allocation or mass allocation in that order (Jerlang et al. 2001).

As it appear, there is a hierarchy in the fuel consumption, showing that demersal and shellfish (excl. mussels) are the most energy consuming fisheries while the most fuel efficient fisheries are those targeting pelagic and industrial fish as well as blue mussels – independent of the allocation method. The following specifically refers to the results based on system expansion.

The most energy intensive fisheries

According to table 3, the most energy-intensive fishing practice is the Norway Lobster fishery. Based on system expansion, fuel consumption is estimated at 6 liter per kg caught lobster. In absolute terms, this fishery was responsible for nearly 16%⁷¹ of the total fuel consumption in Danish fishing fleet in year 2000, considering a total consumption of 197 million liter (Fødevareøkonomisk Institut, 2001b).

Fisheries targeting shrimp, prawn and flatfish are also relatively energy intensive. Fuel consumption here is approximately one liter per kg caught flatfish, shrimp and prawn. In absolute terms, shrimp and prawn⁷² fishery still represent a smaller fuel consumption than flatfish fishery. The latter was responsible for 20% of the total fuel consumption in the Danish fleet in the year 2000 (Table 3).

Average energy intensive fisheries

Cod and herring fisheries have a smaller but still significant fuel consumption, which is respectively 0,36 and 0,18 liter fuel per kg caught fish. In absolute terms, they are both important fisheries and made up nearly 25% of the total fuel consumption in the Danish fishing fleet.

The least energy intensive fisheries

Mussel, mackerel and industrial fisheries are the least energy intensive. The fuel consumption is 0,06 liters per kg of mackerel or industrial fish, while mussels are as low as 0,012 liter per kg caught mussels (including shells). In absolute terms, mussels and mackerel are insignificant, but industrial fish made up one third of the total fuel consumption in the Danish fishing fleet.

⁷¹ Norway lobster constitutes less than 0,33 % of the total catches the same year.

⁷² Shrimp are smaller (max. 8 cm) than prawn (max. 17 cm). The Danish fishery for prawn (Northern Prawn) is mainly localized in the North Sea between Norway and Scotland as well as in the Skagerak (Petersen, 2002). The Danish fishery for shrimp (Common shrimp) mainly takes place in the inner Danish waters (Muus and Nielsen, 1998).

Hence, the two extreme cases in terms of relative fuel input are blue mussels, which have the lowest fuel input, and Norway lobster, which have the highest. The difference in relative fuel consumption between these two fisheries is nearly a factor 500. It should be noted that considerations of meat content are not included here.

Demersal and edible fish - as separate species groups

If demersal fish are perceived as one species group, the relative fuel consumption is 0,82 per kg demersal fish (excl. blue mussels).

Table 4: *Relative and absolute fuel consumption for demersal fish, inclusive shellfish. The data can be derived from table 3.*

Characteristics about fuel input	Demersal fish (incl. shellfish)	
	Incl. Mussels	Excl. mussels
Total catch volume from Danish concerns [mill. kg]	232	122
Relative fuel input [liter per kg caught demersal fish]	0,44	0,82
Absolute fuel input for demersal fisheries [mill. Liter]	103	102

These data can relatively easily be derived from table 3. It is also possible to establish the fuel consumption for edible fish as one big species group. Calculations based on the results in table 3 suggest that the energy consumption is 0,32 liter per kg mixed edible fish. If it is assumed that the average filet yield is around 0,4 for mixed edible fish (see app. 3) and that the energy content in diesel is 36 MJ per liter (see app. 12), this is roughly 30 MJ per kg fish filet from mixed edible fish⁷³.

Finally, a short remark concerning farmed fish: According to the Ministry of Food, Agriculture and Fisheries (2001), it is reasonable to assume that 3-5 kg industrial fish is used to produce one kg of farmed fish. This means that the fishery related energy consumption is 0,2-0,3 liter per kg farmed fish. According to Fiskeridirektoratet (2001a), the Danish production of farmed fish was roughly 33 million kg in the year 2000. Thus, the Danish aquaculture is responsible for roughly 100-165 million kg caught industrial fish, which is roughly 12% of the industrial fishery. According to Nielsen (2002a), most of the remaining industrial fish are used as fish fodder in aquaculture in other countries e.g. Norway.

⁷³ According to Weidema and Mortensen (1995), the energy consumption for the production of meat from pigs, cattle or poultry is in the range of 50 - 100 MJ per kg for primary production. Thus, fish products are probably not worse than average meat products from agriculture – with respect to fuel consumption.

Fuel consumption and vessel size

Based on data from the Danish Research Institute of Food Economics, it has been possible to establish an estimate of the energy consumption for different vessel groups covering the entire Danish fisheries – see figure 3.

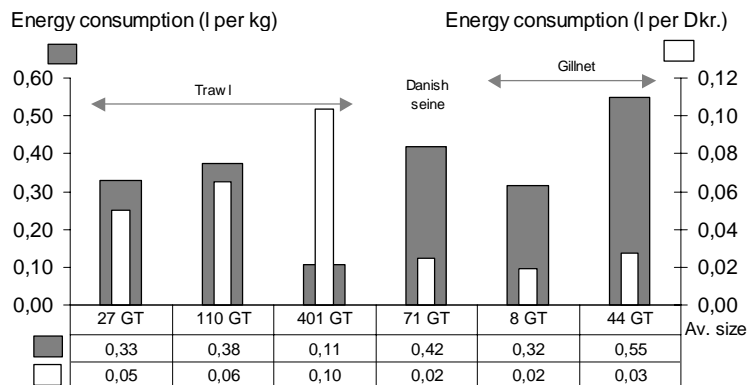


Figure 3. Fuel consumption per kg mixed fish and per catch value in Danish fishery 1999⁷⁴. (Fødevarøkonomisk Institut, 2001a). Calculations are available in app. 5 (Document B).

As the figure points out, fuel consumption increases slightly as a function of the vessel size relative to the catch value (white columns and right axis). In this respect the reader should only compare vessels in the same vessel category, either trawl (three vessels), Danish seine (only one vessel) or gillnet (two vessels).

However, this tendency is not clear when the fuel consumption is measured per catch volume (gray columns and left axis). This illustrates the weakness of the approach where fuel consumption is measured per kg *mixed* fish. The method does not consider the catch composition and is therefore only useful for rough assessments or assessments of vessel groups with a similar catch

⁷⁴ The study includes 321 fishing vessels and more than 99% of the total turnover in the Danish fishery. There are three size categories for trawlers, representing vessels below 50GT between 50 and 200 GT and vessel larger than 200 GT. For Gillnet, there is two size categories representing vessels smaller and larger than 20 GT. The precise average sizes in all categories are illustrated in figure 3. (Fødevarøkonomisk Institut, 2001a).

composition. The latter is the case for the two size categories of gillnet vessels. Here, the small vessels (average of 8 GT) do have lower energy consumption per kg caught fish compared to the large vessels with an average tonnage of 44 GT. This points towards small vessels being the most fuel-efficient for demersal fisheries (gillnet vessels target demersal fish), but a more detailed analysis is necessary and carried out in the following.

Case studies of fuel consumption

To further support the study findings that large vessels targeting demersal fish (incl. shellfish) are more fuel intensive, data for the energy consumption per kg and catch value have been established, for different vessels sizes, applying similar fishing gear and with similar catch composition. The estimates are based on records from fishing vessels comprised in groups of vessels representing a total of 61 vessels (Nielsen, 2002b). System expansion is used for co-product allocation (figure 4).

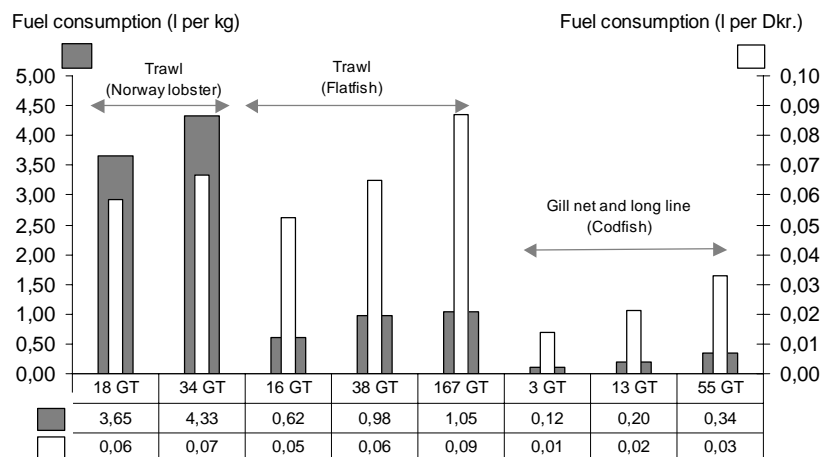


Figure 4: Fuel consumption per kg fish and catch value for three different groups of demersal fisheries in the year 2000⁷⁵(Nielsen, 2002b). Calculations are available in app. 5 (Document D).

⁷⁵ The data for each group is based on vessel accounts. The figures for Norway lobster is based on 23 accounts, European plaice via trawl is based on 16 accounts and finally Atlantic cod via gillnet and long line is based on 22 accounts (Nielsen, 2002b). It should be stressed that no data have been available on single vessel level but only for groups of vessels.

As the figure points out, this analysis supports that large vessels are more fuel consuming in demersal fisheries. The larger vessels consume relatively more fuel per kg caught fish (gray column) as well as per catch value (white column), considering the same species in all three fisheries. The figure shows a clear correlation between liter of fuel per catch value, and fuel consumption per kg fish of a given species.

In spite of the fact that Norway lobster is very energy consuming to catch, the fuel consumption per landing value is relatively low. This underlines that Norway lobster is an extremely valuable product and that the expenses for fuel plays a minor role compared to the potential income from a good catch. The largest fuel consumption per catch value actually appears among the large trawlers targeting flatfish.

Unlike the figure 3, these data do not represent the whole Danish fishing fleet, but only small samples. However, other studies support that the energy consumption increase as a function of the vessel size (Tyedmers, 2001). However, it must be underlined that this conclusion mainly concerns demersal fisheries. For fisheries targeting small pelagic fish such as mackerel, herring and industrial fish, it is indeed questionable whether small fisheries are more energy effective. In this regard, it should also be considered that the position and migration pattern of certain fish stocks makes it difficult or even impossible for small vessels to exploit in some cases (Hansen, 2002).

Fuel consumption and fishing gear

Several studies indicate that passive fishing gears such as Danish seine and gillnet are more energy efficient than active gears such as trawl, measured in fuel consumption per kg caught mixed fish (Endal, 1980; Bak, 1994; Tyedmers, 2001; Ziegler, 2003; Hassel et al. 2001). Nevertheless, a shortcoming is that most of these studies handle co-product allocation by means of mass or economical allocation.

Different fishing gears in demersal fisheries

In the present study, energy data have also been gathered for vessels targeting the same species while applying different fishing gear, using system expansion to account for the co-products⁷⁶. These data have been obtained from fishing vessel accounts in co-operation with the Danish Research Insti-

⁷⁶ System expansion as a concept is explained in app. 3.

tute for Food Economics, and from telephone interviews that cover beam trawlers (Nielsen, 2002b; Beam trawler, 2001). The results show that the fishing gear is of great importance – see figure 5.

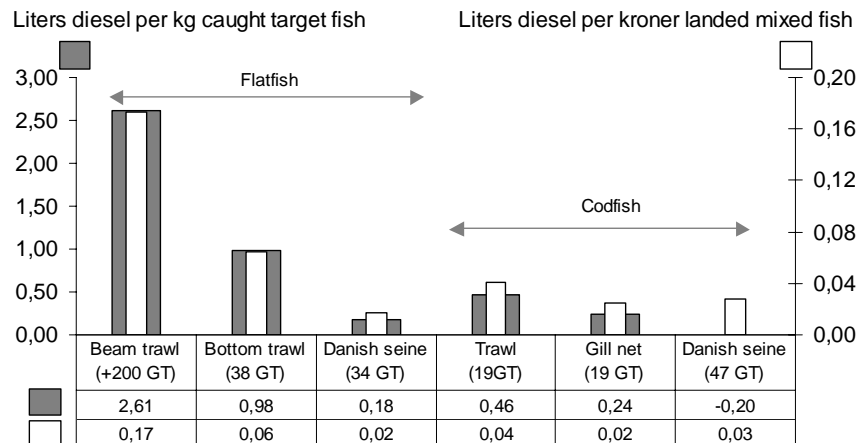


Figure 5. Fuel consumption per kg caught fish for different fishing gears in the year 2000⁷⁷. Allocation is avoided by system expansion (Nielsen, 2002b; Beam-trawl, 2001). Calculations are available in app. 5 (Document D).

As the figure indicates, passive fishing and semi active fishing gear (gillnet and Danish seine) is considerably more energy efficient compared to trawl. Beam trawl vessels targeting flatfish are responsible for a fuel consumption of 2,6 liter of diesel per kg caught flatfish. Compared to Danish seine, beam trawl uses roughly 15 times more energy per kg caught flatfish⁷⁸. The figure

⁷⁷ The data are based on accounts from the fishing vessels. Flatfish via bottom trawl comprises 16 accounts with an average size of 38 GT. Flatfish caught by Danish seine comprises 9 accounts with an average size of 34 GT. Flatfish caught by beam trawl is based on an interview as well as catch data from the owner of several beam trawlers with an average size well over 200 GT. For codfish, the number of accounts is 15 for bottom trawl (av. 19 GT), 22 for gillnet/long line (av. 18 GT) and finally 8 for Danish seine (av. 47 GT). (Nielsen, 2002b; Beam-trawl, 2001).

⁷⁸ Considering reliability, it should be mentioned that the data for beam trawl is based on an interview with the owner of only three vessels. However, the results are consistent with data from Dutch beam trawlers (Tyedmers, 2002). Another point of uncertainty is that the beam trawler (in the group of vessels targeting plaice) and the

also show that fishing vessels applying gillnet can supply codfish with roughly half the fuel consumption of vessels that apply bottom trawl. Still, Danish seine emerges as the most fuel-efficient fishing practice for codfish as well. Actually, it appears that the fuel input is negative. This counterintuitive result arises because the Danish seine fishery, in this case, has a relatively large by-catch of flatfish that substitute for the other more fuel intensive fisheries targeting flatfish (see table 3).

Different fishing gears applied in pelagic fisheries

For herring and mackerel it has been possible to establish the fuel consumption for both pelagic trawl and purse seine in periods with “clean” fishery; fishery with either only herring catch or only mackerel catch. Thus, it has been possible to avoid co-product allocation by technical subdivision of the fishery.

The owner of five trawlers operating from Esbjerg have been interviewed. The vessels co-operate in a so-called “pool-fishery”, where they share one common quota. The average fuel consumption for the five trawlers in periods with only herring landings was approximately 0,15 liter/ kg fish in 1999. The energy consumption in periods with only mackerel landings were approximately 0,1 liter per kg fish.(Pelagic trawl, 2001).

Interviews have also been conducted with the owner of three purse seiners targeting herring and mackerel. Data obtained from this interview suggest that the energy consumption was 0,06 liter per kg mackerel in periods with only mackerel fishery, as opposed to 0,16 liter per kg herring in periods with only herring fishery (Purse seine, 2001).

Danish seine (in the group of vessels targeting cod) are considerably larger than the other vessels in the respective groups. For the Danish seine, this does not compromise the conclusion. Moreover, it just strengthens the conclusion because a larger vessel would probably use more energy per catch, as explained in the previous section. For the beam trawler it is still difficult to tell whether the larger energy consumption is completely or partly related to the larger size instead of the gear. However, fishing gear and vessel size will never be independent variables. Beam trawl as we know it, can only be applied by relatively large vessels with relatively high engine power – see app. 1. Finally, it could be mentioned that additional data for flatfish fishery show similar energy consumption ratios as suggested by the data from Nielsen (2002) – see Danish seine 1 (2001), Danish seine 2 (2001), Danish seine 3 (2001) and Demersal trawl 1 (2001).

Based on these few data, it appears that purse seine is considerably more fuel efficient in mackerel fishery, while there is hardly any difference between purse seine and trawl for herring fishery. I have compared modern trawl fishery with modern purse seine fishery. Data from Ritter (1997) suggests that the difference between trawl and purse seine is a factor two in herring fishery, but in this study, one of the explanations could be that modern purse seine fishery was compared to more traditional pelagic trawlers and not modern super trawlers operating in a pool fishery. However, there are also other possible explanations. According to the owner of the three purse seiners, the reason behind the relatively high energy consumption for herring was that the fishery took place in the international zone close to Norway, which implies a long steaming distance. Thus, other factors come into play and it is basically difficult to make a fair comparison.

Development tendencies

The future development tendencies for energy consumption will be discussed in the following.

Development in energy consumption in the Danish fishery

As mentioned, the energy consumption in the Danish Fishery is around 0,13 liter per kg caught fish in year 2000. In 1999 it was slightly higher (0,15 liter per kg), probably because of smaller landings of industrial fish. It is not possible to go much further back in time using data from the Danish Research Institute of Food Economics. However, it is possible to use data from the Danish Statistics instead. Based on these data, the development in catches and fuel consumption can be established – see figure 6.

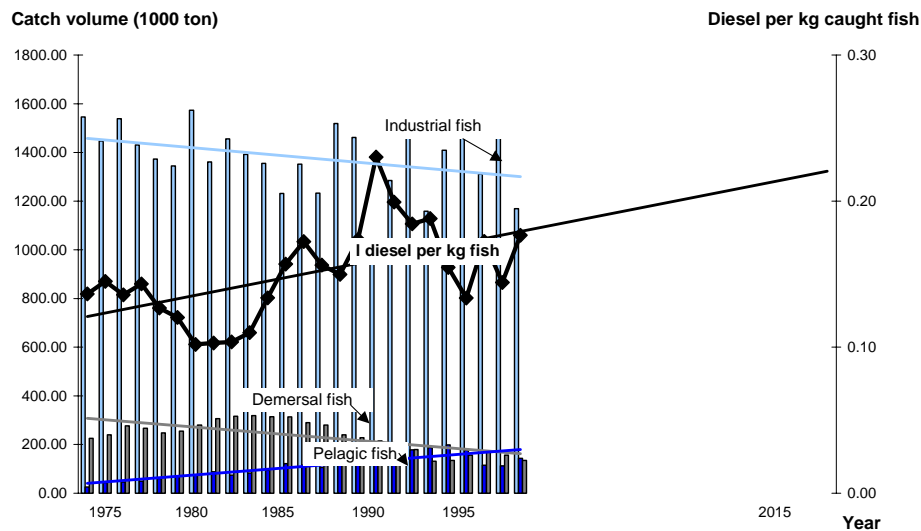


Figure 6: The development in fuel consumption⁷⁹ in the Danish fishing fleet from 1975 to 1998, with to year 2015 (Danmarks Statistik, 1986, 1992, 1999).

As illustrated, the fuel consumption has increased from an average of 0,14 liter per kg caught fish in 1974 to 0,18 liter per kg caught fish in 1998. However, there have been large fluctuations. In the early 1980s the fuel consumption per kg dropped dramatically, while the late 1980s and early 1990s represented a period with a considerable increase in fuel consumption.

The composition of catches obviously varies throughout the period. It is worth to notice that periods with a small energy consumption (1980-83) correlates with periods where the catches of both industrial- and demersal fish are high.

Potential causes behind increase

The key question is what may cause the overall increase we experience over the whole period? It could be many factors. With respect to the species composition the development would most likely suggest a decrease rather

⁷⁹ These data generally shows higher energy consumption than suggested by the Danish Institute of Food Economics. But this does not affect the development tendency.

than an increase in fuel composition⁸⁰. Therefore it is reasonable to believe that the cause for the increase in fuel consumption mainly is related to other aspects such as technological factors and overcapacity. Another important aspect is obviously the abundance of demersal fish species which appear to decrease significantly during the period.

Development tendencies in other countries

A Canadian study of the fuel consumption in Iceland and Canada also show an increase in energy consumption per kg fish in the same period (Tyedmers, 2001). Data for fuel consumption in the Dutch beam-trawl fishery targeting flatfish show a similar tendency – see figure 7.

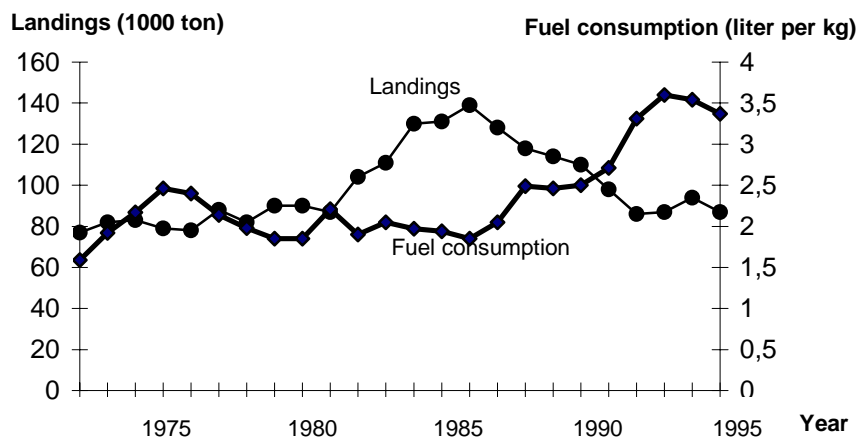


Figure 7: The development in the fuel consumption among Dutch beam trawlers targeting plaice and sole in the period 1972 to 1995 (Tyedmers, 2002).

It appears that the Dutch beam trawl fishery follows the same trend, and that the large increase in fuel consumption also begins in the early 1980s. Another interesting point is that the landing volume and the relative fuel con-

⁸⁰ The increase in fuel consumption from 1983 ‘till the end of the period, takes place when the catches of energy demanding demersal fish decreases significantly. The catches of the less energy demanding industrial fish also decreases slightly, but this is followed by an increase of a similar magnitude in the catches of pelagic fish, which also causes a low energy consumption per kg.

sumption are opposite proportional. Recent Norwegian studies confirm this tendency and it is reasonable to assume that the same relationship exist between fish quota and fuel consumption. The Norwegian study shows that the relationship is most pronounced for the large factory vessels that uses active fishing gear, while smaller vessels applying passive fishing gear has a less well defined relationship between catch volume and fuel consumption. Thus, it is suggested that the small vessels have a greater flexibility in adapting catch effort to the availability of fish.(Huse et al. 2002).

Future predictions

As earlier mentioned, there are plans for major fleet reductions within EU, which also applies to Denmark. This speaks for a reduction in fuel consumption. Nevertheless, an increase in average vessel size and engine power will probably also occur⁸¹. The tendency toward fewer and larger vessels speaks for increase in fuel consumption. In this respect, it is worth to notice that an increase in average vessel size is likely to imply a substitution of passive fishing gears with active fishing gears, which are generally more energy demanding to operate.

It is difficult to predict which of these opposite tendencies will be decisive. It is therefore chosen to base the scenario on extrapolation of the development from 1974 to 1998. This suggests that the fuel consumption will increase from 0,18 liter per kg caught mixed fish in 1998 to around 0,22 liter per kg caught mixed fish in 2015 – *an expected increase of around 20 %*.

4.3 Chemical exchanges

This section focuses on the antifouling agents, as a function of species, vessel size and fishing gear, similar to the structure of section 4.2. However, data for the consumption of cleaning agents and the emissions of wastewater from fishing vessels are also described briefly as part of the chemical exchanges.

⁸¹ The number of fishing vessels operating in the late 1990s was one third of the number operating in the late 1960s, while the capacity of the fleet has increased (Lassen, 2000)

Antifouling agents and species groups

The chemicals that have achieved most attention in the fishery is by far antifouling agents used to prevent algae and other organisms to stick to the hull of the ships. The biocides that have been used so far are mainly copper or tin compounds such as TBT, Zinc-pyrithione, Diuron and Irgarol (Lassen et al. 2001).

Consumption of antifouling agents (input)

It is reasonable to believe that the major environmental impact from these compounds is in the use stage, where they are supposed to kill and demobilize living organisms. The estimates of emissions are based on calculations of the consumption of antifouling agents. The consumption can be derived as 150% of the emissions (Porsbjerg, 2002). Further details are available in app. 6.

Emission of antifouling agents (output)

As mentioned, it is assumed that the emission of antifouling agents is proportional with the consumption. However, not all is released directly to the seawater. Some of the paint is scraped off on the slipway during maintenance and some paint will remain on the hull, under the new layer of paint. According to Martin Porsbjerg from Hempel, a rough estimate is that around 2/3 of the antifouling agents are released to the seawater during use. (Porsbjerg, 2002). Hence, 1/3 remains on the vessel or in wastewater and waste from slipways and shipyards⁸².

It is obvious that big vessels represents larger emission of biocides than small vessels. The Gross Tonnage (GT) is one way to measure the size of a vessel. However, the surface area of the hull is not directly proportional with the GT. Small vessels will typically have a large surface area per GT than larger vessels. Consequently, it has been necessary to gather data for the amount of biocides typically applied per year for different sizes of vessels – see app. 6. Based on: 1) data for the correlation between vessel size (measured in GT), and 2) consumption of antifouling agent per year and 3) the

⁸² Slipways and shipyards have reduced the loss of tin-compounds to the water compartment significantly during the 1980s and 1990s. Hazardous waste is probably still a problem as well as aerosol emissions, which may pollute local surroundings (Lassen et al. 1997).

correlation between consumption and emission of antifouling agents, it has been possible to establish an estimate for the emissions per GT.

Following the same calculation procedure as for energy consumption, the emissions related to the same nine species has been established – see table 5.

Table 5: Absolute and relative emissions of antifouling agents for nine species established based on three allocation methods. The data and calculations are described in app. 6. The main reference are Fødevareøkonomisk Institut (2001b) and (2002b).

	Demersal fish		Shellfish			Pelagic			Ind.
	Codfish	Flatfish	Prawn	Shrimp	N.Lobster	Mussels	Herring	Mackerel	Tobis etc.
	Catch volume (1000 ton)								
	67,80	40,74	5,72	2,58	5,04	109,74	134,96	34,27	1.117,71
Allocation	Relative antifouling emissions (ml per kg caught fish)								
Mass	0,120	0,136	0,088	0,218	0,177	0,003	0,025	0,014	0,016
Value	0,162	0,174	0,167	0,231	0,746	0,014	0,014	0,051	0,008
Sys. Exp.	0,154	0,240	0,455	0,220	0,486	0,003	0,020	0,006	0,007
	Absolute antifouling emissions (liter)								
Mass	8.111	5.559	505	563	891	294	3.383	464	17.467
Value	11.003	7.096	957	595	3.765	1.555	1.850	1.750	8.665
Sys. Exp.	10.436	9.772	2.605	568	2.454	291	2.688	191	8.231

The total emission of antifouling agents is equivalent to 37.236 liter or a total consumption of 55.854 liter. This figure is independent of the allocation method applied.

As for energy consumption, the largest exchanges appear among demersal and shellfish (excl. mussels) while pelagic fish, mussels and industrial fish have the lowest emissions – a conclusion that holds independent of the allocation method. The following specifically refer to the results based on system expansion.

The fisheries with the largest emissions

Fisheries targeting flatfish, prawn and Norway lobster have the largest emissions per kg. In absolute terms the emissions from flatfish is significant (26%) and these three species make up 40% of all emissions from the fishing fleet.

Fisheries with “average” emissions

Fisheries targeting codfish and shrimp represent emissions, which are not among the smallest nor the largest measured per kg caught fish. However, in absolute terms codfish actually represents the largest emissions from any of the nine species categories: 28% of the emissions in the fishing fleet.

The fisheries with the smallest emissions

Fisheries targeting mussels, pelagic fish and industrial fish represent the smallest emissions (that is the four columns to the right in table 5). The absolute emissions for industrial fish are somewhat high (22% of total emissions).

It must be concluded that demersal fish and shellfish are the hot spots concerning emissions of antifouling agents, which is basically the same situation as for energy consumption.

For farmed fish, it may again be assumed that 3-5 kg of industrial fish is used to produce one kg of farmed fish. This means that the consumption will be in the range of 0,03-0,05 ml per kg farmed fish, which is lower than for wild edible fish, where the average is 0,07 ml per kg, as described below (Ministry of Food, Agriculture and Fisheries, 2001).

Demersal and edible fish - as separate species groups

If demersal fish are perceived as one species group, it can be established that the relative emissions is 0,21 ml kg demersal fish, excl. blue mussels (based on system expansion). This can be derived from table 5.

Table 6: *Relative and absolute emissions for demersal fish, inclusive shellfish. Co-product allocation is avoided by system expansion.*

Characteristics about fuel input	Demersal fish incl. shellfish	
	Incl. Mussels	Excl. mussels
Total catch volume from Danish concerns [1000 ton]	232	122
Relative emissions [ml per kg caught fish]	0,113	0,212
Absolute emissions [Liter]	26.126	25.835

It is also possible to establish the emissions for edible fish as “one” species group. Calculations based on the results in table 5 suggest that the emissions are 0,07 ml per kg edible fish. Considering an average filet yield of 0,4 (see app. 3), this is roughly 0,19 ml per kg fish filet.

Antifouling agents and vessel size

The following figure illustrates the emissions of antifouling agents per kg catch and per catch value for different vessel sizes in the Danish fishery in 1999. As for energy consumption, the data represents 99% of the total turnover in Danish fishery (Figure 8).

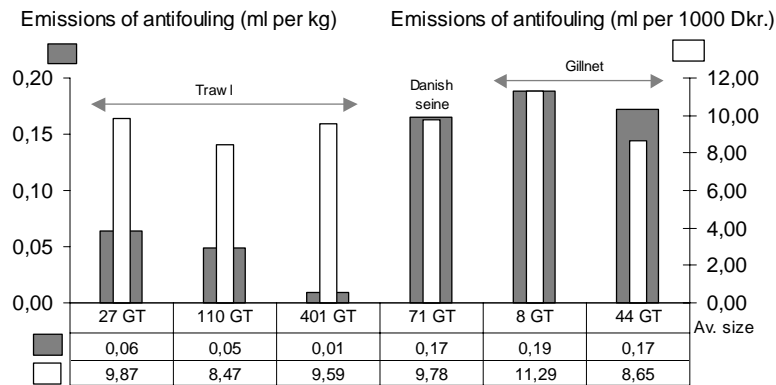


Figure 8: Emission of antifouling agents in ml per kg caught fish and per catch value in Danish fishery in 1999 (Fødevareøkonomisk Institut, 2001a). Calculations are available in app 5 (Document B).

As figure 8 illustrates, there is a tendency that large vessels have a lower emission per kg mixed fish than small vessels. However, this does not seem to be the case if the emissions are measured per catch-value.

Hence, it is important to consider the catch composition. In this respect, I have established estimates of the emissions per kg target fish for different vessel sizes - applying the same fishing gear and with similar catch composition, as for energy. Again, system expansion is applied for co-product allocation (figure 9).

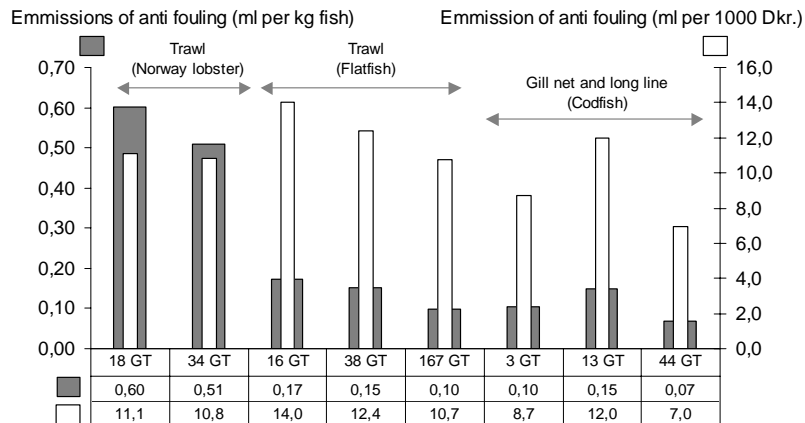


Figure 9: Emissions of antifouling in ml per kg caught fish and per 1000 Dkr for three groups of fisheries targeting Norway lobster, European plaice and Atlantic cod in the year 2000⁸³ (Nielsen,2002b). Calculations are available in app 6 (Document A).

The results in figure 9 confirm that the emissions of antifouling agents decreases as a function of vessel size, even though there is an opposite tendency among the smallest vessels in the gillnet and long line segment.

Antifouling emissions and fishing gear

To establish the correlation between fishing gear and emissions of antifouling, I have gathered data for different vessels targeting the same species using different fishing gears⁸⁴. It has only to some extent been possible to get data for vessels of the same size (Figure 10).

⁸³ The data for each group is based on the same vessel accounts in the energy analysis – fig. 3.

⁸⁴ It may appear irrelevant to analyze the emissions as a function of the fishing gear, as the gear itself has nothing to do with the emissions. However, the effectiveness of the gear may vary, and it must be assumed that effective fishing gear (all other things being equal) results in lower emissions per catch volume than less effective ones.

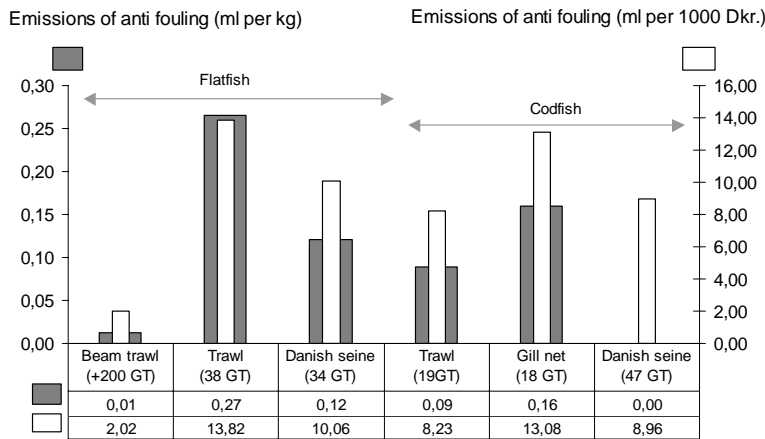


Figure 10. Emissions of antifouling agents per ton caught fish for different fishing gears in the year 2000⁸⁵. Allocation is avoided by system expansion. (Nielsen, 2002b; Beam-trawl, 2001). Calculations are available in app. 6 (Document A).

As it appears, figure 10 provides a somewhat confusing picture. There is no clear tendency that passive fishing gear causes fewer emissions than active gear, nor the opposite⁸⁶.

For the largest vessels representing beam trawl, the figure shows that the emissions per kg flatfish and catch value are very small. This indicates that large vessels have an advantage, but the small vessels representing Danish seine also perform very well (at least in terms of emissions per kg caught codfish). It is not possible to establish a correlation between emissions of antifouling and fishing gear. However, it is striking that beam trawl, which had a high fuel consumption, has a remarkably low emission of antifouling agents. Still, it should be noticed that the beam trawl vessels are significantly

⁸⁵ The data are based on the same accounts as used for the analysis for energy consumption – see figure 5.

⁸⁶ Considering vessels with the same size, it appears that Danish seine performs better than trawl for flatfish – both measured per kg target fish and per catch value. On the other hand, trawl performs better than gillnet for the vessels targeting codfish.

larger than the other vessels in figure 10, and that the emissions tend to decrease as a function of the vessel size, as concluded in relation to figure 9.

Other chemical agents

The following section presents a description of other chemicals used at the fishing stage.

Consumption of cooling agents

Danish fishing vessels use various kinds of cooling equipment. Vessels targeting demersal fish typically have cooling equipment, which serves to hold the ice cold (Danish seine 1, 2001). Vessels targeting industrial and pelagic fish typically have RSW⁸⁷ tanks where cooling equipment keeps the water flow at a certain temperature.

In a Nordic study from the year 2000, it was established that 90% of all Norwegian fishing vessels used R₂₂ as a cooling agent⁸⁸. The same study estimates the total consumption of cooling agents in the Nordic fishery to be 100.000 – 125.000 kg per year. The total catches in Norway, Denmark and Sweden together was 4.376.000 ton. This suggests that the average consumption of R₂₂ was *0,03 gram R₂₂ per kg caught mixed fish in year 2000*. This is a rough estimate and represent an average of all types of fisheries (TemaNord, 2000).

According to an interview with a Danish fisher catching 140.000 ton fish on a typical year, the consumption of cooling agents is roughly 1,5 kg per year including repairs. This is an average⁸⁹ of 0,01 gram per kg caught fish. However, the rough environment and a lack of maintenance can result in far greater leakages in some cases (Hansen, 2003a). Hence, a consumption/emission of 0,03 gram per kg caught fish is used as the most plausible estimate.

⁸⁷That is Refrigerated Sea Water which is used to cool the fish instead of ice.

⁸⁸ The cooling agent R22 is HCFC – 22 with the chemical composition CHF₂Cl. This substance contributes significantly to global warming and has a global warming potential that is 1.700 times larger than CO₂ over 100 year. The Ozone Depletion Potential is only 0,055 times the potential of CFC 11 also termed freon (Pedersen, 2001).

⁸⁹ The cooling equipment in this vessel contained a total of 10 kg refrigerant gas. If we consider a yearly loss of roughly 15%, as estimated by Hansen (2003a), this gives exactly 0,01 gram per kg caught fish (Danish seine 1, 2001).

Emission of cooling agents

It is assumed that the emission of cooling agents is equal to the yearly consumption. Thus, it is assumed that the emission is *0,03 gram R₂₂ per kg caught mixed fish*.

Consumption of cleaning agents

The fishing vessels use various types of chemicals to clean storing rooms, deck, hull and fishing gear. It has only been possible to establish data for the consumption and type of cleaning agents for two vessels. In these cases the amounts were *0,5-0,7 ml cleaning agent per kg caught edible fish* (Danish seine 1, 2001; Danish seine 3, 2001). In one of the cases, which must be considered a worst case, there was only used chlorine for all kinds of cleaning – both inside and outside the vessel. In the LCA case study in part three, the impact potentials will be further analyzed.

Waste water emission (organic matter)

Finally, it should be considered that the fishing vessels have a considerable emission of organic substances.

Pelagic fish. In pelagic fisheries, the fish are stored in RSW tanks with a flow of seawater resulting in an emission of blood-water. Blood-water contains large amounts of easy accessible nutrients for algae etc. The problem is most serious if the emission takes place near the shore or directly in the harbour basin. Nevertheless, it is forbidden to release blood-water in the harbours in Denmark, and the rate of water circulation in the cooling tanks gradually decreases as the vessel approaches the harbour, as the temperature of the fish gradually becomes stable (Ritter, 1997). In an LCA case study of pickled herring, it is established that the blood-water contributed with an organic load of *1-10 gram COD and 1-7 gram BOD per kg caught herring* (Ritter, 1997). Another reference suggests that up to 20-25 % of the total organic load generated from a cannery can be related to blood-water in pelagic fisheries. This would be roughly 50 gram of COD per kg caught fish (Jespersen et al. 2000). The latter is a worst-case estimate. For an average situation, it is assumed that the figure established by Ritter (1997) is the most plausible. As the storing and cooling methods are similar for mackerel, the figure can also be used as an estimate for mackerel.

Demersal and shellfish. It has not been possible to establish data for the amount of blood-water from demersal and fisheries, but it is assumed that the emissions are insignificant.

Waste water emission (cleaning agents)

It is assumed that the emission of cleaning agents is of the same magnitude as the consumption. Thus, the average emission is estimated be around *0,6 ml per kg caught fish*.

Development tendencies

The future development tendencies for the exchanges of chemicals are discussed in the following.

Antifouling agents

Concerning antifouling agents, it is reasonable to believe that we will face a radical technological change in the years to come.

The International Marine Organisation (IMO) has recommend that TBT was phased out in 2003 and that TBT-based products on hulls are completely removed in 2008 – for all ships. Not, all countries have ratified the IMO convention, but in EU the member states have already decided to implement the ban of TBT. In Denmark, the latest regulation of antifouling agents from 2003 also restricts the use of copper compounds by limiting the leaching per surface area.(Allermann, 2004).

It is still allowed to use copper compounds and certain biocides. The major producers of antifouling agents have already developed series of tin or TBT free paints, but with a relatively high content of copper. Even though large amounts of copper is used, it is reasonable to believe that the toxicity levels emitted from fishing vessels will decrease considerably in the following decades. The exact rate of decrease is difficult to predict, and two scenarios have been developed instead. One scenario is a complete change to new tin free paints with a high copper content as we know it today, while the other scenario is a change towards tin free paints with a low copper content. This is further described in app.6.4.

Cooling agents

Regarding cooling agents, the fishery presently uses R22, which is a strong greenhouse gas. Currently, great effort is made to replace such cooling agents with isobutene, carbon-dioxide or other less harmful agents (Pedersen, 2001). As these technologies already exist - and as they are well suited for large cooling facilities, it must be assumed that nearly all (roughly

80%⁹⁰) R22 cooling agents will be gradually substituted within the next 10-15 years.

Other exchanges

It has not been possible to establish any qualified estimates for the developments in cleaning agent consumption and waste water emissions. It is therefore assumed that the situation will remain status quo for these exchanges.

4.4 Other exchanges

Most of the exchanges described in relation to materials, energy and chemicals are “flow-related” exchanges, but there are also a number of “non-flow related” exchanges, which are important for fish products. This include:

- Non-flow related exchange with seabed
- Occupational health and safety aspects
- Animal welfare

These aspects will be discussed briefly in the following, but they will be further analyzed in part three (chapter 10) with respect to impact assessment. In this section, the focus will be the magnitude of the exchange (not the potential impacts or related effects). For instance, the seabed exchange damage will be analyzed with a focus area affected, frequency of fishing and vertical pressure from the fishing gear. In chapter 10, the considerations will include aspects such as background disturbance, type of benthos and sediment structure - variables that are important for an assessment of the impact and the effects.

Exchange with the seabed

The non-flow related exchange with the seabed, occur when fishing gear is dragged over the ocean floor. It is a well known phenomenon, but scientific research considering the magnitude and consequences have so far been lacking.

⁹⁰ The reason why I only assume that 80% is substituted is because regulations sometimes fail due to barriers in the implementation processes.

Important variables

The magnitude of the seabed exchange depend on a series of variables such as (Jennings et al. 2001):

- Surface area that is fished
- Frequency of fishing
- Vertical pressure from fishing gear

It is difficult to estimate the precise exchange from a given type of fishery, because the variables depend on other variables. For instance, the vertical pressure depends on the weight of the fishing gear, the towing speed and the depth where it is used. The vertical pressure is reduced when the towing speed increases and the same is the case if the fishing depth increases (Fonteyne, 2000).

Data about affected area

There is few data available about the total area of affected seabed and the types and magnitude of the impacts in Danish fishery. Still, there are some data available from our neighboring countries, Holland and Sweden (Nielsen and Møllgaard, 1999; Ziegler, 2003).

- 28-kg caught marketable mixed fish per hectare (100 m x 100 m) for a 12-m beamtrawl in the German Bay.
- 5-kg caught marketable mixed fish per hectare for a 12-m beamtrawl in the Southern North Sea.
- 18 kg caught marketable mixed fish per hectare for a 4-m beam trawl in the German Bay.
- 4 kg caught marketable mixed fish per hectare for a 4-m beam trawl in the Southern North Sea.
- 1 kg caught marketable mixed fish per hectare for ordinary bottom trawl (otter trawl) in the German bay.
- 0,6 kg caught cod per hectare for otter trawl fishery targeting cod in the Baltic. The same as 1,7 hectare per kg of caught cod.

These data show that there are great differences in the size of the affected area. On the face of it, beam trawl appear to induce a smaller exchange than otter trawl (mainly because it is so effective), but it should be noted that the penetration depth is bigger, as described earlier in relation to table 2. The high output per hectare is obviously related to the fact that the beam trawl penetrates the seabed relatively more. Thus, it is debatable what is the worse

– a large area affected by a relatively small exchange or a small area affected by a relatively large exchange.

Considerations about different fishing gear and target species

Obviously, exchanges with the seabed only occur when bottom tending fishing gear is applied. Bottom tending fishing gear includes:

- Bottom trawl (incl. beam trawl, bobbin trawl and rock hoppers etc.).
- Scottish- and Danish seine.

Theoretically, bottom tending gear includes pound net, where the fishing gear is attached to the seabed through fishing stakes, but this is disregarded here as the environmental effects on the seabed are assumed to be insignificant. Appendix 1 presents a detailed description of most types of fishing gear applied in Denmark.

Danish seine is also bottom tending, but according to (Andersen and Andersen, 1999; Andersen, 2002a) the gear only have a light contact with the seabed. During the last decades, developments towards heavier draglines and gear that can be operated in rocks, have occurred. This erodes some of the environmental potentials of Danish seine. For further descriptions, see app. 1.

Demersal fish

For fisheries targeting demersal species, it can be established that most of the fish are caught by bottom tending fishing gear.

Codfish. As described in app. 2, 60% of the codfish caught by Danish fishermen, are caught with trawl and pair trawl. Most likely, both categories mainly cover bottom trawl as this is the most commonly used fishing gear in this type of fishery (see app. 1). Typically, trawl used for codfish does not have tickler chains and can even be adjusted not to have seabed contact⁹¹(Hansen, 1986b). This suggests that codfish fishery represents a limited seabed impact, but according to Andersen (1999) bobbin trawl and rock hopper trawl (see app. 1) have become more popular and are accused of entering vulnerable areas not previously fished (Andersen, 1999). Thus, many aspects should be considered.

⁹¹ The tickler chain is used in the Baltic when the cod is spawning (Hansen, 1986b)

Flatfish. Flatfish are caught with bottom trawl (50%), beam trawl (15%) and Danish seine (30%). Thus, 95% of the flatfish are caught with bottom tending fishing gear. As described, it is most likely that beam and bottom trawl represents the largest exchange with the seabed⁹². Flatfish typically live near the seabed or on the seabed. The fishermen therefore add tickler chains to the beam- or bottom trawl to be able to scare the fish up in the trawl. The fishing gear is typically adjusted to have close seabed contact, insured by lead wires and tickler chains. Large beam trawls used for flatfish fishery can be fitted with over 20 tickler chains and can penetrate soft sand to a depth of over 6 cm. (Jennings et al. 2001).

Shellfish

For shellfish, it can also be established that most is caught by bottom tending fishing gear.

Norway lobster. For Norway lobster, 97% of the catches are caught in trawl fishery. This is only bottom trawl, as the lobsters live on the seabed or in caves in the seabed. The trawl is therefore typically fitted with lead wires and/or tickler chains (Hansen, 1986b). Thus, it must be assumed that the exchange with seabed is significant, just as for flatfish fishery.

Shrimp and prawn. For Shrimp and prawn, 40% is caught by trawl, 20% is caught by beam trawl and 37% is unspecified. Obviously beam trawl is bottom tending, but since shrimp and prawn can be caught with pelagic trawl as well, the trawl category is most likely to reflect bottom tending fishing gear as well as pelagic trawl. The seabed exchanges from shrimp and prawn fishery has not been investigated further.

Mussels. 96% of all mussels or blue mussels in Denmark are caught by dredges which are bottom tending. The seabed exchange from this fishery is significant – see app. 1

⁹² Even though impacts and effects are further discussed in chapter 10, it can be mentioned that one of the most comprehensive studies, “the Impact II Assessment” from Holland, concludes that bottom- and beam trawl causes a significant disturbance such as changes in the sediment structure, re-suspension of nutrients and changes in the benthos communities. The study focuses on the ocean floor in the North East Atlantic (Nielsen og Møllergaard 1999, p. 15).

Pelagic and industrial fish

Herring and mackerel. For the pelagic species, bottom tending fishing gear is practically never used (see app. 2). Thus, seabed exchanges is not an issue.

Industrial fish. Finally, 79% of the industrial fish were mainly caught with bottom tending fishing gear – see appendix 2. According to Hansen (2002), the trawl typically have a light contact with the sea floor - using one or few tickler chains. Thus, some level of seabed disturbance is expected to occur, but the exchange is not likely to be of the same magnitude as for fisheries targeting flatfish, Norway lobster or blue mussels.

It must be concluded that flatfish and Norway lobster fisheries probably represents some of the largest seabed exchanges per kg caught fish, while the opposite is the case for herring and mackerel fisheries. Blue mussels fisheries are probably also relatively problematic, while other fish species represents a varying degree of seafloor exchange.

Occupational health & safety

Occupational health & safety (H&S) should also be considered in relation to the fishery. It has not been possible to establish the exact frequency and type of H&S exchange related to different species groups. However, some general figures for the Danish fishery are available.

In chapter 2, it was explained that the total number of full-time employees in the fishery sector were 12.000 in the year 2000. Fishery alone was the employer of 3.000 people (full-time). The total number of reported injuries and work-inflicted sufferings was respectively 250 and 42 in the year 2000. This gives an average of 8,3 reported accidents and 1,4 reported work related sufferings per 100 full-time employees per year (Søfartsstyrelsen, 2000 p. 63-65).

Type of injuries. The average number of mortal accidents were 7,5 accidents per year from 1990-2000, which is 0,25 mortal accidents per 100 full-time employee per year. Injuries are typically broken bones, sprains, open wounds and strokes. For work related sufferings, the typical problem is back injuries (Søfartsstyrelsen, 2000 p. 63- 65).

It has not been possible to distinguish between the segments targeting different species. Still, it can be established that the absolute number of sea accidents per year is roughly similar for vessels below 20 GT and vessels over

20 GT (Søfartsstyrelsen, 2000 p. 44). Vessels under 20 GT represents: 85% of all fishing vessels, 66% of all fishermen and 17% of the total tonnage in the Danish fishery. This indicates that, small vessels probably have a higher number of sea accidents per kg landed fish - while the number of sea accidents per employee is roughly the same for the two groups of vessels (Fiskeridirektoratet, 2001a). However, it must be stressed that sea accidents not necessarily say anything about the occupational H&S problems.

Studies from Norway include information about the number of fatal accidents per employee as a function of vessel size. These data shows that the number of fatal accidents for small fishing boats is more than three times larger than for deep-sea fishing vessels while medium sized vessels represent the average. (Mattsson and Ziegler, 2004). This support that smaller vessels has a poorer performance with respect to H&S aspects, but still the data only represents fatal accidents and only the Norwegian fishing fleet.

According to personal communication with a Danish expert in sea safety (Nielsen, 2003c) larger vessels does not have a better performance with respect to occupational H&S aspects in Denmark. Instead, he argues that vessels operating with passive fishing gear perform better than vessels with active fishing gear such as trawls, because injuries and accidents often occur during handling of otter boards and wires, according the Nielsen (2003c).

This shows that nothing can be concluded without further analysis. Clearly, more research is needed.

Animal welfare

Animal welfare is also an issue in the fishery. The use of hooks obviously makes physical damage to the fish, but physical damage is also involved when other fishing methods are applied. Other factors that should be considered are slow death, stress, and pain during entanglement. Apart from fish, by-catch of marine mammals is an issue to consider.

It is difficult to talk about the “magnitude of exchange” with respect to animal welfare, and it is difficult to distinguish between the exchanges for different species groups. The analysis of animal welfare is therefore further elaborated in part three (chapter 10) with a focus on the impact assessment.

Development tendencies

The development tendencies for the exchanges related to the seabed, H&S as well as animal welfare are discussed in the following.

Seabed impacts

So far, the technological development in the fisheries has been characterized by an increase in average size of the fishing vessels and engine power per vessel. Although the total tonnage has remained relatively stable, the number of fishing vessels remaining in the late 1990s was only 1/3 of the number that operated in the late 1960s. Hence, a considerable number of small fishing vessels with small engine power and passive fishing gear, such as Danish seine, have been phased out.

During the last decades, the danish fishing fleet has experienced a development towards fewer vessels, increased engine power and more active fishing gear such as trawl (Lassen, 2000). The future will depend on the effectiveness of EU programs for fleet reductions. Even though there are organizations representing the smaller vessels - such as "The Danish Society for a Living Sea" - it is most likely that the EU fleet reduction programs will contribute to a further decrease in the number of older, small vessels that often apply passive or semiactive fishing methods. A further increase in the effects on the seabed, measured per kg caught fish must be expected.

Occupational health & safety

During the 1990s, a series of initiatives have been introduced, to improve the situation for occupational health & safety aspects in the fishery. It must be expected that a further improvement will occur in this area, due to the increased attention as well as the development of better and safer technologies – both relative to the number of employees, the catch volume and in absolute terms. Increased overexploitation and overcapacity, may force the fishermen to fish in rough weather and to take more chances. However, it is not assessed that we will experience a further increase in the overexploitation in the following years – as explained in section 4.1.

Animal welfare

It has not been possible to establish any meaningful distinction between different fisheries in terms of impacts on animal welfare – at least not considering fish. Still, it is an issue with respect to by-catch of marine mammals, where current regulations appears to reduce the problems. This is further analyzed in chapter 10.

4.5 Summary & final comments

The key indicators for environmental aspects for nine product types are illustrated below (notice that shrimp and prawn are in one category). The indicators are all per product volume – see table 7.

Table 7: A rough assessment of environmental aspects related to nine species groups. Symbols/numbers are explained below.

Environmental aspects	Demersal		Shellfish			Pelagic		Ind.fish
	Codfish	Flatfish	Shrimp/Prawn	NL	Mussels	Herring	Mackerel	Tobis etc.
Fish resources	4	3-4	Na	2-3	Na	1-2	1-2	1
By-catch of marine mammals	<1-4	Na	<1	<1	<1	<1	<1	<1
Discard	3	3	3	4	1	2	2	2
Fuel	3	4	4	4	1	2	1	1
Antifouling	3	4	4	4	2	2	1	1
Seabed ⁹³	<1-4	<1-4	0-4	<1-4	<1-4	0	0	1-3
H&S aspects ⁹⁴	4	4	4	4	3	3	3	3

Numbers illustrate the magnitude of the exchange per catch volume:

4) Large, 3) medium, 2) small, 1) very small, <1) insignificant, 0) no exchange, Na) not assessed

Grey fields: The magnitude of the exchange is relatively significant (3 or more)

White fields: The magnitude of the exchange is less significant (2 or less)

As it appear demersal and shellfish generally represents the largest exchanges. It should be pointed out that the table reflects crude generalized estimates and that the assessment is relative to the catch volume⁹⁵. Animal welfare is not included here but further analyzed in chapter 10.

⁹³ For seabed exchange, cod- and flatfish can be caught by pound net, which are attached to sticks. This fishery does not have a nsignificant impact on the seabed (symbolized with <1), while beam- and bottom trawl, also used in cod and flatfish fishery, has a high impact potential (4). For pelagic fish, there is typically no seabed contact at all (symbolized with 0). For by-catch of marine mammals, the problem is mainly related to the use of certain types of gillnet in the demersal fishery.

⁹⁴ The H&S aspects for mussels, herring, mackerel and industrial fish has been considered less significant (than other species), because of the large catch volumes per vessel in these fisheries.

⁹⁵ Specifically for industrial fish, it is established that the absolute levels of energy consumption and antifouling emissions deviate significantly from the relative levels.

Demersal and shellfish

The fishery targeting demersal fish often contributes to over-exploitation and is probably also the most problematic with respect to by-catch of marine mammals and discard. With respect to overexploitation, the resource situation is generally worst for round fish and the stocks of Atlantic cod are particularly overexploited. This may reduce the yields in the following years, but from an environmental point of view, it is also worth to focus on effects on genetic diversity and increased vulnerability of stocks in the future.

Both shellfish and demersal fish represent a significant fuel consumption in the fishing stage. For Norway lobster, the average fuel consumption is around 6 liters of diesel per kg caught lobster.

For antifouling agents and seabed exchanges, it is largely the same picture as for energy consumption; demersal and shellfish represents the largest exchanges. The reason is that a significant proportion of demersal and shellfish are caught with bottom dragged fishing gear, such as beam and bottom trawl.

Industrial, pelagic and farmed fish

Considering the last 5-10 years, the resource situation is less severe for pelagic- and shellfish, and industrial fish are within safe biological limits. The positive picture also applies to energy demand and emission of antifouling agents per catch volume. Still, in absolute numbers, industrial fish are quite important because of the large quantities that are caught.

Farmed fish does not induce a direct impact on the sea ecosystem, but contribute indirectly through fish fodder, which is based on industrial fish. Typically 3-5 kg industrial fish are used to produce one kg farmed fish.

Thus, several arguments exist that demersal and shellfish are the groups of fish species representing the largest environmental burden in the fishing stage, but there are significant potentials for improvements.

Small versus large vessel size

The analysis in section 4.2 suggest that the energy consumption for fisheries targeting demersal and shellfish tends to increase as a function of the vessel size. This conclusion is based on a relatively small number of samples, but the tendency is confirmed by more comprehensive studies from Canada. Though, it is reasonable to assume that small vessels often are more energy efficient measured in terms of fuel consumption per kg caught fish or per landing value (for demersal species). It is important to be aware of potential trade-offs with other exchanges. The analysis in section 4.3 suggest that the

emission of antifouling agents per kg caught fish decreases as a function of increasing vessel size.

Passive versus active fishing gear

By comparing vessels with the same size and targeting the same target species, it was also possible to elucidate the energy consumption as a function of the fishing method⁹⁶. The study shows that passive and semi-active fishing gear such as gillnet, long lines and Danish seine are considerably more fuel-efficient than active bottom dragged fishing gears such as beam- and bottom trawl. The difference in fuel consumption is remarkable in some cases and must eventually lead to a debate about the sustainability of certain fishing methods such as beam trawl. The difference in fuel consumption also applies to purse seine versus pelagic trawl, where the catch of herring and mackerel is more fuel efficient in purse seine fishery (a semi-active fishing method).

The analysis also points towards a correlation between fuel consumption and impacts on the seabed. Active bottom dragged fishing gear such as beam and bottom trawl causes the largest fuel consumption but are also responsible for the highest seabed impacts. It appears that it is the same friction (against the seabed) that contributes to the impacts on the seabed as well as the high fuel consumption⁹⁷.

Thus, small vessels employing passive fishing gear appears to be a sound fishing method in many aspects: There is a smaller risk of over-exploitation of stocks (small catches) and the fuel consumption as well as the effects on the seabed are relatively low. However, it must be stressed that there are no obvious advantages in small vessels and passive fishing gear in terms of emissions of antifouling agents nor human health and safety. However, the

⁹⁶ In this regard it is important to stress that vessel size and fishing gear are not independent variables. In reality, small vessels with small engine power more frequently uses passive fishing gear, while fishing methods such as beam trawl only is applied by relatively large vessels with high engine power.

⁹⁷ In this regard, it is also worth to consider that by-catch of benthos and other animals will block the meshes of the net. In extreme cases it may lead to so-called “boil back”, where water is unable to pass through the net (Jennings et al. 2001). Obviously, this will not only greatly reduce the catch efficiency and the selectivity of the fishing gear, but probably also the energy efficiency – which will tend to increase. Thus, we may in fact have at least three correlated variables: Energy consumption, seabed impacts and by-catch of benthos etc.

most important drawback for passive fishing gear is probably the by-catch of sea birds, mammals and ghost netting, which is an issue for gillnet and to some extent long line with respect to sea birds. Modification of fishing gear and bird or mammal scaring devices may reduce these problems, but so far it is still a problem in certain fishing areas (see app. 1).

Development tendencies

It is predicted that certain exchanges will change significantly in the future. This applies to emissions of lead, consumption of fuel, emissions of antifouling agents, cooling agents, seabed impacts and occupational health & safety – see table 8.

Table 8. *Expected changes in environmental aspects, towards year 2010-15*

Type of environmental aspect	Expected change compared to current situation
Consumption and emission of lead	- 80 % (will be substituted by iron)
Energy consumption	+ 20 %
Emissions of TBT (antifouling agent)	-100% (2 alternative scenarios)
Emissions of artificial cooling agents	- 80% (will be substituted by natural cooling agents)
Seabed exchanges	Increase
Occupational health & safety aspects	Decrease

As it appear the most important changes are predicted for lead consumption/emission, energy consumption and consumption and emissions of antifouling agents and cooling agents.

Limitations of the analysis

This section describes the limitations of the MECO analysis of fishing stage with a focus on the obtained data quality - analyzed through five indicators. The first three indicators deal with the degree of accordance with the data quality requirements for temporal, geographical and technological aspects. The last two indicators focuses on the reliability and the completeness of the data sets. The method for data quality assessment is described in app. 4.

General aspects

All of the data have a high degree of accordance with the demands to temporal scope (less than three years of difference) as expressed in the data quality requirements in chapter 3.

As mentioned, the cut-off criterion for material flows is set to 0,1 % of one kg of fish filet dispatched from the processing stage. For the energy con-

sumption, the cut-off criterion has been similar to 0,1 MJ kg of fish filet dispatched from the processing⁹⁸. In the fishing stage, lower material flows are included for antifouling agents and lead used in the fishery as well as HFC based cooling agents. The reason is that these exchanges are believed to imply a high impact potential. At this stage of the life-cycle no (known) exchanges have been excluded due to the cut-off criterion.

Data sets with a low data quality

The data for input and output of *specific fishing gear incl. lead* are from Sweden and represents only data from a few fishermen. The geographical correlation is therefore not ideal, but it is assumed that this is less important as the exchanges related to fishing gear are quite similar in Denmark and Sweden. The low degree of completeness is more problematic, and the uncertainty is therefore assumed to be significant. However, for lead; it should be stressed that the data for lead are supplemented with Danish data from a recently published substance flow analysis where the completeness is considerably higher. As the data in the SFA partly are based on qualified estimates from experts, the overall uncertainty is still assumed to be significant, although it is probably smaller than for the Swedish data.

The data for *chemical exchanges* are generally considered to have a relatively low data quality. The issue here is the lack of reliability. In this respect the data are generally not verified - and partly based on assumptions⁹⁹. The use of assumptions is especially an issue for antifouling agents where several sets of assumptions are combined regarding consumption per tonnage (GT), emissions per consumption and type of paint.

For some data sets, there are also data quality problems in other areas, especially for *cooling agents*, which is based on a large Nordic study with average data based on qualified estimates. For cleaning agents, the completeness is very small as the data only covers a few vessels in a specific vessel segment. Hence, the uncertainty is considered to be largest for cooling and cleaning agents. However, the uncertainty for other exchanges is also considerable.

⁹⁸ It should be considered that the exchanges in this chapter only represent exchanges per kg caught fish and that they should be multiplied with the inverse of the filet yield or roughly 2,5 in average.

⁹⁹ For antifouling agents, some of the assumptions - such as consumption per tonnage - are verified, but this does not mean that the final results are verified.

Data sets with a high data quality

It is assessed that the highest level of data quality is obtained for *energy consumption*. The time, geographical and technological scope meets the data quality requirements and the reliability reflects the data are verified and generally based on measurements, even though some estimates are based on economical expenses to fuel, which have been used to assess the actual fuel consumption. Different types of validation have been used. Data for average species energy consumption have been validated through energy balances since we know the total consumption. However, these data have also been validated through comparison with data from other studies, mainly Tyedmers (2001). For species and size specific estimates, the validation is mainly related to comparisons with data achieved through interviews with fishermen.

Concerning completeness, the estimates for species-specific energy consumption are representative for the Danish fishery and cover a sufficient time period (one year). Furthermore, the data are based on 1518 vessels covering 99% of the turnover in the fishery¹⁰⁰. The estimates for certain species such as herring, mackerel, shrimps and prawns are based on smaller samples. As system expansion is applied to account for co-products, it can be argued that the somewhat smaller completeness in parts of the samples cannot be seen as an isolated phenomenon. However, in practise, calculations have shown that even a large variation in these species categories has a limited influence on other species.

The completeness for estimates of energy consumption for specific fishing gears and vessel sizes are somewhat smaller because the data are based on smaller samples (roughly 10 vessels in average). Still, the overall data quality is relatively good.

Other data sets

For other data sets, the correlation with the quality demands to scope is generally good. For fish boxes, the technological correlation is relatively low

¹⁰⁰ It is previously mentioned that the relative environmental exchanges in the fishery may vary from year to year because of fluctuations in the resource situation. However, this has been compensated for by comparing the fishery in the year 2000 with the average landings in the previous decade - see chapter 2. Furthermore, there have been carried out detailed verifications in app. 5 and 6. Concerning the latter, three different scenarios has mitigated the fast technological development towards new paints.

because I have used data for re-usable plastic boxes used for vegetables. However, this is basically the same type of boxes and it will therefore not affect the result significantly. The reliability reflects that data are verified and partly based on assumptions, or non-verified based on measurements. The completeness reflects that the data are representative from a sufficient or smaller sample and time period. Table 1 provides an overview of the data types and data quality indicators for the exchanges described in the fishing stage.

Table 9. Overview of data quality indicators for exchanges described in this chapter. The two circles illustrate the most problematic data sets. The method used for quantification of indicators is described in app. 4 .

Variables	Data type	Data quality				
		Ti	Ge	Te	Re	Co
Materials						
Biotic resource extraction (over-exploitation)	Semi quantitative	1	1	1	1	1
I/O fish boxes (demersal and shellfish)	Quantitative	1	1	4	2	1
Consumption of ice	Quantitative	1	1	2	2	2
I/O certain fishing gear (iron, LDPE and lead)	Quantitative	1	3	2	2	2
I/O average fishing gear (lead)	Quantitative	1	1	2	4	2
Discard of guts	Semi quantitative	1	1	1	2	1
Amount of discard (average for North sea)	Quantitative	1	1	1	2	2
Amount of discard (gear specific)	Quantitative	1	1	1	2	2
Energy						
Energy consumption per specie	Quantitative	1	1	1	1	1
Energy consumption versus vessel size	Quantitative	1	1	1	1	2
Energy consumption versus fishing gear	Quantitative	1	1	1	1	2
Chemicals						
I/O cooling agents	Quantitative	1	2	2	3	2
I/O cleaning agents	Quantitative	1	1	1	3	2
I/O antifouling per specie	Quantitative	1	1	1	3	1
I/O antifouling per size	Quantitative	1	1	1	3	2
I/O antifouling per gear	Quantitative	1	1	1	3	2
Hazardous waste (antifouling – average)	Quantitative	1	1	1	3	1
Hazardous waste (antifouling – gear specific)	Quantitative	1	1	1	3	2
Emission of blood-water (pelagic)	Quantitative	1	1	1	3	2
Other						
Impact on seabed	Semi quantitative	1	1	1	2	2
Health & safety	Semi quantitative	1	1	1	2	1
Animal welfare	Qualitative	Na.	Na.	Na.	Na.	Na.
Lost fishing gear (ghost netting)	Qualitative	Na.	Na.	Na.	Na.	Na.

The second column describes whether the data are established quantitatively, qualitatively or semi-qualitative.

The last five columns concern data quality. (Ti) refers to time scope correlation. (Ge) refers to geographical scope correlation. (Te) refers to technological scope correlation. (Re) refers to data reliability and (Co) refers to completeness. Small numbers refers to high correlation with the quality demands for scope or high reliability / completeness.

The choice of figures / indicators and the argumentation behind them have not been further described. However, the data quality and the data quality

indicators for the LCA case study in chapter 8-9 are further elaborated in Appendix 13 document A.

Uncertainty and variation

The data sets have a varying degree of uncertainty. The uncertainty can be described by a variation, a mean value and a distribution function. However, the problem is to establish these variables.

If a given data has a low data quality concerning all five data quality indicators, the variation is probably high but the variation and the data quality indicators are not directly proportional to the variables. The reliability of a given data set may be poor because the estimate is based on an industrial expert, but this does not necessarily imply that the variation is high. It is similar for the other indicators. Thus, it is necessary to establish the variation on the basis of background knowledge concerning the given type of process or material. In this respect it is important to know something about the technological development within the type of processes and the variation as a function of geography and technology. In some cases it may be exactly the same technology that is used all around the world. It is also necessary to know something about the typical variation from company to company, if there generally are great variations - even within a certain region - or if the variation is relatively limited. This item is related to completeness but concerning reliability it is also important to know if the type of process changes significantly as a function of time – from month to month or from year to year, and whether there can be expected large differences between measures data and data established from mass balances, assumptions etc.

Variation for the most uncertain data. Based on background knowledge and data quality indicators, it is assumed that the variation is largest (-75%/+200%) for the following data:

- Fishing gear (lead, iron and plastic)
- Cooling agents (HCFC and HFC)
- Cleaning agents (chlorine)

For fishing gear, the uncertainty is mainly due to the fact that the data is based on a limited number of samples rather than the lack of geographical correlation. Despite the additional sources for lead emissions in Denmark, the uncertainty for lead is still considered to be relatively large.

For cooling agents, the uncertainty is mainly due to the fact that the data are based on a total figure for the Nordic fisheries. First of all, this figure is only

a rough estimate. Secondly, it must be assumed that there can be considerable differences between different segments. In this respect, it must be assumed that there are great differences between old vessels, where the cooling equipment has suffered a lack of maintenance, and new vessels with well maintained cooling equipment. Finally, for cleaning agents, the uncertainty is mainly related to a very limited number of samples. In this respect, it must also be assumed that there are great differences between the vessels as the consumption of cleaning agents will depend on the individual behavior and tradition for every fisherman.

Variation of the most certain data. It is assumed that the uncertainty is smallest for the following datasets:

- Energy consumption

The uncertainty is basically small because the data collection encompasses nearly all vessels in the Danish fishing fleet. The uncertainty is slightly larger for estimates of energy consumption as a function of species types, and even larger for estimates where both species types and vessel size or fishing gear is taken into considerations. Thus, the narrower the estimate becomes, the larger the uncertainty becomes because the sample sizes is reduced considerably. In this respect, it must be pointed out that there are probably significant variations between old and new vessels, different types and shapes of fishing gear, different fishing grounds, different levels of experience between fishermen etc. Thus, the variation is estimated to 25% for fuel consumption as a function of species and 35% for estimates as a function of vessel size or fishing gear. Both estimates of uncertainty include uncertainty related to co-product allocation, which is described in the last section.

Variation for other data. The uncertainty for antifouling agents is generally considered to be larger than for energy consumption. There are two important reasons. First of all, the data are calculated on the basis of correlation between consumption of paint and tonnage of vessels. Secondly, it has not been possible to verify the results, by comparing with the total consumption in the Danish fishing fleet. Other sources of uncertainty are the amount of antifouling agents that are released to the sea. Thus, it assessed that the uncertainty is roughly $\pm 50\%$ for antifouling emissions per species group, while it is somewhat higher (around 70%) for emissions related to both species and fishing gear.

I have not further analyzed the other data, but it must be assumed that the variance is somewhere in-between the most uncertain and the most certain

data sets. For other data it is therefore assumed that the variation is roughly 50%. The variation for all data sets is shown below:

Table 10. *Assessed variance for data sets used at the fishing stage.*

Exchange	Assessed variance	
	Min [pct]	Max [pct]
Energy per species	-25	+25
Energy per species and gear	-35	+35
Anti-fouling per species	-50	+50
Antifouling per species and gear	-70	+70
Cooling, cleaning agents, lead and gear	-75	+200
Other	-50	+50

Uncertainty and variation for future estimates

Future estimates are established for all data sets but only six data sets are believed to change significantly. Obviously, time correlation is significantly reduced in future estimates. According to Weidema (2001a), the uncertainty in future estimates is mainly related to changes in the system delimitation that will occur as a result of changes in market trends, production limitations etc.

It is very difficult to estimate variation in future estimates. The changes can be quantitative changes of the exchanges, but also qualitative, such as for antifouling agents, where new and maybe yet unknown types of agents may be used. In this regard, I have developed two future scenarios where the only difference is the antifouling paint used. I have not described the additional uncertainty in relation to future estimates in general, but obviously the uncertainties are considerably larger than for the present situation.

Other methodological aspects

Apart from the data, there are several limitations of the MECO analysis. First of all, the system delimitation has theoretically been based on cut-off criteria, but in reality the analysis also reflects data that have been available, which is not necessarily all the important data. Thus, important data may have been left out.

For exchanges related to energy and antifouling agents, a combination of technical subdivision of the unit processes and system expansion has been used to avoid co-product allocation. This is the best possible way to handle co-products according to the ISO standard 14040. However, there are still uncertainties. As described in app. 5 and 6 there are first of all uncertainties

related to the technical subdivision of fishing categories because the subdivision is based on interviews with a relatively small number of vessels.

Secondly, it can also be argued that some of the assumptions behind the use of system expansion are somewhat uncertain. The most important assumption is that fishery is limited by quota and that practically all quotas are fully exploited.

Obviously, there are species quota which are not fully utilized in some periods, and there are catches that are not registered etc¹⁰¹. Thus, there might be cases where the by-catch in one fishery does not substitute a similar quota in other fisheries – especially in shorter time perspectives. In other words, there is also some level of uncertainty related to the way I have avoided co-product allocation. However, it is never possible to establish anything 100% correct, and after all, it is still assessed that the uncertainty on energy data are among the most certain data. In this regard, it is crucial to understand that there are uncertainty related to the handling of any process that involves co-products, and that the uncertainty is probably larger in other data sets where allocation is made on the basis of mass or volume.

¹⁰¹ In this regard, it is also worth considering the fish that are caught and landed but still not registered (black fish), quota that are swapped with other countries, and different problems such as very low quota on certain species e.g. cod that affect the possibilities to catch other species because cod may be an unavoidable but still illegal by-catch. It must just be concluded that it is not possible to establish a 100% correct picture of the reality.

MECO Analysis – Processing Stage

This chapter provides an overview of exchanges at the fish processing stage. The previous stage (landing and auction) will be described together with three remaining stages in chapter 6 – see figure 1.

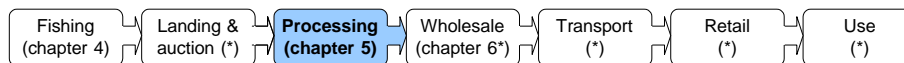


Figure 1: *Illustration of the focus of this chapter – the processing stage*

The chapter follows the same structure as the previous chapter, based on the MECO principle. It has not been possible to describe all the nine species groups separately, as in chapter 4. Instead, it has been chosen to focus on the processing of two types of demersal fish (frozen cod and flatfish), two types of shellfish (frozen mussels and shrimps) as well as two types of pelagic fish (pickled herring and canned mackerel).

Process description

This chapter includes transportation from harbor to processing stage as well as all processes at the processing stage (from arrival of the raw material ‘till dispatch of finished products). Generally, this includes sorting, grading, filleting, trimming, and packaging. Some processes depend on the product type. This is the case for de-icing, breading, canning, souring, freezing etc.



Figure 2. Illustration of different types of white fish processing- with permission from Thorfish A/S.

The consumption of water and energy, as well as wastewater generation, are described most detailed. The product flow and the exchanges are illustrated in figure 3.

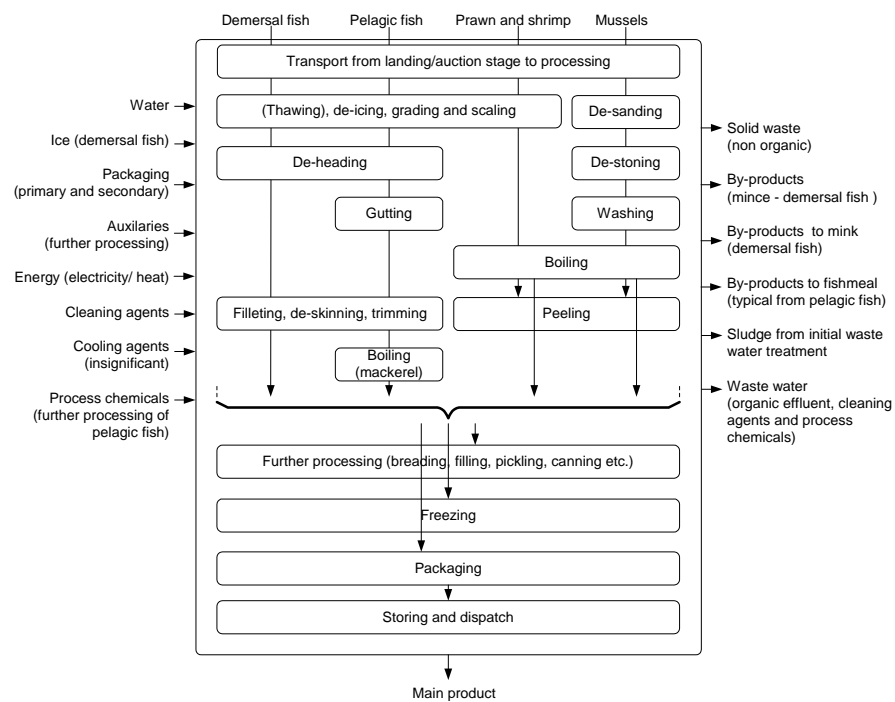


Figure 3. Examples of product flows, processes and exchanges at the processing stage.

Further processing may include marinating of herring, breading of fish fillets from codfish or flatfish, filling of fish fillets, smoking etc.

Data collection and treatment

The data are based on literature studies as well as empirical data, depending on the process or product type. As explained in chapter 3.1, it has been the goal to establish sector average data that represent different types of typical Danish fish processing. The types of fish processing described in this chapter have been selected based on considerations of important product flows, (analyzed in chapter 2.1) and data availability.

All exchanges have been allocated to the main product and are related to one kg of dispatched edible product. Packaging material is also included in the analysis but not included in the functional unit of 1 kg dispatched edible fish product. As all the exchanges are allocated to the main product, the importance of this life cycle stage will be overestimated¹⁰².

General descriptions of data quality requirements, data treatment and methods for co-product allocation and cut-off criteria are available in chapter 3. Descriptions of the limitations of the MECO analysis at this stage, and the obtained data quality, are described in section 5.5.

5.1 Material exchanges

This section deals with renewable materials (fish, water, vegetable products etc). and non-renewable materials such as plastic and aluminum. Effluents in the wastewater are described in chapter 5.3 concerning chemicals.

Data overview – different product types

Table 1 presents an overview of the most important exchanges related to materials for five groups of fish products, representing lean and oily fish as well as shellfish.

¹⁰² Based on the data in app. 12, it is possible to consider substitution of other protein sources from by-products (dependent products), and thereby include avoided exchanges. Avoided environmental impacts are included in the LCA case study in part three.

Table 1: Estimates of the most important material exchanges for five product types, representing demersal, shell- and pelagic fish. All numbers are per kg dispatched product. FF: flatfish filet, CF: codfish filets.

	Frozen cod or flatfish filet	Frozen mussels	Frozen shrimps	Pickled herring in jar	Canned mackerel
Input	<u>Gutted fish:</u> 2,72 kg flatfish, FF 2,42 kg codfish, CF	<u>Whole mussel:</u> 11,70 kg	<u>Whole shrimp:</u> 3,33 kg	<u>Whole herring:</u> 2,17 kg	<u>Whole mackerel:</u> 1,88 kg
	<u>Drinking water:</u> 25-50 l (FF) ^d 24 l (FF) ^a 10-25 (CF) ^d 13 liter (CF) ^b	<u>Drinking water:</u> 20-120 l ^d 12-32 l ^c	<u>Drinking water:</u> 120-175 l ^f	<u>Drinking water:</u> Filleting: 7 l ^d Canning: 8 l ^d	<u>Drinking water:</u> Filleting: 7 l ^d Canning: 35 l ^d
		<u>Ancillaries:</u> Salt: 200-300g ^c		<u>Ancillar. canning:</u> Salt: 158 g ^e Vinegar: 46 g ^e Sugar: 50 g ^e Onion: 196 g ^e Pepper: 20 g ^e	<u>Anc. canning:</u> Tomato paste: 125 g ^f Salt: 16 g ^f
	<u>Packaging:</u> 120 g coated cardboard + 90 g cardboard and 3 g LDPE ^o	<u>Packaging:</u> 30 g cardboard and 1 g PE (bulk) ^c	<u>Packaging:</u> NA	<u>Packaging:</u> 1.400-1500 g glass + 37 g cardboard + 5 g PE ^e	<u>Packaging:</u> 200-300 g aluminum + 63 g cardboard and plastic
Output	<u>Main product:</u> 1 kg frozen fish filet - packages of 300 g each	<u>Main product:</u> 1 kg IQF mussels - 10 kg bulk packaging	<u>Main product:</u> 1 kg frozen shrimps	<u>Main product:</u> 1 kg pickled herring in jar – 205 g filet.	<u>Main product:</u> 1 kg canned mackerel, 80 g filet
	<u>Co-products:</u> 1,72 kg head, bone, skin (FF) ⁱ 205g mince (FF) ^a 1,42 kg (CF) ⁱ 113g mince (CF) ^b	<u>Co-products:</u> 5,40 kg sand ^c 5,30 kg shells	<u>Co-product:</u> 2,33 kg head, bone skin etc. ^d	<u>Co-products:</u> 1,17 kg head bone, skin etc. ^d	<u>Co-products:</u> 0,88 kg head, bone, skin etc. ^g
	<u>Waste:</u> Fish waste in effluent: < 100 g ^a Other: 27 g ^a Filet yield: 0,35 ⁱ	<u>Waste:</u> Fish waste in effluent: NA Other: NA Yield: 0,11	<u>Waste:</u> Fish waste in effluent: NA Other: NA Filet yield: .30 ^d	<u>Waste:</u> Fish waste in effluent: 120 g ^h Other: 19 g ^e Filet yield: 0,46 ^d	<u>Waste:</u> Fish waste in eff. 120 g ⁱ Other: 5 g ^f Filet yield: 0,50 ^g

[a] LCA case study of flatfish – see app. 10 (Company flatfish, 2001, 2002)

[b] Swedish LCA study of cod – average Swedish technology (Ziegler, 2002)

[c] Danish LCA case study of blue mussels – two plants (Andersen et al. 2000)

[d] Danish study of cleaner production in the fish processing industry (Andersen et al. 1996)

[e] LCA case study of pickled herring – average technology (Ritter, 1997)

[f] LCA case study of mackerel in tomato paste (Madsen, 2001)

[g] Environmental analysis of the Danish fishery sector (Miljøstyrelsen, 2004)

[h] Environmental assessment of waste treatment in herring processing (Kromann, 1996a)

[i] Canadian study of average filet yield and protein content of seafood Tyedmers (2000a)

As it appears, most of the data in this table represents only one company (*italic typeface*). The estimates are discussed further in the following sections.

Consumption of water and ice

As shown, the processing stage consumes large amounts of water. For shrimps, the data shows a water consumption of up to 137 liter average per kg product. As the processing of prawn and shrimp are similar, it is assumed that this also represents prawn, while Norway lobster typically is sold unprocessed. Even if the water consumption is overestimated with several hundred percent, it is still significant. High water consumption is also found in other processes that involve boiling, such as processing of mussels.

The water consumption is relatively low for filleting of demersal and pelagic fish. Studies show that the water consumption for flatfish processing is considerably higher than for processing of round fish (Andersen et al. 1996). One of the reasons is that flatfish are smaller and requires more cuts per kg than an equal amount of round fish.

The data for water consumption should generally be used with caution and the water consumption may vary considerably, depending on the size and quality of the fish, the size of the company, technology etc. (Andersen et al. 1996). It should also be mentioned that the data are based on measurements from 1988, even though the references are from the late 1990s. This represents a data quality problem (in terms of overestimation) because cleaner production reduced the consumption considerably in the industry – especially for firms processing pelagic species¹⁰³.

For companies that process demersal and shellfish, it is unknown how much the water consumption has been reduced, but these companies have traditionally not worked intensively with cleaner production (Thrane, 2000b). In this regard, the water consumption for the two case studies of flatfish and codfish are in the lower end of the estimates in table 2.

¹⁰³ As explained later, the consumption has been reduced with at least 50% from 1989-1997 among the most proactive companies in the pelagic segment. This does not represent all the companies in the pelagic segment, and some of the improvements may reflect end-of-pipe solutions. However, it still indicates that the estimates in table 1 represent a worst-case scenario, especially for herring and mackerel.

Consumption of ice

Small amounts of ice are used in the processing of some species such as cod- and flatfish. The fish are sometimes stored in water where ice is added. However, the amounts of ice are relatively small compared to the ice consumption in the fishery. According to Andersen (2003), the amounts are roughly 10-15% of the fish weight – which is 100-150 gram per kg fish.

Consumption of ancillaries

With respect to ancillaries, it is especially the pelagic fish that are important. For instance, pickled herring in jar have an input of nearly 700 gram salt, sugar, onion and pepper per kg herring filet. For canned mackerel, the amount of tomato sauce and salt is also significant – nearly 300 gram per kg filet. In table 2, there are only data for further processing for herring and mackerel. However, other fish species, which are further processed to panned or filled fillets etc. also involves ancillaries such as breadcrumbs, battermix and salt - as well as ingredients for filling (e.g. shrimps) and ingredients for various sauces.

Consumption of packaging

The consumption of typical packaging is described in the following.

Typical packaging for cod- and flatfish

For frozen cod and flatfish products, there are many options for packaging. I have chosen to focus on a solution with coated cardboard in table 2. In the case of “company flatfish”, the material is cellulose based cardboard with a coating of Polyethylene (7% of weight) and a hot melt wax (4% of weight). However, it is also possible to use co-extruded polyethylene (COEX). The plastic solution is considerably lighter (37 gram), and here is used a three layer COEX polyethylene plastic with a thickness of app. 60 μ meter.

Typical packaging for mussels

For mussels, table 1 only provides information about frozen mussels in bulk packaging, which have a low packaging input. However, mussels are also sold in consumer packaging where typical packaging include glass jars or cans, similar to packaging for pickled herring and canned mackerel. Alternatives include light plastic buckets. Other shellfish are sold in a variety of packaging forms, including glass jars, plastic buckets, and cans.

Typical packaging for pickled herring and canned mackerel

The amount of packaging is substantial for the pelagic products such as canned mackerel (2-300 g aluminum) and pickled herring (1,4-1,5 kg glass¹⁰⁴) per kg filet. In both cases, it would be possible to substitute the packaging material with lighter materials based on plastic. For herring, it would be possible to use a plastic bucket of PP instead. My own “kitchen table” measurement shows that a typical plastic bucket of 45 gram contains a drained weight of 400 gram herring filet. This is 115 gram PP per kg filet.

Concerning mackerel, it could be relevant to consider the use of a pouch instead of a relatively heavy aluminum can. This solution is known from other products¹⁰⁵.

Secondary packaging

Additional packaging is necessary for transportation of the products. Typically, there is a cardboard master and plastic film to stabilize the masters on the pallets. For flatfish, the cardboard master makes up 90 gram per kg flatfish product, and in a Swedish LCA study of codfish, it is suggested that the LDPE film makes up roughly 3 gram per kg cod product (Company flatfish, 2003a; Ziegler, 2002). It should be emphasized that these data represent specific product types.

Co-products

Co-products are important environmental aspects because they can substitute other products and consequently reduce the environmental impact considerably. Although the avoided impacts are not directly calculated in this chapter, it provides the calculations together with data provided in app. 12.

Use of organic waste from fish processing in Denmark

As mentioned in chapter 2.2 most of the organic fish waste (90%) from the Danish fish processing industry is used to substitute other products. In this regard, it is used to the following (Kromann, 1996a; Thrane, 2000a):

¹⁰⁴ These data derive from Ritter (1997) and I have verified the data by my own measurements. The latter shows that there should be added roughly 50 gram tin plate for the lid.

¹⁰⁵ A company called *Starkist* actually produces tuna in a pouch with a thin layer of aluminum and without the water content we know from traditionally canned tuna. (See www.starkist.com).

- Human food 1: Mince¹⁰⁶ – substitutes other meat products
- Human food 2: Various parts of the fish can be sold and consumed as luxury products such as herring roe.
- Specialty products: Pharmaceutical products, special oils for the industry etc.
- Animal food 1 (mainly lean fish): Frozen fish or fish silage - substitutes other protein sources
- Animal food 2 (mainly oily fish): Fish meal and -oil – substitutes other protein sources

Considering the total amount of fish “waste” from the Danish fish processing industry in 1998 (except from companies processing mussels), 52% was used to produce fish meal and oil while 33% was used as mink fodder. The rest was used for other purposes such as mince. (Miljøstyrelsen, 1998b). The remaining 10% is used to produce biogas or as fertilizer – thus substituting fossil fuel or artificial fertilizer. Fish waste from wastewater treatment is typically used in biogas production – especially in cases where it has been mixed with cleaning water.

Co-products from cod- and flatfish

If we consider the products in table 1, it appears that the co-products from cod and flatfish products include mince. This is a product that substitutes other meat products and may therefore reduce the environmental impact from processing considerably. It has only been possible to determine the amount of mince in two companies, and the figures are therefore not necessarily representative.

Apart from mince, which is a high value by-product, the by-products consist of skin, bones and heads that is used for animal feed e.g. mink fodder or in the production of fish meal and oil. By-products from whitefish processing are well suited for animal feed – such as mink fodder (Miljøstyrelsen, 1998b). As it will be argued in chapter 8, it must be assumed that the by-product substitutes other protein sources, probably soy protein, in all cases.

¹⁰⁶Minced fish is fish meat that has been separated from the skin and bone in a mechanical bone separator. Mince is primarily frozen in block form and used in the production of formulated seafood including fish sticks, fish cakes, nuggets and added-value or specialty products such as chowders, pâtés, fish balls and gefilte fish. Surimi and flaked fish are other examples of fish products made from previously undervalued fish parts (Jespersen et al. 2000)

Co-products from pelagic fish

Pelagic fish are not well suited for mince production. The same applies to its application as mink fodder (Kromann, 1996a). Instead, most of the waste by-products are used in fish meal and oil production (Miljøstyrelsen, 1998b). Thus, most of the co-products substitutes protein sources, mainly soy protein¹⁰⁷.

Co-products from shellfish

For mussels, the waste consists mainly of sand and shells. 90% of the waste is used to substitute other products. This is the case for parts of the mussel shells, which is used for road construction and fill around drainage tubes etc. The amount used for biogas production is insignificant, while 30% is used as fertilizer and 50% is used for landfill or incineration. The two last categories consist mainly of sand, sludge, shell remains of mussel meat, and other benthos (Miljøstyrelsen, 1998b).

For other shellfish such as prawn and shrimp, it has not been possible to establish a picture of the average use. However, potential use of the by-products such as shells is incineration and biogas production – both activities which substitutes energy production based on fossil fuel (Weidema, 2001b).

Fish spillage via wastewater

As table 2 points out, there is a significant part of the fish raw materials that are lost into the effluent stream. In the case study of flatfish in the present dissertation (see app. 10), it is calculated that around 91 gram of the raw material is lost into the wastewater, of which some 59 gram are separated in

¹⁰⁷ Some companies have succeeded in separating the roe in herring processing, which is sold as salted herring roe e.g. on the Japanese market, where it is seen as a luxury product. On some markets, it is also used instead of real caviar (Thrane, 2000b). In both cases, it must be assumed that the roe substitutes other luxury meat products, and that it indirectly reduces the environmental impact considerably. Finally, it is common practice for some companies to separate the fish oil from the wastewater. The fish oil is sold to the fish meal and oil industry and is mainly used in the processing of fish fodder in aquaculture (Nielsen, 2002a).

Roe and oil as by-products are not specifically mentioned in table 2 because removal of oil can be seen as a kind of initial wastewater treatment (which is not considered here), and because I only have knowledge of one company that sells the roe separately.

the initial wastewater treatment system, in the form of sludge used in biogas production. A part of the remaining raw material will end up in the sludge from the final wastewater treatment and used as fertilizer or in biogas production.

The amount of fish raw material in the effluent stream has also been estimated for herring processing. In this case, the calculation is based on knowledge about the biogas potential in fish waste from processing of herring, which is 0,57 Nm³CH₄ per kg waste, according to Kromann (1996a). The same source suggests that the gas potential is 0,35 Nm³CH₄ per kg COD. It can therefore be deduced that the amount of COD in the fish waste is 1,6 kg COD per kg fish waste. An emission of 190 gram COD per kg product is therefore roughly the same as 119 gram fish raw material (see table 8). This figure is slightly bigger than for flatfish, but is still reasonable because oily fish are processed as whole fish. As mackerel have the same properties as herring, these data have also been used for calculating the material loss for mackerel.

The fish material will substitute other energy sources based on fossil fuel such as in the case of biogas production (Weidema, 2001b).

The filet yield

The filet yield is the weight percentage (w/w) of the processed filet per amount of whole caught fish (live weight).

The amounts of fish fillets that actually reach the consumers ranges from 30-50% of the raw material compared to the case of mussels, where only 10% of caught mussels end up as edible meat.

For cod and flatfish, the typical filet yield is 35%, while it is 46% for herring and 50-55% for mackerel. In table 1, a filet yield of 50% has been used for mackerel because Danish references suggest 50%. It must be stressed that both canned mackerel and pickled herring loses some weight due to water loss. For mackerel, this mainly happens during the sterilization process, while the herring loses some water in the salt brine. Thus, the filet yields for

mackerel and herring will finally be roughly the same, namely around 43% in average¹⁰⁸ (Miljøstyrelsen, 2004; Andersen et al. 1996).

Finally, it should be stressed that the filet yield is not the same as the meat yield, which can be 2-5% higher because of the mince that is produced – in the case of flatfish.

Process analysis

It has not been possible to conduct a complete process analysis for all the material flows in this chapter. Therefore, it is chosen to focus on the water consumption for different processes.

Water consumption in different processes

The distribution of water consumption in two types of fish processing industry is illustrated in table 3.

Table 3. *The distribution of water consumption in lean and oily fish processing industry (Andersen et al. 1996).*

	Lean fish (% of total consumption)	Oily fish (% of total consumption)
Raw material treatment	5-12	9-19
Machine filleting	23-55	40-60
Filet treatment	2-16	
Intermediate cleaning	2-10	
Total cleaning	25-40	8-21
Waste treatment		10-30
Other	10-22	

As the data infers, the largest consumption is related to machine filleting and cleaning. The absolute levels depend on the type and quality of the fish, optimization of process equipment, working procedures and the level of better housekeeping in general.

¹⁰⁸ In table 1, it is chosen to use the large numbers for filet yield, where no water is lost, which gives a better understanding of the amount of waste products. When conducting a life cycle assessment, it will - in most cases - be most reasonable to use the figures for filet that actually reach the consumers.

Cleaner production options

By introducing cleaner production, the water consumption can theoretically be reduced with a factor 2 to 4 in most cases, considering firms that have not yet implemented cleaner production – which is similar to the figures presented in table 2 (Andersen et al. 1996; Jespersen et al. 2000). A typical option is conveyer belts that collect fish waste under the machines and let the water pass through sieve belts. Other options are dry removal of guts by vacuum or mechanical devices, use and maintenance of nozzles for both process and cleaning water etc. Re-circulation can be used in several processes including thawing, water used to transport fish waste in drains, water used for can sterilization etc. (Andersen et al. 1996).

Development tendencies

There are indications that several processes in the fish industry becomes more and more efficient. Especially the consumption of water and packaging will probably be further reduced.

Water consumption

In Denmark, the authorities have launched a series of cleaner production initiatives during the 1990s, mainly directed toward the companies dealing with oily fish. The measures have mainly been directed towards water consumption and wastewater emissions (Andersen et al. 1994, Andersen, et al. 1996). The effect is measured in a benchmarking study of the water consumption for five herring processing companies in Northern Jutland in the period 1989 – 1997 (Nielsen, 2000).

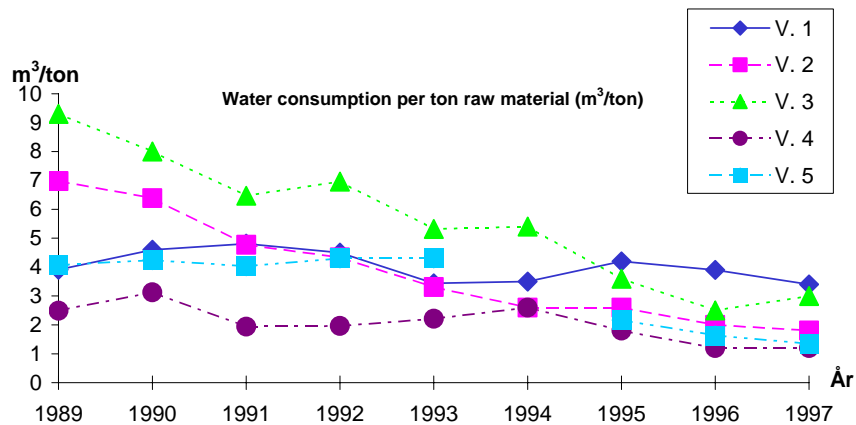


Figure 4: Water consumption per ton raw materials at five pelagic fish industries in Northern Jutland (Nielsen, 2000).

As the figure points out, the average reduction in water consumption is at least 50%¹⁰⁹ over an eight-year period. (Thrane, 2000b).

Some of the companies express that further improvements are gradually becoming more expensive and that improvements in one area such as water consumption often results in increased impacts in other areas such as energy and health and safety (Thrane, 2000b).

It is therefore assumed that further site-specific reductions in water consumption among the first movers (most of the pelagic fish firms) will be small in the following years. Thus, an average reduction of 50% in the water

¹⁰⁹ For pickled herring, it is established that the old method, where the fish are ripened before filleting, consumes 3 to 4 times more water than the traditional method where the herrings are fileted first. A modified version of the old method, where the fish are fileted first and then ripened in a brine containing parts of the guts, reduces the water consumption to nearly the same level as traditional method. The traditional method can also be improved by omitting the vat vinegar brining and instead carry out the whole brining process in the barrels and thereby re-using the salt brine. This will reduce the water consumption with app. 50%.

consumption¹¹⁰ compared to the data presented in table 1, seem to be a realistic estimate in a future scenario for 2010-15.

Consumption of packaging

A Norwegian study has shown that the amount of packaging has been gradually reduced in the Norwegian fish processing industry during the 1990s (Hanssen et al. 2002). Thus, it is assumed that further reductions of approx. 5% will be achieved in Denmark in the next 10-15 years. In this regard, it must also be assumed that materials such as glass and aluminum to some extent will be substituted by plastic products.

Other material flows

It is predicted that other material flows will remain on the same level. It is possible that some flows will be reduced because the production equipment generally becomes more efficient, but it has not been possible to find any exact references to this. Therefore, it is assumed that the other material flows, such as ancillaries as well as waste and co-products, will remain unchanged.

5.2 Energy exchanges

This section describes the energy related inputs, mainly in the form of electricity and heat. First an overview is presented of the whole sector.

Sector level – aggregated figures

The energy consumption in the Danish fish processing industry is typically related to electricity and heat generation by means of gas or oil. In a sector energy study of the Danish fish processing industry (Matcon A/S and Dansk Energi Analyse A/S, 1995), it is established that the total energy consumption in 1992 was 424 TJ for electricity and 848 TJ for heat (gas, oil and district heating). The total amount of raw materials that were processed the same year was 732.000 ton. Thus, the average amount of energy was 0,58

¹¹⁰ As previously mentioned, the water consumption can theoretically be reduced by a factor of two to four in most cases by means of cleaner production, but this is only considered to be realistic for the most proactive companies.

MJ electricity (equivalent to 1,45 MJ primary energy¹¹¹) and 1,17 MJ heat per kg raw material in 1992. If we assumed that the average filet yield is 0,4, this gives 2,55 MJ electricity (as primary energy) and 2,93 MJ heat per kg product – *a total of roughly 5,5 MJ primary energy per kg processed mixed product in 1992, when all the energy is allocated to the main products.*

Data overview (different product types)

The table below provides an overview of the energy input for various segments of the fishery sector. The end-products are the same as described in table 4.

¹¹¹ According to Pommer et al. (2002) it is roughly 40% of the energy delivered to the power plant can be utilized as electricity. Thus, it is necessary to multiply the electricity consumption with a factor 2,5 to convert the electricity consumption into primary energy. According to Simapro 5.1 the difference in green house gas emissions is around a factor two between heat energy consumed in the Danish fish processing industry and consumed electricity (based on gas).

Table 4: Inputs for energy for five different types of fish processing. All units are in MJ per kg product¹¹². References are listed below.

	Frozen cod / flatfish filet	Frozen mussels	Frozen shrimps	Pickled herring	Canned mackerel
Input	Electricity: Codfish: 2,1-3,1 MJ ^{b&k} (CF) 3,8 MJ ^j (FF) Heat: 1,5 MJ ^{b&k} (CF) 2,3 MJ ^j (FF)	Electricity: 3,7-4,4 MJ ^c Heat: 3,6-6,9 MJ ^c	Electricity: 2,8MJ ^j Heat: 10,5 MJ ^j	Electricity filleting: 0,5-0,6 MJ ^{L&e} Electricity canning: 1,0 MJ ^j Heat filleting: 0,6 MJ ^j Heat canning: 1,4 MJ ^j	Electricity filleting 0,5-0,6 MJ ^{L&e} Electricity cann.: 0,1 MJ ^j Heat filleting: 0,6 MJ ^j - herring Heat canning: 0,8-2,7 M ^j

[a] LCA case study of flatfish – see app. 10 (Company flatfish 2001, 2002)

[b] Swedish LCA case study of codfish – average Swedish technology (Ziegler, 2002)

[c] Danish LCA case study of blue mussels – two plants (Andersen et al. 2000)

[e] LCA case study of pickled herring, average technology (Ritter, 1997)

[j] Sector energy analysis (Matcon A/S and Dansk Energi Analyse A/S, 1995)

[k] Case study of company with frozen cod blocks as main product (Company codfish, 2003)

[L] Cleaner production in fish processing – mainly Danish plants (Jespersen et al. 2000)

The data for energy input showed in table 4 does not represent the primary energy input. However, this can easily be established by multiplying the electricity consumption with a factor 2,5.

As the table shows, there are significant variations between processing of different fish species. Indeed shrimps have a high energy consumption. Generally, the highest energy consumption seems to appear in processes that involve hot water or steam, such as processing of mussels, shrimps, canned mackerel and fish meal and -oil¹¹³. Heat generation is typically based on gas, but oil, coal and district heating is also used (LCAfood, 2003). In this respect, considerable environmental improvements can be achieved through

¹¹² As is the case for all environmental parameters, the data varies from company to company and depends on the raw materials, the size of the production, the level of technology (which is average Danish technology in table 4) and the specific kind of end-products. Another cause of uncertainty is the varying percentages of frozen and fresh raw materials as well as the fact that some of the companies may receive a small amount of the raw materials as filets – typically frozen.

¹¹³ Processing of industrial fish into fish meal and oil is not illustrated in the table, but the energy consumption is roughly 8 MJ heat and 0,5 MJ for electricity (Jespersen et al. 2000). The amount of industrial fish needed to produce one kg of farmed fish is in the around 3-5 kg (Ministry of Food, Agriculture and Fisheries, 2001). Thus, the fuel consumption becomes 5-10 times larger per kg edible fish meat – including extra energy needed for processing of fish meal and breeding of the fish.

switching from oil to gas or district heating (Jespersen et al. 2000). The table is discussed and explained in the following.

Data from other studies (validation)

Other data for energy consumption have mainly been available through a sector energy analysis carried out in 1995 involving six Danish companies (Table 5).

Table 5: Energy consumption in the fish processing industry – six case studies (Matcon A/S and Dansk Energi Analyse A/S, 1995)

Company	Product	Heat [MJ per kg prod]	Electricity [MJ per kg product]
1. Rahbekfisk A/S, Fredericia	Raw material: Fresh flatfish fillets Main prod.: Filled, breaded & frozen flatfish fillets	2,6	2,6
2. Rahbekfisk A/S, Kolding	Raw material: Semi manufactured products Main product: Ready made dinners (flatfish)	0,8	1,0
3. Dan-Cod A/S, Esbjerg	Raw material: Semi salted cod products Main product: Spitted and salted cod	0,7	1,3
4. Bornholms konserver	Raw material: Cod roe Main product: Smoked canned cod liver .	3,6	0,6
5. Essi konsumfisk, Esbjerg	Raw material: Fresh whole herring Main product: Herring fillets (fresh, pickled or frozen).	1,4	0,3
6. Najaaq Seafood, Esbjerg A/S	Raw material: Frozen whole shrimp Main product: Peeled shrimps (frozen)	10,5	2,8

From a general point of view, the figures are of a similar magnitude as the figures presented in table 4. This is obvious for shrimps as it is the same reference, but for the other products, it confirms that the energy consumption is relatively low compared to the fishing stage.

Processing of flatfish

As table 5 points out, the electricity consumption for flatfish processing is somewhat lower than estimated in table 4. For company 1 (table 5), which has a similar production to the case study from the present dissertation (reference “a” in table 4), the electricity consumption is only 2,6 MJ per kg processed flatfish instead of 3,8 MJ as suggested in table 4. However, as a large proportion of the raw materials in company 1 are fillets, a difference of 1,2 MJ is reasonable. For heat consumption, company 1 actually represents a higher energy consumption (2,6 MJ per kg product) than suggested in table 4 (2,3 MJ per kg product), but this is a relatively small deviation.

Company 2 processes frozen semi-manufactured flatfish into ready-made dinners. Thus, the company does not carry out filleting. Here, the total energy consumption is 1,8 MJ, of which 1,0 MJ is for electricity, but as this only includes packaging, it is not comparable with the figures in table 4¹¹⁴.

Processing of codfish

Company 3 and 4 process codfish, and the products are salted fish and cod roe, respectively. None of these companies are carrying out filleting and it is therefore not useful to verify the figures for codfish processing in table 4. However, the data shows that further processing may also apply to demersal fish and may consume considerable amounts of extra energy. It is worth noticing the high demand for heat energy for processing of cod roe. Additional data regarding further processing such as hot and cold smoking are described separately in table 7.

Processing of herring

For herring, the data in table 4 suggests that the total energy consumption is 3,6 MJ per kg pickled herring in jar (Ritter, 1997). This includes filleting, marinating and canning. This can be compared to company 5 in table 5, where the total energy consumption is 1,7 MJ per kg product, which is considerably lower. However, it is only some products that are pickled herring, and the processing does not include packaging into cans. Thus, there seems to be good correlation between the data.

Processing of mackerel

Table 5 does not include data for processing of mackerel. For mackerel, the study referred to in table 4, is based on processing of fresh fish and the use of chemical processes for the de-skinning process. However, cutting edge technology for mackerel processing involves processing based on frozen mackerel and the removal of skin by means of steam instead of chemicals. The energy consumption is considerably higher for this technology. An LCA study of a mackerel processing plant with this technology in Denmark, have shown that the energy consumption is around 3,7 MJ electricity and 9,9 MJ heat from gas per kg canned mackerel (Madsen, 2001).

The difference in electricity consumption is probably due to the extra cooling processes as the raw materials are stored in frozen condition for long

¹¹⁴ According to Jespersen et al. (2000), the electricity consumption for filleting of whitefish is 0,5-0,7 MJ per kg product. This figure has not been mentioned before as it appears to be unrealistic.

periods. The extra heat energy is related to steam production used to defrost and de-skin the frozen mackerel. Still, the differences appear to be surprisingly big considering the company described in Madsen (2001) has implemented cleaner production. The case is interesting and indicates that it is worth to be aware of trade-offs for cleaner production solutions.

Processing of shrimp

Processing of shrimps is only analyzed through one case from the sector energy analysis from 1995. In this study, the energy consumption is about 13 MJ per kg product, which is similar to mackerel processing based on cutting edge technology. It has not been possible to verify this further, but the figures appear to be reasonable because the process involves large amounts of steam. The largest amount of steam (37%) is used in the boiling process while 23% is used for thawing the frozen raw materials. Apart from that, the boiler loss is app. 26% (Matcon A/S and Dansk Energi Analyse A/S, 1995).

Processing of mussels

The data for mussel processing are based on a case study of two Danish companies, representing respectively a low and a high level technology. The data suggest an energy consumption of 7-11 MJ per kg product. This is relatively high and mainly related to the steam production for the boiling process. The study shows that significant reductions can be achieved through establishment of heat exchange. Apart from this, there is significant indirect energy consumption through the nitrogen use. This is described in section 4.3.

Process analysis

The distribution between different sources of electricity and heat use are illustrated in table 6.

Table 6: Distribution of energy consumption among 9 companies investigated as part of a sector energy analysis of Danish fish processing companies (Matcon A/S and Dansk Energi Analyse A/S, 1995)

	Electricity (%)	Heat (%)
Processing machines	10	
Process heat	2	30
Pumps	6	
Compressed air	7	
Cooling	55	
Room heating		30
Ventilation	10	
Light	6	
Hot water for cleaning etc.		40
Other	4	
All	100	100

As the data shows, the cooling processes are very important - as well as heating related to processes, rooms, and hot water. It should be noticed that this is an average of nine companies and may not represent all segments of the industry. Within processing of herring, there are examples where process engines are responsible of more than 50% of the electricity consumption, while cooling only amounts to 10-15% (Taabel, 1997).

Typical energy consumption for key processes

Table 7 below shows a series of key figures that can be useful for the estimation of the energy consumption in the fish processing industry:

Table 7. Typical energy consumption for different processes in the fish processing industry. References are mentioned below the table.

Process	Energy consumption
Thawing	0,036 MJ / kg frozen fish ²
Ice production	0,18-0,22 MJ / kg ice ²
Freezing of fish	0,18-0,25 MJ / kg fish ²
Cooling room	0,14-0,18 MJ / liter*year (for 300 m ³ room) ¹
Frost room	0,72-1,08 MJ / liter*year (for 300 m ³ room) ¹
Boiling (pre-cooking mackerel)	0,12-1,86 MJ / kg product ³
Can sterilization (mackerel)	0,72-0,86 MJ / kg product ³
Hot smoking (salmon)	0,22-0,25 MJ/ kg fish excl. ventilation and smoke generator ²
Cold smoking (salmon)	0,11-0,13 MJ / kg fish excl. ventilation and smoke generator ²

References: 1) DEFU (1999), 2) Matcon A/S & Dansk Energi Analyse A/S (1995) and 3) Jespersen et al. (2000)

As it appears, boiling processes may be responsible for a large consumption of energy, but the data also show significant variations. Thus, it is apparently possible to reduce the energy consumption significantly, especially for boiling processes.

Cleaner production options

For freezing processes, cleaner production can imply the use of expelled heat to warm the water used in processes and for room heating. Other solutions are reduction of cool air leaving through doors and windows, switching off lights and the use of plate freezers instead of gyro freezers to the largest extent possible. There is a series of other possibilities related to ventilation, compressed air and other equipment, which is explained in Matcon A/S and Dansk Energi Analyse A/S (1995).

Another way of reducing the energy consumption per kg product is to reduce the product spillage. This type of solution will also reduce other exchanges at the processing stage, as well as the exchanges per kg product in all the other life cycle stages, up-streams in the product chain (including the fishing stage).

Transportation from harbour to processing

The transport from the harbour to the processing stage varies from fish product to fish product. In the LCA case study of flatfish in part three, the average distance from the landing and auction stage to the processing is estimated to be 170 km. The trucks collect fish from several auctions the same day and distributed to several fish industries. Hence, it is reasonable to assume that the trucks are half full both ways. The processing firm is situated in the harbour, but the fish comes from auctions all over the country (Company flatfish, 2002). As there have not been other data available, this is used as the default distance for all fish products. If it is assumed that this transportation is carried out by the same trucks that are used for export (0,88 MJ per ton km full load), it is equivalent to an *energy consumption of 0,3 MJ per kg fish*.

It should be stressed that this does not include transportation for products that are imported as we only consider products caught and processed in Denmark. This is further discussed in chapter 6.

Development tendencies

According to the sector energy analysis from 1995, the producers of processing equipment argue that technology has become more energy efficient. One of the producers that has been interviewed suggests that it is limited how much more energy efficient the equipment has become since the oil crises in the 1970s. It is also mentioned that the companies tend to focus more on water consumption and emissions because of the increased price on water and treatment of wastewater. (Matcon A/S and Dansk Energi Analyse A/S, 1995).

In beginning of the 1990s, Aalborg University carried out a study of the dissemination of cleaner production in the fish processing industry. Among five pelagic fish companies, there was no clear tendency in the development of energy consumption per kg raw material in the period 1989 to 1993 (Andersen et al. 1994).

Qualitative studies of eight fish processing companies in 2001 confirm that the industries generally haven't achieved significant reductions in the energy consumption. Interviews led to the belief that investments directed towards reductions of water consumption and wastewater emission in some cases resulted in increasing energy consumption (Thrane, 2000b). Two cases illustrate this. A life cycle screening of advanced options for wastewater treatment, nano-filtration, suggest that the environmental benefits are eroded by the extra energy consumption related to pumps etc. (NIRAS, 2000). Another example is the advanced mackerel processing with cutting edge technology where the energy consumption amounts to 14 MJ per kg product as explained in section 4.2.

However, it is assumed that small reductions in energy consumption can be achieved through more advanced and automated processing technology with higher filet yields. Thus, an overall reduction of 10% in the energy consumption is a realistic scenario for 2010-2015. In this regard, it has not been possible to make any distinction between different types of fish processing.

No changes are expected concerning transportation (see also description of development tendencies in app. 7).

5.3 Chemical exchanges

This section describes the chemical related inputs and outputs as well as cleaner production options and development tendencies.

Data overview (different product types)

The fish processing industry uses chemicals in cleaning operations for certain processes and in small amounts also in laboratories. The emissions of chemicals are mainly via the wastewater, which also contains organic effluents from the fish (Jespersen et al. 2000; Miljøstyrelsen, 2004). The exchanges in different fish industries are illustrated below. Organic effluents such as COD, N and P would typically be described in the section about materials but are included here as part of the chemicals – mainly for practical reasons:

Table 8: Chemical exchanges for five different types of fish processing. References are listed below.

	Frozen cod / flatfish filet	Frozen mussels	Frozen shrimps	Pickled herring	Canned mackerel
Input	<u>Cleaning agents:</u> Alkali: 2,1 g ^a Alk./chlor: 0,4 g ^a Acid: 0,4 g ^a Disinfect: 1,7 g ^a	<u>Cleaning agents:</u> 3,8 g ^c	<u>Cleaning agents:</u> NA	<u>Cleaning agents:</u> Total: 3,8 g ^e (filleting+cann). <u>Canning:</u> Hydrogen peroxide (bleaching):	<u>Cleaning agents:</u> NA <u>Filleting:</u> NaOH: 20 g ^g HCL: 12 g ^g (De-skinning)
	<u>Cooling:</u> <0,03 g NH ₄ a&b	<u>Cooling:</u> 1,2-1,4 l N ₂ ^c	<u>Cooling:</u> NA	<u>Cooling:</u> NA	<u>Cooling:</u> NA
Output	<u>Wastewater*:</u> BOD: 70 g ^d COD: 100 g ^d Tot-N :NA Tot-P: NA	<u>Wastewater*:</u> BOD: 60 g ^d COD: 75 g ^d Tot-N: 10 g ^d Tot-P: 0,74 g ^c	<u>Wastewater*:</u> BOD: 250 g ^d COD: 300 g ^d Tot-N: 30 g ^d Tot-P: 3,5 g ^d	<u>Wastewater*:</u> Filleting: BOD: 100 g ^d COD: 190 g ^d Tot-N: 5 g ^d Tot-P: 0,4 g ^d Canning: BOD: 80 g ^d COD: 120 g ^d Tot-N: 3 g ^d Tot-P: 1 g ^d	<u>Wastewater*:</u> Filleting: BOD: 100 g ^d COD: 190 g ^d Canning: BOD: 120 g ^d COD: ? Tot-N: 7 g ^d Tot-P: 1 g ^d
	(*) Cleaning agents are discussed in the text				

[a] LCA case study of flatfish – see app. 10 (Company flatfish, 2001, 2002)

[b] Swedish LCA case study of codfish – average Swedish technology (Ziegler, 2002),

[c] Danish LCA case study of blue mussels – two plants (Andersen et al. (2000),

[d] Danish study of cleaner production in the fish processing industry (Andersen et al. 1996)

[e] LCA case study of pickled herring, average technology (Ritter, 1997)

[g] Environmental analysis of the Danish fishery sector (Miljøstyrelsen, 2004)

It should be stressed that the effluent levels of COD, BOD, N and P represents data for 1988 and without any significant form of initial wastewater treatment. The data are therefore a worst-case scenario.

Consumption of cleaning agents

As it appear in table 8, the largest input of chemicals is cleaning agents. The amount and type of cleaning agents are only established in the case study of flatfish, mussels and herring, but in all three cases the type and amount is roughly similar (around 4-5 gram per kg). This is also the case for Company codfish (2002), and studies of other types of food processing show similar amounts per kg product (Weidema et al. 1995).

Consumption of chemicals for wastewater treatment

The treatment of wastewater may also imply the use of different chemicals – both in initial treatment, at the company and the final treatment (public biological/chemical treatment). At the company level, there is typically used flotation based wastewater treatment with air, chemicals, ozone or heat. In some companies, especially in processing of oily fish, also warm or cold centrifugation is also used, and a couple of companies have even experimented with further treatment (micro-filtration). The latter consume significant amounts of chemicals such as AlCl_3 and NaOH .

Because the data for COD emissions in table 8 are before initial wastewater treatments, the amounts and types of chemicals for wastewater treatments are not further analyzed here.

Consumption of process chemicals

As table 8 points out, different chemicals are used for de-skinning (NaOH/HCl) and for bleaching (H_2O_2). According to Jespersen et al. (2000) there is also used antioxidants. However, a discussion with the authors has lead to the conclusion that this is a mistake. It may be used some places in small quantities but is only used in larger quantities within processing of fish meal and -oil.

Consumption and emission of cooling agents

Larger industrial cooling equipment (>150 Kw) such as cooling processes in the fish processing industry is based on ammonia (NH_4^+)¹¹⁵. This does not deplete the ozone layer and in modern and well-maintained equipment the leaks should be insignificant¹¹⁶. (DEFU , 1999; Pedersen, 2001).

¹¹⁵ For smaller cooling equipment (<150 Kw), HFC based cooling agents are typically used, but these will be replaced by natural cooling agents (Pedersen, 2001).

¹¹⁶ A Swedish LCA study establish that a cod processing plant have an input of ammonia of 0,27 gram per kg final product (mainly frozen cod fish blocks). Data from a large Danish company producing codfish blocks shows that consumption has been under 0,1 gram ammonia per kg final product in a period of five years. Finally, the case study of flatfish showed a consumption of 0,01 gram ammonia per kg final product. All these flows are under 0,1% of the product weight, but in the LCA in aprt three they are included in the assessment anyway.

It is therefore assumed that the consumption and emission of cooling agents in the fish processing industry is relatively insignificant in most cases. It should be noticed that ammonia is highly toxic and that leaks may cause a health hazard for employees (DEFU, 1999); however, this is not analyzed further here.

Cooling by means of nitrogen (N₂) is relatively rare in the fish processing industry but it may be the source of considerable indirect energy consumption (Jespersen et al. 2000). In the case study of two companies processing mussels, it was established that the indirect electricity consumption related to the loss of nitrogen from freezing processes was 1-1,4 liter pr kg frozen mussels. The indirect energy consumption related to produce these amounts was assessed to be 2,6-2,8 MJ, which is significant (Andersen et al. 2000).

Wastewater (organic effluent)

As shown, BOD and COD emissions for shrimps and pelagic fish are relatively high compared to demersal fish and mussels. One of the reasons is probably that shrimps are peeled and boiled at the factory. Pelagic fish are also gutted in the factory and apart from that, the oil content in herring and mackerel is high. Finally, the processing stage also involves salting and souring, which generates additional wastewater.

The level of N and P has not been available for all species, but it can be established that processing of shrimps have a high emission of N-tot (30 gram) and Phosphorus (P-tot: 3,5 gram). For the other species, the level is 3-7 gram nitrogen and a considerable lower level of phosphorus. It appears that the emissions of N and P follow the same trend as COD and BOD.

Just as for water consumption, the data are based on measurements from 1988, and the emission represents effluent levels before initial wastewater treatment.

As explained later, first mover companies in the pelagic segment have achieved reductions of at least 50% in COD emissions in the previous decade. Some of these reductions may be due to improvements of initial wastewater treatment but it is also due to reductions of water consumption and separation of fish and fish waste from water currents. Since the data are from

1988 and since many companies have implemented cleaner production during the 1990s, it is believed that the data represents a worst-case scenario, especially for the pelagic segment.

Wastewater (Other outputs)

In the previous section, I have only described the organic outputs, but there are obviously also outputs of cleaning agents, process chemicals and chemicals from laboratories. There have not been enough data available to describe these outputs in this chapter, but in the LCA case study, an assessment is made of the potential environmental impacts related to emissions of cleaning agents.

Processes analysis

It has not been possible to conduct a process analysis for all chemical flows, and it has therefore been chosen to focus on organic effluents from different processes. In this regard, it must be assumed that the organic effluent levels are somewhat proportional to the water consumption. Processing with a minimum of contact between fish and water will lead to lower effluent levels – all other things being equal.

The most water consuming processes are machine filleting and cleaning, which makes up 2/3 of the water in a typical fish plant. (Andersen et al. 1996). The origin of the organic effluents measured in BOD - in typical fish industries - is illustrated in table 9.

Table 9. Overview of the processes that causes BOD in the wastewater (Andersen et al. 1996)

	Lean fish	Oily fish
Raw material treatment	7-20	1-3
Machine filleting	40-80	45-95
Filet treatment	10-25	
Total cleaning	10-30	0-4
Waste treatment		19-53

As the data tells, the largest emissions are related to machine filleting, just as for water consumption. For lean fish raw material treatment, filet treatment and cleaning may also be of importance, while waste treatment is the only major second cause for oily fish. The latter mainly involves transport of the

fish waste, which traditionally has been facilitated through water effluents, where the contact between fish waste and water causes a high content of organic matter in the wastewater (Andersen et al. 1996).

Cleaner production

There are several cleaner production options, which may reduce the effluent levels with a factor 2 to 4, similar to the reduction potentials for water consumption. The options are very similar to the cleaner technologies aimed at reducing the water consumption, such as conveyer belts, dry removal of guts by vacuum or mechanical devices, use and maintenance of nozzles for both process and cleaning water, etc. (Andersen et al. 1996; Jespersen et al. 2000)

Initial wastewater treatment

Other ways of reducing the effluent levels is wastewater treatment. Many Danish fish companies have installed flotation treatment based on ozone, heat or chemicals. With a combined solution with both initial flotation and biological treatment or micro-filtration, the COD level can be reduced by 90-97%. Total-N is reduced by 60-85% and total-P is reduced by 90-99%. (Miljøstyrelsen, 2004).

Hence, the emissions of organic substances, N and P appear to be a limited problem (this is further analyzed in part three). However, it is necessary to consider the environmental impacts from the wastewater treatment process. As previously mentioned, studies show that advanced treatment processes may do more harm than good in terms of environmental impacts (NIRAS, 2000). The exchanges for biological wastewater treatment are included in the impact assessment in part three.

Development tendencies

The development tendencies with respect to chemical exchanges are discussed in the following section.

Wastewater – organic effluents

Parts of the fish processing industry, especially within the pelagic segment, have improved the environmental performance significantly during the 1990s through cleaner production. The results have been reduced water consumption and effluent levels. Figure 5 shows the development in effluent levels per ton raw material for 5 different herring processing companies in the period 1989-1997:

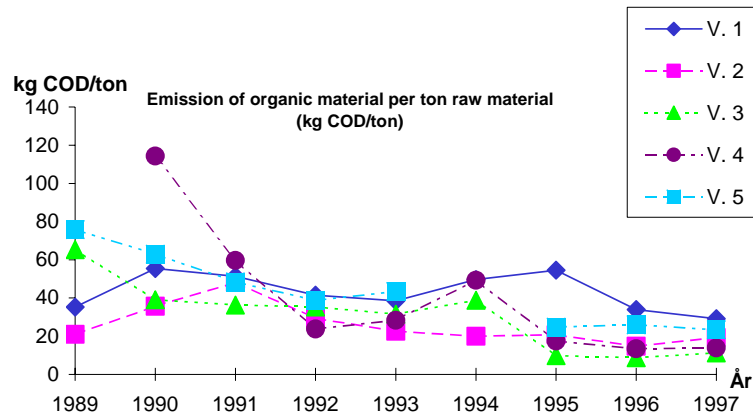


Figure 5: Emission of organic matter per ton raw material. Benchmarking analysis conducted by Eskild Holm Nielsen, Aalborg Universitet (Nielsen, 2000)

As the figure shows, the emission of COD has been reduced by at least 50% among this group of first mover companies. As for water consumption, it is not assumed that these companies will be able to reduce the emissions significantly further, in the next 10-15 years. Qualitative interviews have shown that the companies generally perceive it as too expensive to reach for more improvements. Furthermore, other environmental problems related to the external or internal environment may be side effects of more improvements¹¹⁷ (Thrane, 2000b).

However, it is still possible to achieve improvements in pelagic industries, that are not among the first movers, as well as among the companies that process demersal and shellfish. It is assumed that the effluent levels can be reduced by 50% in average for all companies - compared to the data representing measurements from 1988. For other data, it is assumed that the effluent levels can be reduced by further 20% in a future scenario for year 2010-15.

¹¹⁷ Here I am thinking of aerosols from cleaning operations involving a nozzle that causes respiratory problems as well as nano-filtration of wastewater that causes a high energy consumption (Thrane, 2000b).

Cleaning agents and process chemicals

For cleaning agents, it has not been possible to establish a picture of the development, but it is assumed that cleaning agents will follow the same trend as the water consumption. Less water means less cleaning chemicals – but cleaning related water consumption is typically only about half of the total water consumption. Hence, a further reduction of 25% is assumed realistic, compared to the data presented in table 8.

For process chemicals, it is not been possible to to establish a clear picture of the development tendency for a broader range of companies. It is assumed that the current levels will remain unchanged.

Cooling agents

Currently, mainly ammonia is used as cooling agent in large industrial cooling units such as in the fish processing industry. In the future, it is expected that ammonia or other natural cooling agents, such as CO₂, will be used in all cooling processes in the fish processing industry (Pedersen, 2001). Hence, the contribution to ozone depletion and global warming is assumed to become less significant in the future.

5.4 Other exchanges

There are a number of other environmental aspects that have not even been addressed in section 5.1 to 5.3, this include:

- Occupational health & safety
- Smell and noise

A short analysis of these aspects are presented in the following.

Health and safety

One of the most obvious environmental aspects that have not been addressed yet is health and safety. As explained in chapter 2, fish processing involves the largest number of employees compared to the fishing-, wholesale- and retail stage. Nearly twice as many are employed full time in the fish processing industry as in the fishery. The number of reported accidents and work related injuries within fish processing was respectively 288 and 88 in year 2000¹¹⁸ (Arbejdstilsynet, 2001). However, measured relatively to the number of employees, this is only the same as 5,1 accidents per 100 employees and 1,6 working related sufferings per 100 employees, which is at the same level as in fishery (8,3 accidents and 1,4 sufferings per 100 employees). From a product perspective, the fishing stage will become even more important, but this is discussed in chapter 7.

From a more qualitative point of view, the type and the cause of occupational health and safety problems is illustrated in table 10:

¹¹⁸ The total number of accidents and injuries cover traditional fish processing such as: filleting and canning (227 accidents and 63 injuries), salting and smoking (44 accidents and 20 injuries) as well as fish meal and oil production (17 accidents and 5 injuries) (Arbejdstilsynet, 2001).

Table 10: Examples of causes to and types of H&S problems in the fish processing industry (Arbejdstilsynet, 1999).

Health & safety aspects	Possible causes
Accidents	Work with de-heading, filleting and de-skinning machines. Work involving the use of knives as well as fall accidents because of fish waste on the floor
Skin and respiratory infections	Skin damages because of too much humidity and hand washing – especially in processes such as de-heading, filleting and trimming as well as in processing of shellfish. Respiratory problems caused by organic dust, ammonia and aerosols from processing and cleaning.
Heavy lifts and over-specialized work	Manual transport of fish crates, heavy lifts such as plates with frozen fish and sacks of fish meal and fodder (processing of fish meal and oil / animal fodder). Handling of fish at different machines for de-heading, filleting and trimming. Packaging of individual products such as herring in glass and mackerel in cans.
Psychological impacts	Lack of influence on job content, over-specialized work, monotonous work, work on shifts, lack of co-operation and job security, especially for spec. seasonal jobs
Noise	De-heading and filleting machines as well as centrifuges, salting machines, can transport, filling and locking machines, use of compressors and compressed air.

Most of H&S problems are related to the physical work such as the filleting processes, where it causes skin problems as well as physical problems because of over-specialized working routines. The monotonous work also causes physiological impacts. Another impact that is worth to notice is the respiratory problems from aerosols in the air e.g. from cleaning as well as ammonia that is leaked from the cooling equipment. In this regard, it is interesting that cleaner production such as nozzles and natural cooling agents, may benefit the external environment while creating potential problems with respect to the “internal” environment (work related H&S problems).

Smell and noise

Noise is mainly a problem related to the internal environment (health and safety), which was dealt with in the previous section. In the literature, noise is generally not mentioned as a problem in relation to the external environment in the fish processing industry. However, smell is serious problem in some types of fish industries – especially for fish meal production. The smell from processing of industrial fish is a well-known problem in cities such as Esbjerg.

Development tendencies

Health and safety

Based on experiences from a previous study of the fish processing industry, it is my understanding that the processing industry focuses a lot on occupational health and safety aspects including worker satisfaction in general. The technological development also suggests that machines gradually become more ergonomic and that machines in many cases substitute human labour (Thrane, 2000b). The latter may reduce the absolute level of H&S problems, but obviously not the relative size of the problem. Thus, it is suggested that we will experience some level of decrease in H&S related problems at the processing stage.

Smell and noise

Problems related to smell and noise will probably be reduced gradually as demands through control and enforcement gradually becomes effective. It has been not been possible to predict how great the reduction would be in this case as well.

5.5 Summary & final comments

Besides consumption of the fish, being the “raw material” itself, processing involves consumption of vast amounts of drinking water, ancillaries (only for some products) and packaging material.

From an overall point of view, the chapter has shown that fish processing consumes considerably less energy than the fishery. As mentioned in chapter 4.2, the average energy consumption required to catch one kg of edible fish is roughly 12 MJ per kg, which is similar to about 30 MJ per kg filet. An average processing plant requires roughly 5,5 MJ primary energy per kg of processed fish, without considering avoided environmental impacts from by-products. Thus, fishery is significantly more energy consuming.

However, the processing stage distinguishes itself from the fishery by requiring large amounts of clean water as well as ancillaries and packaging materials for some products. Wastewater emission is also an issue, but practically all fish industries are now connected to effective wastewater treatment plants – mainly public but also private in a few cases (chapter 11.4). Finally, the

industry involves a large number of employees. Thus, health and safety is an important issue as well.

As mentioned, avoided environmental exchanges from co-products are not considered at a quantitative basis in this chapter. This also applies to wastewater treatment and capital goods. However, these aspects are further analyzed in the LCA case study in part three.

Environmental exchanges/impacts from various kinds of fish processing

The key indicators for environmental impacts related to the four themes: materials, energy, chemicals and other, are illustrated in (Table 11).

Table 11: Overall assessment of environmental exchange/impact per product volume, related to five product types.

	Demersal	Shellfish		Pelagic fish	
Environmental exchange	Frozen cod- /flatfish	Frozen mussels	Shellfish (shrimps)	Pickled herring	Canned mackerel
Water	3	4	4	3	3
Pack./ ancill.	2	2-4	2-4	2-4	2-4
Energy	1	2	3	1	1-3
Chemicals	2	2	2	2-4	2-4
H&S	4	4	4	4	4

Numbers illustrate the size of the relativity of the exchange:

4) Large, 3) medium, 2) small, 1) very small, <1) insignificant, 0) no exchange.

Grey fields: The magnitude of the given exchange is relatively significant (3 or more)

White fields: The magnitude of the given exchange is relatively insignificant (2 or less)

As it appear, the picture is opposite of the fishing stage, as demersal fish represent smaller exchanges compared to pelagic fish products. The table is further elaborated in the following sections.

Demersal fish (Cod- and flatfish)

As the table illustrates, there is only one of the production methods that turns out to be considerably more environmentally friendly, namely processing of frozen cod- and flatfish. Processing of frozen cod- and flatfish do not involve significant amounts of ancillaries and the packaging does not involve energy intensive materials such as glass or aluminum, as we see for pickled herring and canned mackerel.

There are variants of the frozen flat- and codfish, such as breaded and filled fillets, where considerable amounts of ancillaries are used. Nevertheless,

these ancillaries will be part of the product, and it is argued that - in some cases - reduced impacts per kg end-product can be the result.

Frozen cod and flatfish fillets are also less energy consuming than products such as canned mackerel, mussels and shrimps – because they do not involve boiling or steam processes.

It has not been possible to distinguish between the different types of fish processing concerning health and safety - unless from the fact that most accident and injuries are reported within traditional fish processing such as filleting and canning, while smoking and salting, as well as fish meal and - oil production constitutes a smaller part of the accidents and injuries. For smell, problems mainly exists for industries that process industrial fish.

Shellfish (mussels and shrimps)

For frozen mussels and shrimps, the consumption of ancillaries and packaging depends on the type of end-product that is produced. The consumption may be limited if the product is IQF mussels, sold in cardboard boxes of various size, such as in the case study mentioned in this chapter. Nevertheless, it can be substantial, if the mussels are sold in a jar with sauce – similar to herring and mackerel. Nevertheless, this is a relatively small production compared to frozen mussels (Andersen et al. 2000).

For other resources such as drinking water, the consumption appears to be larger than for the other types of fish processing mentioned in table 11. This also applies to the energy consumption, which is significant, mainly because of the boiling processes. A significant indirect energy consumption is also related to the consumption of nitrogen.

Pelagic fish (herring and mackerel)

Finally, there is pelagic fish, which are typically processed into pickled or canned products. For these products, the use of packaging in the form of glass or aluminum can be substantial. This also applies to ancillaries such as sugar, salt, sauce etc. The indirect energy consumptions - as well as other related environmental impacts - might be considerable in this case.

The direct consumption of water and energy is relatively low, but the site-specific emissions of organic substances are high, due to the high oil content in the fish as well as the emissions related to the separation of the guts on land.

Other fish products

Farmed fish have not been dealt with separately in this chapter. The processing of farmed fish involves more processing stages and includes (beside the fishery) the processing of fishmeal and -oil, -fodder and breeding before the raw material is achieved. Energy consumption is involved in all the processes, and therefore an important factor. Especially the breeding has been widely discussed in Denmark because it involves the use of disinfectants and medicine beside land use as well as physical and biological effects on water-courses. Furthermore, fresh water ponds may use considerable amounts of energy for pumping and oxidation of water (Miljø- og Energiministeriet, 1999).

Highly versus less modified products

In some cases, it is obvious that the environmental burdens increase when the products are further processed, such as processing of pickled herring in jar. The same applies to mackerel, which has a larger environmental load when it is processed into canned mackerel – extra impacts are related to processes such as boiling, sterilization of cans and production of the cans themselves. In these cases more energy and more materials are used, but the amount of edible product remains roughly the same¹¹⁹. Nevertheless, we also have products where less meat is used to produce a given amount of edible product, such as panned products. Here the meat percentage is reduced by approximately 40% and some vegetable products are added instead. This does probably not increase the environmental burden pr. kg. It should also be considered that further processing in the home kitchen might lead to an increased spillage. These issues will be analyzed further in part three.

Development tendencies

As described, it is assumed that further reduction in several exchanges will be achieved:

¹¹⁹ For mackerel in tomato paste, some consumers would eat only the mackerel while others would eat the tomato paste as well. The figures for input and output for mackerel are based on the assumption that the consumer only eats the mackerel, hence allocating all the environmental impact to the mackerel filets (80 gram per fe) and not the net content of 125 gram mackerel in tomato paste. (Madsen, 2001).

Table 12. *Expected changes in environmental aspects towards year 2010-15*

Environmental aspects	Change from current level (pct).
Water consumption	-50
Packaging material	-5
Energy (processing)	-10
Cleaning agents	-25
Organic matter by wastewater	-50
Health and Safety	Decrease

It is assumed that the water consumption will be reduced, compared to the figure presented in table 1. Cleaning agents and organic load is somewhat proportional to the water consumption. Concerning energy consumption, it is assumed that some processes such as cooling and heating process will become more effective, but at the same time, we have experienced that machines take over more and more processes. Thus, only a small reduction is expected for energy consumption.

Limitations of the MECO analysis

This section presents a description of the limitations of the MECO analysis of the processing stage with focus on obtained data quality according to the procedure in app. 4 as well as methodological aspects.

General aspects

Generally considered, the data for the processing stage has a relatively high data quality, as this stage involves data from a wide number of references, and as this life cycle stage has had the attention of the authorities' attempt to implement cleaner production practices during the last 10-15 years.

Data with a low data quality

Data for water consumption and wastewater emissions are from a publication published in 1996. The same data also appear in more recent publications, but in fact the data can be traced back to measurements from nine companies in 1988. This means that the difference in time is between 10-15 years. This is problematic, because there have been a significant reduction of the water consumption and wastewater emissions in exactly this period – especially in the pelagic segment of the industry. Hence, the estimates are somewhat overestimated - certainly for processing of herring and mackerel. However, they have been used because they are the most consistent dataset yet available as the same measurements cover a wide spectrum of processing types and as the emissions are measured without prior treatment. Some of the pre-

sented case specific data for water consumption, representing the current situation, can be used for verification in the given process types. Thus, it is assessed that the variation in water consumption and wastewater effluents is relatively high.

Other data

For most of the other data sets, there are less than three years difference between the time of study (year 2000) and the time represented by the data. The geographical correlation is even better, as all of the data sets are from the area under study (Denmark). Finally, the correlation for other technological aspects is found good as they represent firms, process and materials under study in all cases.

The reliability is generally assessed to be satisfying. All the exchanges are verified data partly based on assumptions or non-verified data based on measurements. In most cases, the latter has been the case.

Some data are based on survey studies, which are sector averages for types of fish processing. These data represents a sufficient number of companies and adequate periods to even out normal fluctuations. This is the case for estimates of total energy consumption (absolute energy consumption for all fish firms) and occupational health and safety. The remaining estimates only represent one or a few sites, but still cover an adequate period of time (at least one year). These data are representative data from a smaller number of sites (smaller than sufficient sample of sites) but for adequate time periods. In this regard, a sufficient sample size varies, depending on the size of the companies versus the total production, which may vary from a few to ten firms. As some data only represent one or two firms, the completeness is considered inadequate, but still it is not assumed to affect the overall uncertainty significantly. The data types and the obtained data quality is illustrated in table 13.

Table 13. Overview of data types and obtained data quality for the processing stage. Circles illustrate the most problematic data sets, in terms of data quality. The matrix is further explained in app. 4.

Variables		Data types	Data quality				
		Type	Ti	Ge	Te	Re	Co
Materials	Water consumption (product specific)	Quantitative	4	1	1	2	2
	Ancillaries (product specific)	Quantitative	1-2*	1	1	2	2
	Packaging (product specific)	Quantitative	1	1	1	2	2
	Waste and co-products (prod specific)	Quantitative	1	1	1	2	2
E.	Energy (average all)	Quantitative	3	1	2	2	1
	Energy (product specific)	Quantitative	1-2*	1	1	2	2
Chem.	Cleaning agents (product specific)	Quantitative	1	1	1	2	2
	Process chemicals (product specific)	Quantitative	1	1	1	2	2
	Refrigerant gases (product specific)	Quantitative	1	1	1	2	2
	Wastewater (product specific)	Quantitative	4	1	1	2	2
O.	Health and safety	Quantitative	1	1	1	2	1
	Smell and noise	Qualitative					

(*This is only for pickled herring, where the difference between the obtained data and the year of study is more than three and less than six years).

The data quality indicators and the argumentation behind them have not been described further in the MECO analysis. However, the data used for the LCA case study in part three are carefully argued in each case (see app. 13 document A).

Uncertainty and variance

General descriptions of uncertainty, variation and the relationship to the data quality indicators are described in the conclusion of chapter 4. The uncertainty and variance for data described in this chapter are estimated in the following. In the cases where exchanges are established as an interval representing data from more companies, the variance applies to the mean value.

Variation for the most uncertain data. Based on background knowledge¹²⁰ and data quality indicators, it is assumed that the variation is largest (-75% to +200%) for data in the following categories:

- Water consumption
- Wastewater emissions
- Cleaning agents

The reason why the variation is considered large for water consumption and wastewater emissions is that the data references are relatively old and encompass a relatively small sample size. Furthermore, there has been a significant development in cleaner production practices in some segments of the industry (companies processing herring and mackerel). There are data available, which illustrates the development tendencies in these segments through the 1990s, but it has been difficult to tell something about the development in other segments, such as companies processing demersal- and shellfish. As the consumption of cleaning agents also encompasses only a couple of firms - and as the use is proportional with the water consumption - the variation is also assessed to be considerable here.

Uncertainty for other data. For other data such as ancillaries, energy, packaging, waste and sludge, it is assessed that the uncertainty is considerably lower, but still +50%. In this respect, it should be considered that the uncertainty for datasets obtained from company processing flatfish is somewhat smaller (+25%), as I have obtained additional detailed data from one of the largest companies in Denmark. Specifically for mackerel, I have presented data for average technology as well as best possible where the difference in exchanges are greater than 50% - and in this case, an uncertainty of -75% to +200% is probably more realistic. The variation for all data sets is in table 14:

¹²⁰ According to Weidema et al. (2003c) datasets from 80 plants under the Unilever food industry showed coefficients of variance of 50% for energy consumption and 220% for COD and other emissions. It is suggested that the cause of the variation is mainly due to differences in management.

Table 14. Assessed variance for different groups of data sets at the processing stage

Life cycle stage	Exchange	Estimated variance	
		Min [pct]	Max [pct]
Processing (only for flatfish LCA)	Water consumption, wastewater and cleaning agents	-75	+200
	Other (ancillaries, heat, electricity, packaging, waste, sludge etc).	-25	+25
Processing (LCA screenings)	Water consumption, wastewater and cleaning agents	-75	+200
	Other (ancillaries, heat, electricity, packaging, waste, sludge etc).	-50 (-75 mack).	+50 (+200 mack).

As explained in the previous chapter, the uncertainty of future estimates has not been further analyzed – but obviously it is considerably larger.

6

MECO Analysis - Other Stages

Based on the MECO principle, this chapter analyses the most important immediate exchanges related to the landing and auction-, wholesale-, retail-, transport- and use stage, see figure 1.

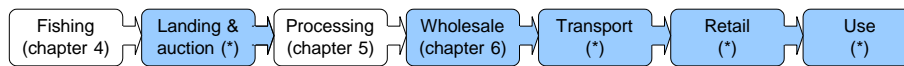


Figure 1: *Illustration of the focus of this chapter, which is the landing-, wholesale-, transport-, retail- and use stage*

The transport stage includes transport for export/distribution, but it is important to be aware that transport also is involved at the processing stage (transport from harbour to factory) and the use stage (shopping).

General descriptions of data quality requirements and data treatment are available in chapter 3. This chapter contains “one” summary for all five stages including a description of the limitations of the MECO analysis, see section 6.6.

6.1 The landing and auction stage

This section has focus on exchanges at the landing and auction stage, see figure 2.

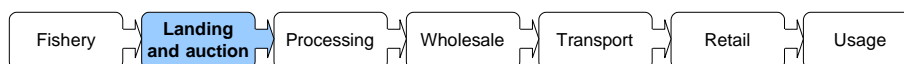


Figure 2: Illustration of focus of section 6.1 (the landing and auction stage).

The section follows the same structure as chapter 4 and 5, based on the MECO principle. At this stage, it has only been relevant to distinguish between demersal and pelagic/industrial fish since only demersal fish are sold at auctions and because the exchanges at this stage mainly are proportional to the mass of the fish.

Process description

Demersal fish are typically landed in fish containers with ice. The fish containers are transported to the collection site and is subsequently transported to and sold at the fish auction – see figure 3:



Figure 3: Landing, grading/sorting and sale at auction – with permission from www.hvidesande.net and Thyboroen fish auction.

For demersal fish, the processes involve un-loading of fish, sorting/grading and icing. Pelagic species are typically pumped directly into the production or into a truck for transportation to further processing. Product flow, input and output are illustrated below – see figure 4.

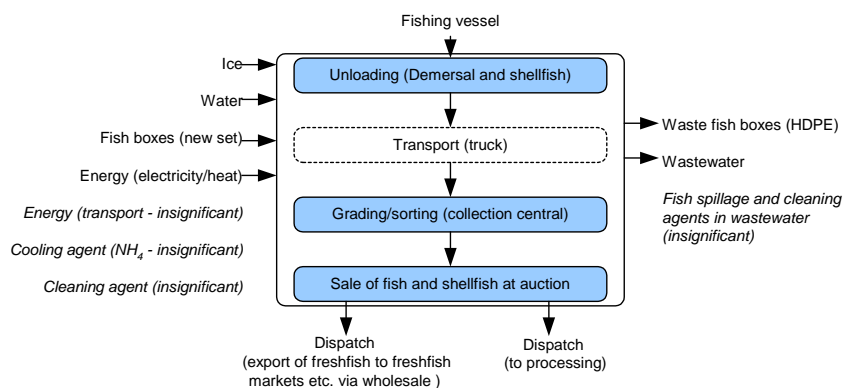


Figure 4. Product flow, input and output for demersal and shellfish during landing and auction. *Italic writing represents flows that are considered insignificant. Data for transport have not been available.*

Data collection and treatment

The data for water and energy consumption are based on personal communication with the manager of Thyborøn harbour and represent a large fish auction (Buhl, 2003). Data for ice consumption are also established from personal communication with a fish-processing expert (Andersen, 2003). Other data are obtained from literature.

Co-product allocation has been handled through mass allocation as the underlying technical causality suggests that the exchanges related to processes such as freezing and cleaning are proportional to the mass of the products. The exchanges are related to one kg of dispatched edible product plus secondary packaging material.

Material exchanges

For demersal fish, the material consumption is mainly related to consumption of ice, water and fish boxes. For pelagic species, it is assumed that the material consumption is insignificant at this stage (Miljøstyrelsen, 2004)

Ice (input)

Demersal fish are typically landed in fish boxes with ice, but before the auction, they are typically sorted and graded again. In this process, new ice is added - a rough estimate is 25% of the fish weight or 0,25 kg ice per kg gutted demersal fish (Andersen, 2003).

In a few cases, the fish have been sorted and graded on sea (Fiskebranchen, 1999). In this case, the fish often remain in the same boxes and are sold directly at the auction without any significant consumption of extra ice – less than 10% of the fish weight or *0.1 kg per kg gutted sea-packed demersal fish* (Andersen, 2003).

Fish boxes (input)

As mentioned, the fish are re-packed at the collection central, which means that a new set of fish boxes are put into use. The material consumption is assumed to be the same as for fish boxes at the fishing stage - roughly *2,6 Gram HDPE per kg whole gutted flatfish – see chapter 4.*

Water (input)

Water is also used at this stage. At the collection central as well as at the auction, a small amount of water is used during grading and cleaning. According to the manager of Thyborøn harbour, the water consumption at the auction is 0,5-1 liter per kg sold fish, which mainly cover cleaning of the production facilities and fish boxes (Buhl, 2003). It must be assumed that similar amounts of water is used for cleaning in the collection central. The total consumption is therefore estimated to *1,5 liter water per kg whole gutted demersal fish.*

Solid waste (output)

It has not been possible to establish credible data for fish loss at this stage. It is assumed that the quantities are insignificant.

Another waste fraction is fish boxes. The amount of waste is equal to the consumption, which is *2,6 Gram HDPE per kg whole gutted flatfish – as earlier described.*

Energy exchanges

For demersal fish, the energy consumption during landing and auction is related to trucks, light, sorting, grading and cooling of storing rooms. For pelagic species, the energy consumption is related to pumping and transport.

Transport

No data have been available for transport during landing and auction. However, it is assumed that the amount of transportation is insignificant, because it involves transport of large quantities over short distances.

Electricity consumption

Lights are used in the collection centrals as well as in the auctions. According to energy accounts provided by Buhl (2003), the electricity consumption at the auction stage is roughly 0,04 MJ per kg sold fish. This energy consumption includes energy for light and cooling. If it is assumed that a similar amount of energy is used in the collection central¹²¹, the total electricity consumption is therefore estimated to *0,1 MJ per kg sold demersal fish*.

It has not been possible to establish data for energy consumption for pelagic fish, but the consumption is probably insignificant as it only involves pumping of the fish.

Heat consumption

As mentioned, the water consumption for cleaning of production facilities and fish boxes is roughly 1,5 liter per kg fish. If it is assumed that all the water is heated and used for cleaning (a worst case approach) - the energy consumption will amount to *0,3 MJ heat energy per kg whole gutted demersal fish*¹²².

Chemical exchanges

The exchanges of chemicals at this stage are mainly related to cooling and cleaning agents as well as waste, but it is argued that these exchanges are insignificant.

¹²¹ Concerning sorting and grading at the collecting centrals, it must be assumed that the electricity consumption is very limited. As explained in chapter 5, a typical fish processing plant uses 10% of the electricity consumption of process engines. It is only a small part of this consumption that is used by grading/sorting machines. However, if we assume that it is 2%, the electricity consumption at company flatfish would be about 0,03 MJ per kg raw material at company flatfish, considering a total of 3,8 MJ per kg product and a utilization factor of 0,37.

¹²² According to Pommer (2000), the energy consumption for heating of cleaning water in fish processing industry (10-60 degrees Celsius) is 0,21 MJ per liter. In chapter 4, it was established that roughly 40% of the heat related energy in a typical fish processing company is used to heating up cleaning water. In company flatfish, this is equivalent to 1,52 MJ per kg product. As the water consumption for cleaning is 10,3 liter per kg product, this is 0,15 MJ per liter cleaning water (see app. 10). An energy consumption of about 0,2 MJ per liter cleaning water must be considered a worst case, as it is not all the cleaning water that is heated.

Cooling agents (I/O)

As mentioned in chapter 5.3, the cooling agents used in large industrial cooling units are typically ammonia. First of all, ammonia is relatively harmless, concerning the external environment compared to HFC gasses. Secondly, the cooling related energy consumption is so low (<0,1 MJ per kg product) that the consumption and emission must be considered insignificant.

Cleaning agents (input)

Small amounts of cleaning agents are used to clean machines, storing rooms and fish boxes. It has not been possible to establish data for this. However, if the consumption of cleaning agents is proportional to the water consumption, the amount will be less than 15% of the amount used in company flatfish – see app. 10¹²³. Thus, also the consumption of cleaning agents is considered insignificant.

Wastewater (output)

Wastewater is generated during cleaning of production facilities and fish boxes. The amount is equal to the consumption – about *1,5 liter per kg sold demersal fish*. The wastewater will contain organic matter from the fish products as well as cleaning agents. Concerning organic matter, it is assumed that this is relatively insignificant compared to emissions in the processing stage, as the fish are handled without cutting. For cleaning agents, it is assumed that the amounts are insignificant, as previously described.

Other exchanges

Concerning “Other environmental aspects”, Occupational health & safety is the most obvious aspect that has not yet been considered. According to Arbejdstilsynet (2001), the number of *registered accidents in fish auctions was only one per year* from 1995 to 2000. The number of *registered working inflicted sufferings was “one to two” per year* in the same period.

These numbers only include fish auctions and it has not been possible to establish the total number of employees. Comparison with other life cycle stages is therefore difficult. However, it can be concluded that the absolute

¹²³ Company flatfish use 10,3 liter water per kg product for cleaning (see. app. 10). During landing, grading and sale at auction, there is used roughly 1,5 liter of water in total. It must be assumed that only some part of this water consumption is used for cleaning.

level of health and safety related problem is limited compared to fishery and processing, where several hundred accidents are registered per year.

Development tendencies

Most likely a growing number of landings of demersal fish will be sea-packed fish due to larger fishing vessels and technological developments. Sea packed fish means that the landed fish are already sorted and graded. This will reduce the consumption of ice and extra fish boxes as well as other exchanges related to the collection central.

It must also be expected that fish auctions gradually becomes larger and more efficient. Tele-auctions will make it possible to sell the fish directly from the vessel before they return to the harbour. Both aspects will reduce the exchanges per kg product.

It is difficult to predict the exact reductions for the different input and output, but a *reduction of 20% per volume of demersal fish* is probably realistic. As previously explained, the exchanges for pelagic fish are not significant at this stage, and future estimates have therefore not been established.

6.2 The wholesale stage

The processes and exchanges at the whole sale stage are described in the following.

Process description

Wholesale covers activities such as packaging and storing during transshipment – see figure 5.



Figure 5. Illustration of three processes at the wholesale stage - packaging, transport and storing. With permission of H.P. Therkelsen A/S.

The product flow, inputs and outputs are illustrated in figure 6. It is emphasized that wholesale involves processed and non-processed fish, which both can be either fresh or frozen. A large proportion of the un-processed fish are sold at fresh fish markets in Europe. As it appears, some of the fish (processed and un-processed) are exported for processing or further processing.

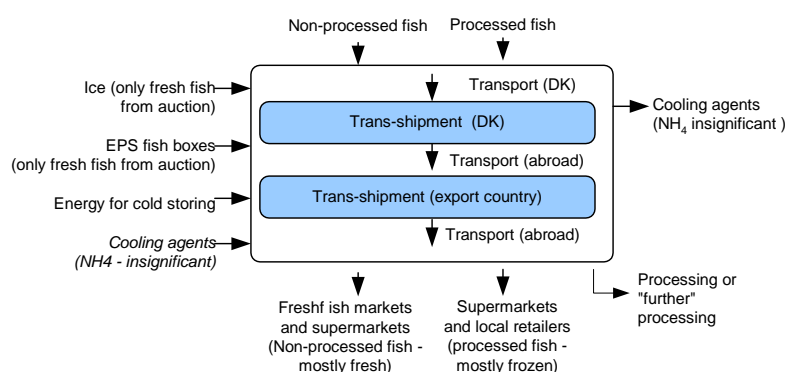


Figure 6: Product flow, input and output during wholesale for both fresh, non-processed and processed fish products.

There are only a few exchanges at this stage, and transport activities are treated separately in chapter 6.3.

Material exchanges

For frozen fish, there is no significant additional material consumption in the wholesale stage.

EPS boxes and ice (input - fresh fish)

For fresh fish, there is additional packaging and icing. After the fresh fish are sold at the auctions, the fish are typically re-loaded in EPS boxes and new ice is added. The material consumption is roughly 300 gram EPS per 10 kg of fish or 30 gram EPS per kg fresh fish (DOR Århus, A/S, 2000a).

The amount of additional ice is less than 25% of the fish weight – thus *not more than 0,25 kg per kg fresh fish* (Andersen, 2003).

Energy exchanges

As explained in chapter 2.1, it is a relatively small proportion of the fish (landed or processed in Denmark) that is sold at the domestic market. The largest proportion is exported to countries such as Germany, France, UK, Spain and Italy. The energy consumption is mainly related to cold storing, as transportation is separately described in chapter 6.3. In this regard, the important variables are storage time, volume of product and specific electricity consumption for cold storage.

Storage time for frozen products

For frozen fish, the total storing time between dispatch and the end destination is generally several weeks or months, according to a large Danish fish exporter (Therkelsen 2003). Another source mentions that the average storing time is roughly one month, which is used as the most plausible estimate in the following (Company flatfish, 2003b).

Storage time for fresh products

According to one of the largest distributors in Denmark, the fresh fish normally reach the terminal in southern Denmark within 12 hours. The total storing time between catch/production to the retailer is 1-3 days, depending on the destination; one day for Northern Germany, 3 days to destinations such as Spain and 2 days at an average. (Therkelsen, 2003).

There exists a multitude of product variants, such as smoked and marinated products, that also are stored at temperatures around 5 degrees Celsius. The storing time for these products are more likely to be of the same order as frozen products because their shelf life is similar.

Product volume (frozen products)

The product volume is a crucial but also difficult parameter to estimate, as it depends on the type of product, utilization of storing rooms etc.

In the case study of flatfish, it is established that the volume of the master cardboard box containing 3,6 kg frozen filets is 18 liter, which is roughly 5 liter per kg filet, see app. 10. If it is assumed that the capacity is used 25%¹²⁴, this represents a volume of 20 liter per kg product (IQF).

¹²⁴ In a Danish LCA study of ham - as a comparison - it is estimated that the utilization is 25% for wholesale storage (Weidema et al. 1995).

Block frozen products use a considerably smaller volume. According to Ziegler (2002), the volume of one kg frozen block fish is 1,25 liter. Considering a utilization ratio of 25% this is equivalent to 5 liter per kg block fish.

Product volume (fresh products)

For fresh products packed in EPS, a 10 kg fish-box typically has a volume of 35-40 liter. Hence, the volume will be roughly 3,5-4,0 liter per kg fresh fish (DOR Århus A/S, 2000a). If we also use a utilization ratio of 25% here, it is equivalent to roughly 16 liters per kg fresh fish.

For product variants such as smoked and marinated products, the volumes vary considerably. However, if we take the example of pickled herring, one kg of fillet represents a volume of roughly 4 liter according to Ritter (1997). Including considerations about utilization ratio, this is also about 16 liter. Thus, it is assumed that 16 liters per kg can be used as a rough estimate in cases where there are no other data available.

Specific electricity consumption for cold storage

The fish terminals in Denmark are typically 1.500 to 3.000 m³, and this is probably not much different from terminals abroad (Therkelsen, 2003). According to DEFU (1999), the energy consumption is roughly 290-720 MJ per m³ per year for freezing houses with a capacity of 1.000-5.000m³. It is therefore assumed that a consumption of 500 MJ per m³ per year is a good estimate, considering the size of the fish terminals.

For cooling houses (fresh fish products), the energy consumption is 43-100 MJ per m³ per year for cooling rooms of the same size. In this case, it is therefore assumed that a consumption of 70 MJ per m³ per year is a reasonable estimate, considering the size of the fish terminals.

Total energy consumption for storage

Based on the previous assumptions and estimates, the energy consumption is calculated in table 1.

Table 1. Energy consumption for one kg fish during wholesale storing

Product type	Storage time [days]	Storage volume [liter]	Specific el. consumption [MJ / liter year]	Energy requirement [MJ / kg]
Frozen products (IQF)	30	20	0,50	0,8
Frozen products (block)	30	5	0,50	0,2
Fresh products or similar	2	16	0,07	0,0
Marinated etc. (perishables)	~ 30	~ 16	~ 0,07	~ 0,1

As the data shows, energy requirement is significant for IQF products, while block fish, fresh¹²⁵ and perishable fish have a relatively small energy requirement. Non-perishables such as canned mackerel does not require cooling.

Chemical exchanges

The consumption of chemicals is mainly related to cooling agents such as ammonia.

Cooling agents (I/O)

As mentioned in chapter 5.3, the cooling agents in large industrial units are typically ammonia. As ammonia is a relatively harmless gas compared to CFC and HCFC and considering the low energy consumption (<0,5 MJ per kg) for all products, it is assumed that the consumption and emission of cooling agent is insignificant – similar to the processing stage.

Other exchanges

In the wholesale and storing stage, the most important environmental impact that has not been considered is occupational health & safety. According to Arbejdstilsynet (2001), the number of *registered accidents was roughly 40 per year* from 1995-2000 in wholesale with fish and fish products in Denmark. In the same period, the number of registered *working related sufferings were roughly 20 per year*. In absolute terms, this is the third highest number in the product chain after processing and fishery.

As mentioned in chapter 2.1 the number of employees in fishery wholesale was roughly 2.200 in year 2000. This gives an average of *1,8 registered accidents and 0,9 working related sufferings per 100 employees per year*. Both the absolute and the relative numbers are considerably lower than for the fishing and processing stage.

¹²⁵ There may be larger energy consumptions per volume and time for products that are stored in short time because there is an energy loss each time products enter or leave the storing rooms. However, this aspect has been disregarded here.

Development tendencies

The future developments for the wholesale stage are estimated in the following.

Energy

It must be assumed that energy consumption in the wholesale stage will be reduced slightly as a consequence of the general technological development. Future options for cooling process include solutions such as sludge ice, which may improve efficiency considerably (Pedersen, 2001).

It has not been possible to establish any precise estimates for the development, but as described later, the development in household freezers have shown *improvement rates of roughly 30%* during the last 10 year (Energistyrelsen, 2002). Considering the high energy prices and the possibilities for new cooling methods such as sludge ice, it must be assumed that similar improvements can be achieved for industrial units within the next 10-15 years.

Other exchanges

It is not assumed that there will be any significant development in the consumption of packaging or ice. This also applies to the development in occupational health and safety aspects.

6.3 *Transport (distribution)*

The exchanges for transportation between the processing and retail stage are in the following. Transport between harbour and processing is described separately in chapter 5 and the transport between retail and use is analyzed separately in the use stage (section 6.5).



Figure 7. Illustrations of different modes of transport: Lorry, train, ship and plane - with permission from Taabel fish export A/S, Maersk shipping and Scandinavian Airline Service.

As illustrated, transportation of fish products can imply road transport (lorry), train, ship and/or plane. Lorry is by far the most dominant transport mode for Danish fish products, especially for export of fresh and frozen products to the European market (Fiskebranchen, 1999). Currently, freight train is used to a very limited degree. Ships are used for transcontinental export to Asia or America. Airtransport is not widely used for export of Danish fish products, but sometimes used for import of exotic fish species (Hansen, 2003).

The product flow as well as inputs and outputs are illustrated below.

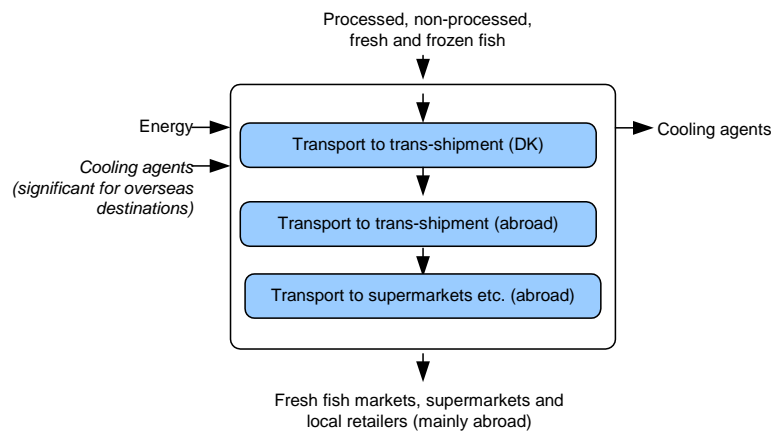


Figure 8. Product flow and immediate exchanges at the transport stage.

Obviously, the output include emissions from the combustion process, but as the figure only is supposed to illustrate the immediate exchanges this is disregarded here.

Material exchanges

The material consumption is mainly indirect and related to the production of transport equipment (cars, trucks, trains, ships and air-planes) and transport infrastructure such as roads, railways, harbours and airports (Drivsholm et al. 2002). In this regard, it should also be considered that capital goods are not included in the scope of this analysis. A discussion of the methodological consequences of this delimitation is carried out in part three.

Energy exchanges

Energy is an important environmental parameter in transport. The distances and the modes of transport are key variables.

Average transport distance

In chapter 2, it was established that South Germany could be used as a rough average distance to the market for Danish fish products. This is a very rough estimate, and it has been necessary to further analyse the export pattern to estimate distances and the modes of transport for different kinds of products – see app. 7.

Typical mode of transport

Based on data provided by one of the largest Danish fish exporters, it is assumed that transportation is conducted by 40-ton lorries with an average mileage of 3 km per liter fuel. The energy consumption has been calculated to be 0,63 MJ per tonkm for frozen products and 0,88 MJ per tonkm for fresh products. (Therkelsen, 2003).

Average energy consumption

Based on knowledge about export destinations for different fish products (Fiskeridirektoratet, 2001a) and the mode of transport, it has been calculated that transport related energy consumption varies between 0,7-2,1 MJ per kg depending on the specific product type. This interval represents whole fresh mackerel with an average transport distance of 815 km and whole fresh Norway lobster with an average transport distance of 2.387 km – see app. 7.

Shellfish are generally transported further and represent a higher energy consumption than the average, while the opposite is the case for products based on pelagic fish (herring and mackerel). However, several aspects are not considered in the average estimate of energy consumption:

- 1) Extra weight for some products, which means more transport per kg fish meat – this can be due to extra packaging or because it is whole fish.
- 2) Extra transport if we include the distance between different processing plants in Denmark.
- 3) Extra transport considering imported and further-exported products.
- 4) Extra transport if overseas destinations.
- 5) Other modes of transportation such as train, ship and plane.

All these aspects are analyzed in app. 7, but the essence is described shortly in the following:

1) Special cases with extra weight

For products where packaging constitutes a significant extra weight, the transport related energy consumption could be significantly higher. It has previously been established that the total product meat percentage of pickled herring in glass is about 25% (w/w), and for canned mackerel the meat content is close to 67% (w/w). Some products, such as frozen whole Norway lobster, whole shrimps and whole prawns also have a meat content that is roughly 30% (w/w).

Therefore, a correction factor should be used for certain products. Based on the w/w percentages as well as the detailed analysis of transport distances and energy consumption in app. 7, I have established some examples:

Table 2: Transport related energy consumption for 16 fish products based on 8 different species – based on transport analysis (app. 7) and the analysis of product spillage (app. 3). All figures are in MJ per kg fish filet/meat.

	Demersal fish		Shell fish				Pelagic	
	Frozen codfish	Frozen flatfish	Frozen prawn	Frozen shrimp	Frozen lobster	Frozen mussel	Herring	Mack-erel
	Filet (IQF)	Filet (IQF)	Peeled (IQF)	Peeled (IQF)	Peeled (IQF)	Peeled (IQF)	Pick. jar	Can
Basic (app. 7)	0,9	1,0	1,0	1,0	~1,0	0,9	0,9	0,8
Corr. (pack)							4,0	1,5
Adjusted	1,0	1,1	1,1	1,1	~1,1	1,0	3,6	1,4
	Whole	Whole	Whole	Whole	Whole	Whole	Whole	Whole
Basic (app. 7)	1,2	1,1	1,2	1,2	2,1	1,3	0,8	0,8
Corr. (meat) ¹²⁶	2,4	2,7	3,3	3,3	3,3	5,3	2,2	2,0
Adjusted	2,9	3,0	4,0	4,0	7,0	6,9	1,8	1,6

As it appears, the transport related energy consumption turns out to be considerably higher when extra packaging is considered as well as low meat content in whole fish. It appears that transport of non-processed fish and shellfish is quite inefficient. Furthermore, the chance that by-products will be used to substitute other food products is smaller when the fish are filleted and prepared at the use stage.

¹²⁶ These figures can be derived from app 3.

2) *Extra transport between factories in Denmark*

As explained in app. 7, the analysis of average transport distances is calculated on basis of rough estimates. However, extra transport between factories is not specifically included, but is considered insignificant in the context of the large uncertainties related to the export distances (see app. 7).

3a) *Production based on imported products*

The focus of this dissertation is fish products caught and processed in Denmark. Therefore it is only strictly necessary to address transport distances from Denmark to the market. In app. 7 it is concluded for certain products that this would increase the transport load with 500-1.000 km.

3b) *Products that are further exported*

It is also important to note that a certain percentage of the exported products are further processed at the destination and subsequently re-exported. However, it is very difficult to estimate the extra transport load that this may cause, as it will vary from product to product. Among the types of fish products that are exported for further processing is semi-manufactured herring, where the packaging sometimes takes place in Germany (Thrane, 2000b).

4) *Markets over seas*

Concerning the cross-continental markets, the most important are Asia, especially Japan. In table 1 (app. 7), three of the product types mentioned are exported to distant markets in significant quantities. These are frozen whole flatfish to Japan and Taiwan, whole shrimp to Japan and Russia and finally frozen whole mackerel to Japan – see app. 7. The transport related energy consumption for products sold to the Asian market is roughly 2,5 MJ per kg, including transport by lorry at both ends of the journey¹²⁷ (see app. 7). The uncertainties taken into account, this is similar to the energy consumption for products exported to south Europe¹²⁸.

¹²⁷ It should be stressed that this figure does not include energy consumption for cooling.

¹²⁸ According to Møller (2003) some fish products (mainly codfish) caught in Denmark and Norway are frozen as whole fish and exported to China where they are defrosted and filleted. Subsequently, the fish filets are frozen again and exported back to the European market. If we apply the figures for export to Asia and consider that the fish is whole on they way to china, this alone could make up 5-10 MJ per kg product including. However, it should be stressed that this dissertation only focus on fish products caught by Danish fishermen and processed in Denmark.

Also, the Danish market has not been included in the analysis because of its limited size. However, the domestic market is important for some products such as canned mackerel and pickled herring. The transport distances are roughly 100-500 km.

5) Other modes of transportation

The previous estimates of the transport load mainly deals with road transportation. Alternatives could be train, ship and air transport.

Train. It is concluded that the fuel saving potential for using train is limited, but some studies show that it may reduce the fuel consumption with 9-79%. Train is especially relevant for conserved, salted and dried fish products with a long shelf life and if the dispatch and destination is close to the railroad infrastructure (see app. 7).

Ship. Transport by ship is mainly used for trans-continental export. If ships were used to transport fish within Europe, and if we assumed that the distance was the same as for road transport, the energy consumption could be reduced by 70%. However, this is not the case. In the Norwegian study of fish transport, it is concluded that ship transport is in fact more energy consuming than road transport when all aspects are taken into account (Anderesen, 2002b).

Air transport. Air transport of high quality fresh fish over relatively long distances is a known phenomenon, but in the case of Denmark, mainly as import. For transport to or from Japan, it is estimated that the energy consumption would increase from 2,5 MJ per kg to roughly 120 MJ per kg if airtransport were used instead of ship. Hence, air transport is indeed very energy intensive, but to put things in perspective, beam trawl fishery targeting flatfish represent a fuel consumption of around 2,6 liter fuel per kg caught flatfish, or around 100 MJ per kg caught fish. With a filet yield of 35% this is nearly 300 MJ per kg filet. A comparison of the energy consumption at different life cycle stages is presented in chapter 7.

Chemical exchanges

The following section includes a description of exchanges of chemicals, mainly cooling agents, at the transport stage.

Anti fouling agents

For transportation by ship, it is worth to consider the emission of anti fouling agents. Some efforts have been made to get an overview of the emissions related to transport of the products, but there is still not sufficient data to estimate the emissions per ton km. Therefore this is omitted here. (Drivsholm et al. 2002).

Cooling agents

According to Pedersen (2001), HFC 134 is used as cooling agent in modern cooling containers. Furthermore, it is assumed that there are considerable leakages because of rough environment. Thus, for frozen products transported by ship to destinations over-seas, the consumption of cooling agents is worth taking into account. However, it has not been possible to establish any reliable estimates of this loss.

Other exchanges

For transport in particular, it is obvious that energy consumption is only a part of the environmental aspects. Other aspects are related to air pollution from wearing of tires and brakes, water pollution through oil spillage as well as wear on tires and road.

Traffic also causes non-flow related impacts such as land use, which has a negative effect on biodiversity, landscape aesthetics etc. Traffic's occupation of land also reduces filtration of rainwater and is a barrier for both humans and animals. Other non-flow related effects are accidents, noise and environmental health and safety. Most of these types of effects are difficult to describe quantitatively and there have not been any data available – not even Health and Safety, described in most of the other life cycle stages (Drivsholm et al. 2002).

It has been considered out of the scope to discuss capital goods in part two, but it should be mentioned that capital goods is a significant factor in transport. This is also discussed in part three together with considerations of site-specific aspects, differences in exposure and threshold levels.

Development tendencies

In app. 7, it is argued that even though we may experience development of more efficient engines and reduced emissions we may also experience an

increasing amount of transport. Hence, any significant changes in the transport related environmental impacts over the next 10-15 years is not to be expected.

6.4 The retail stage

This section focuses on retail, which covers sale of fish products to private consumers. Fish products are also sold to catering, but this is not analyzed here. Retail includes small local fish shops, fresh fish markets and supermarkets, which sells both fresh and frozen fish (Fiskebranchen, 1999).



Figure 8: Illustration of initial frost storage, exposure in shop and secondary packaging at the retail stage. Pictures are used with permission from Thyborøn fish auction and the ISO supermarket chain.

The product flow, processes as well as input and output at the retail stage are illustrated in the figure below.

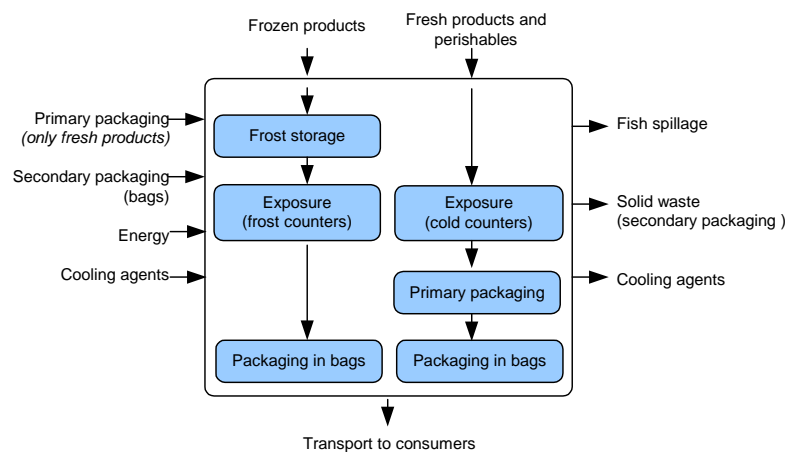


Figure 9. Product flow, processes and immediate exchanges at the retail stage

Material exchanges

The material flow in retail is mainly related to fish spillage and packaging materials.

Fish spillage

Retail receives fish products that are either frozen or fresh. For fresh products, it must be assumed that there is a considerable fish spillage due to lack of durability. However, it has not been possible to provide reliable data in this case. According to the transport manager at company Flatfish, the spillage of frozen products during retail is typically 0,1-0,2 % (Company flatfish, 2003b).

Primary packaging consumption

Frozen products as well as most of the canned and preserved products are packed at the fish factory, and it is therefore only some fresh fish products that consumes additional¹²⁹ primary packaging at the retail stage. The amount of primary packaging for fresh products has not been established; it probably varies considerably, depending on the product type, the amount of fish and the fish shop. As a rough estimate, the figures for primary packaging at the processing stage can be used. In this regard, it is worth to note that an increasing part of fresh fish is packed at the processing plant in MAP¹³⁰ packaging.

Secondary packaging consumption

On the input side, plastic bags are typically used to transport the products from retail to home. In Denmark, most bags are made of plastic (Skov- og Naturstyrelsen, 2000). According to Matthiesen (2003) the typical plastic bag used by large Danish supermarket chains is made of 20 myPE, has a volume of roughly 12 liter and a weight of roughly 18 gram¹³¹. As the total volume of one kg of fresh or frozen fish is roughly 4-5 liter, *roughly 10 gram PE per kg fish* is used.

¹²⁹ Here I stress “additional”, because fresh fish are already packed in EPS plast when they arrive at the retail.

¹³⁰ MAP stands for Modified Atmosphere Packaging. The type and amount of material has not been established.

¹³¹ Typical plastic bags sold in Denmark has a weight of 13-35 gram (From, 2003).

Packaging waste

Frozen products typically arrive in cardboard masters, packed on pallets, wrapped with LDPE film as described in chapter 5. This secondary packaging material ends up as waste at the retail stage. The amount of secondary packaging for frozen products varies considerably between different products, but on basis of three case studies, it is estimated that the amount is *maximum 100 gram cardboard and 5 gram LDPE for typical frozen fish products* (Company flatfish, 2001; Andersen et al. 2000; Ritter, 1997) – see also table 1 in chapter 5.

For fresh products, the packaging waste mainly consists of EPS boxes. As mentioned earlier, the material consumption is roughly 300 gram EPS per 10 kg of fish *or 30 gram per kg fresh fish* (DOR Århus, A/S, 2000a).

Energy exchagnes

According to Bertelsen and Christensen (2002), electricity consumption in retail is dominated by cooling/freezing process (64%) and lighting (33%)¹³². However, this distribution cover average products, and it must be assumed that energy for lighting will be insignificant in an analysis of frozen and fresh fish stored in cold counters. The argument is that products which need cooling only constitutes a relatively small part of all the products sold in a traditional supermarket. In this regard, it must be assumed that electricity consumption for all other products is dominated by energy for lighting (~100%). Thus, I have chosen to only include electricity for cooling, even though this will result in a small underestimation.

It could also be argued to include energy consumption for heating. However, it is assessed that it is reasonable to omit heat consumption as well as the heat substitution from the cooling processes altogether¹³³.

¹³² According to Binder et al. (2003) the distribution is 54% for cooling/freezing and 26% for light, but these figures are apparently only based on one supermarket chain (FDB).

¹³³ According to FDB (2001), the heat consumption varies between 38 and 129 kWh per m², depending on the stores. For the retail chain (Superbrugsen) with the largest turnover among the stores in COOP Denmark, the heat consumption was 360 MJ per m² in 2000. The stores have an electricity consumption of 979 MJ per m². Thus, the heat energy is roughly 37% of the electricity consumption. As suggested by Weidema et al. (1995), roughly 50% of the electricity for cooling equipment substitutes energy for heating. Thus, by omitting heat energy in both cases, we only un-

As for cold storage during wholesale, energy consumption depends on the storage time, the volume, the utilization ratio and the specific electricity consumption for the freezers¹³⁴.

Storing volume and utilization

According to Weidema et al. (1995), the utilization rate for cold counters and cold racks is 80% and 50% respectively. In the present study it is chosen to use 70% as an average utilization factor for both fresh and frozen fish products at the retail stage¹³⁵. Thus, depending on the product type, the effective product volume is:

- One kg frozen filet (IQF): 5,00 liter per kg * 1/0,7 = 7,1 liter per kg
- One kg frozen block filets: 1,25 liter per kg * 1/0,7 = 1,8 liter per kg
- One kg fresh fish or perishables: 4,00 liter per kg * 1/0,7 = 5,7 liter per kg

As it appear, block frozen fish has a relatively small effective product volume. The storing time is also a key variable. This is described below.

Storing time (frozen products)

According to a large Danish supermarket chain, frozen fish filets are typically stored for three weeks in the retail, with two weeks of exposure¹³⁶ (Supermarket, 2002). Other supermarkets may have somewhat different storing and exposure times, but this supermarket chain represents a good average of

derestimate the energy consumption slightly. Still, Weidema has not considered that cooling equipment may leak cold air. Furthermore, the environmental impacts from generating heat energy are typically less than for generation of electricity. All things considered, it is assessed that the omission of heat energy altogether is reasonable. According to Binder et al. (2003), one of the investigated retail stores actually didn't use any heat energy at all because of the heat generated by the cooling equipment.

¹³⁴ According to Weidema et al. (1995) the energy also depends on the specific heat capacity of the products, the product's temperature before storing, and the number of door openings. It is estimated that energy consumption, based on product volume alone, utilization and specific electricity consumption, cover 70% of the total electricity consumption, which is considered adequate here.

¹³⁵ This has been confirmed as a reasonable estimate by Supermarket (2003a).

¹³⁶ According to Ziegler (2002), the retail storage time for frozen codfish is 20 days with 10 days of exposure time in Swedish supermarkets. This is somewhat smaller, and suggests that the figures could be slightly overestimated.

the interviewed supermarkets. It is assumed that it is similar for IQF and block fish¹³⁷.

Storing time (fresh and pickled products)

Fresh products are traditionally sold in fish shops, fresh fish markets and supermarkets. According to a large fish shop in Denmark, fresh fish are typically sold within two or three days (Fishshop, 2003). This is confirmed by Supermarket (2003b), that estimates two to four days. However, it should be noticed that the products could be used for meat balls etc. in a second life cycle. Thus, the storing time may be longer¹³⁸.

Fresh fish are also sold in MAP packaging¹³⁹. According to the largest producer of MAP packed fish products in Denmark, the shelf life is about 8 days but the fish are sold after 3-4 days at an average (Thrane, 2000b). For fresh fish as a whole, it is assumed that a storing time of 3 days is good average.

According to Supermarket (2003a, 2003b), the storing time for average perishables exemplified with typical pickled herring, the storing time is two to three weeks. Consequently, I have used the same storing time as for frozen products (3 weeks with two weeks of exposure).

Specific electricity consumption (frozen products)

According to DEFU (1999) the specific electricity consumption varies considerably between different types of counters. Frost gondolas vary from 22-36 MJ per liter per year, while frost shelves vary from 13-29 MJ per liter per year. The lowest specific energy consumption (13 MJ per liter per year) is for closed frost shelves. As an average, I have chosen to use 25 MJ per

¹³⁷ According to Supermarket (2003b), which represents a large retail chain of medium sized stores, the average exposure time for frozen fish filets is 2-4 weeks, but it is mentioned that specialty products such as shellfish may endure 3-6 months with exposure. According to Supermarket (2003a), the average exposure time for traditional frozen fish products is 3-4 weeks. Some products such as salmon may only be stored for 5-7 days, while minced fish in blocks and specialty products such as certain shrimps and prawns are stored up to 6 months.

¹³⁸ It is difficult to verify this, but we know that fresh lean fish can be stored from 7-21 days at -0,5 °C, while fat fish can be stored 2-3 days at the same temperature (Andersen, 1998).

¹³⁹ For lean fish, a combination of 30% oxygen, 40% carbon dioxide and 30% nitrogen is used. For fat fish, various combinations e.g. 60% carbon dioxide and 40% nitrogen (Andersen, 1998) is used.

for closed frost shelves. As an average, I have chosen to use 25 MJ per liter per year.

The specific electricity consumption for frost storage before exposure is assumed to be similar to the storage at the wholesale stage – that is 0,5 MJ per liter per year.

Specific electricity consumption (fresh products and perishables)

According to DEFU (1999), energy consumption varies considerably for the different kinds of cooling shelves and gondolas. The lowest energy consumption is for cooling shelves (4,3 MJ per liter per year), while single frost gondolas have an energy consumption of up to 14,4 MJ per liter per year. I have chosen to use an average of three suggestions, which is 8 MJ per liter per year

The specific electricity consumption for the cold storage before exposure is assumed to be similar to storage at wholesale stage 0,07 MJ per liter per year.

Estimated energy consumption

Based on previous assumptions, the storing related energy consumption in retail can now be estimated – see table 3.

Table 3: Energy consumption per kg fish for frost and cold storing at the retail stage

Product type	Storage time [days]	Exposure time [days]	Effective product volume [liter]	Spec. el consump. storage [MJ / liter year]	Spec. el consump. shop [MJ / liter year]	Energy requirement [MJ / kg]
Frozen filet (IQF)	7	14	7,1	0,5	24	6,6
Frozen filet block	7	14	1,8	0,5	24	1,7
Fresh products	-	3	5,7	0,07	8	0,4
Perishables	7	14	5,7	0,07	8	1,8

As the table shows, the average energy consumption for frozen IQF filets is estimated at 6,6 MJ per kg. For frozen block fish, energy consumption is considerably lower; 1,7 MJ per kg¹⁴⁰. Energy consumption for fresh products is relatively insignificant while perishables have an energy consumption similar to block fish per kg fish meat. It should be stressed that the estimate for perishables has a high level of uncertainty – due to the rough estimate of storing time.

It should be noted that the figures above do not include energy consumption related to lighting and room heating. However, it is assumed that these energy levels will be relatively insignificant for this kind of products.

Chemical exchanges

For chemical input and output it is assumed that the most important parameter is most likely cooling agents.

Cooling agents (I/O)

Typically two kinds of cooling equipment is used in supermarkets and fish stores. One type is called “plug-in equipment”. Here the compressor is mobile, and the equipment can be moved around. The other type is cooling systems, where the centrally placed compressors feed several cooling systems. This is termed “remote cooling systems”. The latter implies long distances of pipes, which cause relatively high losses of cooling agents – typically around 20% per year. The total installed amount of cooling agents in Danish retail is estimated to be about 400 tons 1999, which gives a yearly loss of cooling agents of 80 ton. The type of cooling agent is typically HFC 134 a and R 404 a¹⁴¹. The total energy consumption for cooling processes in Danish retail is about 450 GWh per year. (Pedersen, 2001).

¹⁴⁰ A Swedish LCA study of frozen block fish suggests that the energy consumption is 1,1 MJ per kg related to storing during retail (Ziegler, 2002). The difference is related to different assumptions for exposure time and utilization. First of all, the Swedish study uses an exposure time of 10 days instead of 14 days in the present study. Secondly, the Swedish study assumes that the utilization is 100% instead of 70% as assumed in this study. With the same utilization factor, the Swedish figure would be 1,6 MJ per kg

¹⁴¹ R 404 A is a mix of HFC143a (52%), HFC-125 (44%) and HFC-134a (4 %). The Global warming potential is 3260 gram CO₂ equivalents (100 year) and the ODP is close to zero. HFC134 is a single agent (CHF₂CF₃) with a global warming potential of 1300 CO₂ equivalents (100 year). The ODP is close to zero. (Pedersen, 2001).

Thus, it can be calculated that the average consumption or emission of cooling agents from retail is 0,05 gram cooling agents per MJ used for cooling. This means that the average consumption/emission of cooling agents can be estimated, as follows:

Table 4: Consumption and emission of cooling agents in frost and cold storing at the retail stage

Product type	Energy Requirement [MJ / kg]	(I/O) of R404a per MJ [gram/MJ]	(I/O) of R404 a / HFC 134a [gram/kg]
Frozen filet (IQF)	9,3	0,05	0,47
Frozen filet block	2,3	0,05	0,12
Fresh products	0,5	0,05	0,03
Perishables	2,5	0,05	0,13

The emission for IQF filets is nearly 0,5 gram per kg, which is relatively significant, contrary to fresh products. As the cooling agent has a strong greenhouse potential, it may have a significant environmental impact – but this is further analyzed in part three (chapter 8-9).

Other exchanges

Apart from exchanges related to materials, energy and chemicals there are no other important environmental aspects at the retail stage. Health and safety issues may play a role together with various aspects related to noise and land-use, but this has been disregarded here, partly due to lack of data. Land-used is discussed in chapter 10.

Development tendencies

The development tendencies for exchanges at the retail stage are discussed in the following.

Materials

It is assumed that material consumption and solid waste generation will remain at the same level as today – based on simple prediction.

Energy

For energy consumption, technological development will probably ensure higher efficiency in cooling processes – just as it is assumed for households (described later). As mentioned under chemicals, the use of natural cooling

agents such as CO₂, propane and ammonia will most likely increase significantly, but some of these units use more energy than the older CFC based units (Pedersen, 2001). It is assumed that the energy reduction will be about 30% similar to other cold storing processes in this project.

Chemicals

According to Pedersen (2001), there is currently a development towards substitution of HCFC based cooling agents with natural cooling agents such as CO₂, propane, and ammonia. In Denmark, some supermarkets have substituted the cooling agents already, and it is predicted that natural cooling agents will be the most commonly used cooling agent in 2010-15. A rough estimate is that 80% of the artificial cooling agents is replaced by natural cooling agents towards 2010-15.

6.5 The use stage

The exchanges in the use stage are presented in the following. As illustrated in figure 10, the use stage includes transport, storing, cooking and dishwashing.



Figure 10. Illustration of the different processes at the use stage – with permission from Electrolux..

It is important to be aware that the fish products mainly are exported to and consumed in other European countries. The product flow, including processes and immediate exchanges are illustrated in figure 11.

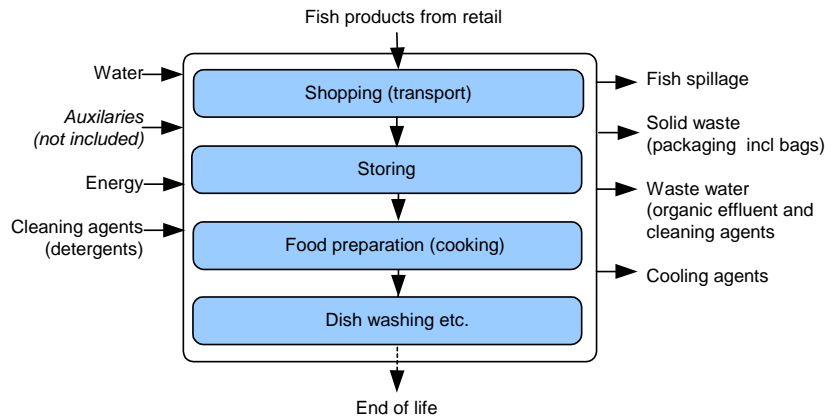


Figure 11. Product flow, processes, input and output at the use stage

As it appears, the use stage involves many processes and exchanges. Except for fish spillage, all exchanges at this stage are per kg served fish.

Material exchanges

The material exchanges are described in the following, with a focus on the consumption of water and energy and the generation of fish spillage (fish waste) and packaging waste.

Water consumption

Food preparation and dishwashing is estimated to be responsible for a consumption of about 30 liters of clean water per kg fish meat served in average (see app. 8.1). In this regard, water consumption for food preparation is estimated to 12 liters while dishwashing is estimated to use around 17 liters per kg meat served (Wrisberg, 2001; Green Network 2002).

If the dishes are done in a machine, the water consumption for dishwashing may be reduced to around 7 liter if a modern dishwashing machine is used. If dishwashing is done by hand, the water consumption may be around 25 liter per liter served fish meat (Stamminger, 2002) – see app. 8.1

This suggests that there is a potential for water savings by using a washing machine, but obviously, it depends on the consumer behavior. For instance,

the result would be quite different if we compared a half full machine where the dishes have been rinsed in running water first, with hand washing without running water and other waste full behavior. Thus, large uncertainties exists here.

Consumption of auxiliaries

Similar to packaging, there is a huge range of alternatives for auxiliaries, depending on the recipe and the fish product. It should also be considered whether the auxiliaries should be allocated to the fish product or it should be seen as accessories (as part of a meal). If the consumer prepares breaded filets in the kitchen, the auxiliaries include breadcrumbs, flour, eggs, and salt. In addition, the oil or butter for the frying process should be included.

However, the type and amounts of auxiliaries depends so much on the type of recipe used and the amount of product prepared, that a quantitative analysis covering a wider range of products would be meaningless to perform here. In the LCA case study of flatfish in part three, auxiliaries are included in the assessment.

Fish spillage (organic waste)

It is assumed that fish spillage at the use stage is 10% or *around 100 gram per kg consumed fish* (Green Network, 2002; Weidema and Mortensen, 1996a). Ideally, it should be considered that part of the leftover might be packed, re-stored and consumed at a later time. However, this has not been further analyzed.

Packaging waste

Consumption of packaging is probably mainly an issue for left-overs. Left-over may be wrapped in aluminium foil or packed into a plastic container. However, it has been chosen not to include a further analysis of leftovers.

Concerning packaging output, the primary packaging of the product as well as the bag used for transporting the products home – end up as waste. Thus, the total amount of packaging waste is equal to the primary packaging, described in chapter 5, added to the amount of packaging for the bag. Therefore it can be calculated that the the packaging waste, in the case of a frozen cod or flatfish filet, would be *120 g coated cardboard or 37 g LDPE. For pickled herring and canned herring it is estimated to respectively 1.400-1.500 gram glass or 2-300 gram aluminium.* Apart from this, there will also be small amount of secondary packaging - roughly *10 gram PE (bags) per kg served fish.*

Energy exchagnes

The energy consumption at use stage is related to shopping, storing, food preparation and dishwashing.

Shopping

The energy consumption for shopping is considerable and there are great differences among species / product types, as illustrated in table 5.

Table 5: Transport related energy consumption for shopping based on economical allocation¹⁴² (see app.8.2). All figures are in MJ per kg filet.

	Demersal fish		Shell fish				Pelagic	
	Frozen codfish	Frozen flatfish	Frozen prawn	Frozen shrimp	Frozen lobster	Frozen mussel	Herring	Mack-erel
	Filet (IQF)	Filet (IQF)	Peeled (IQF)	Peeled (IQF)	Peeled (IQF)	Peeled (IQF)	Pick. jar	Can
Energy consumption (MJ per kg)	12,5	10,4	~14,4	14,4	39,6	11,1	8,3	8,1

In short, it is assumed that the shopping is performed with an average car and that the trip distance is 8 km (roundtrip). Allocation is performed on the basis of value considerations of the total purchase per shopping trip and the average value of the respective fish products. It should be noted that considerations of the weight of the products have been irrelevant as value has been used as the allocation parameter. Further details and methodological discussions are available in app. 8.2

Cold storage

For cold storing the energy consumption depends on the storing time, but also other variables such as the type of freezer (chest freezer versus upright freezer), the type of refrigerator, as well as the product's volume, utilization etc.

Shortly described, it is assumed that the products are stored in average modern freezers and refrigerators according to Danske Elværkers Forening (1998). The product volume is similar to previous stages 5 liter for IQF, 1,25 liter for blockfish and 4 liter for fresh fish and perishables. Furthermore, it is

¹⁴² As described in chapter 3, economical allocation is used as default parameter in the lack of a better method.

assumed that the utilization is 50% as recommended in Weidema et al. (1995). The average storing time is estimated on basis of common sense and consideration of shelf life and freezer volume. Assumptions, calculations, and methodological choices are further described in app 8.3. The results of total energy requirements for various types of fish products are illustrated in table 6, below.

Table 6: Energy requirements for cold storing at the use stage

Time	Three scenario for storing time [days]			Volume [liter]	Specific energy consump. [MJ/l/day]	Corresponding scenarios for energy requirement [MJ/kg]		
	Short	Med.	Long			Average	Low	Av.
IQF fish	14	30	60	10	0,018	2,5	5,4	10,8
Block fish	14	30	60	2,5	0,018	0,6	1,4	2,7
Fresh fish	1	2	3	8	0,01	0,1	0,2	0,2
Perishables	14	30	60	8	0,01	1,1	2,4	4,8

As it appears, the energy consumption, especially for freezing, can be considerable. In the average scenario (storing one month) is estimated that the energy consumption is 5,4 MJ per kg frozen IQF product and 1,4 per kg frozen block fish.

Food preparation

Energy consumption is also related to food heating - unless we are dealing with fish products used for cold meals such as pickled herring and canned mackerel. Calculations are also carried out in app. 8. The energy consumption has been established for three different recipes with roughly 50% fish and 50% vegetables etc. The recipes have been prepared in two types of ovens as well as stove. Co-product allocation has been performed by system expansion – see app. 8.4. The total energy requirement per kg prepared fish are illustrated below:

Table 7. Total energy consumption for one kg of fish in three different recipes, where co-product allocation is avoided by system expansion (Københavns E, 2002)

	Steamed flatfish filet [MJ]	Fish Florentine [MJ]	Green fish paté [MJ]
Stove	1,9		
Oven (trad./warm air)		6,2	5,3
Microwave oven	0,5	1,7	0,8

Apart from the data established above, Electrolux test kitchen has measured the exact energy requirement for pan-frying of breaded 250 gram flatfish. The study illustrated that it would require 3,3 MJ per kg fried breaded flatfish filet on a traditional electric stove (Electrolux, 2002¹⁴³).

In all the examples mentioned above, it should be mentioned that the energy requirement is established for portions of 150-400 gram fish. If the portions had been prepared in larger quantities, the energy consumption would have been smaller per weight. Hence, the figures should not be used to represent cooking of very large proportion nor food preparation in professional kitchens and catering.

As the data shows, oven is the most energy intensive preparation method, while microwave is at least three times as efficient. As described in app. 8.4, considerable energy savings can be made through the use of smaller traditional ovens, especially during initial heating. For small portions prepared at small lengths of time, small ovens can save a significant amount of energy.

Dishwashing by machine

Dishwashing can be carried out by hand or machine. In Denmark nearly 60% of the consumers uses dishwashing machine. The energy consumption for machine washing is relatively high and requires electricity to heat up the water - instead of hot water from district heating. The amount of energy used per item is therefore closely related to the amount of water used. According to Danske Elværkers Forening, an average dishwashing machine requires 5,4 MJ per load. If it is assumed that the machine is 75% full, the energy consumption will be 7,2 MJ or 0,7 MJ per dish. If it is further assumed that the fish meat content is 100 gram and is responsible for 1/3 of one dish (see app. 8.1), the total energy requirement will be 2,3 MJ per kg served fish¹⁴⁴.

Dishwashing in hand

If the dishes are washed by hand, it is more difficult to estimate energy consumption as it depends very much on the washing technique. According to Stamminger (2002), the energy consumption is 8,6 MJ for 12 dishes if hand washed. This is relatively close to the estimate above for machine wash, especially because the energy consumption for machine washing does not

¹⁴³ See excel file in app. 8.

¹⁴⁴ According to Weidema and Mortensen (1996a) energy consumption per kg food is typically around 0,8 MJ and 1,8 MJ per kg food, which is somewhat lower than my estimate.

include extra energy for initial rinsing in water. Thus, it is estimated that the energy consumption is of the same order of magnitude as for washing by machine. Obviously, the machine uses “electricity” while dishwashing by hand typically will involve another energy source, depending on the country.

Chemical exchanges

The consumption of chemicals is mainly related to dishwashing detergents while the emissions are related to organic effluents in wastewater as well as emissions of cleaning agents and cooling agents from cold storage.

Consumption of cleaning agents

It is obvious that preparation of food and dishwashing involves cleaning agents.

Concerning the quantities, it can be established that for hand-washing typically 2-3 ml are used per 5 liters of water. If it is assumed that 5 liters of water is used for two dishes, where the fish is responsible for 1/3 of the water consumption, it would be equivalent to 3-5 ml per kg fish. (Grøn Information, 2001b)

According to Grøn Information (2001a), the total Danish consumption of washing liquids is roughly 4.000 ton hand-dishwashing liquids and 2.500 ton machine washing liquids. According to I/S Økoanalyse (1996), the consumers use machines in 60% of the cases. Thus, it can be argued that the washing liquid consumption for machine-washing is probably less than for hand washing of dishes. Thus, 5 ml cleaning agents per kg fish can be used as a worst case estimate.

Wastewater – organic effluent

According to Wrisberg (2001), the COD load related to eating and dishwashing is roughly 45 gram per person per day in average. If it is assumed that one kg of fish can cover 35-100%¹⁴⁵ of the total energy demand for a person per day, this would suggest that the organic load is 16-45 gram COD per kg fish. This is a rough estimate, and it probably only covers fish products that do not contain brine or sauce that are discarded.

¹⁴⁵ The normal energy intake is around 10 MJ per person per day, and the energy content in fish varies from 3,5-10 MJ per kg (Veterinær og Fødevarerdirektoratet, 2000; Andersen, 1998).

For some products such as pickled herring, studies have shown that the organic load in the use stage is very high – roughly 820 gram per kg consumed fish, assuming a spillage of 10%. The reason is that brine has a high COD content, mainly because of the sugar (Ritter, 1997).

High organic loads may also be related to other perishables and non-perishables such as canned fish (e.g. mackerel or tuna) in oil, or fish that are in some kind of sauce - similar to whole fish and shellfish, which are prepared in the kitchen. Data for these product types are not available, but it is assumed that the organic load from these products hardly will exceed the organic load from pickled herring, mentioned above.

Wastewater – cleaning agents

The consumption of washing liquids is of the same magnitude as the amount used in the fish processing industry, and obviously these chemicals will also be present in the wastewater. The effects will be further analyzed in part three (chapter 8-9).

Cooling agents

In the use stage, there are also emissions of cooling agents, estimated to be about 5-10% of the installed amount per year¹⁴⁶. The type of cooling agent is typically HFC-134a. Even though an increasing number of freezers and refrigerators use hydrocarbons such as isobutene, it is assumed that there still are a number of older models on the European market. In a future scenario, it will be another matter.

In the hotel and restaurant business in Denmark, it is assumed that the installed amount of cooling agents is 40 ton, and the yearly cooling related electricity consumption is estimated to be 70 GWh. The yearly loss is also assessed to be 5-10% (Pedersen, 2001). This means that the emissions of cooling agents are roughly 0,008-0,016 gram per MJ or 0,012 gram per MJ in average¹⁴⁷.

¹⁴⁶ Typically, there will not be re-filling at the use stage and it is therefore not relevant to consider consumption of cooling agents. Cooling agents for the initial filling is used, but the exchanges related to production of cooling equipment is perceived as part of the capital goods not included in the analysis.

¹⁴⁷ According to Pedersen (1998), the average content of cooling agents in a household freezer is 70-150 gram. The loss of cooling agents is 5-10% per year, which is about 10 gram cooling agent per year. Considering an upright freezer with a yearly energy consumption of 400 KWh or 1440 MJ is similar to 0,007 gram of cooling

Based on these figures, the average emission of cooling agents can be calculated (table 8):

Table 8: Consumption and emission of cooling agents in frost and cold storing at the use stage.

Product type	Energy Requirement [MJ / kg fish]	Emission of HFC-134a [gram/MJ]	Emission of HFC-134a [gram/kg fish]
Frozen filet (IQF)	5,4	0,01	0,06
Frozen filet block	1,4	0,01	0,02
Fresh products	0,2	0,01	<0,01
Perishables	2,4	0,01	0,03

As illustrated, emissions of cooling agents are considerably lower in the use stage compared to retail. It should be stressed that there are no consumption of cooling agents because household freezers are not recharged.

Other exchanges

As described, it has been chosen to include the transport between retail and home in the user stage. In this respect, a series of other environmental aspects should be considered. This is described in chapter 6.3.

Regarding other pre-cooking activities, there are no significant environmental effects not covered in this section. However, at the cooking stage, it could be considered to include different aspects of kitchen safety and human health aspects.

Development tendencies

Development tendencies for exchanges at the use stage are discussed in the following.

Materials

The water consumption for dishwashing machines has been improved considerably for new machines in the latest years (Grøn information, 2001a; Ussing et al. 2001). As these machines will diffuse to the market and as fur-

agent emission per MJ. This is of the same magnitude as calculated with the other method above.

ther improvements will be possible, it is likely that the water consumption for dishwashing will be further reduced by 15% over the next 10-15 years. It is also reasonable to believe that the percentage of consumer using washing machines will increase – which will contribute to a further reduction of water consumption according to Grøn Information (2001a).

Norwegian studies suggest a reduction in packaging materials and a change from heavy to light materials (e.g. from glass to plastic) in consumer packaging (Hanssen, 2002). This will reduce the packaging waste at the use stage, but probably mainly be related to products in glass or aluminium.

As mentioned, it is assumed that the fish spillage is about 10% in average at the use stage for processed products, and of course considerable higher for whole fish. Any significant changes in this area are not to be expected.

Energy

Regarding energy consumption, the electrical kitchen appliances have generally become considerable more efficient during the last 10-20 years. The yearly energy consumption for a freezer has fallen from 605 kWh in 1990 to 439 kWh in 2001, which is a reduction of nearly 30% (Energistyrelsen, 2002). It must be assumed that the improvements in efficiency will continue – although the improvement rate may be slightly slower. Still, it must be assumed that older models which still are used will be replaced by far more energy efficient models. Thus, a further reduction of 30% within the next 10-15 years is realistic, compared to the medium scenario, previously described.

Chemicals

It is most likely that isobutene and other natural cooling agents will replace HFC based cooling agents by 2010-15. Thus, the contribution to global warming and ozone depletion in the use stage will only be related to the energy consumption.

Concerning dishwashing detergents, it is difficult to predict the future developments. Probably not much will happen concerning the amounts used, but we could hope that eco-labeling will be more common and that dishwashing agents will become less toxic. However, this is discussed further in part three.

6.6 Summary & final comments

This summary is somewhat different than the summaries in chapter 4 and 5, as it is chosen to focus less on the difference between fish species, as these generally are less pronounced for these stages. As the most significant exchanges are related to the use stage, this stage is treated separately after a common description of the auction, wholesale, transport and retail stage.

Landing & auction, wholesale, transport and retail

The exchanges at the landing and auction stage are limited in size and type. The same applies to the wholesale stage, but it should be noted that the occupational health & safety impacts at this stage are quite significant. There are a significant number of accidents and work related sufferings – absolute as well as relative to the work force.

At the transport stage, the energy consumption is relatively limited compared to the energy consumption in fishery and processing stages, but still it cannot be categorized as insignificant – especially if we include other aspects such as accidents, noise, smell, landuse etc. During the last decade, the focus on particle pollution has increased, and today it is believed that high exposure to particle pollution from diesel engines cause serious human health impacts. However, this discussion is elaborated in in part three (chapter 10).

Apparently the difference in energy consumption is very limited between truck and train while airplane is very energy demanding and would be responsible for an energy consumption of more than 100 MJ per kg when fresh fish is exported to Asia (~10.000 km), see app. 7. Still, this is seldom used for export of Danish fish products.

The exchanges at the retail stage are relatively large in terms of energy consumption and related emissions of cooling agents due to the use of remote cooling equipment with long stretches of pipes with cooling agents. However, development suggests that natural agents will replace cooling agents. Other exchanges are relatively insignificant at this stage.

The use stage

Compared to the other stages analyzed in this chapter, the use stage involves many different and significant exchanges. Still, the uncertainties are considerable because of limited amounts of information about the consumer behavior.

Resources. The analysis shows that water consumption is the most important immediate material exchange. Food preparation and dishwashing is estimated to be responsible for a consumption of about 30 liters of clean water per kg fish meat served, in average. It is estimated that water consumption could be reduced to roughly 20 liters if a modern dishwashing machine is used. In average, water consumption here is of a similar magnitude as water consumption in the processing stage.

Fish spillage is estimated to be around 10% in average at this stage. This is important because it indirectly contributes to higher exchanges in all other stages, measured per kg consumed fish. Thus, a reduction would imply a significant improvement potential.

Energy. Concerning energy consumption, there are four important processes: Transportation for shopping, storing/cooling of food, food preparation, and dishwashing. Due to considerable uncertainties, it is not possible to tell which of these four activities are the most important in general, and it definitely also depends on the product types (especially the volume). The energy consumption per kg prepared fish product is generally larger than for the processing stage. If the consumer chooses to shop by bicycle and avoid cooking in a traditional oven, energy consumption can be reduced significantly.

Chemicals. As mentioned, cooling and cleaning agents are used and there are emissions of wastewater containing organic and chemical effluents. As household freezers/refrigerators are not refilled, the cooling agents only appear as emissions because I only consider immediate exchanges and not the production of the equipment. In the current situation, it must be assumed that the cooling agents typically used are HFC based compounds with a high global warming potential, just as in fishery and retail stages. However, the emissions are considerably smaller than in the retail stage, where even larger energy consumption and long cooling pipes result in a considerable loss of gasses.

The amount of cleaning agents is similar to what is used in the processing stage, but again it is extremely important to consider the chemical properties of the agents to be able to compare anything – see part three.

Concerning emissions of wastewater effluents, the levels are typically lower than 50 gram COD per kg fish. This is less than at the processing stage, but there are some fish products, such as pickled herring, where the pickling

emissions can amount to 800 gram COD per kg fish. This is considerably more than any other stage of the life cycle.

Development tendencies

The predicted development tendencies for the different life cycle stages and exchanges are illustrated in table 9.

Table 9. *Expected changes in environmental aspects towards year 2010-15.*

Type of environmental aspect	Expected change compared to the current situation
Landing and auction stage (all exchanges)	-20%
Wholesale stage (only electricity)	-30%
Retail (electricity)	-30%
Retail (cooling agents)	-80% (substitution with natural agents)
Consumer (water)	-15%
Consumer (energy)	-30%
Consumer (cooling agent)	-80% (substitution with natural agents)
Detergents	Reduced eco-toxicity potential

The most important change is predicted for cooling agents, where it is assumed that artificial cooling agents will be substituted with natural cooling agents such as CO₂, propane, and ammonia.

Limitations of the MECO analysis

This section describes the limitations of the MECO analysis for the life cycle stages discussed in this chapter.

General aspects

First of all, it is important to stress that uncertainty is considerably greater at the life cycle stages described in this chapter than in the previous chapters regarding fishery and fish processing. One of the reasons is that more assumptions have been used, especially regarding the use stage, where only limited information is available about consumer practice. The uncertainty is considerable in all stages in this chapter, but considering the size of the exchanges, it is obviously the uncertainties at the use stage that are most important. Most of the obtained data have a high correlation concerning time scope, and this is not described any further.

Concerning the cut-offs, cooling agents at the retail and use stages have been included in the descriptions even though they are below the cut-off level.

Smaller flows are also included for specific cleaning agents as well as for specific elementary flows in the wastewater.

Geographical and technological correlation

For geographical scope, the most important deviations are at the retail and use stages, where the data are based on Danish experiences, while the goal was to base the information on exchanges in the other European countries where the products are sold, prepared, and consumed. Even though these deviations are significant, it should be stressed that the LCA in part three will include data for energy production and other related processes in the specific import countries.

Finally, there are some data sets in all stages that deviate significantly from the quality demand concerning technological scope. This mainly applies to the landing and auction stage. For instance, the technological correlation for reusable fish boxes is relatively low because part of the data represents vegetable boxes. This also applies to solid waste. Technological correlation for heat energy is also low at the landing and auction stages, which is because the data are estimated indirectly through data for water consumption. Finally, the technological correlation is also low for cleaning agents at the landing and auction stages because the data are based on the assumption that the amount of cleaning agents per liter cleaning water is similar to data found in the fish processing industry. The lack of correlation in the landing and auction stages is therefore quite limited, but the low level of observed exchanges suggests that the influence on the end-result is insignificant.

Finally, it should be mentioned that the technological correlation also is particularly low for fish spillage at the use stage. The reason is that the data are based on measurements from a professional kitchen involving preparation of many types of food besides fish. In other words, the data are from related processes and materials from the same technology (a kitchen).

Reliability and completeness

Concerning data reliability, it has been necessary to base the estimates on assumptions at a higher degree than we have seen in the previous chapters. Therefore the reliability score is considerably lower - see table 9.

In the retail and use stages, nearly all data are non-verified estimates partly based on assumptions. An example is shopping assumptions that are made concerning car type, distance, total purchase and product price. Obviously, the uncertainty in such estimates will be considerable.

The reliability is also relatively low for ice consumption in the landing/auction and processing stage. This is because the estimates are based on average estimates from an industrial expert.

All the exchanges related to the lifecycle stage in this chapter are illustrated in table 10 together with a quantitative assessment of the data quality according to the method described in app. 4.

Table 10. Overview of data types and quality in this chapter, based on Weidema (1998).

	Variables	Type	Data quality indicators				
			Ti	Ge	Te	Re	Co
Landing & auction	Water	Q	1	1	2	2	2
	Ice (demersal fish)	Q	1	1	1	4	2
	Fish boxes (new set)	Q	1	1	4	2	1
	Solid waste	Q	1	1	4	2	1
	Energy (electricity)	Q	1	1	2	2	2
	Energy (heat)	Q	1	1	4	3	2
	Cleaning agents (total)	Q	1	1	4	2	2
	Waste water (only amount)	Q	1	1	2	2	2
Wholesale	Health and Safety	Q	1	1	2	2	1
	Packaging for fish sold as fresh fish (EPS)	Q	1	1	1	2	2
	Ice for fish sold as fresh fish	Q	1	1	1	4	2
	Energy cooling (fresh and frozen)	Q	1	1	1	2	3
Transport	Health and Safety	Q	1	1	2	2	1
	Average energy consumption	Q	1	1	1	3	2
Retail	Shopping bags	Q	1	3	2	2	2
	Packaging waste (frozen)	Q	1	1	1	3	2
	Packaging waste (fresh)	Q	1	1	1	3	2
	Spillage (only for frozen fish)	Q	1	3	2	3	2
	Energy (electricity)	Q	1	3	2	3	2
	I/O Cooling agents	Q	1	3	2	3	1
Use	Water consumption	Q	1	3	2	3	2
	Ancillaries	NQ					
	Packaging waste	Q	1	1	1	2	2
	Fish spillage	Q	1	3	4	2	2
	Energy (shopping-transport)	Q	1	1	1	3	2
	Energy (storing)	Q	1	3	2	3	2
	Energy (food preparation)	Q	1	3	2	3	2
	Energy (dishwashing)	Q	1	3	2	3	2
	Cleaning agents (dishwashing)	Q	1	3	2	3	2
	Cooling agents (storing)	Q	1	3	2	3	1
	Waste water (organic effluent)	Q	1	3	3	3	2

The data quality indicators and the argumentation behind them have not been described further in the MECO analysis. However, the arguments have been carefully described in relation to the data used for the LCA of flatfish in part three. As the data quality is much similar – the reader may address app. 13 (document A) for further explanation.

Uncertainty and variation

General descriptions about uncertainty, variation, and the relationship to the data quality indicators are described in the summary of chapter 4.

Based on background knowledge and data quality indicators, it is assumed that the variation is largest (-75% to +200%) for exchanges in the use stage.

As earlier mentioned, there are many assumptions at each stage - for instance for shopping, where assumptions have to be made for car type, distance, total purchase etc. Concerning water consumption, the wide variety of kitchen practices is also a factor – especially for dishwashing, where tests show differences of more than 100% in the water consumption, depending on washing technique. Co-product allocation is also an issue in all these processes, and system expansion has only been used for energy consumption during cooking. Thus, the data will also depend on allocation method and how much food there is prepared at the same time in each case.

For other life cycle stages and exchanges it is assumed that the variation is slightly smaller but still about $\pm 50\%$. The reason is that most of the data are based on general figures and assumptions or data from only one firm in some cases. The variation for all data sets is shown below:

Table 11. Assessed variance for different groups of data sets at the remaining stages.

Life cycle stage	Exchange	Estimated variance	
		Min [pct]	Max [pct]
Landing and auction	All exchanges (energy)	-75	+200
Wholesale	Electricity (volume)	-50	+50
Transport	Energy (distance, loading etc).	-50	+50
Retail	Electricity (volume)	-50	+50
Use	All exchanges (shopping, storing, food preparation and dishwashing)	-75	+200

As explained in the previous chapter, the uncertainty for future estimates has not been further analyzed, but obviously it is considerably larger.

Conclusion on MECO Analysis

Part three addressed research question 1: What characterizes the environmental impacts from the different groups of Danish fish products in terms of environmental exchanges, types and magnitudes of impact at different life cycle stages?

To answer part of this question, the MECO analysis included an analysis of the most important immediate exchanges¹ for a wide range of fish products – representing all species groups in Danish fishery. Instead of describing each life cycle stage separately, as it has been done in chapter 4-6, the conclusion discusses the key exchanges separately. This conclusion includes a table that provides an overview of the results and presents key potentials for improvement. Uncertainties and limitations of the MECO analysis are briefly discussed at the end.

Key exchanges where fishing stage is hot-spot

First, it is chosen to describe the most important immediate exchanges for which the fishing stage represents the largest exchanges and therefore can be considered the hot-spot.

Exploitation of fish resources (and related issues)

Obviously, overexploitation of fish species only occurs in the fishing stage. This is mainly a concern within the demersal fishery in Denmark – especially in fisheries targeting codfish such as Atlantic cod. The impacts and

¹ It should be emphasized that an analysis of immediate exchanges is limited in the sense that it only tells something about key environmental variables such as energy consumption measures in MJ. Thus, it doesn't tell anything about the environmental impacts related to these variables.

seriousness related to overexploitation of fish resources are discussed in chapter 10.

The fishery is also responsible for by-catch and discard. By-catch cannot be avoided in most cases, and is typically not a problem considering overexploitation. However, if the by-catch consists of marine mammals (marine mammal entanglement) or species that are overexploited or even close to extinction (e.g. some sorts of rays) - it can be a serious problem. In the Danish fishery, such problems mainly occur within the demersal fishery – especially where gillnets are used.

Discard is mainly an ethical problem considering the waste of valuable food resources, and there are no studies to my knowledge - that suggests significant contribution to nutrient enrichment. Discard may increase as a function of the by-catch if the by-catch consists of unwanted fish (e.g. under-sized fish, over quota fish, no quota fish or fish of a low value).

It is obvious that overexploitation leads to changes in the ecosystems with consequences for future catch opportunities and fishery related employment. As mentioned, the effects of overexploitation will be further analyzed in chapter 10.

Lead pollution

Fishery is also the hot-spot concerning lead pollution. Many types of fishing gear contains considerable amounts of lead. A considerable amount of the lead is lost at sea. It should be stressed that lead is currently being phased out of fishery (substituted with iron compounds), and that a future scenario is expected to reflect a considerable reduction if not elimination of lead from the fishery.

Heat and combustion related energy consumption

The fishing stage clearly represents the largest consumption of heat and combustion related energy – especially for demersal fish. Table 2 shows heat and combustion related energy consumption per kg consumed product for nine different species groups². Calculations are based on mass flow considerations in app. 3. For demersal and shellfish, the analysis represents individual frozen fish in cardboard packaging of 300-400 gram, except for cod -

² I have chosen to subdivide the energy consumption in heat/combustion related processes and electricity consumption. The reason is that the emissions from electricity generations are considerably higher than for heat generation.

which is block frozen - to illustrate the difference. For herring, the analysis includes pickled herring in glass jar, while mackerel includes canned mackerel. Only the immediate energy consumption is included – see table 2:

Table 2. *The immediate heat and combustion related energy consumption – MJ per kg consumed fish product - for eight different species. All products are frozen except the pelagic species. For mass flow and calculations, see app. 3 and 13 document G.*

	Demersal fish (frozen filets)		Shell fish (boiled, peeled & frozen)				Pelagic (pickled/canned)	
	Codfish (block)	Flatfish (IQF)	Prawn (IQF)	Shrimp (IQF)	N. lobster (IQF)	Muss. (IQF)	Herring (jar)	Mack. (cann.)
Fishery	41	110	101	136	941	5	16	5
Landing	1	1	1	1	0	4	0	0
Processing ³	2	3	12	12	12	6	3	3
Wholesale	0	0	0	0	0	0	0	0
Transport ⁴	1	1	1	1	?	1	4	2
(if whole ⁵)	4	5	5	5	8	9	2	2
Retail	0	0	0	0	0	0	0	0
Consumer ⁶	14	11	16	16	44	12	9	9
Total	63	131	135	171	1006	37	34	20

As it appears, the fishing stage is the hot-spot for both demersal and shellfish. For Norway lobster, the fishery represents 94% of the total heat- and combustion related energy consumption. For prawn, shrimps and flatfish, the fishery is responsible for 75-85%, while it is a little less for codfish – around 67%. The fishing stage is less dominant for herring (49%) and mackerel (25%), but overall it is definitely the most important stage.

It also appears that the use- and processing stages are somewhat important, especially for shellfish - but still the magnitude is relatively small, at least

³It is assumed that the energy consumption for processing of prawn and Norway lobster is the same as for shrimps as it involves the same processes.

⁴ Based on transport analysis in app. 7. The data does not include extra transport for imported raw materials or re-exported products.

⁵ The energy consumption for transport of whole frozen fish, based on app. 7.

⁶ Include energy for shopping, storing, food preparation and dish washing by machine. For food preparation, energy requirement for pan-frying is applied, except for pelagic fish that are assumed to be served cold. Preparation in an oven would require more energy while preparation in a microwave oven would require less.

compared to the fishing stage for demersal- and shellfish. Finally, transport may play a role as well, especially if the fish is exported whole (up till 24% for mussels). The reason is that transport of whole fish includes transport of ice for cooling and transport of skin, bones, head and (shells).

Considering the importance of the processing stage, especially energy consumption for shellfish is important. However, the average energy consumption for processing edible fish is 3 MJ heat energy per kg processed file⁷. This is less than 10% of the average fishery related energy consumption – 35 MJ per kg processes edible fish⁸.

Antifouling agents (biocides)

Several chemicals are involved in the production of fish products. The analysis has focused on biocides, cleaning and cooling agents as well as process chemicals.

The fishing stage is the only stage that contributes with emissions of harmful biocides such as TBT, Sea-nine and copper. For a codfish, which represents an average emission, we are talking about an emission of roughly 0,5 ml biocides per kg consumed fish assuming that we need 3,14 kg caught codfish per kg consumed codfish, see app. 3.

As for lead pollution, it is assumed that the emissions of harmful biocides will be significantly reduced in a future scenario. TBT will be completely removed from paint within a few years, but still it should be considered that copper and other biocides such as Sea-nine will be allowed – at least until other chemicals or methods are developed to prevent fouling.

Non-flow related impacts (fishery)

There are also a number of non-flow related environmental impacts. This mainly includes damage inflicted to the seabed, and occupational health and

⁷ This relatively low energy consumption may reflect that we only have a few industries processing shrimp and prawn in Denmark. However, it is also most likely that some of the fish industries considered in this study produce semi-manufactured products that needs further processing. However, if we compare with the empirical data obtained in my study, the figures do not appear unrealistically low.

⁸ The average fuel consumption per kg caught fish is 0,32 liter (12 MJ). If we assume that the average file^t yield for edible fish is 0,35, this is equivalent to 35 MJ per kg processed file^t.

safety. For both types of impacts, the fishing stage represents the largest exchanges.

Damage to the seabed. The impacts on the seabed occur when bottom tending fishing gear is applied. It is mainly bottom- and beam-trawl, which penetrates the seabed and damage plants and animals in its path. Thus, only fisheries targeting demersal and shellfish inflict damage to the seabed. The effects are further described in chapter 10.

Occupational health & safety. Not all life cycle stages have been thoroughly investigated concerning occupational health & safety aspects. However, the analysis points towards fishery and fish processing as the hot-spot here also. The number of injuries and work related sufferings in total as well as per employees and ton produced filet - are illustrated in table 3.

Table 3. The number of reported injuries and work related sufferings at different stages without distinctions between species and product types. For calculations see – app.13 (document I).

	Injuries			Sufferings		
	Total number	Per 100 empl.	Per 1000 ton filet sold	Total number	Per 100 empl.	Per 1000 ton filet sold
Fishery	250,0	8,3	0,2 ⁽⁹⁾	105,0	1,4	0,1 ⁽¹⁰⁾
Auction	2,0	Na	Na	3,0	Na	Na.
Processing	288,0	5,1	0,4 ⁽¹¹⁾	88,0	1,6	0,1 ⁽¹²⁾
Wholesale	40,0	1,8	Na	20,0	0,9	Na
Transport	Na	Na	na	na	na	Na
Retail	Na	Na	na	na	na	Na

⁹ This is a very rough estimate. I have divided the total number of injuries with the total catch (multiplied with 0,4) of edible fish by Danish fishermen in the year 2000 (Fiskeridirektoratet, 2001a). Industrial fish have been left out and the figure is therefore somewhat overestimated. The multiplication with 0,4 reflects a filet yield of 0,4 - which I have used as the approximation for the average filet for edible fish including shellfish. See also app. 13 (document I)

¹⁰ See footnote 9. The only difference is that this is sufferings instead of injuries.

¹¹ This is also a rough estimate, calculated as the total number of injuries divided with the total sale of edible fish and shellfish from the processing stage in the year 2000 (Fiskeridirektoratet, 2001a). See also app. 13 (document I)

¹² See footnote 11. The only difference is that this is sufferings instead of injuries.

As it appears, the processing stage becomes the hot-spot for H&S considering the high number of injuries - in a product perspective. However, it should be considered that large uncertainties exist and that the analysis is incomplete with respect to other stages. Furthermore, the type of accidents and injuries should be included in the assessment as well. In this regard, several deaths occur each year at the fishing stage, which points towards fishing as the hot-spot. Thus, it is most reasonable to conclude that both the fishery and processing stage are hot-spots.

Key exchanges where processing is hot-spot

There are also some aspects for, which the processing stage appears to be the most important stage in the life cycle. This includes consumption of ground water, ancillaries, packaging materials and emissions of wastewater.

Water consumption

The water consumption per kg consumed fish product, in the different life cycle stages, is illustrated in table 4.

Table 4. The water consumption measured in liter per kg consumed fish product considering eight different species. All products are frozen except the pelagic species. For mass flow and calculations, see app. 3 and 13 (document H).

	Demersal fish (Filletted & frozen)		Shell fish (boiled, peeled & frozen)				Pelagic (pickled/canned)	
	Codfish	Flatfish	Prawn	Shrimp	Norway lobster	Mussels	Herring	Mackerel
Fishery	<1	<1	<1	<1	<1	<1	<1	<1
Auction etc ¹³	4	4	6	6	2	0	0	0
Processing ¹⁴	17	28	132	132	132	35	17	46
Wholesale	<1	<1	<1	<1	<1	<1	<1	<1
Transport	<1	<1	<1	<1	<1	<1	<1	<1
Retail	<1	<1	<1	<1	<1	<1	<1	<1
Consumer ¹⁵	19	19	19	19	19	19	19	19
Total	43	55	160	160	157	58	39	69

Even though there are large uncertainties related to the estimates, it is clear that mainly the processing and use stages are responsible for the consumption of ground water. Especially shrimp have a high water consumption because of the boiling processes. Data have not been available for prawn and Norway lobster, but for prawn it is basically the same processes which are involved. Norway lobster is typically not processed, but for both prawn and Norway lobster I have used the data for shrimp processing as a worst-case estimate.

¹³ Mussels and pelagic fish typically do not involve collection central and auction.

¹⁴ These figures refer to data in chapter 5. For codfish, it is estimated that the average is 15 liter per kg processed fish. This is at the low end of the interval in table 1, which represents data from 1988, similar to case studies from the present time. For flatfish, it is assumed that it is 25 liter per kg in average. This is based on considerations similar to codfish. For shrimps, it is assumed that the water consumption is 132 liters, which is also at the low end of the interval provided by Andersen et al. (1996). The total water consumption for filleting and further processing of herring and mackerel is based on Andersen et al. (1996), but the figures in table 1 are reduced by 50% because the data are from 1988, and other studies suggest that the consumption has been reduced through cleaner production by at least 50% until 1998 (see chapter 5 – development tendencies).

¹⁵ This is based on the assumption that dishwashing is carried out by machine. Dishwashing by hand would probably result in a higher water consumption – see app. 8.

It is important to stress that the consumption of water in the use stage mainly takes place in “other European countries”. Further considerations about environmental impacts related to water consumption are discussed in part three – mainly chapter 10.

As explained in chapter 5, there are indications that the water consumption in processing stage is overestimated, while the opposite appear to be the case for the use stage. Thus, for some products it is very likely that the use stage is responsible for higher water consumption than the processing stage. If the fish are prepared as whole fish this is obviously true in all cases.

Considering the differences between species, the picture is somewhat similar to the differences in energy requirement. Shellfish represents the largest water consumption considering the whole life cycle, while demersal and pelagic fish have a somewhat lower water consumption.

Consumption of packaging and ancillaries

Packaging. The most important life cycle stage for packaging is definitely processing¹⁶, especially for pelagic fish where canned mackerel can be responsible for the consumption of 300 gram of aluminium per kg fish filet, while pickled herring in jar can be responsible for 1,5 kg glass per kg processed fish. It should be mentioned that a range of other products such as shrimps, prawns, mussels are sold in jar or steel cans as well.

In addition, significant amounts of packaging are used at the wholesale stage – for whole fresh fish and shellfish. The consumption is around 30 gram EPS per kg whole fish - or roughly 75 gram EPS per kg filet (assuming that 40% is filets/meat). For fresh products, it should also be considered that additional packaging is used at the retail stage. Still, it is considered that pelagic fish are the most important, followed by shellfish and finally demersal fish.

Ancillaries. The amounts and types of ancillaries used depends on the product type. Examples are sugar, salt, corn products, vinegar, onion, pepper, tomato paste, and oil. For some products, such as pickled herring, the amounts can be significant (more than the fish content itself). The environmental impacts for ancillaries are further assessed in part three.

¹⁶ The processing stage is also considered the hot-spot for packaging in other studies of food products, such as Weidema et al. (1995) and Ziegler (2002).

The consumption of ancillaries is also greatest at the processing stage – especially for products that are further processed such as pickled herring, canned mackerel and various fish and shellfish products, sold in different sauces. In this regard, it is worth distinguishing between ancillaries that are used as part of the edible product, e.g. ancillaries for breading of filets, and ancillaries that are not supposed to be consumed, e.g. the brine in a jar of pickled herring. In the last example, it is likely to increase the exchanges per kg meat, while the opposite may be the case if the ancillaries substitutes fish meat. However, it obviously depends on the type of ancillaries and consumer behavior.

Energy (electricity)

The electricity consumption is illustrated in table 5. Calculations are based on mass flow considerations in app. 3.

Table 5. The electricity consumption measured in MJ per kg consumed fish product - for eight different species. All products are frozen, except the pelagic species. For mass flow and calculations – see app. 3 and 13 (document F).

	Demersal fish (frozen filets)		Shell fish (boiled, peeled & frozen)				Pelagic (pickled/canned)	
	Codfish (block)	Flatfish (IQF)	Prawn (IQF)	Shrimp (IQF)	N. lobster (IQF)	Muss. (IQF)	Herring (jar)	Mack. (cann.)
Fishery	~0	~0	~0	~0	~0	~0	~0	~0
Landing	0,3	0,3	0,4	0,4	0,1	1,3	0,0	0,0
Processing ¹⁷	2,8	4,2	3,1	3,1	3,1	4,5	1,2	0,7
Wholesale	0,2	0,9	0,9	0,9	0,9	0,9	0,1	0,0
Transport ¹⁸	~0	~0	~0	~0	~0	~0	~0	~0
(if whole ¹⁹)	~0	~0	~0	~0	~0	~0	~0	~0
Retail	1,9	7,3	7,3	7,3	7,3	7,3	2,0	0,0
Consumer ²⁰	8,4	12,9	12,9	12,9	12,9	12,9	5,2	2,5
Total	13,6	25,5	24,5	24,5	24,2	26,8	8,4	3,2

As it appears, the use stage dominates with respect to electricity consumption. Around 50% of the total electricity consumption is related to this stage for all products. The most important processes are cold storage, food preparation, and dishwashing. The retail and processing stages are also relatively important. If we disregard the fishing stage, the electricity consumption is a significant part of the total energy consumption – especially if we consider that electricity consumption generally cause higher emissions per MJ (roughly a factor 2 more with respect to green house gas emissions per MJ).

¹⁷It is assumed that the energy consumption for processing of prawn and Norway lobster is the same as for shrimp, as it involves the same processes.

¹⁸ Based on transport analysis in app. 7. The data does not include extra transport for imported raw materials or re-exported products.

¹⁹ The energy consumption for transport of whole frozen fish, based on app. 7.

²⁰ Include energy for transport, storing, food preparation, and dishwashing by machine. For food preparation, the energy requirement for pan-frying is used except for pelagic fish, assumed to be served cold. Preparation in an oven would require more energy, while preparation in a microwave oven would require less.

Even if we include the fishing stage, this is actually still the case for certain products based on mussels and mackerel.

Cooling agents

For cooling processes, HFC based agents (e.g. R22, R134a and R404a) is used currently at the fishery-, retail- and use stages. The consumption/emission is most significant in the retail stage and amounts to 0,52 gram per kg-consumed fish. The consumption in the fishery can be up to 0,14 gram per kg consumed fish (Norway lobster), but is generally lower. In the use stage, the maximum emission is less than 0,1 gram per kg-consumed fish (IQF). Thus, the retail stage represents the most important exchanges concerning cooling agents, mainly due to the remote units with long pipe lines, carrying in the cooling agents from the (remote) compressor to the cooling units in the retail store. The retail stage also uses cooling agents with the highest global warming potential per gram.

Process chemicals

For certain products such as mackerel, NaOH and HCL are used in the de-skinning process, and during the processing of pickled herring, hydrogen peroxide is used to achieve bleached fillets. The amounts of NaOH and HCL can be significant - a total of about 35 gram per kg consumed fish. As only the immediate exchanges are considered here, it must be assumed that the effects of acid and alkaline agent are limited, as they probably neutralize each other. The largest producer of canned mackerel in the world (situated in Denmark) uses steam instead of chemicals in the de-skinning process.

Cleaning agents. The largest amount of cleaning agents per kg consumed fish is in the processing and use stages, closely followed by the fishing stage. In all cases, it is less than 5 ml per kg-consumed fish. The eco-toxicological effects of chemicals used in the processing and fishing stage will be analyzed further in part three.

Wastewater

Concerning wastewater, the processing stage is generally the most important stage. In this regard, pelagic fish and shellfish have the highest organic loads. This is partly because these species are not gutted at sea. It is also because pelagic fish generally have a higher fat content.

However, the use stage is the most important for some products such as pickled herring, where discard of the brine can cause a large organic load, mainly due to the sugar content. Similar emissions may arise from other canned products containing extra oil etc.

For other products, the use stage is relatively insignificant, which also applies to the fishery.

Concerning wastewater, it is also worth considering the emission of chemicals such as remains of cleaning agents as well as process chemicals. The latter are mainly of concern at the processing stage. The eco-toxicity potentials are further analyzed in part three.

Occupational health & safety

As mentioned previously it is assessed that the processing and fishing stage both are hot-spots with respect to occupational health impacts.

Other important stages

The use stage appears to be important with respect to water consumption as well. In addition, the use stage represents a considerable energy consumption (in fact, more than the processing stage) and significant emissions of wastewater for certain products such as pickled herring. The use stage also involves a significant amount of transport and waste from packaging materials and fish spillage.

The transport stage may be relatively important when the fish products are transported as whole fish - at least per kg consumed fish meat. Still, at an average, the energy consumption in the transport stage is less than for shopping related transport in the use stage – at least based on the assumptions made in this project, which include an average shopping distance of 8 km (roundtrip) by car.

Overview

As an attempt to provide some sort of overview of the results, I have summarized key environmental aspects and their importance for each life cycle stage in table 6. It should be pointed out that the table does not include consumption of non-renewable resources and waste²¹.

²¹ The reason is that the immediate consumption of non-renewable resources is insignificant compared to the indirect consumption e.g. related to energy. The same applies to waste. Both aspects are separately discussed in chapter 10.

I have distinguished three species types: Demersal fish (D), shellfish (S) and pelagic fish (P), which are described in different rows in the respective life cycle stages. In this regard, it is assumed that all demersal and shellfish are individually frozen filets (IQF) while pelagic fish consist of pickled herring in jar and canned mackerel – see table 6.

Table 6: Key environmental exchanges and their size, relative to other stages within the same category. The table represents the situation around year 2000. Symbols are explained just below the figure.

Lifecycle stage	Species	Materials						Energy			Chemicals				Other	
		Expl. Of bio. resources	Discard	By-catch of mammals	Water consump	Consump. Pack/ancill.	Solid lead waste	Heat & combustion	Electricity	Wastewater emission	Biocide emission	HFC, HFC	Cooling ag.	Process & cleaning	Seabed im-pacts	Occupational H&S
Fishery	D	4	3	4	<1	<1	4	4	0	1	4	3	2	4	4	
	S	4	4	<1	<1	<1	4	4	0	1	4	3	2	4	4	
	P	2	2	<1	<1	<1	4	2	0	1	1	3	2	0	4	
Landing	D	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	No data	
	S	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	No data	
	P	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	No data	
Process-ing	D	0	0	0	3	2	<1	1	2	2	0	<1	2	0	4	
	S	0	0	0	4	2-4	<1	2	2	2	0	<1	2	0	4	
	P	0	0	0	3	2-4	<1	1	1	2	0	<1	3-4	0	4	
Whole-sale	D	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	2	
	S	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	2	
	P	0	0	0	<1	<1	<1	1	<1	<1	0	<1	<1	0	2	
Trans-port	D	0	0	0	<1	<1	<1	1	0	<1	0	<1	<1	0	No data	
	S	0	0	0	<1	<1	<1	1	0	<1	0	<1	<1	0	No data	
	P	0	0	0	<1	<1	<1	1	0	<1	0	<1	<1	0	No data	
Retail	D	0	0	0	<1	<1	<1	1	3	<1	0	3	<1	0	No data	
	S	0	0	0	<1	<1	<1	2	3	<1	0	4	<1	0	No data	
	P	0	0	0	<1	<1	<1	1	1-2	<1	0	3	<1	0	No data	
Con-sumer	D	0	0	0	3	<1	<1	2	4	1	0	1	2	0	No data	
	S	0	0	0	3	<1	<1	2	4	1	0	1	2	0	No data	
	P	0	0	0	3	<1	<1	2	4	1-4	0	1	2	0	No data	

Magnitude of exchange: 4) Large, 3) medium, 2) small, 1) very small, <1) insignificant, 0) no
Grey fields: The magnitude of the given exchange is relatively significant (3 or more).
White fields: The magnitude of the given exchange is relatively small (2 or less)

As indicated with grey cells, the fishing stage is the hot-spot for the largest number of immediate exchanges – particular for demersal and shellfish. This is the case for exploitation of fish resources, discard, by-catch, solid lead waste, heat and combustion related energy consumption, biocide emissions

and seabed impacts. For energy consumption and seabed impacts, this conclusion also applies to pelagic fish, but this is discussed later.

However, the processing and use stages also represent large exchanges for packaging/ancillaries, water consumption, wastewater and processing and cleaning agents. Furthermore, this stage is very important with respect to occupational health and safety. In the fishing stage, the largest exchanges apply to demersal and shellfish, but at the processing stage, pelagic fish represents larger exchanges than demersal fish in most cases.

Practically all stages include exchanges of potentially high importance except for the landing and auction stages.

Future developments

It should be stressed that the analysis of future development tendencies suggest major technological changes concerning lead pollution from fishery as well as antifouling and cooling agents, which are described in the category chemicals. As lead and antifouling only are of concern in the fishery, this point will reduce the importance of the fishing stage in a future scenario. Still, we should consider that other biocides will replace TBT and may still be of concern. The substitution of HFC's will mainly reduce the impacts from the retail stage.

On the other hand, I have predicted that the energy consumption and the impacts on the seabed in the fishery will gradually increase - while the energy consumption in other stages is predicted to decrease. Overall, there is nothing in the MECO analysis, which suggests a reduced importance of the fishing stage – relative to other stages. Table 3 in chapter 8 contains an overview of the expected development in key exchanges at the different life cycle stages.

Key potentials for improvements

Some of the most obvious improvement potentials are discussed in the following. Most attention is given to the fishing stage, which must be considered to be the environmental hot-spot according to the MECO analysis.

The fishing stage – changes in species composition

At the fishing stage, there are great differences in the energy consumption between different species - about factor 600 between Norway lobster and

blue mussels. However, this does not necessarily reflect an improvement potential – at least not if we still want to maintain the same total output.

On the face of it, it appears to be a good idea to reduce the fishery species representing a large fuel consumption and increase the fishery for – lets say mackerel. However, the current production pattern mainly reflects the availability of the given species and not the demand or other objectives related to energy efficiency (see chapter 3). Nearly all species are fully exploited, and a decrease in the fishery after one species will not necessarily result in an increase for another species (at least not proportionally). Therefore, recommendations about changes in species composition are very difficult to make – also considering the large uncertainties related to multi-species assessments. Basically, such measures will only be effective if implying changes in the relative quotas between species, while they will have no effect if directed towards the consumers.

An easy solution would be to reduce the quota for energy consuming species e.g. Norway lobster and just live with the consequences – may it be a reduction in the total output! Still, this would require a proportional reduction in fleet capacity to avoid a proportional increase in the illegal fishery. A reduction of fleet capacity is a good solution²² to many problems, but so far, this goal has proved very difficult to obtain.

Fishery – changes in fishing practices

The fishery is also characterized by the use of a suite of fishing methods – also for the same target species. It appears that this represents one of the largest improvement potentials. Based on the data for fuel consumption per kg caught target species (see chapter 4, table 3), it can be calculated that it is theoretically possible to save around 30 million liters (30.000m³) of diesel per year by substituting beam trawl and bottom trawl with Danish seine in the Danish fishery²³. This is roughly 800 truck loads²⁴ of diesel per year or

²² First of all, there are less vessels to catch the same fish and secondly it would most likely reduce the overexploitation and therefore result in more fish.

²³ The average fuel consumption is 0,97 liter per kg caught flatfish corresponding to an absolute fuel consumption of 39,6 million liters for all flatfish in year 2000. Danish seine (applied by vessels with an average size of 34 GT) uses only 0,18 liter fuel per kg caught fish, which would correspond to 7,3 million liters if all flatfish were caught with Danish seine.

²⁴ The load capacity of a Shell delivery truck incl. semi-trailer is roughly 37 m³.

more than 15% of the total fuel consumption for the entire Danish fishing fleet.

It is also assessed that considerable improvement potentials can be obtained within the pelagic fisheries by substituting traditional trawl fishery with modern trawlers working together in so-called pool fishery, or by applying modern purse seine vessels instead. I have not investigated the improvement potential within shellfish fisheries. However, it is reasonable to assume that large improvement potentials exist within Norway lobster fishery, considering a fuel consumption of more than 6 liter per kg caught lobster.

The positive side effects of energy reductions obtained by promotion of passive and semi-active fishing gears would include reduced impacts on the seabed and increased demand for labour in the fishery, as the vessels with passive fishing gear generally employ considerably more fishermen. However, we should also consider potential trade-offs. In this regard, beam trawlers actually have a better environmental performance than Danish seine, considering emissions of antifouling agents. Furthermore, some types of gillnet fisheries still have problems with respect to by-catch of marine mammals and ghost netting.

The fish processing industry

The fish processing industry is probably the most important stage considering water consumption, and it appears that the industries have very different performances. In the pelagic segments, introduction of cleaner production practices have reduced the water consumption significantly during the 1990s. This indicates that there are large improvement potentials, also within other segments of the fish processing industry (demersal and shellfish). Cleaner production may reduce the immediate exchanges such as the consumption of water and energy as well as emissions of wastewater with a factor 2-4 for companies that haven't implemented cleaner production practices yet. There are also improvement potentials related to the consumption of packaging materials, which may reduce the indirect exchanges, e.g. related to the production of aluminium cans for canned mackerel. Both aluminium and glass can be substituted by plastic.

The use stage

At the use stage, there are several improvement potentials. The mode of transport used for shopping is an important factor for the energy consumption, which can be reduced by using bicycle or public transportation for shopping. Another and more radical solution would be to promote delivery

services, which could be combined with internet shopping, so-called home shopping – see Orremo and Wallin (1999).

This problem may also be solved by organizing the shopping around other activities in such a way that it only contributes to increasing the transport distance marginally. Cooling and storing of food also consume large amounts of energy, which may be reduced by selecting a smaller freezer and thus store less food in the freezer. However, if large amount of stored food reflects that the family buys a lot of groceries per shopping trip, there is clearly a trade-off between energy for storing and energy for transport.

The improvement potential for food preparation is mainly related to how the fish are heated. It is possible to save large amounts of energy by using microwave oven instead of traditional oven or even stove. This is especially the case for small amounts of food. The most efficient use of a traditional oven is when large amounts of food are prepared in the oven at the same time. Obviously, it is also possible to save energy by utilizing the oven before the desired temperature is reached, and by switching off the oven somewhat before the food is ready - thus using the after-heat. Other advice includes the use of lid and to use the fridge for defrosting frozen food. The MECO analysis also suggests that dishwashing by machine is most efficient considering the direct consumption of water and energy. However, the washing machine is not necessarily the best environmental choice. In order to make this conclusion, it would be necessary to include considerations of the energy production (dishwashing machines requires electricity while dishwashing by hand is based on heat energy e.g. from district heating).

Also the environmental impacts from production and disposal of the machine should be considered.

Improvement potentials in other stages

It is assessed that the largest improvement potentials exist within the fishery-, processing- and use stages. Other stages, which are important in terms of exchanges, are transport and retail stages. Obviously, improvements can be obtained here as well. For the transport stage, improvements could be obtained by a reduction of transport of whole fish (processing as close to the harbour as possible), while the use of train instead of lorry does not necessarily represent an improvement potential, according to Norwegian studies used in my analysis.

For the retail stage, the most important factor is a reduction of the exposure time of frozen products in the supermarkets. However, it is difficult to see how this can be obtained without a detailed analysis.

Limitations of the MECO analysis

The following section contains information about the main limitations of the MECO analysis in part two.

Scope

At the use stage, data from Denmark have been used, which doesn't match the data quality requirements (see chapter 3). It has been the intention to provide data from central and southern Europe, where most of the products are consumed. However, the MECO analysis only includes immediate exchanges, and it must be assumed that the difference in parameters such as energy consumption between an average refrigerator in Denmark and countries in central and southern Europe is relatively small. In the LCA study in part three site-specific data from central and southern Europe are included for related processes such as energy production.

Environmental exchanges and energy consumption over the cut-off criteria may have been unintentionally disregarded, but considering the wide range of processes that are described, it must be considered inevitable.

Co-product allocation

Handling of co-product allocation has been carefully described in chapter 3. As mentioned, co-product allocation is either avoided - as it is the case for key exchanges at the fishing stage (combination of technical subdivision and system expansion) - or has been based on considerations of the underlying physical relationships. It should be stressed that the MECO analysis does not include avoided exchanges from by-products that occur at the processing stage. This implies that the environmental impacts at the processing stage are overestimated. The avoided exchanges will be included in the LCA case study in part three.

Uncertainty and variance

It has been the intention to use as many references as possible to increase the validity and certainty of the data presented. However, it has also been the goal to cover a wide range of processes. Hence, for some processes there is only one reference. The latter is a weakness and the data should generally be used with utmost care.

Estimates of variance have been carried out in the respective chapters. The variance on the exchanges is estimated to be smaller than -75% and +200% in all cases²⁵. For key exchanges, such as energy consumption and emissions of antifouling agents in the fishery, the variance is estimated to be down to ±25%. Chapter 9 contains a more detailed description of uncertainties for all life cycle stages.

Types of exchanges

The MECO analysis included impacts on the seabed, but not land-use. Nor did it include data for animal welfare, noise, odour, accidents – e.g. traffic accidents and visual aspects. However, all these aspects are separately analyzed in part three - chapter 10.

²⁵ In the cases where exchanges are established as an interval representing data from more companies, the variance applies to the mean value.

LCA of Flatfish (Characterization)

This chapter contains a life cycle assessment of two flatfish products, that is individual quickly frozen (IQF) flatfish filets and frozen breaded filets. The chapter is structured after the ISO standard in LCA presented in chapter 3, but normalization and weighting as well as the interpretation phase is presented in chapter 9 – together with LCA screenings of other types of fish products.

The concept of LCA and the ISO standard for life cycle assessment (ISO 14040) has been described in chapter 3 – before the MECO analysis. Thus, it is important that the reader is familiar with chapter 3 first.

Even though the LCA methodology has been introduced, it is chosen to begin with a presentation of why LCA is applied here and what the potentials of LCA are. Furthermore, special attention is given to the consequential LCA approach, which only has been introduced briefly in chapter 3.

8.1 Why LCA – potentials of LCA

LCA is a tool that can be used to assess where and how different parts of the product chain contributes to various potential environmental impacts e.g. global warming and ozone depletion.

Thus, it is a tool that is tailored to assess the environmental impacts from products and to provide a basis for prioritization in relation to product development, environmental criteria for eco-labeling and other forms of environmental regulation.

Prioritization in two dimensions

The most important advantages of the LCA tool are that it covers the whole life cycle and that the exchanges are “translated” into potential environmental impacts. Hence, the LCA can be used as a basis for prioritization in two dimensions - prioritization between the boundaries of different life stages and for prioritization between different types of environmental impact.

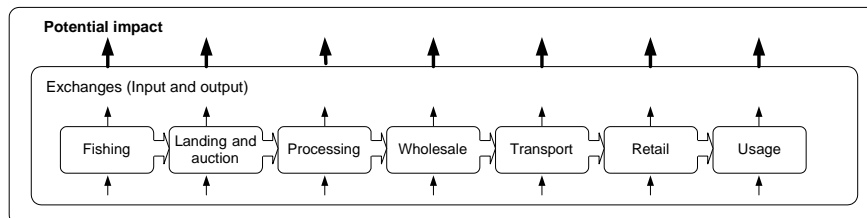


Figure 1: Transformation of exchanges into potential environmental impacts in a life cycle assessment perspective.

In other words, it becomes possible to elucidate where the environmental impacts occur in the lifecycle, which processes and substances that generates them, and how important they are. This knowledge is highly relevant for decisions and prioritization in relation to environmental targets at company level, but also at society level e.g. in relation to environmental regulation.

However, it must be stressed that LCA studies are not objective or strictly scientific. LCA studies are based on many assumptions and shortcomings. It is only a model of the world - not the real world.

In this respect, Weidema (2001a, 2003a) suggests that the most important methodological choices are related to the system delimitation. However, there are other very important aspects as well, such as the choice of impact categories. If impact assessment is included in the LCA, it is also important to be aware of the value-based choices that are inherent in normalization and weighting as well. The methodological choices and the shortcomings of LCA are further discussed in chapter 9.

LCA screening versus detailed LCA

The ISO standard for life cycle assessment is a framework with room for different ambition levels. Normally LCA practitioners distinguish between a conceptual LCA, a screening LCA and a detailed LCA (Jerlang et al. 2001). There is no clear definition of the different types of LCA, but the main characteristics are described below:

- A *conceptual LCA* is typically a qualitative assessment of processes and environmental impacts at different life cycle stages.
- A *screening LCA* includes an inventory of data, typically obtained from databases or literature sources. This type of LCA can be used to identify environmental hot-spots and can be used as a basis for a full LCA. An LCA screening includes impact assessment, but this may only include a relatively limited number of impact categories compared to a full LCA.
- A *detailed or full LCA* includes a relatively detailed inventory including empirical data e.g. down to 1% or less the product weight. A full LCA typically cover a wider range of data types and impact categories than applied in a LCA screening. The LCA also includes a more detailed analysis of uncertainty, sensitivity and consistency.

It is important to realize that the ambition level may vary in other areas as well, and there are many ways to configure an LCA study. Different ambition levels can be chosen concerning a variety of aspects in the different stages, such as the number of life cycle stages, system delimitation and cut-off criteria, data types, data quality, data verification, data description, impact assessment methods, impact categories, sensitivity-, uncertainty-, and consistency-analysis. This is further described in Wenzel (1998).

The LCA in this chapter is considered to be a full LCA. The inventory includes a wide variety of exchanges down to a cut-off criteria of 0,1 % of the product weight (dispatched from the processing stage). Apart from that, a relatively wide range of impact categories is used. In this respect, I have included qualitative assessments of impact categories, which are not considered in the applied LCIA method (the EDIP method). The analysis also includes a whole chapter that critically discusses the results and their uncertainty/validity.

LCA is an iterative process and one should ideally begin with a low ambition level, and gradually increase the ambition level. In this regard, the present LCA is conducted with a basis in several LCA screenings of other types of fish products (pickled herring, frozen mussels and canned mackerel). This has initially helped to focus the study, but obviously it has also been an iterative process to conduct the LCA. In this regard, intermediate results have continuously helped to shape the LCA and to guide the data collection. This iterative process is not directly reflected in the study, but is part of the learning processes behind it.

As mentioned in chapter 4, the results from previous LCA screenings were the main reasons why the MECO analysis focused on the fishing stage and the consumption of energy and emission of antifouling agents.

Consequential LCA

In recent years, the LCA community has increasingly begun to distinguish between attributional LCA (traditional or static LCA) and consequential LCA. The most important difference between these two types of approaches is related to the system delimitation.

In an attributional LCA, the system delimitation is typically defined as consisting of the historical or present supply chain. The geographical and technological scope is defined in advance and may delimit the LCA to include processes from a certain region representing a certain level of technology. However, this does not reflect what is happening according to advocates of consequential LCA (Weidema, 2001a, 2003a).

Instead of focusing on certain processes in a certain region, the consequential LCA asks the question: Which processes and product systems are affected by a change in demand as a result of a potential product substitution - at any point of the product chain. In this regard, the affected suppliers may not be the suppliers in the present supply chain. In fact, that is often the case if quota or other market-constraints restricts the existing suppliers from expanding the production volume. As an example, a marginal change in demand for fish is not likely to change the fishery since it is regulated by quota¹. Therefore, competing food products such as chicken, minced pork

¹ Another example is electricity, where a change in demand will not affect the windmills because their production are restricted by the installed capacity. In other

meat or farmed fish² will be the ones affected. In other words, the consequential LCA method implies that the geographical and technological scope cannot be established in advance. Instead, it should be separately defined for each product and process. In the following, I have tried to explain some of the key elements for system delimitation in consequential LCA, but for methodological details, it will be necessary for the reader to consult Weidema (2001a, 2003a).

Scope considerations in consequential LCA.

Considerations of temporal, geographical and technological scope are also necessary in a consequential LCA, but this is done more indirectly in the search of the affected suppliers.

First, the market-based system delimitation (used in a consequential LCA) implies an estimation of whether the change in demand affects a specific process or a specific market. If there are specific ties to certain suppliers, it only remains to establish where the given suppliers are situated and which level of technology they represent.

If there are no ties to specific suppliers (this is often the case for energy and different types of ancillaries), it must be established whether the market is local, regional or even global, such as for soy protein. This is related to the geographical scope. However, we also have to consider which type of suppliers we affect. In this respect, the method of Weidema (2003a) suggests that in general, we will affect the most competitive producers (presumably high level of technology) in expanding markets (because we affect the new capacity being installed). It is assumed that the opposite happens if the market is in regress (because we then affect the capacity that is being taken out of the market)³ – when considering a small scale of change over a long time perspective.

words, their production does not depend on demand – considering marginal changes.

² According to LCAfood (2003) it is difficult to assess which product is affected, and instead several food products are mentioned as possible substitutions.

³ An example is chlorine, bought on a European market with two types of suppliers. One type of supplier uses outdated technology based on mercury while the other suppliers using diaphragm processes without mercury. The question is who is affected by a change in demand, assuming that there are no specific ties to a specific supplier? In this case, the procedure of Weidema will suggest that it is the outdated technology that is affected - because the European market trend is decreasing for chlorine. Hence, a change in demand will tend to affect the least competitive sup-

Regarding the time perspective, the procedure suggests that changes with a short time horizon will affect the least competitive suppliers as they have spare capacity to adjust quickly in the short term. At a longer time perspective, the market trend that is important, but in this regard it should ideally also be considered that the market trend may change over time, and that the technological development may change. For large scale changes⁴, it should also be noticed that the change in itself may change the market trend. In this respect, it also becomes necessary to consider the direction of change.

As it appears, there are several aspects that should be considered individually, but the different aspects should also be considered as a group because they influence each other. For further details about scope considerations – see Weidema (2001a, 2003a).

Handling of exchanges from co-production

The procedure in market-based system delimitation also affects the way co-production allocation is handled, or - more precisely - avoided. This is done by system expansion - which can always be applied according to Weidema (2001b). Again, we must pose the question: Which activities are affected by a change in supply of one or several dependent products, resulting from a change in output of the determining product⁵?

When the affected activities are identified - which can be done in a three-step procedure - it remains to subtract the avoided⁶ environmental exchange from the determining product, or the opposite if the dependent product is of interest (Weidema, 2001b).

Considering the dependent output of a given co-producing process, it is assumed that an increase in output will result in a proportional decrease in production of the competing product somewhere else in the economy - over

plier, which is assumed to be the suppliers using the outdated mercury-based technology.

⁴ Theoretically, a large scale could be the consequence of many small scale changes occurring simultaneously or over a longer time period.

⁵ The terms dependent and determining products are described in chapter 3 and are mentioned in the list of abbreviations as well.

⁶ The avoided environmental impact is the impact that will not occur as a result of the assumed product substitution.

time⁷. In rare situations, there may not exist any competing products – but this is not further discussed here.

As illustrated in the introduction to chapter 3 there are four phases of an LCA: Goal and scope definition, Inventory, Life Cycle Impact Assessment and Interpretation. As explained, this chapter includes a LCA of two flatfish products and the following section presents the first phase “Goal and scope definition” according to table 1 in chapter 3.

8.2 Goal and scope

The goal and scope for the MECO analysis and the LCA are relatively similar. Thus, the focus of this chapter will be areas with differences between the MECO and the LCA analysis.

Purpose of study

The purpose of the quantitative LCA is to provide quantitative knowledge about the contribution of potential environmental impacts from fish products.

The intended application of the LCA is mainly to provide a basis for possible measures by Danish authorities - which can effectively promote fish products that represent smaller environmental impacts in a life cycle perspective (red. cleaner fish products). The focus is hot-spots and improvement potentials with respect to production processes - rather than environmental consequences of product substitution e.g. fish versus other meat products or one type of fish species versus another fish species. As described in chapter 2, the production in the fishery sector is limited by quota on the resource, and I have assessed that the potential to reduce the overall environmental impact potential by the type of product substitutions mentioned above will remain limited. The reason is that “nearly” all fish species are fully exploited and probably will remain so – considering the large and probably still increasing demand. Thus, the sector is not able to respond to an increase in demand. A

⁷ Similarly, a decrease in output of the dependent product is supposed to result in a proportional increase in production somewhere else in the economy.

decrease in demand may reduce the prices on certain fish species, but it is my assumption that fishery is controlled by quota reflecting the resource situation, and that prices is a secondary factor in this game.

Therefore, I have not found it relevant to provide a detailed description of the functional units, with respect to qualitative aspects, market niches, product alternatives etc. Instead, the functional units have simply been selected to represent typical Danish fish products - in this regard demersal fish, which are the most important in the Danish fishery - in terms of value (see chapter 2) and environmental impacts according to the MECO analysis (chapter 4-7). Finally, it should be stressed that no previous LCA studies (or screenings) of flatfish have been performed before. The functional units for the detailed LCA are:

- One kg of consumed flatfish⁸ based on frozen plain filet in consumer packaging of 300 gram.
- One kg of consumed breaded flatfish filet based on frozen breaded filet in consumer packaging of 300 gram. This product has a fish content of 60% while the breading makes up the remaining 40% of the net weight.

The reason that I have chosen to include bread flatfish is that a large part of the flatfish production in Denmark data includes breaded flatfish. Furthermore, data were available from the same case company.

Obviously, these functional units only represent one species group and a small part of all fish products. Still, it should be stressed that the generalization in chapter 9 includes a discussion of what they represent - compared to other products - as well as LCA screenings of other product types described in the MECO analysis (IQF shrimp, IQF prawn, IQF blue mussels, IQF Norway lobster, pickled herring in glass jar and canned mackerel).

The LCA study of flatfish includes scenarios reflecting different production methods, packaging forms as well as various future scenarios. The main target audience is Danish authorities and fish processing companies. However, the target audience encompasses a wide range of other actors, described in more details in chapter 3.

⁸ In the Danish fishery, this mainly includes European Plaice (more than half measured in weight) but also flounder, dab, smear dab, sole, turbot, brill and halibut.

Scope

The Danish fishery sector is relatively small, and it is not realistic to expect a revolution in the technology used over the next 10-20 years. The technology used in fishery, processing and distribution has changed incrementally over the last 50-100 years and the development tendencies suggest further incremental changes for most exchanges, except exchanges in fishing gear, anti-fouling agents and cooling agents, which all will change very fast in the next decade.

Hence, the study considers a relatively small scale of changes where it is the intention to reflect the environmental consequences of marginal changes such as reductions of energy consumption with 10-15% within the sector.

Time scope

Considering the time perspective, two scenarios are developed – the first represents the situation as it is (year 2000), while the second represents a future situation around year 2010-15.

Geographical and technological scope

As for the MECO analysis, the main supply chain include average Danish producers from cradle (sea) to gate (transport) and foreign firms at the retail and use stages. Thus, the choice of the consequential approach does not affect the way the main supply chain is treated, as the main supply chain is considered fixed. However, the approach influences the way co-product allocation is handled as well as system delimitation for suppliers and processes that are not a part of the main product chain (related processes and products e.g. consumption of heat and electricity). There are several challenges in using the consequential approach, such as:

- To estimate the activities/product systems that is affected by a change, both in relation to system delimitation but also co-product allocation.
- To predict the market trend on different markets.
- To use the consequential approach consistently.

As mentioned, Weidema (2003a) suggests several data, procedures and default assumptions, which may help in relation to the first two items. Concerning the latter, most of the databases, which are currently available uses different methods for system delimitation and co-product allocation. Therefore they should be used with care. However, data generated without the consequential approach can be used in cases where the influence on the result is of minor importance.

It should be added that capital goods have not been included in the analysis, except for data for energy, obtained from the ETH database.

Affected suppliers for related processes

Electricity. It can be debated whether the marginal electricity source in the Nordic grid is gas or coal based power plants. I have used gas as the marginal source of electricity in Denmark (Nordic grid), as suggested by Weidema (2003a) for the years to come. However coal has been used in the sensitivity analysis. For processes that take place in central and southern Europe, coal is used as the marginal technology. This is also expected to be the situation in the next decade and therefore used in the future scenarios - see also www.lcafood.dk.

Heat. Different fuels are used to produce heat applied in the Danish fish processing industry. Therefore, a national mix of energy carriers specific for the fishery sector has been applied. For the fish processing industry, it is assessed that around 70% of the heat energy derives from natural gas, while 13% and 16% derives from coal and oil respectively. Only 2% comes from district heating⁹. The data have been established through (Danish NAMEA, 1999) Further description of the data are available at www.lcafood.dk. These data have also been used for the future scenario as a default.

Soy-protein. According to Weidema (2003a), soy protein is sold on a global market. Weidema argues that soy protein is the marginal protein source for fodder purposes. Protein by-products (dependent products) from industry are constrained by the demand for the main products (determining products). The affected supplier/technology is therefore probably soy-beans from Argentina. For further details, see Weidema (2003a) or www.lcafood.dk

Rapeseed oil. Soy oil is constrained by demand for the dependent product soy protein, and according to Weidema (2003a), rape-seed oil from Europe

⁹ It is assumed that 75% comes from co-production of heat and electricity, but the Marginal environmental exchanges are considered small because: 1) the marginal heat produced at combined heat and power plants is usually in excess, and 2) that other factors than availability of excess heat from electricity production determines the size of the district heat network in the years to come. For the remaining 25% it is assumed that the heat is produced at district heat plants based on biomass – e.g. wood chips (LCAfood, 2003)

(e.g. Germany) or Canada is the marginal suppliers. Data from the LCA food database reflects European producers - see www.lcafood.dk

Grain. The production of cash crops is determined by market demand, and different kinds of farms react differently to changes in the market. Environmental impacts associated with marginal wheat, spring barley, winter barley, rapeseed, potatoes and sugar beet production have been determined as a weighted average of impacts associated with each crop at each farm, see www.lcafood.dk.

Sugar. Sugar is only used for the LCA screening for pickled herring. The marginal demand for sugar in Denmark will supposedly not influence processes in Danish sugar beet production and Danish sugar industry. As data for the marginal suppliers has not yet been established, data are still obtained from Danish sugar production, based on an envisioned scenario, see www.lcafood.dk.

Aluminium. Aluminium is only used for screening of canned mackerel. According to Widema (2003a), aluminium is sold on a global market. The production is unusual in being so much electricity demanding that the localization of the production plant is chiefly determined by the availability of cheap sources of electricity. The overweight of hydropower, prevailing in the average attributional LCA data for aluminium production will also be the result of a market-based LCA data for aluminium. Therefore, it has been considered reasonable to use average data from the ETH database.

It should be pointed out that future scenarios are generally based on the same affected suppliers and databases as the present time situation. This is obviously a source of uncertainty as some processes - e.g. transport - develops relatively fast. However, this source of uncertainty applies to all the life cycle stages. Furthermore, the study includes qualitative discussions of impacts that are likely to change significantly because of technological changes.

Co-product allocation for immediate exchanges

At the fishing stage, I have used technical subdivision combined with system expansion to avoid allocation for energy consumption and antifouling agents¹⁰.

¹⁰ For other exchanges, allocation is performed according to mass. However, the exchanges are insignificant and the influence on the final result is only marginal.

In the LCA, I have also applied system expansion to account for the avoided exchanges related to the by-products (dependent products) at the processing stage. The avoided products include soy protein and meat products from agriculture. Data for these products are obtained from the LCAfood database (LCAfood, 2003), while conversion factors are described in app. 12.

At the use stage, economical allocation is used for shopping while system expansion is applied for cooking where several ingredients are prepared together. In other cases, allocation is made on basis of underlying technical causal relationship. An example is transport, where mass is used as the allocation parameter because the maximum load capacity is limited by the mass of fish products.

Co-product allocation for related processes exchanges

Co-production is also an issue for a number of related processes such as production of NaOH and chlorine, soy-protein, rapeseed oil and waste/wastewater treatment.

Concerning packaging materials and chemicals in general, allocation is performed by mass in the ETH and Buwal database – see ETH-ESU (1996) and Buwal (2001). Thus, large uncertainties exist, but as the contribution to the environmental impact potential are insignificant, the data have been used without further modification. Data for waste treatment are also used directly from the ETH database¹¹, but here allocation is based a physical/chemical causal relationships.

For soy-protein, rapeseed, and other food products that are affected, co-product allocation is avoided by system expansion. Specifically for wastewater treatment, co-product allocation is based on physical causal relationships. As the emissions from Danish wastewater treatment facilities are regulated through emissions standards, marginal changes in concentrations do not influence the emissions. The only parameter affected in this respect is therefore the energy consumption¹². However, it is argued that the water volumes probably do affect the emissions to the sea, and water volume is therefore also considered. A discussion of the preconditions for these assumptions is available in chapter 9.3 (uncertainty related to system delimitation).

¹¹ One of the most obvious weaknesses of the waste treatment processes in the ETH database is that avoided energy production is not included. This is further discussed in the sensitivity analysis in chapter 9.

¹² This assumption is further discussed and analyzed in the sensitivity analysis.

Process description

The scenarios are based on data from the MECO analysis of flatfish, supplemented with detailed company specific data at the processing stage. The main product chain - as well as avoided products included in the system expansion - are illustrated in figure 2.

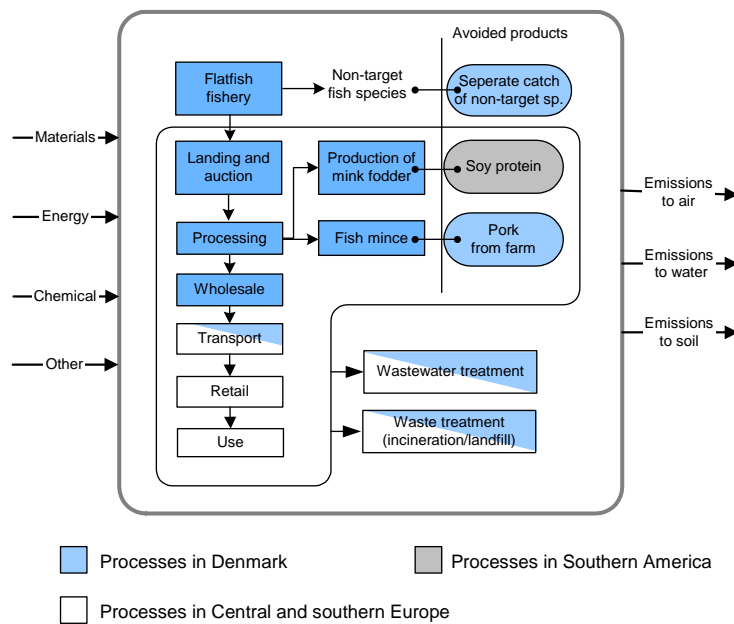


Figure 2: The main product chain and avoided products included in the system expansion for frozen flatfish filets

As illustrated, retail and use stage take place in Central and Southern Europe, as most of the products are exported to markets in these regions. The data for related processes, such as energy production, reflect this scope, but it has not been possible to establish country specific data for immediate exchanges related to storing, food preparation, and dishwashing. Furthermore, I have used Danish data for waste- and wastewater treatment for all processes. Obviously, the transport stage also mainly takes place outside Denmark, but as transport is performed by Danish companies and reflects Danish technology and fuel (at least to some extent), the geographical scope is considered to be Denmark.

Some of the avoided products are produced in South America. Many other processes take place abroad, such as production of chlorine, metal, aluminium and plastics, but these are not shown in figure 2.

Method for impact assessment

I have chosen to use the Danish method for life cycle impact assessment called the EDIP¹³ method. The method is mainly developed to be used for electro-mechanic products and obviously have some limitations concerning impact categories. However, most of the processes take place in Denmark, and it is therefore essential that the method reflect relevant impact categories for Denmark and Danish background levels for the normalization step and Danish reduction targets for the weighting step.

Characterization in the EDIP method

Environmental input and output have been estimated by summarizing input and output (Q_i) from all production processes (p) associated with the given fish product (see Wenzel et al. 1997).

$$Q_i = \sum Q_{i,p}$$

Environmental impact potentials ($EP_{(j)i}$) associated with specific substances (i) emitted in the the fish product's product chains have been determined by multiplying total emissions of substances (Q_i) with specific equivalency factors ($EF_{(j)i}$) for specific categories of impacts (j).

$$EP_{(j)i} = Q_i \times EF_{(j)i}$$

In the present dissertation, all equivalency factors represent an updated version of the method known as EDIP-96 described in Wenzel et al. (1996). The updated version used in this project was last edited 4. august 2003 by Anne Merete Nielsen from 2.-0 LCA consultants as part of the lcafood project¹⁴ (LCAfood, 2003). The adjustments are described in the Simapro PC tool available in app. 13 (document C) and are partly based on data from the LCAfood project and data from Stranddorf et al (2001).

¹³ Environmental Development of Industrial Products.

¹⁴ I have added a characterization factor for cleaning agents and performed small changes of some normalization references, but this is further described in the Simapro data files in the appendix. 13.

Environmental impact potentials $EP(j)$ associated with the fish products have been determined by summarizing contributions to environmental impacts from all emitted substances in the product's product chain.

$$EP_{(j)} = \sum EP_{(j)i} = \sum (Q_i \times EF_{(j)i}).$$

Considering each of the impact categories separately, the impact potential is basically the sum of exchanges multiplied by the impact factor ($EF(j)i$) of each exchange. In this regard, it is important to notice that we only consider impact potentials. Whether the potentials materializes, will depend on a long series of other factors such as precise fate, exposure, background concentrations, recipient robustness etc.

Impact categories

It is important to consider the goal of study and not least the functional unit when the impact categories are selected. However, I have chosen to select from the list of default impact categories included in the PC version of the EDIP method. This is mainly because these impact categories are most operationalized, but I recognize that this is a serious limitation of the study. Therefore, I have conducted a separate analysis of a range of other impact categories, relevant for fish products. This is done in chapter 10. The LCA in chapter 8 and 9 include the following impact categories (j):

- Global warming potential (100 years) – measured in gram CO₂ equivalents
- Stratospheric ozone depletion potential – measured in gram CFC₁₁ equivalents
- Acidification potential – measured in gram SO₂ equivalents
- Nutrient enrichment potential – measured in gram NO₃⁻ equivalents
- Photochemical ozone formation potential (smog) – measured in C₂H₄ equivalents
- Eco-toxicity potential – measured in m³ water/soil

The PC version of the EDIP method includes three additional impact categories that I have disregarded in the quantitative LCA in chapter 8 and 9. This includes:

- Human toxicity
- Waste generation – bulk, hazardous, slag and ashes and nuclear – measured in volume.

- Depletion of non-renewable resources - fossil fuels and metals, also measured in kg

Human toxicity has been disregarded due to unreliable results¹⁵. Waste has not been included because of inconsistencies with the databases used and finally depletion of non-renewable resources¹⁶ has been disregarded due to the lack of methodological consensus among researchers in the international LCA community (Udo de haes et al. 2002). All categories, which have been disregarded in the quantitative LCA in chapter 8-9, are discussed separately in the qualitative LCA in chapter 10.

The EDIP impact categories, which have been included and disregarded, are illustrated and grouped in table 1.

Table 1. EDIP impact categories included in the LCA in chapter 8-9 and categories intentionally left out and treated separately in chapter 10 see (*).

Spatial impact	Environment	Resources
Global	Global warming (GWP) Ozone depletion (ODP)	(*)Fossil fuels (*)Metals
Regional	Photochemical ozone formation Acidification Nutrient enrichment Eco-toxicity (persistent) Human toxicity (persistent)	
Local	Eco-toxicity (non-persistent) (*)Human toxicity (non-persistent) (*)Waste - Bulk waste - Slag and ashes - Hazardous waste - Nuclear waste	

Global effects are effects that affect the entire planet, while regional impacts happens on a scale from 100-1000 km roughly. Local impacts are limited to

¹⁵ The EDIP method generally suggests that benzene and lead emissions into air is the main cause of human toxicity. However, such emissions have been greatly reduced since the creation of the database. Furthermore, the data for the fishing stage does not include emissions of this level of detail. Finally, the human health effects from particle pollution has not been sufficiently implemented in the EDIP method.

¹⁶ For resources, the results are also difficult to interpret and compare to the other impact categories, due to differences in weighting methods.

the immediate vicinity of the source or influence and the geographical extent is therefore typically measured in one or a few kilometers. (Wenzel et al. 1997).

Eco-toxicity and human toxicity include three sub-categories each. For eco-toxicity, two of the sub-categories are categorized as persistent eco-toxicity (chronic water and chronic soil), while the last is non-persistent with a local scale of impact (acute water).

8.3 Inventory

As previously mentioned, the data collection for the LCA is mainly based on data from the MECO analysis, supplemented with data for flatfish processing. In this regard, data have been gathered from one large flatfish processing company – concerning ordinary flatfish filet as well as breaded flatfish filet.

Calculations of the exchanges, which have been entered in the Simapro program, are available in app. 9-11, and data for related processes and products are available in app. 12 together with data for energy conversions generally applied in the LCA. Simapro datafiles and all immediate exchanges in the LCA (excel file), including exchanges that have been disregarded due to the cut-off criteria¹⁷ are available in app. 13 (document A) This list includes main references and data quality indicators.

Data for related processes (indirect exchanges)

Obviously, data is required for a large number of other products and processes than those involved in the main product chain. In this respect, I have chosen to use the following databases:

¹⁷ As mentioned in the MECO analysis, I have included immediate (direct) exchanges down to 0,1% of 1 kg product dispatched from the processing stage. For energy flows, I have included flows down to 0,1 MJ of 1 kg product dispatched from the processing stage.

- ETH-ESU 96 available in Simapro 5.1 is used for materials, energy processes, chemicals transport (except in the fishery) as well as solid waste treatment (incineration).
- LCAfood database available in Simapro 5.1 is used for ice production, water consumption and food products such as grain, sugar, rapeseed oil, various products potentially substituted by fish mince and waste (pork¹⁸ meat and soy protein) as well as certain processes such as wastewater treatment and combustion of diesel on fishing vessels (see www.lcafood.dk)
- Apart from data in existing databases in Simapro, I have used data from various literature sources and data obtained empirically. This includes data for production of mink fodder, production and washing of fish boxes and data for the substituted amount of soy protein per kg fish offal. This is further described in app. 12.

The Simapro datafiles are available in app. 13 (document C).

For consistency reasons I have chosen to use data from the ETH database as much as possible, even though other databases such as Buwal in a few cases include data that matched better. Furthermore, this database has been used in the LCAfood project. The data quality related to the databases is further described in the following.

The ETH database

The descriptions of the ETH database in the following are based on the ETH database manual, available in the Simapro 5.1 LCA PC tool. See also ETH-ESU-96 (1996).

Temporal correlation. The ETH database is relatively old (roughly 10 years). However, I have discussed the consequences in the evaluation as part of the overall interpretation in chapter 9. In a future update, it will be relevant to use data from the EDIP database and the Ecoinvent database as well, but this has not been available during the present dissertation.

Geographical and technological correlation. The data cover the Swiss and Western European situation. This area includes Denmark and is assessed to represent Denmark in most cases. However, a specifically Danish database

¹⁸ It is assumed that the fish mince substitutes minced pork meat. The arguments for this assumption are described in app. 10.

would have been preferred in most cases – except for the retail and use stages.

Reliability. The ETH database is known as one of the most detailed databases – partly based on empirical studies.

Completeness. The advantage of the ETH-ESU database is that it is the most complete among the databases included in the Simapro PC tool. The ETH database includes capital goods (infrastructure, roads etc). and land use for all energy processes. As energy consumption is involved at all stages, it is assessed that this will not jeopardize the consistency of the study.

Other aspects. In general, the environmental impacts from multiple output processes has been allocated using arbitrary parameters such as mass, energy or concentration. Obviously, this is not the preferred method for allocation in a consequential LCA, but other databases have not proven to be better at this point. Fortunately, the ETH database is so detailed that it has been possible to avoid co-product allocation by technical subdivision which is the case for energy production where electricity based on gas and coal fired power plants with no co-production of heat are involved.

For certain chemicals such as NaOH and Chlorine, this may have lead to an over- or underestimation, but as these chemicals have an insignificant contribution to the impact potential, this has been considered to be insignificant.

The LCAfood database

Temporal correlation. The LCAfood database is completely new and errors may occur as it is used in a draft version. For further details - see www.lcafood.dk

Geographical and technological correlation. The data mainly cover Danish processes and products, but it includes data for products in other countries in cases where the marginal suppliers are not likely to be Danish. For instance, this is the case for soy protein and rapeseed oil. The database was created with the intention to generate data for consequential LCAs similar to the present study. The geographical and technological correlation is assessed to be satisfying. For further details - see www.lcafood.dk.

Reliability. As mentioned, the LCAfood database is used in a draft version and it may include minor errors. Processes in the food sector are derived from a variety of sources. Data on production in agriculture have been de-

terminated by a "top-down" approach where statistical data on a national level have been broken down to represent specific processes. Data on other processes have been determined by a "bottom-up" approach, where data from a limited number of sources have been used to represent the national level.

Data on other processes are collected from a broad spectrum of sources (interviews, factory records, branch analysis, green accounts etc). and details can be found in each process data sheet. For further details see www.lcafood.dk.

Completeness. The completeness is generally good, but obviously, the data for agriculture products are best, as they are generated on basis of a top-down approach representing all activities in the sector – similar to the fishery data in the present dissertation.

Data include main input (resources, raw materials, water and energy) and main output (products and waste as well as emissions into air and water). Capital goods as well as packaging materials, cleaning agents, pesticides, and medicine are not included (www.lcafood.dk).

Other aspects. Many processes in the food sector produce more than one product, and environmental emissions associated with specific products have been determined by system expansion, which is consistent with the methodology applied in the present dissertation. Data for related processes are also obtained by the ETH database and match the methodological approach in this report as well.

Other data

Other data include data for production of mink fodder, production and washing of fish boxes - and data for the substituted amount of soy protein per kg fish offal are further described in app. 12.

8.4 Impact assessment (Characterization)

This chapter includes the first step of the impact assessment - termed characterization - which is considered the most objective step of an impact assessment. The next steps: Normalization and weighting - sometimes described under the heading valuation - are more value based, especially the weighting, and are treated separately in chapter 9.

Characterization results for ordinary flatfish filet

In the LCA case study of flatfish, the functional unit is one kg consumed frozen flatfish filet (IQF) in consumer packaging made of cardboard in boxes of 300 gram each. The results presented here only include characterization (the first step of impact assessment). As mentioned, I have used the LCA-food EDIP version for characterization. Chapter 9 includes an uncertainty and sensitivity analysis, but the results presented in this chapter are continuously verified by comparing with results obtained by alternative LCIA methods, the Dutch Eco-indicator 99¹⁹ and the CML 2 baseline 2000 method²⁰. Furthermore, I have discussed some methodological aspects during presentation of results – especially considering site-specific aspects.

The characterization results for one kg consumed flatfish filet based on consumer packages of 300 gram filet in cardboard boxes is shown in figure 1.

¹⁹ The Ecoindicator 99 is a damage oriented LCIA method. The method operates with three damage categories, representing damage to human health (unit: DALY= Disability Adjusted Life Years; this means that different disabilities caused by diseases are weighted), ecosystem quality (unit: PDF*m²yr; PDF= Potentially Disappeared Fraction of plant species) and resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade). I have applied the default method which is the Hierarchist version, representing a medium time perspective, and consensus among scientists have determined whether various effects are included. For further details, see Goedkoop and Spriensma (2000).

²⁰CML 2 baseline 2000 uses a problem-oriented (midpoint) approach similar to the EDIP method. For further details, see Guinée et al. (2001).

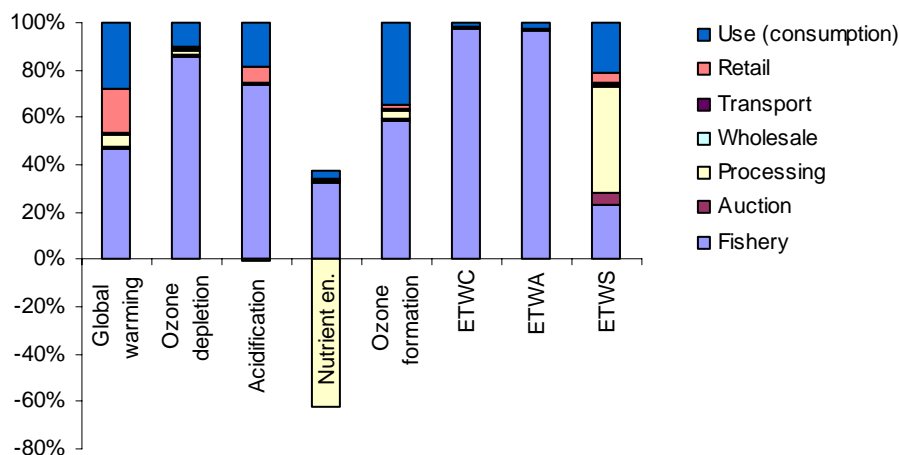


Figure 3: Characterization results from LCA of one kg consumed flatfish filets (IQF). Based on the LCAfood EDIP version.

The indicator results are presented in table 2 as well:

Table 2. Indicator results reflecting the results in figure 3.

Global warming	Ozone depletion	Acidification	Nutrient en.	Ozone formation	ETWC	ETWA	ETSC
g CO ₂ eqv.	g CFC ₁₁ eqv.	g SO ₂ eqv.	g NO ₃ eqv.	g ethene eqv.	m ³	m ³	m ³
2.09E+04	0,0127	156	-147	24	1.70E+05	1.72E+04	36

Each of the impact categories is separately discussed in the following. Readers with access to Simapro 5.1 can download the Simapro datafiles in app. 13 (document C) and verify the results - including results obtained with other LCIA methods.

GWP 100 – gram CO₂ equivalents (100 year time horizon)

The global warming potential is mainly related to the fishery (47%), use (28%) and retail (18%). For the fishery, the contribution mainly comes from the combustion of diesel. Nothing suggests that the fuel consumption in the fishery will be reduced in the future. In fact, Denmark has experienced an increase in fuel consumption per kg caught edible fish over the last 20-30

years. In the retail stage, the contribution mainly comes from electricity consumption (coal) but the emission of cooling agent (HFCs)²¹ also plays a role.

Verification. The Dutch method ECOindicator 99 (H/A), as well as CML 2 baseline method shows similar results with respect to global warming (47% related to fishery), and it is estimated that these results have a relatively minor uncertainty.

Stratospheric ozone depletion potential – gram CFC₁₁ equivalents

The potential contribution to ozone depletion (ODP) is also mainly linked to the fishery (86%), partly due to the production of diesel (58%) and partly due to emissions of cooling agents HCFC-22 (28%) from the vessel' cooling systems. The contribution from the production of diesel is caused by the emission of Halon 1301, which was used in cooling processes at the oil refineries in the beginning of the 1990s. Halon is probably not used anymore in developed countries, but more recent data have not been available (ETH-ESU, 1996; Goedkoop, 2003). An omission of halon altogether does not change the conclusions, but this is further discussed in the evaluation in chapter 9.

Verification. The EcoIndicator 99 and the CML 2 baseline show very similar results.

Acidification potential – gram SO₂ equivalents

For the acidification potential, we have more or less the same situation – the largest contribution comes from the fishery (74%) - mainly NO_x, followed by use (18%) and retail (7%) - mainly SO_x in both cases. The processing stage

²¹ The GWP values in figure 3 represents the global warming potential in a 100 year time horizon. This means that the method assess the different gasses GWP value relative to that of CO₂ over a time horizon of 100 years. For some gasses, such as nitrous oxide, the relative strength increases if a time horizon of 500 years is used instead. For other gasses, e.g. methane, the strength increases if a time horizon of 20 years is chosen. Thus, we are dealing with a non-linearity, but in LCA it is common practice to use a time horizon of 100 years. In this study CO₂ represents more than 90% of the contribution in all life cycle stages - except for retail. At the retail stage, HFCs make up around 35% of the contribution to GWP. According to Wenzel et al. (1997), the average difference in GWP value for HFCs is greater with a factor 2,5-3,0 in a 20 year time horizon, compared to a 100 year time horizon. Thus, in a 20 year time horizon, HFCs would become the dominant emission at the retail stage – considering global warming.

contributes with a small avoided impact potential due to the substitution of soy protein from by-products.

Verification. When the EcoIndicator (99) method is applied, the fishery dominates even more (about 85%), while the opposite is the case according to the CML 2 baseline, where the fishery only contributes with around 35%. The largest contribution, according to EDIP and EcoIndicator, is NO_x , but in the CML method, NO_x is only included as NO_2 for this impact category. Thus, the CML method suggests that the use and retail stage is relatively more important at the expense of the fishery. As the results proposed by the EDIP method is somewhat in-between, the results suggested by the two other methods, the discrepancies, have not been investigated further.

Site-specific considerations. According to Wenzel et al. (1997), contributions to acidification in robust areas such as the sea are less significant²². As most of the Danish fishery takes place in the North Sea, it must be assumed that the actual acidification potential related to the fishery is significantly smaller than suggested above. Hence, the use stage might be the most important when site-specific aspects are considered - but this is not further analyzed.

Nutrient enrichment potential – gram NO_3^- equivalents

For nutrient enrichment, it is also the fishery that is most dominant (33%) – mainly due to NO_x emissions to air. NO_x is also the dominant emission for the other life cycle stages including the use stage. In the processing stage, the emissions of wastewater are treated in a biological wastewater treatment facility, and the impact potential is therefore insignificant. The avoided product (in this case mainly soy protein) causes a negative impact potential at the processing stage (-60%). This is mainly due to avoided water borne emissions of N and P from agriculture in South America.

Verification. When the EcoIndicator 99 method is applied, the contribution from fishery becomes even more significant, but in this method N and P are not included in the characterization factors, and it is therefore difficult to compare. When the CML baseline method is applied, the contribution from

²² According to Wenzel et al. (1997) emissions of SO_2 from ocean going ships will be absorbed in the Sea where it does little harm. It can be debated whether fishing vessels can be compared with ocean going ships, and it is possible that coastal vessels or vessels operating in the inner Danish waters may contribute significantly to acidification.

fishery is reduced with a factor 17 compared with results obtained with EDIP. Thus, the use stage becomes the most important in this case. However, the CML method uses PO_4 as the reference substance (suited for Dutch conditions), and I have therefore considered that the results obtained with EDIP are more reliable and suited for Danish conditions²³.

Site-specific considerations (the positive impact potential). Nutrient enrichment is partly a problem related to the aquatic environment (especially lakes, rivers and coastal areas), where it may lead to oxygen depletion through an increase in algae production (aquatic eutrophication). However, it is also a problem on land, where it may change certain types of ecosystems (that we want to preserve), and may lead to increased vulnerability and sensitivity to different stress factors (terrestrial eutrophication). Finally, it is also becoming a problem in relation to pollution of ground water resources²⁴. In all cases, the tolerance limits are exceeded in many areas in Denmark. (DMU, 2001)

The EDIP method does not distinguish between these different types of effects. Thus, it only provides a crude estimate on the overall contribution to different environmental problems in different recipients. Apart from this, site-specific considerations are still absent. If we focus on aquatic eutrophication, this mainly occurs in lakes, rivers and coastal areas, where the contribution from water emissions from agriculture generally plays the most important role. Obviously, there will be a significant difference in impact potential if we compare a certain emission (measured in NO_3 equivalents) from a 10 meter tall smoke stack from a fishing vessel in the North sea - with a similar wastewater emission directly into the coastal zone e.g. from agriculture. However, the EDIP-97 method does not treat air emissions any different than water emissions. Furthermore, the EDIP-97 method does not consider where the emissions occur or to which extent the nutrients are bio-available etc. (DMU, 2001; Wenzel et al. 1997). Thus, it must be assumed

²³ In Denmark, eutrophication is often a problem in the sea, especially in coastal waters where nitrogen is the limiting parameter for algae growth – not phosphorus (DMU, 2001). In recent years, increased attention has been given to phosphorus – especially considering the eutrophication potential in lakes. Still, it should be emphasized that the EDIP method reflect a worst case situation where nitrogen and phosphorus both are the limiting parameters for algae growth - in the sea as well as inland waters. (Hauschild, 1996)

²⁴ This is obviously not a problem related to oxygen depletion but instead human toxicity.

that the contribution to nutrient enrichment is smaller than suggested in figure 3 because the emissions from fishing vessels often appear in the open sea with a long distance to sensitive recipients – both considering terrestrial and aquatic eutrophication. Furthermore, it must be assumed that the contribution to aquatic eutrophication is even smaller because air emissions tend to spread over larger areas.

The EDIP method is being developed to include some site-specific factors in a version termed EDIP-2003, but this method has not been available during the data treatment in this dissertation – see Hauschild and Potting (2003).

Site-specific considerations (the negative impact potential). If we consider the negative contribution to nutrient enrichment related to avoided soy production at the processing stage, site-specific aspects can actually be turned upside down if certain assumptions are made. If we assume:

- 1) that fodder protein is sold on a global market where Argentina is the most sensitive supplier to a change in demand²⁵
- 2) that nutrient enrichment in relation to soy bean production in Argentina is an insignificant problem²⁶ and
- 3) that vegetable fat is a global market, where European or Canadian producers of rapeseed oil are most sensitive to a change in demand²⁷

- the nutrient enrichment potential at the processing stage would be increased to +37% instead of –60%. The reason is that a smaller demand for soy protein would result in a smaller production of soy oil in Argentina, and therefore an increased production of rapeseed oil in Europe - or maybe Canada - where nutrient enrichment is a problem in most countries. This conclusion appears to be far fetched, but in my opinion, the assumptions are not unrealistic and show that the impact potential is very sensitive to site-specific consideration in some cases.

²⁵ As previously mentioned, this is a reasonable assumption according to Weidema (2003a).

²⁶ This may and may not be the case. I have not investigated this further, but in cases where the river flows fast (e.g. in mountains) and where the rivers are connected with coastal areas with great water depths (this is often the case in South America) – it must be assumed that the chances for eutrophication are relatively low.

²⁷ As previously mentioned, this is a reasonable assumption according to Weidema (2003a).

Photochemical ozone formation potential – C₂H₄ equivalents

For photochemical ozone formation (summer smog), the main contribution also comes from the fishery (59%) due to the emission of non methane VOC (hydrocarbons except methane) – mainly from the production of diesel, but also the combustion process itself. This is also the case for the use stage (35%) – mainly related to shopping by car. In this regard, it is worth to stress that hydrocarbons from traffic have been significantly reduced since the database was developed in 1994, due to catalytic converters, but this is discussed in the evaluation in chapter 9.

Verification. The EcoIndicator 99 method does not include a category termed photochemical ozone formation, but instead includes respiratory organics that includes most of the substances that causes ozone formation. The results according to this method are similar to the results obtained from EDIP. However, the CML method suggests a lower contribution from the fishery (35%), but this method also measures photochemical oxidation instead of ozone formation. The reference substance in CML is C₂H₂ instead of ethane used in the EDIP method. Thus, more weight is given to the use stage at the expense of the fishery according to CML. The methodological differences have not been investigated further.

Site-specific aspects. This impact category is also sensitive to site specific considerations. Summer smog is a problem in cities but also in the countryside, where ozone has a negative impact on the crops. Actually, the ozone concentration in Denmark is larger at the countryside than in the cities (Hauschild, 1996). Substances that contribute to ozone formation may drift over long distances, but according to Wenzel et al. (1997), a site-specific factor between 0 and 1 should be applied for emissions in sparsely populated areas (low background NO_x levels) such as deserts or the sea. Hence, the impact from fishery is probably significantly smaller than suggested in figure 1. If we use a site-specific factor for the fishery of less than 0.5, the user stage becomes the most dominant. It is difficult to assess if this is reasonable or not, but as transport during shopping often takes place in highly populated areas, the human health aspects of ozone formation is probably far more serious than the emissions generated in the fishery.

Eco-toxicity potential (water acute, water chronic and soil chronic)

The EDIP method includes three types of eco-toxicity: Eco-toxicity water (acute and chronic) as well as eco-toxicity soil (chronic). The unit is m³, expressing the water or soil volume required to dilute the given exchange to a concentration below the Predicted No Effect Concentration (PNEC). For further details, see Wenzel et al. (1997).

Both categories of eco-toxicity water are dominated by the fishing stage, which contributes with around 98% of the total eco-toxicity potential in both categories. By far, the most important contribution comes from TBT released from anti-fouling paint. For acute eco-toxicity, TBT in the fishing stage contributes with 88% of the total eco-toxicity potential in the entire life cycle of the product, while it is 89% for water chronic eco-toxicity. The remaining contribution to acute and chronic eco-toxicity is related to energy consumption in other life cycle stages – mainly the use stage²⁸. The most important substances here are Strontium and heavy metals such as selenium and copper – from mining activities²⁹. For eco-toxicity soil (chronic), the main contribution is from the processing³⁰, fishery and use stages. Generally, the uncer-

²⁸ Specifically for cleaning agents, the contribution to ETWA also appears to be somewhat high (the fourth most important substance but only 1% of the total impact potential). However, it should be stressed that I have used a worst case approach where the characterization factors for all cleaning agents reflect the worst cleaning agents among a group of typical cleaning agents used in the industry according to “Bilaga till kemisk-tekniska kriteriedokument 15 juni 1999-14 juni 2003 version 2.4” which can be downloaded from the Danish Ecolabel authority (www.ecolabel.dk). According to Dall (2002), modern hand washing-up liquids do not induce any harm to the environment. Still, it is argued that machine dish-washing liquids may be harmful in some cases. However, this may not be the case for washing liquids used in other parts of Europe, where Danish fish products are consumed. Still, it must be assumed that increased focus on the effects on the water environment - as well as eco-labeling - in the future will reduce or completely remove the content of agents, which are harmful to the water environment.

²⁹ According to Goedkoop (2003), these emissions are related to long term leaching from mining activities. Goedkoop argues that it is debatable whether long term leaching should be included. He also expresses that the future Eco-invent database will include data with both long and short term leaching, which indicates that it is basically a question of modeling, whether it should be included. Thus, there are great uncertainties in this area.

³⁰ The most important substances are acetone followed by formaldehyde and benzene emitted to air. In the processing stage, the main contribution comes from paper production, but a further analysis shows that nearly all of the acetone emissions come from energy production based on oil, which is assumed to be involved in the paper production according to the ETH database. If I used data for packaging material from the Buwal database, there was no significant contribution to eco-toxicity soil. Basically, all in this category is related to energy production, but the uncertainties are so large that the only reliable conclusion is that the fishery, processing and use stages are all potentially important.

tainty for eco-toxicity is large, but this is discussed in the interpretation in chapter 9.

Verification. In the EcoIndicator 99 method, eco-toxicity is only included as an overall impact category, where the impact potential is measured in terms of lost biodiversity. This method suggests that the use stage is the hot-spot (60%) mainly due to air emissions of heavy metals. However, as the method does not include TBT (not even in the egalitarian version, representing long time perspective and a minimum of scientific proof), comparison is difficult.

The CML method includes three categories for eco-toxicity (freshwater-, marine- and terrestrial eco-toxicity). According to this method, 99% of the impact potential to freshwater eco-toxicity is due to TBT. However, the Danish fishery is only operating in the marine environment – which makes this assessment somewhat irrelevant. For marine and terrestrial eco-toxicity, the method suggests that the use- and retail stages are dominating, due to emissions of Hydrogen Fluoride and heavy metals. The TBT emissions appear to be somewhat insignificant here. This questions the dominance of the fishing stage – as suggested by the EDIP method. Still, I would assume that the TBT emissions are the most important factor as suggested by EDIP, because TBT emissions from ships are known to have caused widespread hormone disruptions among snails and mollusks in the inner Danish waters.

Site-specific aspects. The EDIP method suggests that critical exposure to acute eco-toxicity is unlikely for emissions to the marine environment. This would include release of TBT from Danish fishing vessels. Thus, site-specific considerations would reduce a significance of TBT in the ETWA impact category. Still, the fishing stage would remain dominating in this impact category if anti-fouling agents were disregarded altogether. This is due to emissions of heavy metals from the production of diesel. Furthermore, it could be argued that the contribution to ETWA caused by TBT remains somewhat important for emissions occurring in coastal areas and harbours.

The hot-spots

Overall, the fishing stage must be considered the dominating stage with respect to all the impact categories assessed here, but the use- and retail stages are also relatively important for some impact categories. Generally, the processing stage appears to be one of the least important stages in the life cycle, except for the contribution to eco-toxicity soil.

The dominating role of the fishing stage is evident when we consider global warming and ozone depletion. Considering eco-toxicity, the fishing stage is

also completely dominating for toxicity water, acute and chronic, while three stages are potentially equally important for eco-toxicity soil chronic, namely fishery, processing, and use.

When site-specific considerations are included, the fishing stage becomes less important for acidification, nutrient enrichment, photochemical ozone formation and eco-toxicity, but I have not quantified this further.

Also, if we assume that nutrient enrichment is not a problem in South America (Argentina), the processing stage may become the second most important stage for nutrient enrichment, after the fishery.

Thus, for acidification, nutrient enrichment and photochemical ozone formation, I can not exclude the possibility that the use stage will turn out as the most important stage – considering the effects that actually will occur. Specifically for nutrient enrichment, it could also turn out to be the processing stage, but this is a rather theoretical assumption. Basically, it should be emphasized that the EDIP method only provides a very rough estimate of the contribution to nutrient enrichment.

For all impact categories, it is possible that the technological changes (cleaner fuels, filter solutions, substitution of CFCs etc) made since the database was established (in the early 1990s), will reduce the impact potentials. It can be expected that some stages have been more affected by this development than others, and the relatively old database is therefore a source of uncertainty. This is further discussed in the interpretation in chapter 9.

The hot-spots described above only apply to: 1) A specific type of fish product, 2) an average production method, 3) a present time situation and 4) a limited set of impact categories. The first three items will be further elaborated in the following sections, while other impact categories will be discussed in chapter 10.

Characterization (breaded flatfish filet)

I have also carried out an LCA of “breaded” flatfish filets – which increases the scope with respect to product types investigated. Here, the functional unit is one kg consumed frozen breaded flatfish filet (IQF) in consumer packaging (cardboard boxes), each of 300 gram. The characterization results are illustrated in figure 4.

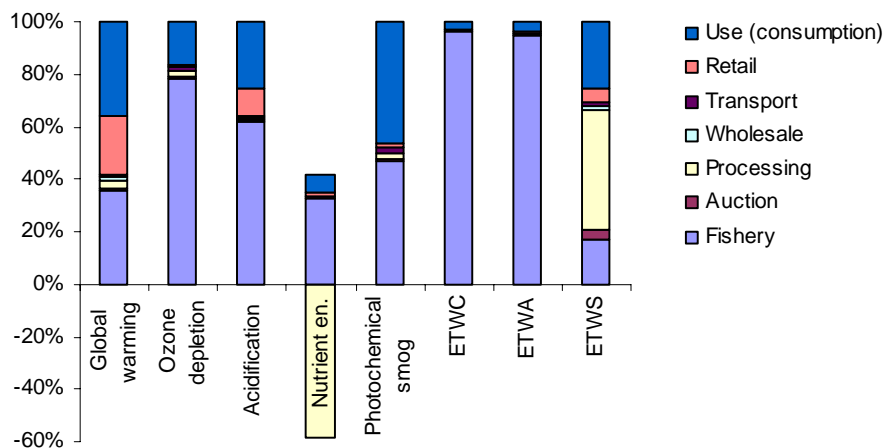


Figure 4: Characterization results from LCA of one kg consumed “breaded” flatfish filets (IQF).

The most obvious difference, compared to ordinary flatfish filet, is that the fishing stage is less important for all of the impact categories. However, it is still completely dominating for eco-toxicity water. The reason is that the breaded product only has a meat content of 60% while it is 100% for ordinary flatfish filet.

The breading consists of raw materials such as wheat flour, potato starch and small quantities of sugar, salt and spices. The bread crumbs are made in a process that involve bread baking and drying, which is relatively energy intensive³¹. Still, the breading has a very small influence on the impact categories that are included in this LCA. The breading only has a significant

³¹ This is a worst-case situation, as by-products from industrial bakeries are used as well. However, if we consider the marginal production, it is perfectly relevant to include energy for baking of bread, as this is the processing method for breadcrumbs that is most likely to be affected by a change in demand. In this regard, it should be stressed that recent studies performed at 2.-0 Consultants suggest that the affected processes could be production of animal feed. The reason is that there probably is produced too much bread crumbs and that the marginal production is used for animal feed. Thus, a change in demand for breadcrumb should affect the production of animal feed according to this theory. (Weidema, 2003b). However, I have not included these results in my studies.

influence on the impact category “nutrient enrichment”, where it increases the potential with roughly 20%.

Compared to ordinary flatfish filet, the environmental impact potential is 20-40% smaller for all impact categories except for nutrient enrichment. In this category, ordinary flatfish filet has a 60% smaller impact potential. In spite of extra energy consumption in the fishing stage, the ordinary flatfish filet performs better, which is mainly due to the larger substitution of soy protein in the processing stage. Thus, it cannot be established which of the product types has the smallest environmental impact because it cannot be excluded that nutrient enrichment is worse than all other impact categories (aggregated) – without normalization and weighting.

Considering hot-spots, the situation is still that the fishing stage generally is dominating, but the use stage becomes equally important for global warming and photochemical ozone formation as well as eco-toxicity soil. If we include the site-specific considerations, the use stage is definitely the hot-spot for photochemical ozone formation – but still it is difficult to tell how much the site-specific aspects will influence acidification and nutrient enrichment.

Results based on different fishing methods

The following section includes different production scenarios with focus on different fishing methods – to further analyze the improvement potentials described in the MECO analysis.

Improvement potentials (Passive versus active fishing gear)

As illustrated in chapter 4, the energy consumption in the fishery varies considerably as a function of the fishing method – both with respect to vessel size and fishing gear. Flatfish are typically caught with bottom trawl (42%), Danish seine (29%), beam trawl (15%) and gill net (12%), see app. 2. In figure 5, I have compared the impact potential (aggregated for all life cycle stages) for flatfish caught with bottom trawl (38 GT) and Danish seine (34 GT). Data have been obtained from chapter 4.

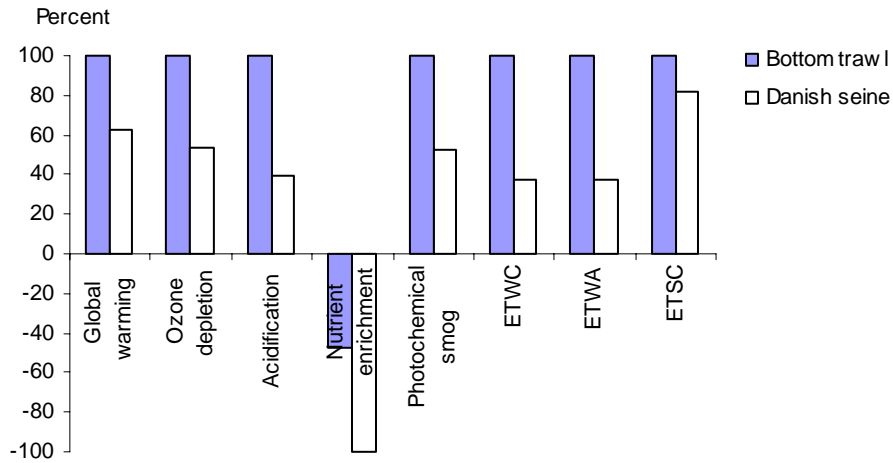


Figure 5. Characterization results for one kg consumed flatfish filet caught with Danish seine and bottom trawl, respectively

As it appears, flatfish caught with Danish seine performs so much better at the fishing stage that the total impact for the entire life cycle is reduced by a factor two in most cases. Data has not been available for flatfish caught with gill net, but generally speaking, the exchanges are similar to those of Danish seine.

If we compare Danish seine (38GT) with beam trawl (200 GT+), the difference becomes even greater – at least for most of the impact categories (figure 6).

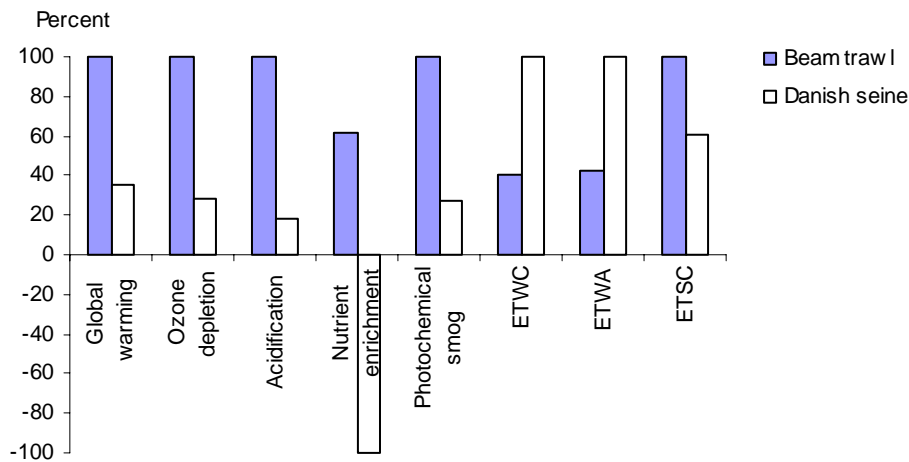


Figure 6. Characterization results for one kg consumed flatfish filet caught with Danish seine and beam trawl, respectively

This example confirms that there are large improvement potentials for most of the impact categories, but beam trawl actually performs better for eco-toxicity water³². This is mainly because beam trawl vessels are considerably larger, which gives a smaller hull surface per gross tonnage, as described in the MECO analysis (chapter 4)³³. Thus, in some cases we are faced with a trade-off between energy consumption and emissions of anti-fouling agents.

³² For Danish seine, 90% of the contribution to eco-toxicity water, acute and chronic, comes from TBT, while only 20% for beam trawl. In this regard, toxicity related to fuel consumption cumulate that the difference in TBT emissions is around a factor 10.

³³ In chapter 4, it was also established that it is not possible to establish a general correlation between emissions of antifouling agents and fishing gears. However, the LCA confirms that very large vessels (e.g. as for beam trawl) have an advantage in this respect – even considering the increased eco-toxicity potential related to the higher energy consumption.

Hot-spots for different fishing methods

Flatfish caught with Danish seine represents a scenario where the impact from the fishing stage is smallest, considering different fishing methods. In fact the exchanges in terms of energy consumption and emissions of anti-fouling agents are roughly half for this particular fishery, compared to the average edible fish (all species except industrial fish) caught in the Danish fishery. Thus, it is interesting to analyze to which extent the fishing stage remains important for this particular scenario (figure 7).

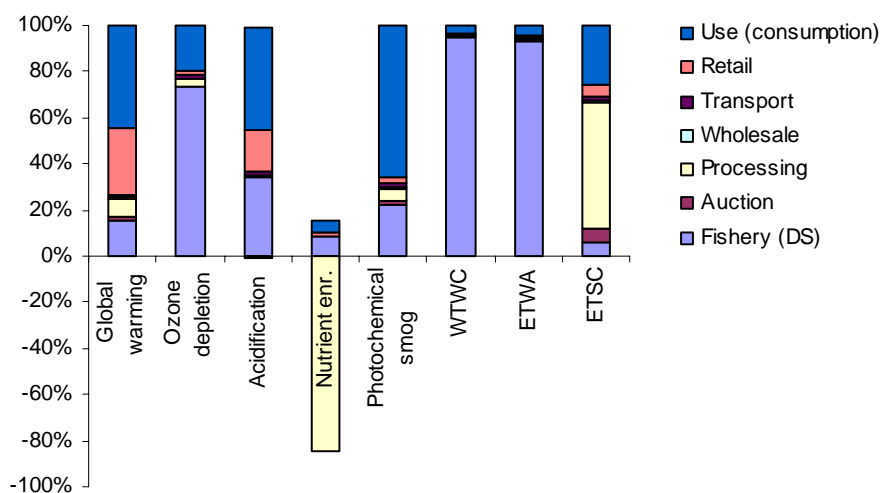


Figure 7: Characterization results for scenario reflecting one kg consumed flatfish filet caught with Danish seine

As it appears, the fishing stage becomes considerably less dominating in the scenario where the fish are caught with Danish seine³⁴. Obviously, the use and retail stage becomes proportionally more important. This also applies to the processing stage, but considering the large negative contribution for nutrient enrichment, this stage still has a relatively low significance. In this

³⁴ It should also be mentioned that the high ozone depletion potential from the fishery in the Danish seine scenario comes from the cooling agent R22, used in the fishery, while it is Halon 1301 used during the production of fuel that are the most important substance in the average scenario.

regard it should still be considered that the high contribution to eco-toxicity soil related to processing is highly questionable.

Hence, it is no longer possible to conclude that fishery is the most important stage. Instead, it can be established that there are three important stages: Fishery, use, and retail - in this order. In the scenario where the flatfish are caught by beam trawl, the fishing stage becomes completely dominating for all impact categories. In this regard, it should be considered that the fuel consumption is 2.6 liter per kg caught flatfish, which should be multiplied by nearly three, when we estimate the fuel consumption per kg consumed flatfish.

Future scenarios

As earlier mentioned, there is a number of exchanges that are expected to change considerably over the next decade. The MECO analysis (chapter 4-6) included an analysis of expected changes for key exchanges, and the results are summarized in table 3:

Table 3. *Development tendencies towards 2010-15, where scenario two represents a best possible solution concerning anti fouling agents.*

Life cycle stage	Change (scenario 1)	Change (scenario 2)
Fishery	<ul style="list-style-type: none"> • Energy consumption (+20%) • TBT is substituted by "Sea Nine" • Lead in fishing gear (-80%) substituted by iron • HCFC-22 (-80%) substituted by natural cooling agents 	<ul style="list-style-type: none"> • TBT and "Sea Nine" is completely removed and only a small concentration of copper (10% w/w) is used. • The rest as sc. 1
Landing & auction	<ul style="list-style-type: none"> • Energy consumption (-20%) 	<ul style="list-style-type: none"> • As sc. 1
Processing	<ul style="list-style-type: none"> • Water consumption (-50%) • Energy consumption (-10%) • Cleaning agents (-25%) • Wastewater, COD (-50%) 	<ul style="list-style-type: none"> • As sc. 1
Wholesale	<ul style="list-style-type: none"> • Energy consumption (-30%) 	<ul style="list-style-type: none"> • As sc. 1
Transport	<ul style="list-style-type: none"> • No change 	<ul style="list-style-type: none"> • No change
Retail	<ul style="list-style-type: none"> • Energy consumption (-30%) • HFC (-80%) substituted with natural cooling agents 	<ul style="list-style-type: none"> • As sc. 1
Use	<ul style="list-style-type: none"> • Water consumption (-15%) • Energy consumption (-30%) • HFC (-80%) substituted by natural cooling agents 	<ul style="list-style-type: none"> • As sc. 1

I have developed two scenarios. The first represents a situation where TBT is substituted by the presently best alternative “Sea Nine”. The second scenario represents a situation where TBT is substituted by a paint, which only contains copper in a 10% w/w concentration as the only important biocide from a toxicity point of view. It should be pointed out that this does not reflect a presently known technology, but represents my guess on a best possible solution around year 2010-15.

Future scenario one (“Sea Nine”)

The key question is whether this future scenario changes the conclusions from the present situation - which points towards the fishing stage as the most important, followed by the use and retail stages. The answer must be no – see figure 8.

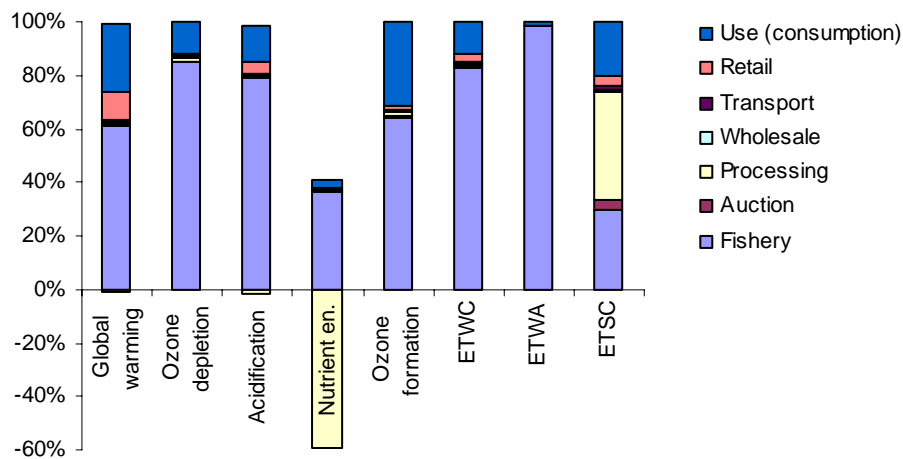


Figure 8: Characterization results for future scenario reflecting one kg consumed flatfish filet caught with average fishing method.

As it appears, the fishing stage actually becomes even more important for the five traditional impact categories – all except the three for eco-toxicity (compare with figure 3). This happens at the expense of the use and retail stages, where reduced energy consumption and substitution of cooling agents results in a reduction of the impact potential for all categories³⁵.

³⁵ As previously mentioned, I have not included future forecasts for related processes such as future exchanges for electricity production, transport etc. This is obvi-

For eco-toxicity water, the fishing stage contributes with 98% for eco-toxicity water acute and 84% for eco-toxicity water chronic. This is somewhat less than for a business as usual scenario with TBT, but still significant. For eco-toxicity soil, the change is insignificant, and I will refer to the previous discussion.

If we consider the absolute levels (compared to the present situation), the total impact potential is slightly lower (10-15%) for global warming and ozone depletion³⁶ and somewhat higher for all three regional/local impact categories (due to higher energy consumption in fishery). However, the largest change is for eco-toxicity chronic that drops 90% (due to substitution of TBT), while eco-toxicity water acute actually increases (see figure 9 – next section). The reason is that the concentration of "Sea Nine" is higher than for the paint containing TBT - while the $PNEC_{wa}$ value is the same. As previously mentioned, eco-toxicity water acute is not likely to be a problem of great concern for emissions taking place on open sea. Therefore it is most likely that "Sea Nine" is indeed a better alternative considering the great reduction in eco-toxicity potential for water chronic. As mentioned in app. 6 risk assessment studies that compares TBT with "Sea Nine" suggest that "Sea Nine" is less problematic, but still not un-problematic.

Future scenario (best possible antifouling paint)

I have also considered a future scenario where it is assumed that there will be developed an effective paint with copper (10% w/w³⁷) as the only biocide. In this case, the largest contribution for eco-toxicity water, acute and chronic,

ously a source of uncertainty, but as long as the various technological improvements apply equally to all the life cycle stages, the characterization results will not change. If we only consider the fishery, one of the most important related processes is the emission related to combustion of diesel. In this respect, it must be expected that the emissions of sulfur will be greatly reduced in the future – partly due to reductions in sulfur content in the fuel. However, this will probably not reduce the impact potential from fishery significantly as the contribution from sulfur compounds is relatively limited. According to the European Environmental Agency (2003a), the transport related emissions of substances contributing to acidification have been reduced by about 25% from 1990 to 2000.

³⁶ This is due to the substitution of HCFC and HFC cooling agents. I have only assumed that 80% is substituted, but probably the percentage will be higher. Furthermore, cooling agents for related processes will presumably also be substituted, and we can therefore expect a significantly higher reduction for ozone depletion than suggested here.

³⁷ The copper concentration is around 40% w/w in most other paints.

still comes from the fishing stage (72% and 77% respectively) – mainly due to emissions of strontium related to energy production. As previously mentioned, the strontium is due to long-term leaching from coalmines and oil extraction, but it is debatable how it should be included in the new databases. If we disregard strontium, copper emissions from the antifouling agents still represent the largest contribution to eco-toxicity water, chronic and acute (roughly 70% in both cases).

Compared to the present situation, the total potential for eco-toxicity (water acute and chronic) will be reduced significantly. The two future scenarios compared to the present time situation (year 2000) are illustrated in figure 8.

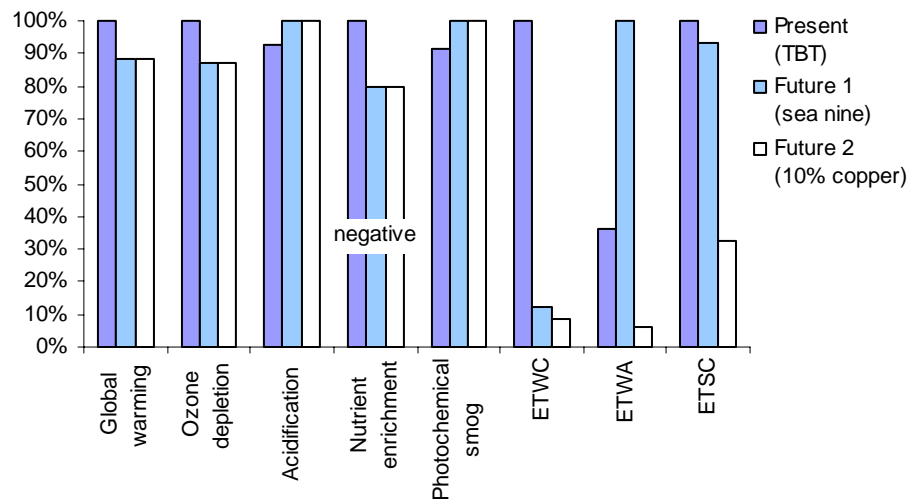


Figure 9. The total impact potential for the two future scenarios compared to the present time situation around year 2000.

As it appears, the eco-toxicity potential is reduced by roughly 90% compared to the present time situation, while eco-toxicity soil will be reduced roughly 70%. Thus, referring to the trade-off between antifouling agents and energy consumption for the comparison between Danish seine and beam trawl, it is likely that energy becomes the deciding parameter in the future. However, this will be further analyzed in chapter 9.

8.5 Summary & final comments

This section includes a summary but does not include the interpretation with uncertainty and sensitivity analysis (phase 4 of an LCA according to the ISO standard). Therefore, it is somewhat short.

The interpretation is included in chapter 9, where the evaluation addresses the analysis in this chapter as well as the normalized and weighted results for flatfish and other fish products in chapter 9.

Ordinary flatfish filet (IQF)

The characterization results of ordinary flatfish filet (IQF) suggests that the fishery is the hot-spot in the five traditional impact categories (global warming, ozone depletion, acidification, nutrient enrichment and photochemical ozone formation), followed by use and retail in this order. The fishery is also completely dominating for eco-toxicity water, acute and chronic, while the processing and use stages are relatively important for eco-toxicity soil as well. In chapter 9 it will be elucidated whether eco-toxicity soil is important compared to the contribution to the other impact categories.

These results reflect the impact "potential" and do not include site-specific considerations. However, the studies suggest that site-specific considerations tend to reduce the importance of fishery for the regional and local impact categories (acidification, nutrient enrichment, ozone formation and ETWA). This is particularly the case when fishery is conducted in areas distant from the shore. Thus, one cannot exclude the possibility that other stages are hot-spots for the local and regional impacts categories when we consider the actual impact that will occur. In this respect, I particularly think of the use stage, but also the processing stage for nutrient enrichment. However, any statement in this regard would require new and even more comprehensive studies of these particular aspects.

Breaded flatfish filet(IQF)

The chapter includes an LCA of breaded flatfish as well. Breaded flatfish have a considerably smaller impact potential per kg consumed fish product. The reason is that the fish content is 40% smaller. Basically, fish meat reflects larger potential impacts than vegetable products used for the breeding,

at least for the impact categories considered here³⁸. However, the fishing stage is still among the three most important stages for the traditional five impact categories (together with use and retail), while it is completely dominating for eco-toxicity water (acute and chronic).

Overall, it is assessed that the fishery, use and retail stages are the hot-spots for both types of flatfish products. If we only consider the potential impact, it is reasonable to say that the fishing stage is the most dominating stage. The processing stage is a joker in two aspects. It may prove that it causes an indirect contribution to nutrient enrichment – if certain assumptions are fulfilled - and it could prove to be important for eco-toxicity. The latter is further investigated in chapter 9, while the first remains an open question. In this respect, it should be emphasized that nothing suggests that the direct wastewater emissions from the processing industry are important in terms of nutrient enrichment.

Future developments

Future scenarios suggest that the fishing stage will remain important even though TBT is substituted. The alternative antifouling paints are also somewhat problematic, and both future scenarios suggest that fishery will remain dominating for eco-toxicity water (acute and chronic) even though the toxicity potential is greatly reduced from antifouling agents. Furthermore, the fuel consumption is expected to grow in the fishing stage, while the energy efficiency probably will increase in other life cycle stages. Obviously, such predictions are very uncertain, but at least it is certain that this has been the trend so far.

Key improvement potentials

The LCA for flatfish strengthens the conclusion that the fishing stage is important. The results suggest that it is possible to obtain a factor two improvement for all six impact categories by substituting bottom trawl with Danish seine in the fishing stage, considering the whole life cycle.

If we disregard the impact category “eco-toxicity”, it is possible to obtain a factor 4-5 improvement by substituting beam trawl with Danish seine. However, the eco-toxicity potential actually increases when switching from beam trawl to Danish seine. This is due to the extremely low antifouling emissions

³⁸ For an impact category such as land use, the impact potential for vegetable products would be much larger than for fish – but on the other hand, the opposite would be the case for seabed impacts.

per kg caught fish in beam trawl fishery. Still, it should be considered that future regulations of antifouling agents would greatly reduce the impact potential. The relative importance of antifouling agents in the future scenarios will be further analyzed in chapter 9.

LCA of Flatfish & Other Fish Products

(Valuation & Interpretation)

The results in chapter 8, provided a valuable insight into the impact potential, but it did not tell us whether some impact categories are more important than others (which they typically are). Theoretically speaking, it is possible that the processing stage, which has the highest impact potential for ETSC, could be the overall most important stage if this impact category proves to be much more important than other categories. Thus, in order to improve the assessment of hot-spots in the life cycle, it has been found necessary to conduct a so-called valuation, which includes a normalization and/or weighting of the results. The normalization implies that the impact potentials in each impact category are compared a reference. The weighting step goes a step further by adding a weighting factor that ideally reflects the importance of the respective impact categories. This means that all impact categories are converted to “one” common scale that shows the relative importance of the characterization results.

Structure

The chapter includes five sections. The two first sections present the normalized results and the weighted results for the two flatfish products analyzed in chapter 8. The third section includes a generalization where LCA screenings of six other fish products are presented as weighted results. Finally, the two last sections presents different aspects of the last phase “Interpretation”– see figure 1.

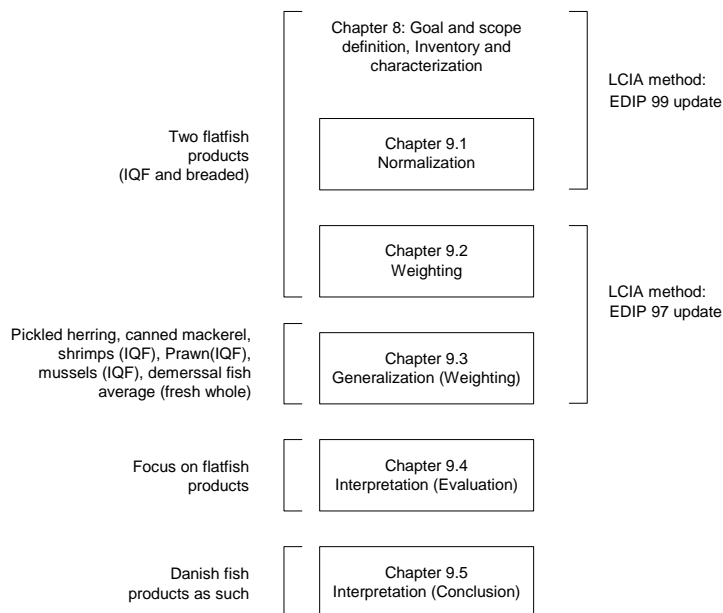


Figure 1. Content of the LCA in chapter 8-9 with a focus on products analyzed and methods applied in different phases.

As it appears, the generalization (9.3) includes LCA screenings of a number of fish products, which have also been analyzed in the MECO analysis in chapter 4-7. This provides a wide perspective on Danish fish products and enables conclusions that address Danish fish products as such.

In chapter 8, the impact categories were treated separately together with a discussion of validation and site-specific aspects. Chapter 9 has a somewhat different structure, as considerations about validation and site-specific aspects, only with a few exceptions, are discussed separately in section 9.4 “Valuation”.

9.1 Normalization - LCA food method (flatfish)

As mentioned, the normalization step implies that the impact potentials, obtained in the characterization step, are compared to a normalization refer-

ence. The EDIP method uses the average exchange for one person in one year as the normalization reference. (Wenzel et al. 1997).

The most updated normalization references for Denmark are established in the LCAfood project, which includes normalization references for 1999, but only for Denmark. The normalized results presented in this section (9.1) are therefore only based on Danish normalization references (Weidema, 2003c) – see table 1 in this chapter. This is not in accordance with the EDIP-96 method, which recommends that global references are used for global impact categories, and that Danish references can be used for local and regional impacts as default³⁹(Wenzel et al. 1997).

Still, I have chosen to use the updated references at the normalization step to provide an analysis that partly represents a different approach⁴⁰, and partly represents more updated normalization references.

Results - ordinary flatfish filet

The normalization results for one kg of frozen flatfish based on the LCAfood normalization references for Denmark are illustrated in figure 2. It should be noted that I have illustrated the normalized values in separate columns for each stage. Aggregated values have not been chosen because the uncertainty can be different for each impact category. Furthermore, it would not be difficult to include eco-toxicity if the impact categories were aggregated – as the normalized values are much higher for this impact category:

³⁹ The EDIP method suggests that the normalization reference ideally should reflect the area of impact, but partly due to the lack of data, this has been difficult to operationalize so far (Wenzel et al. 1997).

⁴⁰ The different approach implies not only that Danish normalization references are used for all impact categories; it also implies that the normalization references in the LCAfood version reflect activities operated by Danish economic agents rather than activities physically limited to Denmark.

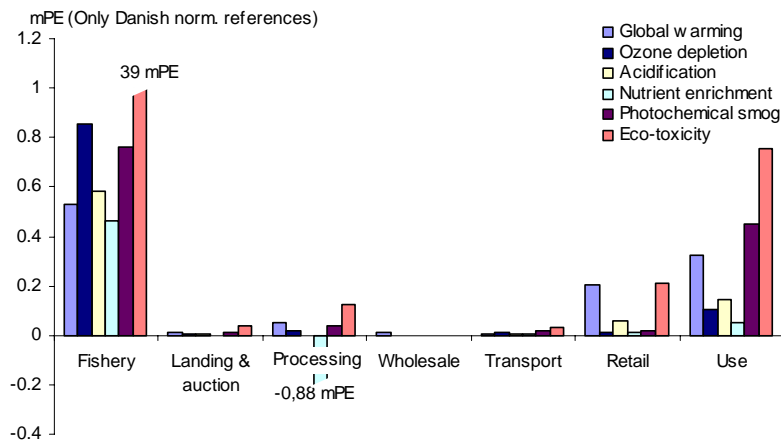


Figure 2: Normalization results of one kg consumed frozen flatfish (IQF), caught with the average fishing method.

As the figure shows, the number of person equivalents (normalized values⁴¹) is largest at the fishing stage, followed by the use and retail stages. The processing stage is even less important than the retail stage, and is characterized by a negative contribution to nutrient enrichment.

The fishery is particularly dominating for eco-toxicity - mainly due to the emissions of TBT (90%). It should be stressed that eco-toxicity mentioned here represents the aggregate result⁴² for all three sub-categories of eco-toxicity⁴³. Measured separately, the contribution would have been roughly 60 mPE for ETWC and ETWA respectively, and 0,02 mPE for ETSC. Generally speaking, the normalized values for ETSC are insignificant for all

⁴¹ The normalized results may be difficult to understand intuitively, but the data can also be illustrated in another way: If we consider the total number of person equivalents for 1 kg of flatfish for global warming, it is 1,13 mPE measured per year. If we measure this in PE per day, it is 0,4 PE (we simply multiply with 365 days per year). Thus, if we consume one kg of ordinary flatfish filet caught by the average fishing method, we contribute with 40% of the average green house gas emissions of a Danish citizen per day.

⁴² Basically, this is the sum of the normalized values for all three subcategories, divided by three.

⁴³ I have normalized each impact category separately and subsequently added them and divided the aggregated result with three.

stages and shows that the large contribution to ETSC described in chapter 8 is indeed insignificant – considering the overall contribution to eco-toxicity.

Hot-spot and processes analysis

The results suggest that the fishing stage is the hot-spot, independent of the relative importance (weighting) of the different impact categories, because it dominates in all categories. The important processes are combustion of diesel and emission of antifouling agents. Still, it should be noticed that the use and retail stages are relatively important as well.

In the use stage, a large contribution comes from transport during shopping activities. The most important processes are shopping followed by electricity consumption (50% for storing and 50% for cooking and dishwashing) – except for global warming, where electricity consumption is the most important process.

For the retail stage, the dominating process is electricity for storing in all impact categories. However, emissions of cooling agents also have a significant influence on global warming, while the production of plastic bags have a significant influence on ozone depletion and photochemical ozone formation.

Results based on different fishing methods

Similar to the analysis in chapter 8, I have also chosen to illustrate the normalized results for one kg consumed ordinary flatfish filet - caught with different fishing methods. In chapter 8, I compared bottom and beam trawl with Danish seine, but in this chapter I compare Danish seine with the average fishing method (presented in figure 2) instead of bottom trawl. The results are shown in figure 3.

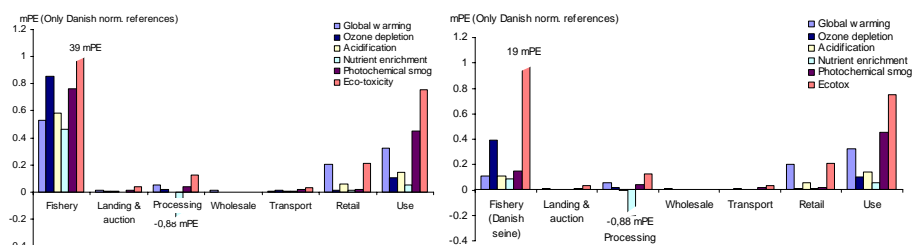


Figure 3: Normalization results of one kg frozen flatfish filet caught with the average fishing method (left) and Danish seine (right).

As it appears, the improvement potential in terms of normalized values is considerable for all impact categories. In this respect, it should be noticed that the exchanges for the average fishing method are similar to the exchanges for bottom trawl, with the exception that emissions of antifouling agent are slightly higher for bottom trawl.

If we compare beam trawl with Danish seine the improvement potential becomes even larger – see figure 4.

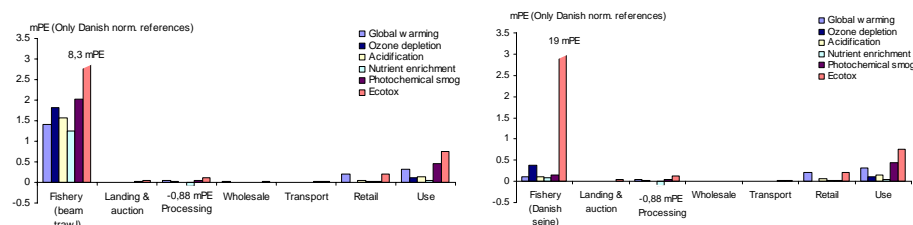


Figure 4: Normalization results of one kg frozen flatfish filet caught with beam trawl (left) and Danish seine (right).

As it appears, the fishing stage is completely dominating in the beam trawl scenario due to the large fuel consumption (2,61 liter per kg caught flatfish).

The Danish seine scenario reflects a large improvement potential with respect to all impact categories, except eco-toxicity, due to low emissions of antifouling agents for beam trawlers. As the difference is significant, we are

clearly still faced with a trade-off situation between fuel consumption and anti fouling agents⁴⁴.

Trade-off between energy and anti fouling

As described in chapter 4, the low emissions of antifouling for beam trawl is a result of large vessels (+200 GT) and large catches compared to the size of the vessel⁴⁵. Hence, although beam trawlers are considerably more fuel consuming per kg caught fish, they have smaller emissions of antifouling agents per kg caught fish. The normalized results show that we are still facing a trade-off after the normalization step. However, a rapid development of new antifouling agents must be expected. This is further analyzed in the following section.

Future scenarios

The normalized results for the two future scenarios are presented in the following.

Hot-spots

Based on the forecasts (see table 3, chapter 8), the normalized results would only change slightly - see figure 5 and compare to figure 2.

⁴⁴ In the Danish seine scenario, the total number of person equivalents for eco-toxicity (aggregated over the whole life cycle) is 20 mPE, of which 88% comes from TBT emissions in the fishing stage. The remaining eco-toxicity mainly comes from copper from the anti fouling agents - as well as strontium from the use stage. For the beam trawl scenario eco-toxicity only make up 8 mPE (over the entire life cycle), of which less than 20% is related to TBT emissions in the fishery. However, the fishing stage is still dominating (88% of the total eco-toxicity potential). Most of the remaining eco-toxicity is related to the long term leaching of strontium and heavy metals from oil extraction due to the high fuel consumption for beam trawl.

⁴⁵ One could argue that this is made possible through the large energy consumption.

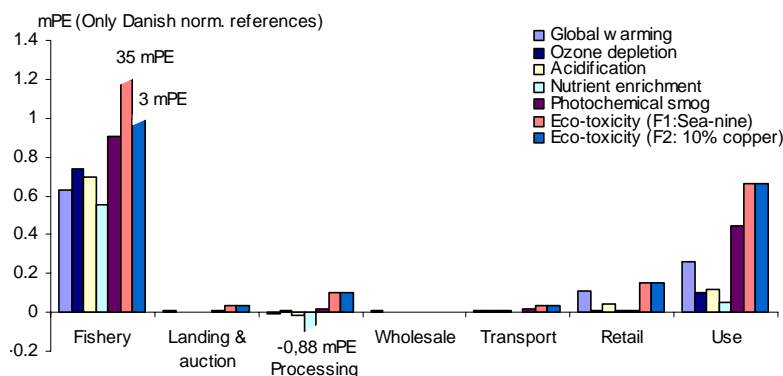


Figure 5: Normalized results for one kg consumed flatfish filet caught with the average fishing method - in the two future scenarios F1 (with "Sea Nine" antifouling) and F2 (with 10% copper as the only biocide). For eco-toxicity in fishery, numbers illustrate the magnitude. Thus, the difference between F1 and F2 is much greater than illustrated by the columns.

As shown, the fishing stage will remain the most important stage⁴⁶, which is also the case for scenarios where Danish seine and beam trawl is used⁴⁷, but the contribution to eco-toxicity is significantly reduced in the future scenario (F2) where TBT is substituted by the eco-friendly copper paint.

In the F1 scenario, where TBT is substituted with "Sea Nine" and copper, the reduction is small (from 39 to 35 mPE), but this covers a large contribution to ETWA (100 mPE) and very small contributions to ETWC (7 mPE) and ETSC (0,06 mPE).

⁴⁶ As previously mentioned, I have not considered future changes in related processes and products. Obviously, we will see technologies that are more efficient in a number of cases. In this regard it is worth to notice that the contribution to ozone depletion, which mainly comes from cooling agents used in oil refineries in the future scenario, probably will be reduced considerably compared to this scenario, which actually represents the early 1990s.

⁴⁷ In this regard, antifouling agents ("Sea Nine" and copper) are still the most important contribution factors in F1 except for beam trawl, where the energy consumption becomes the dominating factor. In F2 antifouling agents are no longer the most important factor.

Trade-off between energy and antifouling

If we consider the trade-off between energy and antifouling agents in the comparison of Danish seine and beam trawl, my studies shows that beam trawl still performs somewhat better for eco-toxicity in F1, while Danish seine performs far better for eco-toxicity in F2. The latter is because beam trawl represents a higher fuel consumption, which contributes significantly to eco-toxicity.

If we assume that antifouling agents (TBT, sea-nine and copper) have an insignificant contribution to ETWA in the marine environment due to site-specific considerations, Danish seine also performs considerably better for eco-toxicity in F1. Actually, the improvement potential would roughly reflect a factor 4-10 for all impact categories separately in both F1 and F2. Thus, all things considered, small vessels applying Danish seine may have a problem with antifouling agents in the present scenario, but the LCA results indicates that this situation will change as TBT is phased out.

9.2 Weighting – EDIP 97 update (flatfish)

Even if two types of impacts are equally important according to the normalized impact potentials, it does not necessarily mean that they are equally serious. Thus, the weighting step is intended to reflect the seriousness of the impact. Some aspects of the seriousness can be established on a pure scientific basis (e.g. exposure, background concentrations, threshold levels, irreversibility, size of area impacted, time scale of impact). Other aspects are more related to the perceptions and values among people, opinion-leaders etc.

Introduction

The EDIP method uses political reduction targets for the weighting step, as they reflect a combination of scientific and value based aspects (Wenzel et al. 1997). Basically, the normalized results are multiplied by the weighting factor which is the impact potential in year x divided by the target impact potential in year x +10. In the present study, year x is 1994. This can also be interpreted as yet another normalization as we can obtain the weighted results by dividing the characterized results by the target impact potential in year x +10.

Methodological aspects

In the previous sections, I have used the LCAfood version, which represents characterizations and normalization factors for Denmark, updated to 1999. However, there have not been developed any weighting factors as part of this version. Hence, even though it is the most updated method, it is less suitable to provide weighted results. Therefore, it is chosen to use an updated version of EDIP-96 (hereafter referred to as “EDIP 97 update”) to establish the weighted results. In this respect the normalized results based on the LCA-food version can be seen as a background for verification, where all weighting factors are one⁴⁸.

The EDIP 97 update has been developed as part of the Danish consensus project – see Busch, 2003. In this version, the normalization represents the year 1994, while the weighting factors reflect the reduction targets from 1994-2004. For each impact category (x), the weighting factor is therefore defined as:

$$\text{WF (x)} = \text{Impact potential for x in 1994} / \text{Target impact for x in 2004}$$

I have chosen to use Danish normalization references for regional and local impact categories while global normalization references are used for global warming and ozone depletion⁴⁹. The reason for choosing the Danish instead of the European references (as suggested) is that I have focused on Danish

⁴⁸ In the Danish LCAfood project Bo Weidema argues that the weighting factors could be set to one as long as we have not developed a more reliable set of weighting factors than the factors established in the EDIP method (Weidema, 2003b). One of the most obvious weaknesses of the weighting factors in the EDIP method is for ozone depletion – where it is possible to argue for a weighting factor between zero and indefinite. Furthermore, the remaining weighting factors are so similar that they hardly distinguish between the seriousness of the different impact categories – according to Weidema. These aspects will be discussed in the following.

⁴⁹ In the EDIP-97 update, three sets of normalization and weighting factors are developed – one set for Denmark, one set for EU countries and one set representing the global situation (Busch, 2003). In the EDIP-96 method it was recommended that global factors were used for global warming and ozone depletion, while Danish factors were used as a default for other regional and local impact categories (Wenzel et al. 1997). In the EDIP-97 update, the EU factors have become more reliable and it is now recommended to use the EU factors as a default for regional and local impacts. The reason is that it provides a better scope for industrial products that often involve processes in different countries and which are marketed in various European countries (Busch, 2003).

regulation and policies. Still, I have used the EU references as a sensitivity analysis. The global references for global impacts are chosen in accordance with the recommendations for weighting in the EDIP method⁵⁰.

Normalization references and weighting factors

Bold numbers in table 1 illustrate the normalization references and weighting factors used in the LCA. The table also contains other references and weighting factors such as the references used in the LCAfood version for comparison:

Table 1: *Normalization references and weighting factors for the EDIP 97 method (Busch, 2003) as well as the LCAfood version of the EDIP method (Weidema, 2003c).*

	Normalization references (kg or m ³ per capita per year)				Weighting factors			
	Global- EDIP97	EU-15 EDIP97	DK- EDIP97	DK- LCAfood	Global- EDIP97	EU-15 EDIP97	DK- EDIP97	DK- LCAfood
Global warm	8.700	-	-	18.353	1,13	-	-	-
Ozone dep.	0,10	-	-	0,013	44,00	-	-	-
Acidification	-	74	101	199	-	1,27	1,34	-
Nutrient enr.	-	119	260	431	-	1,22	1,31	-
Ozone form.	-	25	20	19	-	1,33	1,26	-
ETWC	-	3,52E5	7,40E4	2,87E6	-	1,18	1,67	-
ETWA	-	2,91E4	7,91E5	2,86E5	-	1,11	1,73	-
ETSC	-	9,64E5	6,56E5	5,71E5	-	1,00	1,56	-

Italic figures: Normalization references applied in the previous section.

Bold figures: Default normalization- and weighting factors applied in the following sections. EU-15 references and weighting factors are used in the validation.

Weighting factors. The only weighting factor that clearly distinguishes itself from the others is the weighting factor for ozone depletion (44), in the EDIP 97 update. This is even higher than in EDIP-96, but this is because the new weighting factor reflects the reduction target for industrialized countries.

⁵⁰ The EDIP method suggests that the normalization reference ideally should correspond to the area of impact. Obviously nutrient enrichment in Brazil would not be perceived as a problem in Denmark, and therefore Danish reduction targets would not reflect the seriousness of the problem. Thus, for regional and local impacts, the normalization reference should ideally be Vietnam, if the exchange takes place in Vietnam. The EDIP method is prepared for such considerations, but so far this approach has not been fully implemented. For global impacts it is recommended to use global normalization references (Wenzel et al. 1997).

Even though it appears too high, it is recommended to use the weighting factor 44 for emissions that take place in Denmark and other European countries. Still, I would argue that it is possible to argue for a much smaller weighting factor because the problem is under control in the industrialized countries⁵¹ (Busch, 2003). This underlines the uncertainties and the importance of applying different weighting sets in the sensitivity analysis.

Normalization references. It is important to stress that the normalization references for Denmark are somewhat different in the EDIP-97 update, compared to the LCAfood version. The normalization reference for global warming, acidification and nutrient enrichment are roughly a factor two lower in EDIP-97 update, while it is a factor 38 lower for ETWC in the EDIP-97 update. This will obviously contribute to higher impact indicators, especially for ETWC. On the other hand, the references are higher in the EDIP-97 update for other categories such as ozone depletion (a factor eight) and ETWA (a factor three).

Apart from the fact that the LCAfood version is more updated, the main reason for the differences that occur is probably that the LCAfood version include all activities that are owned by Danish companies. In this regard, EDIP 97 only includes activities that takes place in Denmark. As an example, the LCAfood version includes TBT emissions from all shipping activities in the Danish economy while the EDIP 97-update includes shipping activities in the Danish sea territory.

Thus, we can expect somewhat larger contributions according to the EDIP 97 update - also for ozone depletion, as the weighting factor is 44 even though the normalization reference is a factor 8 higher as well.

Results – flatfish products

This section includes weighted results for flatfish products. All results are based on the updated EDIP-97 method where global normalization references are used for global impacts, while Danish references are used for regional and local impacts.

⁵¹ Denmark and the other EU-15 countries have decided to completely phase out the consumption of ozone depleting substances before 2004 (Busch, 2003).

Ordinary flatfish filet

The weighted results for one kg consumed ordinary flatfish filet caught with the average fishing method is illustrated in figure 6:

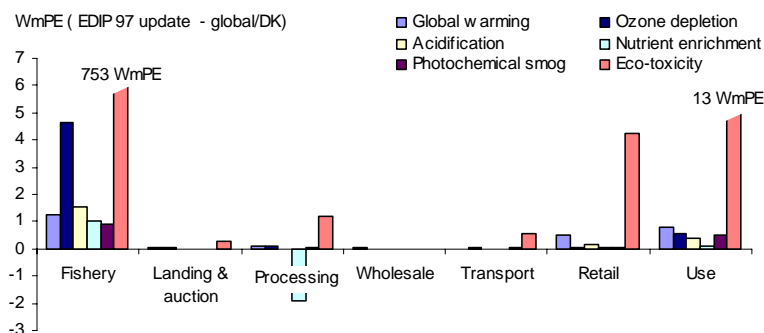


Figure 6: Weighted results measured in WmPE⁵² for one kg consumed ordinary flatfish filet, caught by average fishing method.

As predicted, the figure shows that the weighted impact potential is somewhat higher, compared to the normalized results based on the LCAfood version – see table 1.

The fishing stage has the largest contribution for all impact categories including global warming, but the contribution to ozone depletion⁵³ and eco-toxicity⁵⁴ dominates in particular.

The use and retail stages also have significant contributions, especially for global warming. This is mainly due to electricity consumption, based on coal, for both stages.

Process analysis (ordinary flatfish filet)

Due to the modeling, I have included transport processes at the processing and use stages as well. If all transport processes were aggregated in the

⁵² WmPE stands for Weighted Milli (10⁻³) Person Equivalents.

⁵³ This is related to cooling agents used during production of diesel as well as cooling agents (HCFC-22) used on the vessels to cool down the ice.

⁵⁴ This is caused by the TBT emissions from fishery (90%), while the remaining is copper (~5%) and strontium from oil extraction (~5%).

transport stage, it would appear that transport is one of the most important processes after the fishery – see figure 7.

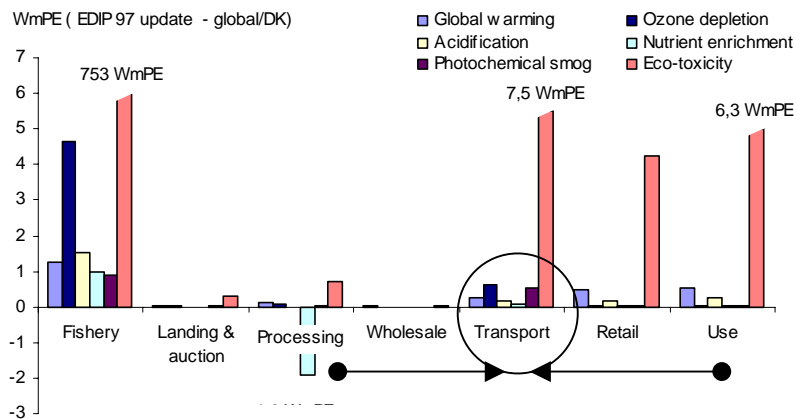


Figure 7: Weighted results for one kg consumed ordinary flatfish filet - caught with average fishing method. In this figure, all transport processes are allocated to the transport stage.

As it appears, transport is not that important concerning global warming but mainly contributes with ozone depletion and photochemical ozone formation (smog). It is mainly electricity consumption, used for storing, that dominates the last two life cycle stages – if we disregard the transport for shopping. Thus, three key processes can be distinguished; fishing operation, transport and cold storage.

Breaded flatfish filet

The weighted results for one kg consumed breaded flatfish is illustrated in figure 8:

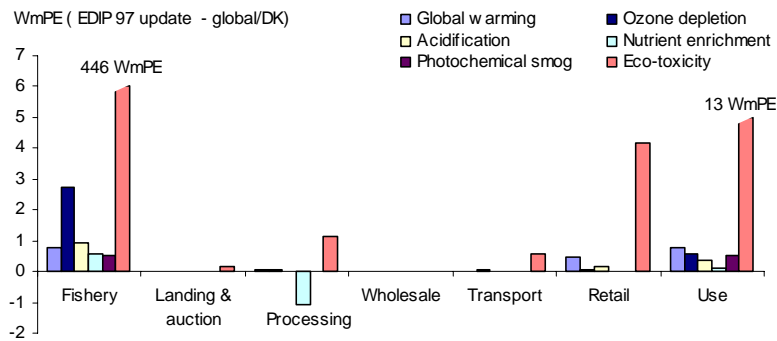


Figure 8: Weighted results for one kg consumed “breaded” flatfish, caught by average fishing method.

As it appears, the overall impact potential in terms of WmPE⁵⁵ is considerably smaller than for plain (glazed) flatfish, which has 40% larger meat content. This is similar to the difference observed in the characterization step in chapter 8.

Obviously, the use and retail become relatively more important, and in terms of key impact categories such as global warming, the use stage is similar to the fishing stage. Finally, it is worth to notice the reduction in avoided impacts at the processing stage⁵⁶, where the smaller meat content is obviously accompanied by less by-products that are able to substitute soy protein.

Results based on different fishing methods

As previously mentioned, flatfish are caught using different fishing methods. This section includes comparisons between the average fishing method and Danish seine, and between beam trawl and Danish seine – similar to the results presented at the normalization step. The difference between flatfish caught with the average fishing method and Danish seine, in terms of weighted person equivalents, according to the EDIP 97 update, are illustrated in figure 9.

⁵⁵ WmPE: Weighted Milli Person Equivalent

⁵⁶ Nutrient enrichment is only minus one WmPE for breaded flatfish, compared to minus two 2 WmPE in for ordinary flatfish filet.

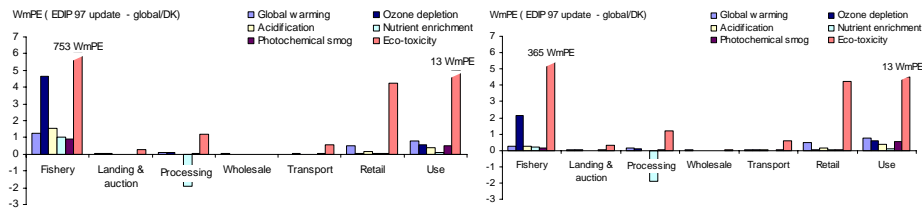


Figure 9: Weighted results for one kg consumed flatfish, caught with the average fishing method (left) and Danish seine (right) respectively.

As it was the case for the results presented under normalization, the Danish seine scenario represents a considerable improvement potential for all impact categories.

The difference between flatfish caught with beam trawl and Danish seine are illustrated in figure 10:

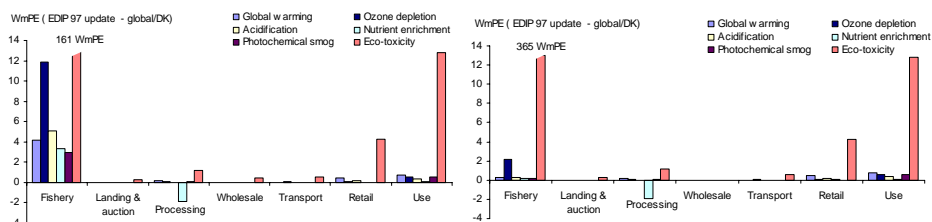


Figure 10: Weighted results for one kg consumed flatfish, caught with beam trawl (left) and Danish seine (right), respectively.

As illustrated, the beam trawl scenario has a significantly higher impact in the fishing stage, except for eco-toxicity⁵⁷. If we aggregate all the life cycle stages, it can be established that the Danish scenario reflects a factor six improvements compared to the beam trawl scenario – considering the five traditional impact categories. Concerning other important stages and process, I refer to the previous comparison of the normalized results in this chapter.

⁵⁷ With respect to eco-toxicity, the total contribution is 180 WmPE for the beam trawl scenario (90% is from the fishery), while it is about 380 WmPE for the Danish seine scenario (95% is from the fishing stage). However, it is important to stress that the main contribution in the beam trawl scenario is strontium from oil extraction (~70%) while TBT only contributes with 20%. In the Danish seine scenario the main contribution is 94% from TBT, 4% from copper and only 2 % from strontium.

Trade-off between energy and antifouling

As earlier mentioned, we are facing a trade-off between energy consumption and antifouling agents when comparing flatfish caught with Danish seine and beam trawl.

The weighting step should ideally be able to solve this problem by addressing the relative importance of the different impact categories. If we aggregate all impact categories over the entire life cycle (it could be argued to do so after the weighting step) - the number of weighted person equivalents becomes roughly twice as large for the Danish seine scenario – in a business as usual situation⁵⁸.

This indicates that Danish seine may not be a better solution – such as the situation was around year 2000. However, there are large uncertainties for eco-toxicity, and the EDIP method actually recommends treating toxicity separately. In this respect we may obtain a factor six improvement for all impact categories except eco-toxicity, while the latter will increase with a factor two, roughly. This could be interpreted as an overall improvement – even considering the TBT scenario (the situation around year 2000). As previously mentioned under characterization and normalization, the trade-off situation becomes easier to solve in the future scenarios where the dominance of eco-toxicity is reduced.

Future scenarios

Two different future scenarios are described in the following.

Hot-spots

Based on the future estimates, it appears that the weighted results will change slightly, mainly for eco-toxicity – see figure 11.

⁵⁸ It should be mentioned that the use of the LCAfood version of the EDIP method update suggest that the eco- and human toxicity potentials are considerably lower, due to higher normalization references.

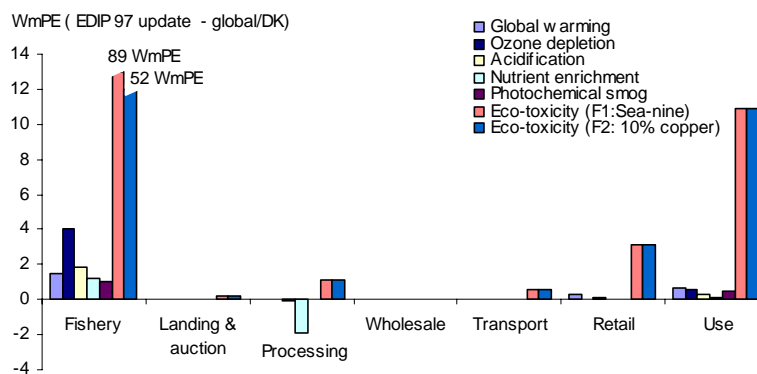


Figure 11. Weighted results for one kg consumed ordinary flatfish filet, caught by average fishing method in the two future scenarios.

As it appears, the fishery, use and retail stages are still the hot-spots in the future scenario. As suggested under characterization and normalization, the most significant change in the future scenarios is related to antifouling. Obviously, the fishing stage becomes less important for eco-toxicity, but the fishery still dominates the eco-toxicity category in the two future scenarios.

In the normalization step (based on the LCAfood normalization references), the eco-toxicity potential at the fishing stage was reduced from 39 mPE to 35 mPE in F1 and down to 3 mPE in F2. For the weighted step, based on EDIP 97 update, the eco-toxicity potential is reduced from 753 WmPE to 89 WmPE (F1) and 52 WmPE in F2 in the fishing stage⁵⁹. Thus, we see a larger reduction in F1 mainly because ETWA has a very small relative importance in the EDIP 97 update. Basically, ETWC is dominating, due to low normalization references.

Hence, the weighted results for F1 and F2 confirm that the fishing stage is the most important, which is also the case for scenarios where Danish seine and beam trawl are used.

⁵⁹ Copper make up 35%, while "Sea Nine" only make up 15% of the impact potential for eco-toxicity in F1. In F2, copper, which is the only biocide, only make up 14 % of the eco-toxicity potential. In F2, the main contribution to eco-toxicity is related to energy consumption for all fishing methods. In F1, antifouling agents still play an important role for the contribution to eco-toxicity, for all fishing methods except beam trawl.

Trade-off between energy and antifouling

The weighted results based on the EDIP-97 update shows no trade-off situation in the two future scenarios.

If we aggregate the impact categories and consider an aggregated single indicator for one kg consumed flatfish filet, it appears that it will be possible to obtain a factor 9 eco-efficiency improvement for the “traditional” five impact categories by switching from beam trawl to Danish seine in the fishing stage alone – see figure 12 (left). Due to the difference in scale, eco-toxicity is treated separately and the improvement potential is only a factor 3-5. A factor 3 can be obtained if it is assumed that the future anti fouling paint is based on “Sea Nine” and copper in a 40% w/w concentration – see figure 12 (middle). A factor 5 can be obtained if a paint is developed, which only contain copper in a 10% w/w concentration - see figure 12 (right).

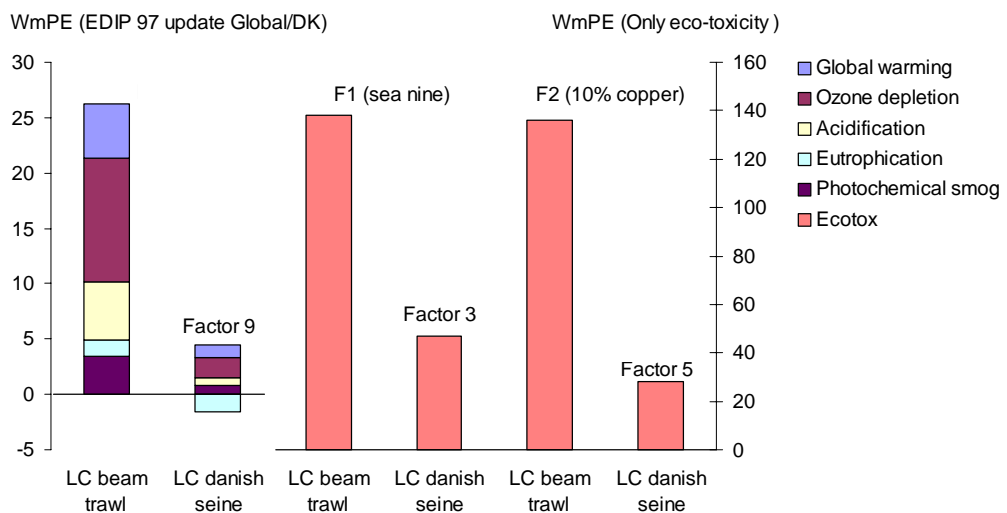


Figure 12: Improvement potential considering the aggregated weighted impact potential for one kg consumed flatfish filet caught with beam trawl and Danish seine, in the two future scenarios F1 and F2

As I will explain in the evaluation, the uncertainty for eco-toxicity is considerable and the weighted values may have been overestimated in a number of cases.

Obviously, this type of aggregation should be used with caution, and large uncertainties apply. However, the difference is so remarkable, that even large uncertainties with a considerable bias, would hardly change the overall conclusion⁶⁰. In this respect, it is worth to note that the difference in fuel consumption in the fishing stage alone is a factor 15.

9.3 Generalization (LCA screenings of other fish)

As explained in chapter 2, it appears that the export of Danish edible wild fish products are dominated by four groups of products:

1. Prepared or conserved fish – dominated by pelagic fish and shrimp
2. Fish filets (fresh and frozen) – dominated by cod, flatfish and herring
3. Breaded and ready made fish dishes - dominated by cod and flatfish
4. Whole fresh fish - all species groups

The LCA of frozen flatfish (plain and breaded) represents some of the products in category two and three, but the following will include a more detailed analysis of how representative it is in terms of environmental impacts, compared to other products. Furthermore, I have conducted a separate analysis of the environmental impacts for fish products from the other categories.

How representative is the flatfish LCA?

It is difficult to establish exactly how representative the plain and breaded flatfish are, compared to other fish species that are landed by Danish fishermen and further processed in Denmark.

⁶⁰ If we only consider the contribution to eco-toxicity related to anti fouling agents, it can be established that Danish seine contributes with 22 WmPE in F1 (70% from copper and 30% "Sea Nine") and 3,8 mPE in F2 (only copper). For beam trawl it is 2,6 WmPE in F1 (70% from copper and 30% from "Sea Nine") and 0,6 WmPE in F2 (only copper). Thus, in F1 Danish seine contributes with 19 WmPE more for eco-toxicity while it is only 3,2 WmPE more in F2. Thus, if we disregard the energy related eco-toxicity potential, Danish seine would still perform considerably better in F2, as the total difference in other impact categories (aggregated) is around 20 WmPE.

However, if we consider the fishing stage, the fuel consumption for flatfish is 0,97 liter per kg in average. Both concerning energy consumption and emissions of antifouling agents, the flatfish LCA represents average demersal fish (excl. mussels) – see chapter 4.

For average edible fish, the fuel consumption is roughly three times smaller, which also applies to emissions of antifouling agents. Thus, for average edible fish the impact potential at the fishing stage will be roughly three times smaller.

For the processing stage, clearly the energy consumption is the most important factor for the impact potential for the six impact categories used in the previous LCA⁶¹.

For processing, it was previously established (see chapter 4) that the average immediate energy consumption was around 1 MJ electricity and 3 MJ heat energy per kg fish product – which is somewhat lower than the data used for the flatfish LCA 3,8 MJ electricity and 2,3 MJ heat per kg fish product. Thus, compared to the average fish processing, the flatfish LCA actually appears an overestimate, but obviously some fish product use energy intensive ancillaries and packaging material⁶² (this is discussed later).

Concerning transport, the flatfish LCA corresponds to the average transport distance for edible fish, but obviously some products such as pickled herring are more transport demanding per km because of the higher product weight per kg filet.

For retail and consumption, the flatfish scenario is representative for most other fish that are sold frozen and prepared hot. For food preparation, I have assumed that the fish are fried in a pan, which represents the average energy

⁶¹For wastewater it should be noticed that the environmental impacts are insignificant after wastewater treatment.

⁶² Concerning packaging, it is assessed that coated cardboard boxes – each containing 300 gram fish filets, as used in the LCA case study – represents an average scenario for frozen fish filets. Frozen fish filets are mainly sold in cardboard boxes, but also in a variety of other packaging forms such as various forms of plastic (PE) including plastic with a very thin layer of aluminium-foil (Company flatfish, 2002). Due to the lack of reliable data for packaging in the ETH-ESU 96 database, alternative packaging forms have not been assessed here

consumption, considering extremes such as preparation in microwave and traditional oven. A large contribution in the use stage comes from shopping by car, and here I have assumed that the average consumer uses car and travels a total distance of 8 km per shopping trip (see app. 8). Obviously not all consumers use cars, and it must be assumed that this has led to some overestimation.

Overall assessment

All things considered, a rough assessment suggests that flatfish is representative for the average frozen fish filet products except for the fishing stage, where it represents three times higher exchanges for energy and antifouling, compared to average edible fish products. However, this is not the case for breaded flatfish where the exchanges related to fishery are 40% lower – nor is it the case for the production scenario, where Danish seine is used. In fact, the latter has half of the exchanges for fuel and antifouling compared to average edible fish. It should also be considered that ancillaries and energy intensive packaging materials might contribute to a considerably larger impact potential for some fish products at the processing stage.

LCA screenings of other fish products

I have considered it necessary to conduct a number of LCA screenings for other fish products, illustrated by the color blue in figure 13. Bold boxes represents the processes for the LCA on ordinary and breaded flatfish previously described.

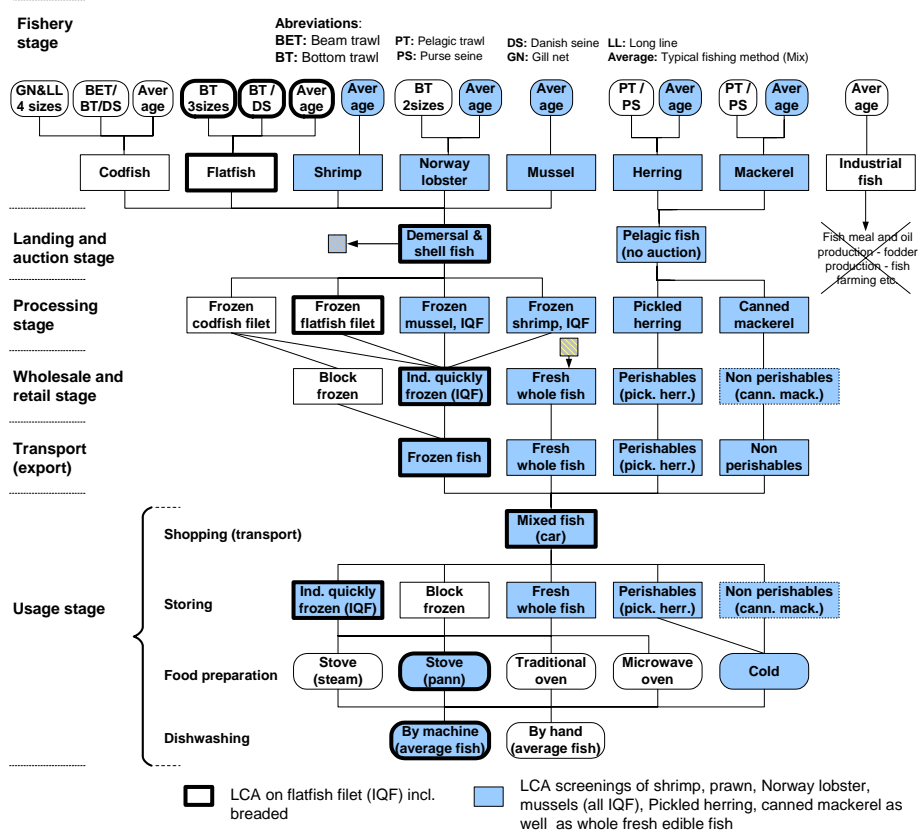


Figure 13. Illustration of different process (round box) and product distinctions (square box) made in the MECO analysis. The connections show potential scenarios. Dash and dot lines illustrate processes considered insignificant in terms of exchanges.

As the figure shows, the LCA screenings (blue boxes) include five different fish species and a number of processes of which some are the same. The LCA on ordinary and breaded flatfish filet are illustrated with bold boxes. Obviously, it is possible to make many scenarios, but the figure only illustrates processes and products included in the MECO analysis.

LCA screening of pelagic fish (category one⁶³)

Pelagic fish is one of the main export articles from the Danish fish processing industry and is mainly exported as prepared or preserved fish (measured in terms of fish meat volume). Considerable amounts are also exported as whole fish and fresh filet (especially for herring). However, it must be assumed that a large part of these products are further processed abroad. Thus, pickled herring and canned mackerel are the most interesting products in this category.

Methodological aspects. As pelagic fish mainly are sold directly to the processing industry, the landing and auction stages have been disregarded. The exchanges at the fishing-, processing-, transport- and use stages have been modified according to the typical exchanges described in the MECO analysis in chapter 5. Regarding processing of pickled herring, data for vinegar, onion and pepper have not been included. Data for sugar have been obtained from the LCA food database, while data for NaOH, and HCl are from the ETH database. Furthermore, data for glass and plastic is obtained from the Buwal database, where I have used virgin glass (no recycling). Apart from this, the databases and allocation procedures are similar to those used in the flatfish study⁶⁴. It should be stressed that the data from the MECO analysis mainly are obtained from a LCA screening of pickled herring which operates with a functional unit of 205 gram filet in a jar 295 gram glass, a 50 gram tin lid and 354 gram marinade (Ritter, 1997).

For canned mackerel, it is assumed that the oil consists of rapeseed oil, which is used in considerable parts of the canned mackerel products (Madsen, 2001). Data for ancillaries such as sugar and rapeseed oil has been achieved from the LCAfood database. Data for aluminium is obtained from the ETH database for aluminium (0% and 100% recycled respectively), while data for aluminium-cann production is obtained from Madsen (2001). Data for all immediate exchanges at the processing stage are obtained from Madsen (2001) as they represent the largest company in the world and considerably larger exchanges than suggested by other references – see chapter 5. The study by Madsen is based on a functional unit of one canned mackerel

⁶³ This refers to the product categories presented in the beginning of section 9.3.

⁶⁴ As in the flatfish, LCA data for NaOH and chlorine are based on mass allocation. Ideally, data based on system expansion should have been used, but as the environmental impacts from NaOH and chlorine are insignificant, it has been assessed that the uncertainty for these data are of minor importance.

with a net weight of 125 gram, with 80 gram mackerel filet and 30 gram oil. The weight of the can is 17 gram.

For the weighted results for pickled herring in virgin glass and with pickled herring in plastic bucket (PP)⁶⁵, see figure 14.

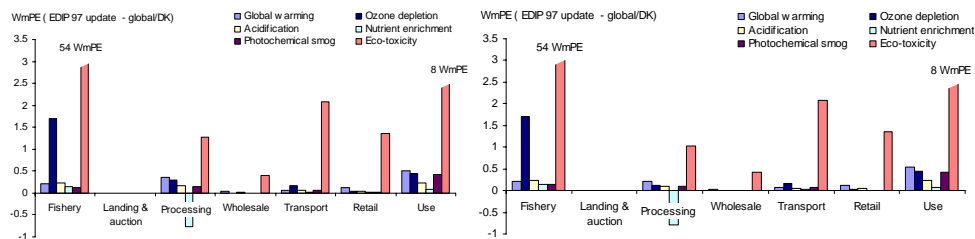


Figure 14: Weighted screening results for one kg consumed pickled herring in glass jar (left) and plastic bucket made of PP (right).

As it appears, the LCA screenings confirm that the processing stage is relatively important for pickled herring, but the impact potential can be significantly reduced by switching from glass to plastic⁶⁶ or recycled glass, but the latter has not been further analyzed. In both cases the large contribution from processing mainly comes from the packaging, but it should be emphasized that I have used a worst case with virgin materials in both cases⁶⁷. The study also confirms that the transport stage becomes more important at the expense of retail and that the dominating role of the fishing stage becomes less explicit.

I have also developed two scenarios for canned mackerel, representing the use of virgin aluminium and 100% recycling of aluminium – see figure 15.

⁶⁵ In the scenario with plastic packaging, the amount of packaging is estimated based on a functional unit that contains 400 gram filet per bucket of 45 gram.

⁶⁶ It should be stressed that I have used data from the Buwal database for the materials and that ETH data would have resulted in higher impacts – at least for plastic. However, there were no ETH data available for glass and I therefore used Buwal data in both cases – to obtain a fair comparison.

⁶⁷ It should be stressed that the difference in eco-toxicity between glass and plastic is very uncertain, as I have used the Buwal database for glass and the ETH for plastic. Generally speaking, the ETH database has higher contributions to toxicity – probably because it is more detailed.

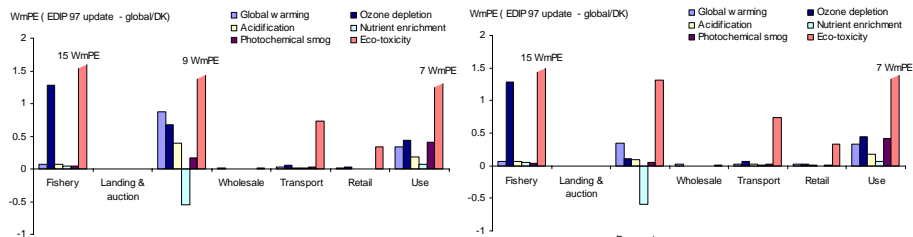


Figure 15: Weighted results for one kg consumed mackerel in oil based on virgin aluminium (left) and 100% recycling of aluminium (right)

This case also shows that the processing stage can be important for some product types, but it is also illustrated that a large improvement potential exists if aluminium is re-cycled. The improvement would probably be even greater if aluminium cans were substituted with the pouch mentioned in chapter 5.

This shows that packaging is indeed important, but for canned mackerel the results also reflect relatively high immediate energy consumption at the processing stage. I have based this scenario on a worst-case approach based on data obtained from Madsen (2001)⁶⁸.

A comparison between the pelagic products analyzed here and the LCA results for flatfish filet show that the transport stage is more important for pickled herring, due to weight of glass and marinade, while the use stage has smaller impacts, especially for canned mackerel.

LCA screening of shellfish (category one - continued)

To further improve the basis for generalization, I have also conducted LCA screenings of four frozen processed shellfish products (IQF shrimp, IQF prawn, IQF blue mussels and IQF Norway lobster). As described in chapter 3, Norway lobster is typically not processed, but this is assumed to be the case here anyway (worst case).

⁶⁸ Other production methods - where the production is based on fresh raw materials and where chemicals (NaOH) are used for the de-skinning process instead of steam - will reduce the impact potential, due to lower energy consumption. See chapter 5.

Methodological aspects. As for pelagic fish, the LCA screenings of shellfish are based on the data available in the MECO analysis in chapter 5. For mussels the data in the MECO analysis are mainly obtained from a LCA screening of 1 kg IQF blue mussels (Andersen et al. 2000). This means that the amount of packaging is relatively small compared to shrimps, prawn and Norway lobster, where the amount of packaging is estimated from the LCA of flatfish, where the functional unit only is 300 gram filet in consumer packaging.

The results for shrimp and prawn are similar apart from the fishing stage, where shrimps have a slightly higher impact potential due to the larger fuel consumption. It is assumed that both products are frozen shrimps/prawns (IQF) packed in cardboard boxes⁶⁹. The results are illustrated in figure 16.

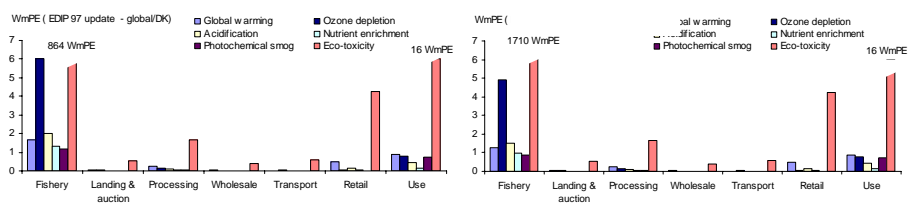


Figure 16: Weighted screening results for one kg consumed shrimp IQF (left) and prawn IQF (right), caught by average fishing methods.

Obviously, fresh shrimp and prawn can also be packed in tinsplate or aluminium and produced with different kinds of marinade. This is an example of scenarios not included in the MECO analysis and therefore not presented as part of the LCA screenings. However, it must be assumed that we would see some of the same tendencies as for pickled herring and canned mackerel with a somewhat higher impact potential at the processing stage – especially for aluminium. However, the exchanges at the fishing stage are considerably higher (roughly a factor 15) compared to mackerel, and the fishing stage would therefore still be the hot-spot.

If we compare with the flatfish LCA, the major difference is that shrimp and prawn have a considerably larger impact in the processing stage. This is mainly because the processing of shellfish involves one or more boiling processes.

⁶⁹ Calculations in Simapro shows that there is practically no difference if the products were packed in plastic

Finally, I have conducted an LCA screening of blue mussels and Norway lobster – two products that represent respectively a very low and a very high energy consumption in the fishing stage. The only extra material used is nitrogen for cooling at the processing stage for blue mussels. These data are obtained from the ETH database. The results are illustrated in figure 17.

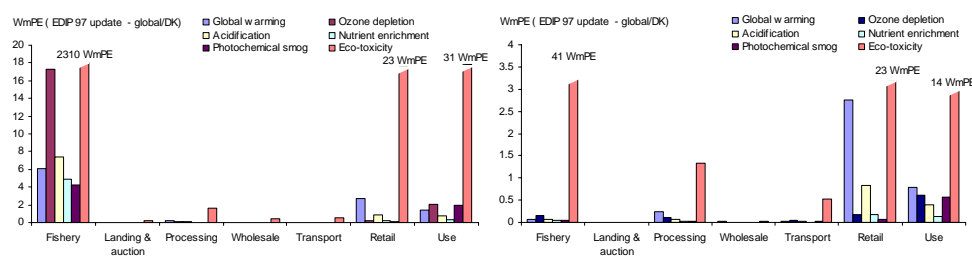


Figure 17: Weighted screening results for one kg consumed Norway lobster IQF (left) and blue mussels IQF (right), caught with average fishing methods. Notice the difference in scale!

The results of these two screenings look as if they are mirrored, but the difference in scale (second axis) should be considered. In fact, the difference is basically that Norway lobster represents large energy consumption in the fishing stage, while the opposite is the case for blue mussels. It is interesting that the processing stage has a relatively small importance in both cases⁷⁰.

Compared to flatfish and other products analyzed in this section, the retail stage is relatively important. This is because it is assumed that both Norway lobster and blue mussels are specialty products with a longer exposure time in the supermarket⁷¹.

⁷⁰ As a worst case approach, it is assumed that the exchanges for processing of Norway lobster is similar to shrimp and prawn, but - in fact - I have no data for processing of Norway lobster, and as described in chapter 3, these are typically exported as whole frozen or fresh. Thus, it is most likely that some of the impacts from the processing stage actually should be moved to the use stage, but this has not been further analyzed here.

⁷¹ Interviews with various supermarkets have unveiled that some specialty products (such as mussels and certain other shellfish) may have an exposure time of up ‘till 6 months in some cases (see chapter 6). Therefore, I have used an exposure time of 3

LCA screening of fresh fish (category four)

As explained, fresh fish is also a large export article from Denmark. The export encompasses most species and it would be too much to present all the separate LCA screenings here. Therefore, I have made an average scenario that considers fish products based on average demersal fish excl. mussels⁷² that are exported fresh and whole.

Data for this species group have been separately described in chapter 4, and for the remaining stages I have simply used average data for fresh fish presented in chapter 5 and 6. The only new material that has been used is EPS (Expanded Poly Styrene), where data has been obtained from the Buwal database. For wastewater, I have used a worst-case scenario where the COD emissions are 300 gram per kg prepared fish, similar to the processing stage for shrimp – according to chapter 5. Considering the use stage, a large amount of fish waste is assumed to be treated in public waste incineration facilities, where the environmental impacts are relatively small. The results appear in figure 18.

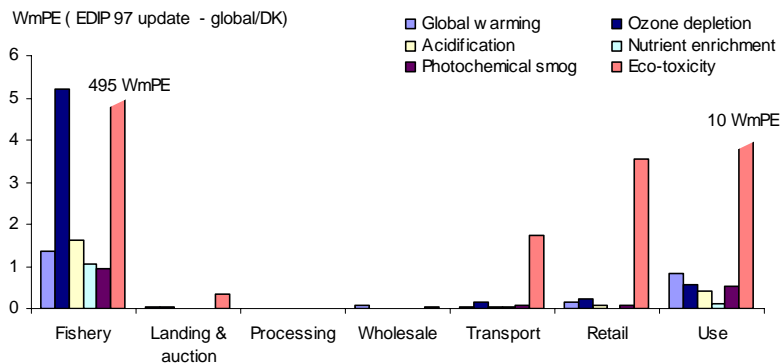


Figure 18: LCA screening for fresh demersal fish excl. mussels

months in these two cases. For the other fish products, 3 weeks have been used as an average.

⁷² Mussels are also exported as whole, but have not been included here because the meat content deviate so much from other species that a collective grouping would be too difficult. As mentioned in chapter 3, pelagic fish are also exported whole, but as it must be assumed that a great proportion of especially herring is further processed abroad – these have not been included as well.

Compared to the frozen flatfish products, it is generally the same picture except from slightly higher impact potential at the fishery, auction, transport and use stages - and obviously no impacts related to processing.

The increase at the fishing stage occurs because I have assumed that the average filet yield for this group of species is relatively low (0,3 kg filet per kg caught fish)⁷³.

At the auction, additional EPS packaging is used before the fish are dispatched.

The increase in the transport and use stages is mainly because the fish are filleted at the use stage, and larger amounts of products have to be transported per kg filet. Basically, a considerable amount of “water or fish waste” is transported when the fish are exported whole⁷⁴.

The retail stage has relatively small impacts due to the lower storing time.

There are several environmental disadvantages in exporting the products as fresh fish. Basically, it increases the need for transport, and by-products are not substituting other products. Even though I have not accounted for this, it must also be assumed that increased spillage will occur for fresh products. On the other hand, energy savings will occur related to cold storage.

From an overall point of view, the results emphasize the importance of the fishing stage – but obviously, the fishing stage would have been less important if mussels, mackerel and herring had been included. However, fish that are exported to fresh fish markets in central and southern Europe are mainly demersal fish (Fiskebranchen, 1999).

Overall assessment of eco-toxicity for LCA screenings

As illustrated in chapter 4, the emissions for antifouling agents follow the same pattern as energy consumption with highest emissions among demersal fish (especially Norway lobster) and the smallest emissions for mussels,

⁷³ In this regard it should be considered that the species group include shellfish with a relatively low filet yield and that the private household probably utilize slightly less of the fish meat than when the fish are processed by professionals.

⁷⁴ Furthermore, EPS boxes and ice reduce the trucks' load capacities with roughly 25% compared to transport of frozen fish (see app. 7A).

pelagic fish- and shellfish. Obviously, the impact potential is generally remarkably high and large uncertainties definitely exist – but probably least at the fishing stage. This is discussed in the interpretation.

The results show that the fishing stage is the most important for eco-toxicity (mainly due to antifouling agents) for all product types – even blue mussels and canned mackerel, where the consumption of energy and antifouling agents from the fishing stage is relatively low. The second most important stage is the use stage for all products except for canned mackerel, where the contribution to eco-toxicity at the processing stage is high due to the consumption of aluminium.

In the future scenarios this will probably still be the case for all products due to other biocides than TBT or the energy consumption, except canned mackerel and frozen blue mussels due to their low energy consumption.

9.4 Evaluation (Interpretation)

According to the ISO standard on life cycle assessment, the interpretation phase should include an identification of significant issues, evaluation (completeness, sensitivity and consistency control), and finally conclusion and recommendations (Jerlang et al. 2001).

In the present report, the identification of significant issues has been discussed together with the results in chapter 8 and 9. This section contains the evaluation while the conclusion is described separately in the following section – even though it is also part of the interpretation.

Concerning the evaluation, I have chosen to structure the chapter somewhat different than suggested in the standard. First, I have discussed uncertainties and sensitivity related to data. Secondly, I have discussed methodological uncertainty related to characterization, normalization and weighting. Finally, I separately discuss aspects of completeness and consistency. As flatfish has been the main object of the LCA, the focus will primarily be on flatfish.

Introduction to uncertainty

I have separated the discussions of uncertainty in uncertainty related to data and methodological aspects, related to system delimitations, co-product allocation etc. Obviously, methodological uncertainty can be related to the data uncertainty this has not been further analyzed.

Data uncertainty

Obviously, there are large uncertainties in the LCA presented in part three. The uncertainties are partly related to the data used – *garbage in equals garbage out*. In this regard, I have operated with data quality indicators related to scope, reliability and completeness – and the assessment was that many datasets varies from –75% to +200%. Obviously, the uncertainties for the forecasts are even larger.

Methodological uncertainty

Data uncertainty is only a part of the overall uncertainty. Based on the analysis in the following sections, I find the methodological choices to be more important than the data uncertainties.

Concerning methodology, the results can be significantly influenced by decisions made during system delimitation and methods used for co-product allocation. In LCIA, uncertainties derive from the establishment of characterization factors where the temporal aspect is one of several uncertainty factors⁷⁵. It is also important to stress that the characterization results only reflect the impact *potential*. This means that the impacts may not even occur. This is especially the case for regional and local impact categories, where it is obvious that some recipients are more sensitive to nutrient enrichment, acidification, smog or toxicity, than others. Site-specific aspects are very important in this respect – but apart from considering where the emissions occur, the ideal method would include considerations on background concentrations, exposure etc.

Additional uncertainties derive from choices with respect to normalization references – for instance whether we should use local or global references. Similarly, there are large uncertainties related to weighting factors. In the

⁷⁵ For instance, we could choose to consider the contribution to ozone depletion in a 10 year perspective instead of a indefinite time perspective as suggested in the EDIP method. The same applies to global warming, where it could be argued to use 50 years or 500 years instead of 100 years as recommended.

EDIP method, the weighting step can be interpreted as yet a normalization, where the reference reflects the target reference for 2004. In some cases, the target reference is established from extrapolation or interpolation, and therefore additionally uncertain. Furthermore, weighing factors for eco-toxicity only reflect an average situation for a group of key chemicals and not the overall reduction target for all chemicals – because it simply does not exist⁷⁶. Basically, the methods presently used for weighting are very uncertain, but a right answer does not exist. The nature of the problem is that it is subjective – the choice will always be subjective.

Uncertainty and sensitivity analysis in this report

The data uncertainty is only a small part of the total uncertainty, and I have therefore chosen to conduct a qualitative/descriptive uncertainty assessment instead of a quantitative oriented assessment where uncertainty margins have been established. The latter would be absurd – partly because uncertainties can be hidden in places where we have not even looked for it, and because more or less arbitrary assumptions have to be made in a number of cases – e.g. concerning distribution functions etc. Instead, I will challenge some of the main results, namely that the most important stages according to the quantitative LCA is fishery, use and retail stages. The conclusion on the uncertainty and sensitivity analysis include a discussion of uncertainty and sensitivity related to breaded flatfish and the LCA screenings, as well.

Data uncertainty

Aspects of data uncertainty and sensitivity are discussed in the following.

Immediate exchanges (uncertainty)

As mentioned in part two, the data uncertainties are assessed to be smallest at the fishing stage, where key exchanges related to energy are verified by energy balances for the whole fishery. Table 2 provides an overview of the estimated variance for different types of exchanges used in the LCA. For exchanges which already represents intervals, the variance applies to the average value.

⁷⁶ If we were able to establish a separate weighting factor for each relevant chemical, the weighting factor for TBT would go towards indefinite as well - as the target is that it should be completely phased out in Denmark before 2004.

Table 2: Overview of assessed variance in immediate exchanges, part three.

Life cycle stage	Exchange	Estimated variance	
		Min [pct]	Max [pct]
Fishery	Energy per species	-25	+25
	Energy per species and gear	-35	+35
	Antifouling per species	-50	+50
	Antifouling per species and gear	-70	+70
	Cooling, cleaning agents, lead and gear	-75	+200
	Other	-50	+50
Landing and auction	All exchanges (energy)	-75	+200
Processing (only for flatfish LCA)	Water consumption, wastewater and cleaning agents	-75	+200
	Other (ancillaries, heat, electricity, packaging, waste, sludge etc).	-25	+25
Processing (LCA screenings)	Water consumption, wastewater and cleaning agents	-75	+200
	Other (ancillaries, heat, electricity, packaging, waste, sludge etc).	-50 (-75 mack).	+50 (+200 mack).
Wholesale	Electricity (volume)	-50	+50
Transport	Energy (distance, loading etc).	-50	+50
Retail	Electricity (volume)	-50	+50
Use	All exchanges (shopping, storing, food preparation and dish washing)	-75	+200

Considering the relatively small exchanges at the fishing stage, it is clear that the fishing stage will remain one of the most important stages – even if we chose the lowest possible value for each type of exchange.

Immediate exchanges (sensitivity)

As it appears, large uncertainties exist for key exchanges at the use stage. In this respect, I have analyzed the effect of a reduction of 75% at the fishery, retail and use stage combined with an increase at the processing stage of 200% (a quite unrealistic scenario considering the uncertainty of +/-25% for energy consumption at the processing stage). The results for ordinary flatfish filet are illustrated below.

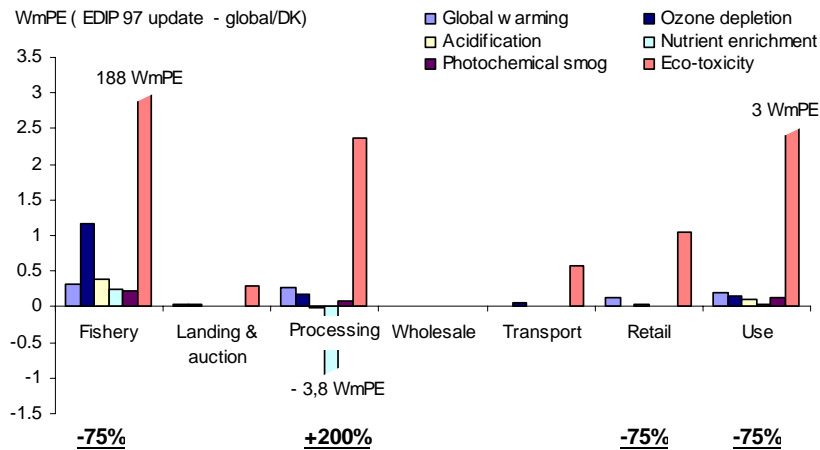


Figure 19: Weighted results (EDIP 97 update) for ordinary flatfish filet with suppression of life cycle stages that previously (see figure 5) have been considered the most important and accentuation of the processing stage previously estimated to have a relatively small importance.

As it appears, the conclusion is that the fishery, use and retail stages remain the most important stages. Obviously, the data uncertainties will be even larger in the future scenarios, but I have not conducted any further analysis of this. In a deeper analysis, a critical review of the assumptions made to develop the scenarios in chapter 4-6 would be relevant.

As mentioned, I have focused on flatfish in this analysis, but I would assess that the results apply to other demersal fish and shellfish as well. The reason is that the uncertainties, as well as the exchanges at the different life cycle stages, are roughly the same.

For pelagic fish products, a sensitivity analysis of this kind would obviously further emphasize the importance of the processing stage. The importance of the fishing stage would become very small – especially for mackerel, and it would no longer be possible to characterize this stage as a hot-spot.

Related processes (uncertainty)

The data uncertainties for present and future exchanges are not only related to the immediate exchanges but also the data obtained from related processes – mainly databases. However, these databases are typically not delivered with uncertainty intervals, and a quantitative assessment has not been possible.

Instead, I will refer to the data quality assessment in chapter 8.3, where I have stressed that the uncertainty probably is highest for the ETH database due to the lack of temporal correlation. For transport in particular, large reductions in benzene and NO_x, SO_x and VOC emissions have occurred during the last ten years. According to Miljøstyrelsen (2003), reductions in NO_x, SO_x and VOC emissions from traffic has been around 20-30% during the last 10-15 years. Similar reduction rates have been observed in EU in the period 1990-2000 (European Environmental Agency, 2003). As mentioned, we have probably also experienced a reduction in the consumption and emission of halons during fuel production.

Related processes (sensitivity)

Particularly for transport but also for energy processes, the reductions in NO_x, SO_x and VOC emissions is believed to have caused an overestimation of nutrient enrichment, acidification and photochemical ozone formation. However, the overestimation is probably smallest at the fishing stage because the data for combustion are obtained from separate and more updated literature references. *Thus, the fishing stage is more likely to be relatively underestimated (compared to the other stages).*

If we disregard halon altogether, HCFC22 from the fishery still constitutes nearly 97 % of the total ozone depletion potential. Cooling agents are also used in the rest of the product chain, but not HCFC22. Instead HFCs or natural cooling agents, such as NH₃, are used. Both types have insignificant ozone depletion potentials.

Uncertainty related to system delimitation

Aspects of uncertainty related to the system delimitation and co-product allocation are discussed in the following.

Considerations about the geographical scope

As mentioned earlier, the systems are limited to include processes in Denmark carried out by Danish producers from sea to wholesale while central and southern European countries are representative for the retail and use stages. Obviously, this does not represent Danish fish products bought and consumed in Denmark, which would have resulted in a smaller contribution to global warming, as gas is used as the marginal energy source in Denmark.

Obviously, it should also be considered that a considerable part of the fish exported from Denmark are imported or landed in Denmark by foreign fish-

ermen. These products may represent somewhat different exchanges, especially for transport (see app. 7), but as the purpose has been to elucidate the hot-spots in the product chain in a Danish regulation perspective, this has been less relevant. The reason is that Danish environmental regulation has relatively small possibilities to influence exchanges related to foreign fishing fleets, auctions, processing industries, wholesalers and fish exporters. Obviously, this is even more the case for the retail and use – but the export is so large (95% of all fish products processed in Denmark) that a focus on Danish retail and consumers would be somewhat irrelevant.

Considerations about system expansion and co-product allocation

System expansion has been carried out in a number of cases, including the fishery, processing and the use stages. In this respect, the identification of affected processes involves considerable uncertainty – partly due to assumptions about affected processes and partly due to data uncertainties within the selected processes.

At the fishing stage, one of the main assumptions is that the fish quotas are fully utilized and that by-catch in one fishery substitutes the quota in another fishery targeting the given by-catch. However, it could be argued that by-catch in many cases remains un-registered or is thrown out. Furthermore, it can be argued that some species are not fully utilized in some periods. The stock of Norway lobster has presumably not been fully utilized during the last decade but as the fishery has gradually increased, the fishery may be limited by quota or natural limitations in the following years. If it had been assumed that no quota existed for Norway lobster fishery, the distribution of fuel consumption between the species would probably have changed significantly because this fishery is the most fuel intensive. However, it would not change the overall fuel consumption because I have considered the entire Danish fishery. The data presented in chapter 4 include exchanges of energy and antifouling agents based on mass and value allocation. In this regard demersal and shellfish represent the largest exchanges – independent of the allocation method applied⁷⁷.

⁷⁷ It is also worth to mention that results based on system expansion are believed to provide the most accurate picture of the distribution of exchanges even though there are uncertainties involved here as well. Basically, the other methods represent even larger uncertainties due to the more arbitrary allocation parameters such as price and mass. As an example, economical allocation in the combined herring and mackerel fishery would have suggested that mackerel represent considerably larger exchanges than herring even though the opposite is the case.

At the processing stage, I have assumed that fish waste used for mink fodder eventually substitutes soy protein because soy protein is the marginal protein source. However, it is not necessarily true that a given reduction in demand for a product will lead to a proportional reduction in production of the given product. In other words, the production volume is not necessarily fully elastic. Furthermore, it may not only be producers in Argentina (as assumed here) that are affected - even though the largest import of soy protein to Denmark is from Argentina now. For the fish waste processed to mince, I have assumed that it substitutes pork meat, but it could also substitute other products such as chicken or farmed fish. Arguments for choosing pork meat are available in app. 10.

Co-product allocation based on mass has been applied in a few cases. This is the case for a few exchanges at the fishing stage, cleaning agents (all stages) and process chemicals used at the processing stage. However, all these exchanges have a marginal influence on the end-result and are therefore considered insignificant. In other words, a more detailed analysis would not give a significant contribution to the certainty of the results.

Assessment of sensitivity for system delimitation and allocation

To illustrate the sensitivity to methodological choices for co-product allocation and system delimitation, I have established a scenario where I have used mass allocation in the fishery and where the fish waste at the processing stage substitutes 50% less soy protein and pork meat⁷⁸. Furthermore, I have assumed that coal is the marginal electricity source for all processes in Denmark as well. Finally, I have assumed the utilization in the transport stage is 50% instead of 90% as previously assumed.

This scenario is chosen because it reduces the exchanges at the fishing stage as much as possible, while the opposite is the case for the processing stage, transport and use stages.

⁷⁸ As mentioned in app. 10 data for chicken have not been available. It should be noticed that the calculations in Simapro are based on the assumption that the substitution by pork meat takes place at the agricultural level. The assumption that minced fish actually substitute frozen minced pork delivered from the slaughterhouse would be more reasonable. However, this would have reduced the impact potential at the processing stage even more.

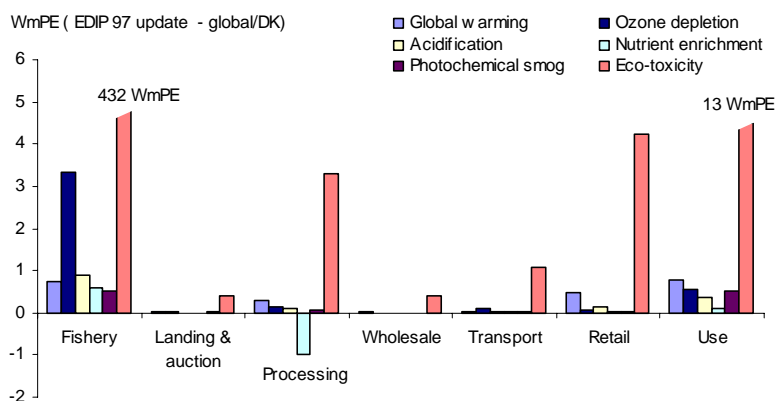


Figure 20. Weighted results for an extreme case of flatfish filet where the processing stage is emphasized as much as possible

As it appears, the processing stage becomes somewhat more important, especially for global warming, which is due to the use of coal as the marginal electricity source instead of gas. Still, the fishing stage has the largest contribution to weighted person equivalents.

Based on discussions with other LCA practitioners within food products, I have realized that I have probably underestimated the amount of product spillage during the life cycle – I have only assumed that there is a very small spillage at retail (0,1-0,2%) and a 10% spillage at the use stage. *However, a larger product spillage would only emphasize the processes upstream and therefore stress the importance of the fishing stage.*

It is also worth to stress that the process chains for antifouling agents have not been terminated. This means that I have not considered the production of the antifouling agents. I expect that the production involving considerable amounts of copper has a relatively significant additional environmental impact, *which again would have lead to an even higher impact potential at the fishing stage.*

Specific considerations about allocation in wastewater treatment plants

As previously described, I have assumed that a change in the amount of wastewater delivered to the treatment plants does not affect the emissions of COD, N and P to the recipient, but mainly the consumption of energy at the plants. This assumption is based on studies carried out by 2-0 LCA consultants as a part of the LCAfood project in Denmark (www.lcafood.dk). The

main argument is that the plants are regulated and that the emissions to the recipient mainly are influenced by emissions standards and not the concentration of the wastewater received.

Separate studies conducted as a part of the present study unveils that it is worth considering the wastewater volume as well – the LCAfood database has focused on N, P and COD emissions. According to Bo Skovmark at Northern Jutland County, the emissions limits for wastewater treatment mainly address the concentration of the wastewater. Thus, if the fish processing industry increases the volume of wastewater, the result would probably be a proportional increase in the absolute emissions of COD, N and P according to Skovmark (2003). This statement is confirmed by the environmental manager Kim Rendel at one of the largest wastewater treatment plants in Denmark, Lynetten A/S in Copenhagen (Rendel, 2003).

According to Skovmark (2003) and Rendel (2003), the wastewater treatments plants also have maximum allowances concerning the maximum water emissions, but these are only guidelines and typically do not affect the plants.

Thus, it appears that the water volume received by the treatment plant may affect the absolute emissions - in some cases, at least. I have therefore assumed that the maximum allowed emissions are proportional with the flow from the fish processing industry, which typically has the largest emissions of wastewater in the product chain. I have based the data for wastewater treatment on a study by Kromann (1996) which include data for consumption of iron sulfate, energy for pumping and emissions to the recipient according the emissions limits (8 mg N per liter, 1,5 mg P per liter and 15 mg COD per liter).

Sensitivity. To find a case that represents the largest contribution of wastewater, I have used shrimp where the water emissions are assumed to be 120 liter per kg processed shrimp, and where the total COD emissions is assumed to be 300 gram. In this case, the most important contribution to nutrient enrichment at the processing stage is indeed emissions from the wastewater treatment plant (11 gram NO_3) after characterization. However, the total contribution for all life cycle stages is 316 gram NO_3 , where 82% comes from fishery and 10% comes from the use stage. As this represents a worst case - with respect to the emissions at the processing stage - it must be considered that emissions of wastewater are insignificant, compared to other sources of nutrient enrichment such as combustion of fossil fuel – especially in the fishing stage.

Still, site-specific considerations, as well as considerations about the difference in emissions to the air compartment and the water compartment, are necessary to fully validate this conclusion. This has not been done in the present dissertation.

Uncertainty related to characterization

There are multiple sources of uncertainty in the characterization step, and it would be impossible to describe all of them. Instead, I focus on a few important aspects and compare with results obtained by other methods.

Uncertainty for eco-toxicity

The substances contributing to eco-toxicity are numerous and studies of the eco-toxicity are limited with respect to test organisms, long-term effects and effects that we typically have little knowledge of, such as genetic effects and hormone disruption effects. It has therefore been my ambition to find the right order of magnitude when assessing toxicity.

Uncertainty for global warming and ozone depletion

For some impact categories, there is a temporal dimension that has a large influence on the results, e.g. for global warming and ozone depletion.

In this regard, my studies have shown that a considerable change of the result can be obtained if we use a time horizon of 10 years instead of indefinite for ozone depletion. *The short time horizon emphasized the emissions of HCFC20 from the fishing stage, and therefore stress the result that the fishing stage is important.* Still, HCFC are currently being phased out, and therefore less relevant to even consider.

Validation

The characterization results presented in chapter 8 were continuously compared to results obtained by two Dutch methods for LCIA, the EcoIndicator 99 and the CML 2 baseline, both available in SimaPro. Generally, there was good correlation between the methods – especially for the two global impact categories global warming and ozone depletion.

Still, some discrepancies exist, especially for eco-toxicity water, where the CML method suggests that TBT is insignificant in the marine compartments. However, I find the results obtained by the EDIP method more reliable –

mainly because the results are consistent with effects that have been observed during the 1990s in the inner Danish waters.

Studies have shown that sea snails in the marine environment are extremely vulnerable to biocides released from ships. In Denmark, sex changes have been observed for 10 different kinds of sea snails – mainly because of biocides from antifouling agents such as TBT and copper compounds⁷⁹. These results show that TBT definitely cause serious problems in the marine environment as well, and I have therefore assessed that the EDIP method suggest the most reliable results.

Potential versus actual impacts (site-specific aspects)

The uncertainties related to whether the impacts really occur were also briefly discussed in each of the impact categories in chapter 8. Site-specific considerations are one of the most important aspects in this regard. The fishing stage is particularly important in this respect because the emissions take place at sea with low background concentrations and a long distance to terrestrial recipients and human exposure. Thus, the actual impact for acidification, nutrient enrichment, photochemical ozone formation and ETWA will probably be considerably smaller for emissions at this stage (Wenzel et al. 1997). This also applies to human toxicity water and air, but this impact category is discussed in chapter 10.

Site-specific considerations are also relevant at the processing stage. In chapter 8 it was discussed that nutrient enrichment may not even be a serious problem in South America where it is assumed that we have a large avoided contribution to nutrient enrichment due to the substitution of soy protein. If nutrient enrichment isn't a problem, it could lead to the counterintuitive conclusion that the avoided soy protein could contribute with a positive contribution from European rapeseed oil production. It is also concluded that the

⁷⁹ For the most vulnerable types, the sex change appears in all areas of the Danish waters. 1 ng TBT per liter may cause sex changes among sea snails. This implies that an average container ship can pollute 100 billion liters of seawater per day with a TBT concentration, which potentially causes sex changes among sea snails. TBT is able to bio-accumulate in the food chain. Some of the highest concentrations are found in Sea Porpoises. In laboratory tests it has been rendered probable that TBT and its decomposition products can weaken the immune system among animals and increase the risk of cancer among humans. In foreign studies, alarming concentrations of butyltin (the decomposition product from TBT) have been found in human blood, probably as a result of consumption of fish and shellfish (Foverskov et al. 1999; Strand and Jacobsen, 2000).

emissions from the processing stage are insignificant after wastewater treatment, compared to contributions from combustion of fossil fuel in other stages, especially the fishing stage. However, it is important to notice that the EDIP method does not distinguish between water and airborne emissions in the impact category “nutrient enrichment”⁸⁰. In this regard, it is often argued that water-borne emissions in coastal areas, which include emission from wastewater treatment plants, are the most important factor contributing to eutrophication (DMU, 2001). It can be argued that the EDIP method addresses two problems at the same time, namely nutrient enrichment of terrestrial ecosystems such as the moors of Jutland and nutrient enrichment of fresh water and seawater, which can cause eutrophication. However, I would argue that an impact category at this level of aggregation causes uncertainties and that it becomes difficult to trust and interpret the results.

Finally, we have the transport and use stages where it must be assumed that the level of exposure is relatively high. This is especially the case for air emissions from traffic that occurs in urban areas. *Obviously, these site-specific aspects would reduce the influence from fishery at the expense of other stages, especially the transport and use stages.* However, the fishery still has large impact potentials for the two global impact categories global warming and ozone depletion. Apart from that, it is not likely that site-specific considerations for the regional and local impact categories will reduce the impact potential to zero – especially not for fisheries that take place in the inner Danish waters or close to the coast.

Uncertainty related to normalization

Aspects of uncertainty related to the normalization phase and normalization factors are discussed in the following.

⁸⁰ Consequently, the method does not consider that Nitrogen emissions to fresh water and phosphorous emissions to marine recipients typically only have a small impact because these substances typically are not limiting parameters for algae growth in the respective recipients. Finally, COD emissions are not included in the method. This is somewhat counterintuitive as COD is one of the main parameters used to regulate the wastewater emissions in food industry. In this regard, COD may cause an immediate oxygen deficiency while N and P are more related to eutrophication, which may cause oxygen deficiency indirectly.

Uncertainty for normalization factors

As we have seen, there are considerable differences in the normalization factors – even for the same region – depending on the method used. The LCAfood version of the EDIP method reflects larger normalization references in most cases, which is mainly due to a different approach. As mentioned, the LCAfood version focus on activities operated by Danish economic agents rather than activities physically limited to Denmark.

It is not possible to choose one model, which is the most correct – at least it strongly depends on the purpose of study or the decision context. The purpose of the present study is mainly to provide suggestion to how Danish authorities can promote cleaner fish products. This is a strategic decision concerning Danish policies and management practices. Therefore, it can be argued that the focus should be activities that take place within the geographical region of Denmark.

This suggests that the EDIP 97 update is the most relevant method in this context, even though it is less updated. In this project, I have used the LCAfood version for the normalization step in chapter 9.1, while the EDIP 97 update is used to establish the weighted results in 9.2 and 9.3. As both methods largely generate the same conclusions, and as the weighted results obtained by the EDIP-97 update are further validated by Ecoindicator 99 and CML 2 baseline⁸¹, it is assessed that the level of uncertainty with respect to conclusions is limited.

Extreme results for eco-toxicity

As mentioned in the description about uncertainty for characterization, the uncertainty for eco-toxicity is large and the ambition level of the EDIP method is merely to find the right order of magnitude. This uncertainty becomes very explicit when the impact potentials are normalized. Here we see that the normalized values appear to be on a different scale than the normalized values for other impact categories. The rather high normalization values can be caused by an overestimation at the characterization step but may also be due to an underestimated normalization references.

⁸¹ I have not validated the normalized results separately in chapter 9.1, but as the weighted results are based on other normalization references and references for other regions (for GWP and ODP), this serves as a validation in itself.

Differences in normalization references (EDIP 97 versus LCAfood)

The normalization references are larger for the LCAfood version of the method, and the results are therefore generally less for all local and regional impact categories. However, this does not cause a significant bias in the results, as it influences all the life cycle stages.

However, one of the most interesting differences is that the normalized results - according to the LCAfood version - suggest that eco-toxicity water acute is very important, while the focus is eco-toxicity water chronic that by far has the largest contribution according to the weighted results, based on the EDIP 97 update. This difference was also expected and described during the presentation of table 1. As in appear in table 1, the reason is mainly that the normalization factor for ETWC is very high in the LCAfood version, and it is assumed that this mainly is caused by the fact that the method include Danish shipping activities abroad, which represents high levels of chronic toxicity due to emissions of antifouling agents.

If we trust the results obtained by the LCAfood version, antifouling agents will still have a relatively large impact potential in the future because the level of ETWA remains high. However, if we trust the EDIP 97 update, the new antifouling agents will become much less important. If we assume that acute eco-toxicity in the marine environmental is a small problem altogether - due to site-specific arguments - the latter would be the case at all circumstances. The latter is the most plausible in my opinion and the argument is also presented in Wenzel et al. (1997).

Uncertainty related to weighting

As mentioned, the weighting factors are all relatively close “one” for the EDIP 97 update version, except for ozone depletion, where it is set to 44 as it is a global impact and as we therefore should use the global reduction targets to establish the weighing factor. However, it is also argued that the weighting factor would be indefinite for Danish and European conditions⁸². Probably it could also be argued that the weighting factor should be zero because

⁸² As for other weighting factors in the EDIP method, the weighting factor is established on basis of political reduction targets. However, if the method was to be followed strictly, it could be argued that the weighting factor for Denmark should be indefinite because it is the political goal to reduce the emissions of ozone deleting substances by 100% in Europe within the year 2004 (Busch, 2003).

the problem is already taken care of, and mainly is a problem related to historical emissions rather than future emissions, at least considering Europe. Thus, it is also strongly recommended to use different weighting factors – especially for this impact category.

As previously illustrated – ozone depletion has a large contribution to the weighted impact potential, especially at the fishing stage. In all cases, I have used the recommended weighting factor of 44. In this regard, it could be argued that the weighting factor is considerably lower (maybe even zero), and data uncertainties suggest that the emissions are already too high, due to old databases. If we also consider that the ozone depleting substances probably will be completely substituted within a short number of years, it could be argued that we should disregard this impact category all-together. *This would reduce the impact potential at the fishery significantly, but not change the conclusion.*

As a final step, I have chosen to verify the weighted results by using other methods such as EcoIndicator 99 (H/A) and by using EU references for regional and local impact categories in the EDIP 97 update instead of Danish references⁸³. As the CML method does not include the weighting step, this method has not been used⁸⁴.

Results obtained with EDIP 97 update and EU references

Weighted results based on the latter are illustrated in figure 21:

⁸³ In this regard, it is also worth to note that the normalized results based on the LCAfood version for the EDIP method can serve as some sort of verification as most of the weighting factors are close to one. If we compare with the results based on the LCAfood version, the number of person equivalents becomes considerably smaller but the distribution of person equivalents between the life cycle stages remains the same. Obviously, the reason is that the normalization references in this method are higher for all impact categories, due to the differences previously explained.

⁸⁴ Still it can be established that the normalized results based on the CML method show a similar distribution of impact types.

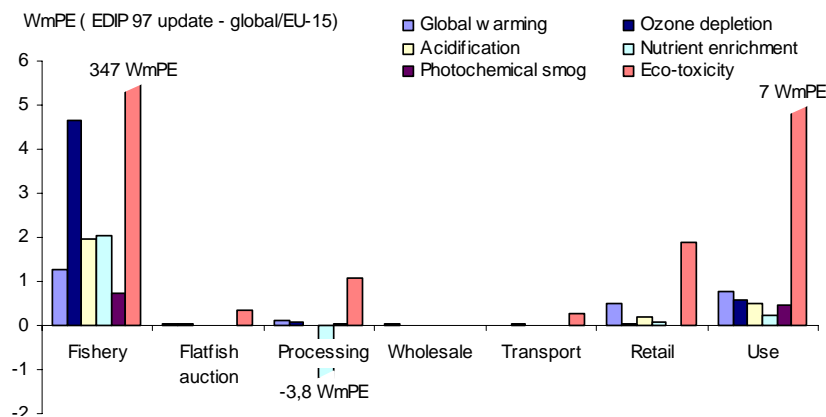


Figure 21: Weighted results for one kg consumed ordinary flatfish filet, based on EDIP 97 update but with EU references and weighting factors for local and regional impact categories.

It appears that the results, or at least the tendencies, are the same as when Danish normalization references and weighting factors are applied (compare to figure 6). Still, the number of weighted person equivalents is somewhat higher for acidification and nutrient enrichment – mainly due to lower normalization references. For eco-toxicity, we see the opposite, as the number of weighted PE are roughly half, compared to the normalized results in section 9.2 (figure 6). This is also mainly because the normalization reference for eco-toxicity in EU is larger than the Danish references (at least according to EDIP 97), but the Danish weighting factors are also larger. In this regard, it is worth to stress that the LCAfood version suggest even larger normalization references than for ETWA and ETWC than the EDIP 97 version with EU references.

Results obtained with the Ecoindicator 99 (H/A) method

As a final validation, the results are compared to weighted results obtained with the Ecoindicator 99 (hierarchist version)⁸⁵, described in chapter 8.3. It is not possible to obtain weighted results by the CML 2 baseline 2000 method.

As described in chapter 8.3, the results are reduced to three damage categories in the Ecoindicator 99 method: Damage to ecosystem quality, damage to

⁸⁵ In the hierarchic version, there is a balanced time perspective, and consensus among scientists have determined inclusion of effects.

human health and damage to mineral and fossil resources. For further details see chapter 8.3. I have only included the impact categories previously used in the EDIP method. The Ecoindicator 99 also includes a weighting step. The weighting factor is established by an expert panel and only includes weighting between the three damage categories. In the version used here, I have used the average and recommended weighting set – for further details see Goedkoop and Spriensma (2000). Results obtained with the EcoIndicator 99 (H/A) method are illustrated in figure 22.

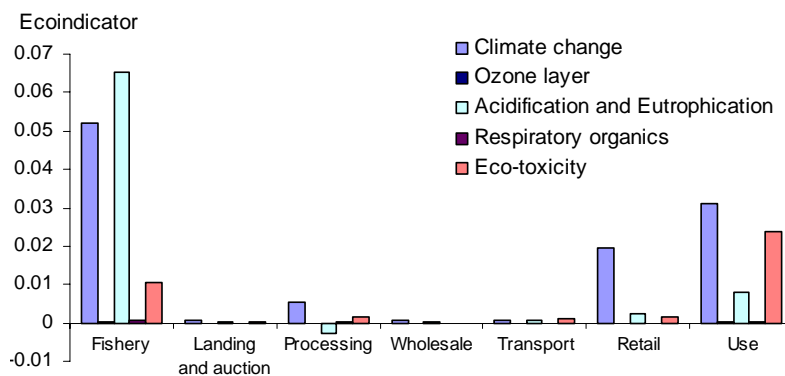


Figure 22: Weighted results for one kg consumed ordinary flatfish filet caught with the average fishing method, based on the Ecoindicator 99 methods (H/A).

The results based on the Ecoindicator 99 method (recommended hierarchic version with average weighting) confirm the tendencies suggested by the EDIP 97 update. Still, there are three main differences.

First of all, the negative contribution to nutrient enrichment (here in an aggregated category with acidification) does not appear to be that important, at least not for the processing stage, where the EDIP method suggested a large negative contribution. As explained earlier, this is because the EcoIndicator does not include N and P emissions to water.

Secondly, it appears that ozone depletion and respiratory organics (somewhat similar to ozone formation⁸⁶) are relatively insignificant. This is related to the fact that the Ecoindicator method “translate” these impact categories into an indicator for human health (DALY⁸⁷), and that these two impacts contribute relatively little to the overall health impairment. This actually also apply to global warming.

Thirdly, the contribution to eco-toxicity from the fishery is somewhat low compared to other methods. However, the method does not include a characterization factor for TBT, and the result is therefore unreliable on this point. The Ecoindicator 99 measures eco-toxicity potential in terms of lost biodiversity, and maybe it could be argued that sex-changes of mussels and reproductive deficiencies caused by TBT do not have an important impact in terms of biodiversity. However, it is difficult to establish a detailed explanation. The method is relatively new, it uses a new approach (damage oriented – top down approach), and it must be expected that several methodological shortcomings exists. Obviously, the method has other strengths and includes a much wider number of impact types – some of these are discussed in chapter 10.

Consistency analysis

Consistency may cover a large number of aspects such as consistency in the use of references, data quality, methods for co-product allocation and system delimitation. Considering the purpose of this study, the question is whether the methodological choices and arguments, as well as data types and quality, lead to any bias of the results concerning the importance of the individual life cycle stages.

Data quality

Concerning data quality, it has previously been mentioned that the data quality is highest at the fishery and processing stages, while data for the use stage

⁸⁶ As opposed to respiratory inorganics, which mainly represents human health effects from particle pollution.

⁸⁷ As mentioned in chapter 8.3, DALY is disability adjusted life years. The DALY scale was originally designed to assess the rationales of national health budgets. The scale goes from 0 to 1 – the latter meaning completely dead. If a type of cancer normally is fatal 10 years before the natural life expectancy, the method will count 10 lost life years in each case. This means that each case has a value of 10 DALYs. For further details see Goedkoop and Spriensma (2000).

have been difficult to establish very precisely. However, this does not necessarily lead to any bias of the results. The fact that the data quality is highest at the fishing stage is in accordance with the fact that this stage is one of the most important stages. It could be argued that higher data quality should have been achieved at the use and retail stages as well, due to their relatively high importance.

System delimitation

I have focused on Danish processes from sea to wholesale, while the retail and use stages take place in central and southern Europe. This is in accordance with the purpose of study, which is environmental regulation in Denmark. However, the use of databases does not reflect Danish processes e.g. for energy consumption and transport. This is due to the fact that I have used the ETH databases for most of the background processes. Danish data have not been available in Simapro, and the ETH database has been the natural choice for several reasons, as earlier described. Furthermore, this choice has been adopted consistently in all life cycle stages – for energy, materials and chemicals. In the LCA screenings, data for materials have been obtained from another Swiss database (Buwal) in a few cases, e.g. for glass.

The data from the ETH database includes capital goods for all energy processes, but not for materials and chemicals. This may have contributed to an overestimation of all energy processes and energy-intensive materials. This especially applies to the fishing stage, which is the most energy intensive life cycle stage.

Specifically for the fishing stage, no credible data were available for combustion processes, and I have therefore used literature data obtained from the European Environmental Agency. In some aspects, these data have been more accurate, but the level of detail is also less. This means that data for particulate matter, as well as benzene and other heavy metals, are absent. This has been considered in the uncertainty analysis.

Generally, all process chains have been terminated, but exchanges related to the production of antifouling agents have not been included. It is assumed that these exchanges could have contributed with a significant impact potential for eco- and human toxicity – partly due to the large emissions of copper. Obviously, this would have increased the impact potential at the fishing stage, but I have not conducted a sensitivity analysis.

Co-product allocation

Co-product allocation has been carried out according to the guidelines in ISO 14040, which recommends technical subdivision and system expansion to avoid co-product allocation in the first place. However, in a number of cases, this has not been done. This only concerns immediate exchanges in a few cases where the environmental exchanges have been considered insignificant, e.g. for exchanges at the fishing stage that does not address energy and antifouling. Furthermore, arbitrary allocation parameters, such as mass, have been used to establish data in the ETH and Buwal database in a number of cases. This has been discussed in the previous section about assessment of uncertainty related to system delimitation, where a sensitivity analysis is conducted as well.

Completeness analysis

Completeness has been used to describe data quality and focus on the number of plants investigated, and the representatives of the data. However, completeness can also be discussed in relation to the entire LCA study. In the present study, a number of exchanges have intentionally been left out. This includes data for:

1. Lost fishing gear, wastewater, guts and discard from demersal fishery (fishing stage)
2. Natural cooling agents in the future scenario for fishery (fishing stage)
3. Consumption and emissions of cooling agents during transport (processing and transport stage)
4. Cleaning agents for wholesale, transport and retail
5. Electricity for light (retail stage)
6. Heat contribution from cooling processes (retail and use stage),
7. Heat contribution from cooking (use stage)
8. Ventilation during food preparation (use stage)

Ad.1) Apart from heavy metals (lead included in eco-toxicity), solid waste in terms of lost fishing gear (iron, plastic etc). has been disregarded at the fishing stage. Basically, there has not been any relevant impact category to describe it, but chapter 10 includes a discussion of this aspect. Wastewater generated in demersal fishery has been disregarded because no data have been available. However, data for blood-water from RSW tanks in the pelagic fishery shows that the contribution to nutrient enrichment is relatively insignificant.

Discard of fish and guts have also been disregarded. Studies of Dutch beam trawlers shows that direct and indirect discard is rapidly consumed by opportunistic scavenging species, such as birds, crabs, starfish and fish. Damaged benthos is mainly consumed by fish, while discarded fish are mainly consumed by invertebrate scavengers (Fonds and Groenewold, 2000). Hence, the organic loads from demersal fishery contribute to increased recycling of fauna and fish through the food web, but are not likely to cause eutrophication⁸⁸.

Concerning guts, ICES have conducted a study of the effects from discarded guts in the Baltic cod fishery. Oxygen deficiencies are a common problem in the Baltic, and this area is also where the problem of deep-water oxygen deficiency is most pronounced. However, a simple carbon budget shows that the oxygen requirement for discarded offal is insignificant ($\ll 1\%$), compared to other sources of oxygen consumption (ICES, 1999 p. 25). It should also be considered that the cod would die anyway. Concerning eutrophication, a recent study suggests that fishery in the Baltic actually has an overall positive impact because huge amounts of N and P are removed from the sea via the fish (Hjerne and Hansson, 2002).

Ad. 2) Consumption and emission of natural cooling agents (e.g. CO₂) have not been included at the fishing stage, nor the retail and use stages. The reason is that these exchanges are both under the cut-off criteria and considered relatively insignificant in terms of environmental impacts, considering the small amounts. Ammonium has a significant potential impact on human toxicity, but this impact category has not been considered in the quantitative LCA.

Ad. 3) Consumption and emissions of cooling agents for the transport stage has also been disregarded. The reason has been a lack of reliable data. However, it must also be assumed that the amounts are relatively small considering that the transport typically lasts for one or maximum two days. For

⁸⁸ This is supported by other studies such as ICES (1999) and Hjerne and Hansson (2002). The latter concludes that fishery in the Baltic ecosystem is actually a net remover of organic matter. This means that it can also be disputed whether blood-water from pelagic fisheries actually contributes to eutrophication. In this regard, it is also worth pointing out that only a small proportion of the blood-water is released in coastal areas, where eutrophication is a problem.

transport of fish product overseas, it would be necessary to further assess the importance of consumption and emission of cooling agents.

Ad. 4) The consumption and emission of cleaning agents have been omitted for the wholesale, transport and retail stages. Firstly, data have not been available, and secondly it is assumed that the amounts used are insignificant and considerably smaller than the cut-off criteria.

Ad. 5) For light in retail, it has been argued that the exchanges are insignificant and therefore disregarded (see chapter 6).

Ad. 6) For heat contribution from cooling processes, the exchange has not been included because it has been considered that this would require that other aspects such as cold air loss, number of door openings etc. should have been considered as well. Other studies suggest that the heat contribution and the substitution of other heat sources are relatively significant (Weidema et al, 1995). It must therefore be assumed that this omission may have caused some overestimation of the energy consumption at the retail and use stage.

Ad 7 & 8) At the use stage, I have also omitted considerations of heat contribution from cooking. Obviously, the cooking process contributes with large amount of heat – especially if an oven is used. However, I have assessed that consideration of heat contribution would require an additional assessment of heat loss and energy consumption for ventilation. Instead I have omitted these parameters altogether.

Finally, it should be considered that I have used a number of databases that have not been particularly developed to the EDIP method. This means that a number of exchanges have been disregarded – mainly because the EDIP method does not include characterization factors for all substances. However, it is also possible that exchanges have been disregarded due to differences in names for some substances. This has been a particular problem for the impact categories non-renewable resources (metals and fossil fuels) and waste – which are treated separately in chapter 10. Thus, exclusion of important exchanges may have occurred in some cases. However, if this has been the case, it must be considered a random type of error that is unlikely to cause a bias in the results.

Summary

The results obtained from the uncertainty and sensitivity analysis tend to confirm that the fishery, use and retail stages are the hot-spots for ordinary

flatfish filet. Different types of uncertainties were analyzed and summarized in table 4.

Table 4. *Types, magnitude and significance of uncertainty according to the sensitivity analysis for the LCA on flat fish.*

Type of uncertainty	Uncertainty	Sensitivity
Data (Immediate exchanges)	Large uncertainty, especially in use stage	Fishery, use and retail remain hot-spots – even in extreme cases.
Data (Related processes)	Generally emissions of NO _x , SO _x , VOC and benzene have been overestimated – especially for transport processes based on the ETH database	As a result, all transport related processes are overestimated for acidification, nutrient enrichment and ozone format. This applies to the processing, transport and use stages – but not the fishery, where the ETH database has not been used. The fishing stage is therefore most likely underestimated.
Data (Spillage)	Some uncertainty for spillage – probably underestimated	The fishing stage is most sensitive to uncertainty related to spillage – underestimation of spillage will lead to most underestimation of the fishing stage
Data (lack of terminated chains)	Small uncertainty considering lack of data for antifouling production.	
Method – system delimitation (geographical scope)	Small uncertainty – I assume the use stage takes place in central and southern Europe	If the use stage were in Denmark, it would probably reduce the impact potential at the use and retail stages (slightly). Still, the significance is considered to be very small.
Method – system delimitation (co-product allocation)	Medium uncertainty	The fishery, use and retail stages remain the hot-spots even in extreme cases, where all methodological choices are changed to reduce their relative importance.
Method - characterization	Site-specific aspects are generally a large source of uncertainty for local and regional impact categories – at least when we consider the effects that actually will occur.	Site-specific considerations would reduce the importance of the fishing stage relative to other stages – especially stages, which involve transport. Site-specific considerations would also increase the importance of wastewater from processing !!
Method - Normalization	Somewhat large uncertainty on local and regional impact categories.	The fishery, use and retail stages remain hot-spots independent of the method applied
Method - weighting (specific)	Unrealistic high weighting factor for ozone depletion.	The high weighting factor for ozone depletion mainly influence the fishing stage !!
Method - weighting (general)	Subjective	It is confirmed that the fishery, use and retail stages are the hot-spots when other methods are used for the LCIA

As it appears, it is particularly worth to address site-specific considerations as a source of uncertainty that may question the importance of the fishery for the local and regional impact categories. However, there are other sources of uncertainty that suggest that the fishery is underestimated. Considering the significance of the impact potential for the fishing stage and the uncertainties that points in different directions, it is assessed that it can be confirmed that the fishery, use and retail stages indeed are the hot-spots for ordinary flatfish filet (IQF).

As mentioned, the focus of the uncertainty and sensitivity analysis has been ordinary flatfish filets, but uncertainties and sensitivities shown in table 4 also apply to breaded flatfish and the LCA screenings of demersal and shellfish (except mussels). Considering ancillaries, data have been lacking for pickled herring, and the consumption of the vinegar, onion and pepper have not been included.

Consistency and completeness

The analysis of completeness suggests that the fishery may have been underestimated due to lack of data for antifouling agent production, but on the other hand, capital goods are only included for energy processes which tend to emphasize the importance of the fishing stage, which is energy-intensive. The inconsistency relates to the data sources for combustion in the fishery (data from EEA) and other stages (data from ETH), discussed in the sensitivity analysis, and tend to underestimate the influence of the fishery.

Considering the consistency, the omission of cooling agents during transport processes may have lead to a small underestimation of the use, transport and processing stages in this order, while the omission of heat contribution from cooling agents may have lead to a small overestimation of the impact potential at the use and retail stages. However, no aspects of inconsistency are likely to significantly change the results.

9.5 Conclusion (Interpretation)

In the previous chapters, I have presented the characterization results for ordinary and breaded flatfish, which included a discussion of site-specific issues and scenarios for different production methods as well as future scenarios (chapter 8).

Normalized results were presented in chapter 9, but only for ordinary flatfish. This also included different production methods and future scenarios. Finally, chapter 9 included weighted results for ordinary and breaded flatfish including different production methods, process analysis, future scenarios and a generalization with LCA screenings of seven other fish products.

LCIA results for flatfish

The most important results from the LCIA of flatfish are presented below.

Hot-spots

The characterization results as well as the normalized and weighted results for ordinary and breaded flatfish filets suggest that the fishery, use and retail stages are the hot-spots for the impact categories considered here (global warming, ozone depletion, acidification, nutrient enrichment and eco-toxicity). For ordinary flatfish, it would be reasonable to say that the fishery is the most important stage in terms of potential impacts, while the difference between the use and fishing stage is less pronounced for breaded flatfish.

The role of eco-toxicity

According to the weighted results, the importance of eco-toxicity appears to overshadow all other impact categories after normalization and weighting – mainly due to eco-toxicity water chronic (ETWC) related to TBT. On the other hand, eco-toxicity soil chronic (ETSC) has a very small importance after normalization and weighting. This shows that the processing stage is indeed insignificant with respect to eco-toxicity, even though the contribution to ETSC is large.

The most important processes

Three processes have been distinguished as the most important in the life cycle of flatfish products, namely:

- Fishery
- Transport
- Cold storage

All the processes are important in terms of energy consumption. Transport is involved in the processing, transport and use stages. Storage is mainly involved in the retail and use stages also, and has a significant contribution to global warming, due to electricity consumption based on coal.

Wastewater emissions have not been considered important in terms of impact potential in any of the lifecycle stages, however it can not be excluded that site-specific considerations and a distinction between water and airborne emissions could change this conclusion.

Future scenarios

The future scenarios, which are supposed to reflect the situation within the next 10-15 years, suggest that the fishery, use, and retail stages will remain the hot-spots. Considering energy consumption, it is assumed that the energy consumption will increase at the fishing stage, while it will decrease for all other stages except transport, due to efficiency improvements. However, the contribution to eco-toxicity at the fishing stage will also be reduced significantly.

Improvement potentials

The largest improvement potentials have been observed within the fishery, where substitution of beam- and bottom trawl with passive fishing gear such as Danish seine or gillnet may reduce the impact potential considerably. Still, beam trawl actually has a smaller emission of antifouling agents compared to Danish seine. However, it is assessed that the advantage of beam trawl in this respect will be greatly reduced in the future, when hazardous biocides gradually are substituted for alternatives.

Based on normalized results obtained with the LCA food references, it is assessed that eco-efficiency improvements between a factor 4-10 can be obtained for the various impact categories in both future scenarios.

Furthermore, the weighted results based on the EDIP 97 update suggest that an improvement of a factor of 12 can be obtained for the aggregated weighted values for all impact categories except eco-toxicity – in both future scenarios as well. The latter would imply an improvement of a factor of 3-6 depending on the scenario. It is generally not recommended to use the aggregated indicator for assessments of this type, but still it is assessed that the result is so remarkable that it should be emphasized despite the uncertainties.

As described in chapter 7, there are also improvement potentials at other stages that address important processes such as transport and cold storage. However, the improvement potentials are not so obvious here, apart from improvements in efficiency that takes place in any case. In this regard, improvement potentials related to substitution of aluminium and glass packaging is an exception, but this does not concern flatfish products. For transport, it could also be argued that shopping by car could be substituted with shopping by bicycle, public transport, or delivery service. Still, this type of change requires a fundamental change of consumer behavior.

Can the results be trusted?

The results presented above are considered to have a high degree of validity. Firstly, a similar tendency is observed among the characterized results, the normalized, and the weighted results. In this regard, the normalized and the weighted results are obtained with two different versions of the EDIP method. Secondly, the characterized and weighted results are separately validated by other LCIA methods. Finally, I have carried out an analysis of uncertainties and sensitivities (valuation). The analysis addresses uncertainties related to data, system delimitation and different methods for treating co-products and confirms the conclusions – even when challenged with extreme assumptions intended to prove the opposite.

The main uncertainties with regard to the conclusion stem from site-specific aspects that tend to reduce the dominance of fishery for the impact categories - acidification, nutrient enrichment, photochemical ozone formation and acute eco-toxicity – when we consider the probability of the effects really occurring. Thus, it is not possible to exclude the possibility that the use stage is equally dominating or even more dominating for one or more of these categories, especially for breaded flatfish filet.

Generalizations (LCA screenings)

LCA screenings has been conducted for six other fish products, and it has therefore been possible to draw conclusions for all main groups of Danish fish products

Hot-spots for other species

Demersal and shellfish. The LCA screenings also suggest that the fishery, use and retail stages are the hot-spots (in this order) for products based on frozen shrimp, prawn and Norway lobster (all in cardboard packaging). In this regard, it is reasonable to consider the LCA of ordinary flatfish filet as a product representing demersal and shellfish (except mussels) sold as IQF – as one group. Still, the processing stage is slightly more important for shellfish due to the relatively energy intensive boiling processes. Furthermore, glass, aluminium or steel packaging would also further increase the impact potential, but these packaging materials have only been analyzed for mackerel and herring.

Pelagic fish. For pelagic fish exemplified by pickled herring in glass jars and canned mackerel, the processing and transport stages are relatively more important, while the opposite is the case for the fishery and retail stages. The exchanges at the fishing stage are relatively small for this species group (especially for mackerel and mussels), and the indirect energy consumption related to the processing of glass and aluminium for packaging is significant. Thus, in this case, it can be argued that the processing and use stages are the more important, followed by the fishery and transport stages. Retail also has some importance for pickled herring, while the impact potential becomes relatively insignificant for canned mackerel, which can be stored at room temperature.

Future scenarios

Future scenarios have not been developed for other fish products than flatfish. However, there is no reason to believe that the development should be significantly different for other species.

Improvement potentials

As explained in chapter 7 considerable improvement potentials exist within other fisheries, as well. Energy efficient fishing methods, which can be applied in demersal fisheries instead of bottom and beam trawl, include gill net, Danish seine and long line. In pelagic fisheries, energy efficient fishing

methods include purse seine opposed to traditional trawl. In shellfish fisheries, the alternatives to trawl are less obvious, but it is hard to believe that no alternatives exist to the currently very fuel consuming Norway lobster fishery, which alone is responsible for 15% of the total fuel consumption in the Danish fishery and 0,3% of the total catches (see chapter 4.2). In this respect, passive fishing gear such as pots and traps should also be considered, even though it may be unrealistic in a number of cases.

It should be emphasized that the fishing gears that generally are more fuel efficient also represent fishing methods with induce a low or no impact on the sea bed and which generally represent low direct and indirect discard of fish and benthos per kg caught fish, according to international studies (see chapter 4, and app. 1).

Based on data and results obtained in this dissertation, I assume that factor 4-10 improvements are obtainable for several fish products other than flatfish.

However, it should be noted that the hot-spots for pelagic fish and mussels include the processing stage, and that it is important to consider substitution of energy intensive packaging such as glass and aluminium. Furthermore, large improvement potentials exist for transport, especially in the use stage, where shopping by car can be substituted by shopping by bicycle, public transport or by a more efficient delivery service. Obviously, such changes are more difficult to accomplish by traditional regulation, as it is a question of lifestyles as well.

Can the results be trusted?

Even though the LCA screenings for the other fish products are somewhat less detailed, it is assessed that the validity is relatively high. For pelagic products, a large source of uncertainty is related to the production of packaging material, such as aluminium and glass. I have presented results based on 0% re-cycling as well as 100% re-cycling, reflecting the maximum level of uncertainty. Apart from this, it is assessed that site-specific aspects also play the largest role here. In this respect, it would definitely be possible to argue that the fishing stage is not a hot-spot for canned mackerel and mussels when including site-specific considerations – especially in a future scenario where TBT is phased out.

I have not conducted uncertainty and sensitivity analyses for other products than flatfish, but the following comparison with LCA results obtained from other LCA studies serves as a validation in this respect.

Comparisons with other LCA studies

As part of the validation, the results from the LCA in the present dissertation, are compared with results from other LCA studies of fish.

Hot-spots according to other LCA studies of fish

The results for herring, mackerel, and mussels are generally consistent with conclusions obtained in previous Danish LCA screenings of pickled herring, canned mackerel, and blue mussels. (Ritter, 1997; Andersen et al. 2000 and Madsen, 2001). In parallel with the present study, LCA studies of fish products based on wild cod have been conducted in Sweden and Island. The results of these studies also point towards the fishery as the most important hot-spot (Ziegler et al. 2003; Eyjólfsdóttir et al. 2003).

The present dissertation also suggests that the use and retail stages play significant roles and again the energy consumption is a key parameter. Even though other studies have pointed in the same direction, e.g. Ritter (1997), the present study suggest a considerably larger importance of the use stage than suggested in any other studies – to my knowledge.

Important processes

Considering all types of fish products, four processes have been distinguished as the most important in the life cycles:

- Fishery (fishing stage)
- Production of packaging, glass and aluminium – only for certain products (processing stage)
- Transport (mainly transport stage and use stage)
- Cold storing (mainly retail and use stages)

All the processes are important in terms of energy consumption. This conclusion is confirmed by a recent Swedish LCA study of codfish (Ziegler et al. 2003).

As mentioned earlier, wastewater emissions have generally not been considered important in terms of impact potential. This conclusion contradicts the results from the Swedish LCA study, which claims that emissions from processing imply a significant contribution to eutrophication (Ziegler et al. 2003). However, it should be considered that the Swedish study operates with other data for degree of cleaning and other assumptions concerning the affected processes and emissions. As previously discussed, the EDIP method does have some methodological weaknesses considering assessment of nu-

trient enrichment, including lack of site-specific considerations. Based on the present study it is therefore not possible to falsify the Swedish study in this matter. However, the present study indeed provides a reason to seriously question the focus on wastewater emissions from the fish processing industry.

Hot-spots according to other LCA studies of meat

Based on characterized results for cattle and pork established in the LCA-food project (see www.lcafood.dk) it also appears that the primary production is the hot spot for meat products from agriculture. This is not surprising and similar results have been obtained in previous LCA studies e.g. Weidema et al. (1995).

If we compare fishery with agriculture, it appear that average edible fish products performs better than pork and cattle – with respect to global warming and nutrient enrichment. For other parameters such as ozone depletion and eco-toxicity the fish products performs worse – at least in a scenario representing the situation in the fishery around year 2000. A more accurate comparison would require that the various products reflected the same system delimitation and scope. This is not the case, and for instance, pesticides have not been included in the LCA food database.

The better performance with respect to global warming confirms the results for fuel consumption in chapter 4, which suggested that average edible fish represented around 30 MJ per kg meat while meat products from agriculture represented between 50-100 MJ per kg meat. This would suggest that fish products are nothing to worry about, but the interesting thing is that we have huge variations in the fuel consumption as a function of fishing gear and target species. Thus, some fishing methods are definitely worth addressing in the search for improvements.

Graphic overview

To provide the reader with an overview of the data presented, I have illustrated the types of exchanges that have been assessed in the LCA and their significance – see table 5. The qualitative LCA in chapter 10 will include an impact assessment of the other exchanges included in the MECO study, as well as exchanges not yet addressed by the MECO study nor by the LCA (animal welfare, noise, odour, accidents, visual effects, human toxicity, waste and resource consumption).

Table 5: Selected results from the MECO analysis combined with results from the Quantitative LCA. The figures presented in the table are similar to the figures presented in a similar table in chapter 7.

Lifecycle stage	Species	Materials					Energy		Chemicals			Other			
		Expl. Of bio. resources	Discard	By-catch of mammals	Water consump	Consump. Pack/ancill.	Solid lead waste	Heat & combustion	Electricity	Wastewater emission	Biocide emission	HCFC, HFC Cooling ag.	Process & cleaning	Seabed im-pacts	Occupatio-nal H&S
Fish-ery	D				<1	<1	4	4	0	1	4	3	2		
	S				<1	<1	4	4	0	1	4	3	2		
	P				<1	<1	4	2	0	1	1	3	2		
Land-ing	D				<1	<1	<1	1	<1	<1	0	<1	<1		
	S				<1	<1	<1	1	<1	<1	0	<1	<1		
	P				<1	<1	<1	1	<1	<1	0	<1	<1		
Proc-essin-g	D				3	1	<1	1	2	2	0	<1	2		
	S				4	1-4	<1	2	2	2	0	<1	2		
	P				3	1-4	<1	1	1	2	0	<1	2-4		
Whole sale	D				<1	<1	<1	1	<1	<1	0	<1	<1		
	S				<1	<1	<1	1	<1	<1	0	<1	<1		
	P				<1	<1	<1	1	<1	<1	0	<1	<1		
Trans-port	D				<1	<1	<1	1	0	<1	0	<1	<1		
	S				<1	<1	<1	1	0	<1	0	<1	<1		
	P				<1	<1	<1	1	0	<1	0	<1	<1		
Retail	D				<1	<1	<1	1	3	<1	0	3	<1		
	S				<1	<1	<1	2	3	<1	0	4	<1		
	P				<1	<1	<1	1	1-2	<1	0	3	<1		
Con-sumer	D				3	<1	<1	2	4	1	0	1	2		
	S				3	<1	<1	2	4	1	0	1	2		
	P				3	<1	<1	2	4	1-4	0	1	2		
In-significant according to the LCIA:					X		X					X			
Significant decrease due to regulations:							X				X	X			

Magnitude of exchange: 4) Large, 3) medium, 2) small, 1) very small, <1) insignificant, 0) no

Grey cells: The magnitude of the given exchange is relative significant (3 or more).

White cells: The magnitude of the given exchange is relative small (2 or less)

As illustrated in the bottom of the table, there are a number of exchanges, which have been assessed to be insignificant - according to the quantitative LCA. This includes water consumption, consumption of packaging except glass and aluminium, solid waste from fishing gear, wastewater including emissions of process and cleaning agents. Furthermore, there is another group of exchanges that are assessed to be important but which are predicted to decrease significantly due to future regulations. This includes biocides and HCFC/HFC cooling agents.

Recommendations

I would therefore argue that most interest should be given to the remaining exchanges – these are exchanges that represent a considerable impact potential and which are not addressed by current or future regulations. My studies suggest that wastewater emissions from the processing stage are relatively insignificant in terms of impact potential. Hence, my results seriously question the rather intensive regulatory focus, which so far has addressed the fish processing industry, and not least the wastewater emissions.

Overall, the LCA draws the attention to a few variables: Energy, biocides and packaging made of glass or aluminium used for certain products. Without considerations of species, the energy consumption is generally largest at the fishing stage followed by the use and retail stages, but for some products, the processing stage is important as well. In this regard, the fuel consumption in the fishery is expected to grow, while efficiency in processing, retail and household appliances will probably increase, according to my studies. Thus, all things point towards increased awareness about environmental impacts related to energy consumption at the fishing stage.

Qualitative LCA (Other Impacts)

The previous two chapters included a quantitative LCA of two flatfish products and a number of LCA screenings of other fish products. However, the studies only considered six flow related impact categories, mainly determined through the choice of impact assessment method – in this case the EDIP method.

The purpose of this chapter is to challenge the previous conclusions by focusing on other impact categories, including non-flow related impacts. According to the ISO 14040 standard, this is a part of the interpretation, but due to the large number of alternative impact categories for fish products and the more qualitative approach applied in the assessment, it has been kept as a separate analysis in this chapter. Apart from being more qualitative, the analysis is less detailed and probably more uncertain – but the analysis should only be seen as a validation and discussion of conclusions previously made. In the analysis, all the main groups of Danish edible fish will be addressed.

There are a number of immediate exchanges that were described in the MECO study, but not included in the LCA. This includes; exploitation of fish resources, discard, by-catch of marine mammals, ground water consumption (not included as resource in LCA), seabed impacts and occupational health & safety (see table 1).

By addressing these impact categories and further assessing the damage, this chapter will provide a basis for assessing the importance of the respective exchanges. However, I also address exchanges and impact potentials, which have not been included in the MECO study, nor in the LCA (e.g. land use and human toxicity).

10.1 Selection of alternative impact categories

Chapter 8 and 9 included an assessment of the potential impact for six impact categories based on the EDIP method.

Default list of potentially relevant impact categories

Alternative impact categories have been selected from a default list of potentially relevant impact categories - inspired by Wenzel et al. (1997), Guinée et al. (2001) and Udo de Haes et al. (2001) – see table 1.

Table 1: Default list of potentially relevant impact categories, with information about whether and how they have been assessed in the MECO analysis, in the quantitative LCA or in the present chapter. Brackets mean that the assessment is cursory or only represents a comment.

	Environment assessment			Assessment method
	MECO study	LCA ch. 8-9	This chapter	
---- Environmental impacts ----				
Global warming	-	Yes	-	Quantitative - EDIP method
Ozone depletion	-	Yes	-	Quantitative - EDIP method
Acidification	-	Yes	-	Quantitative - EDIP method
Nutrient enrichment (Terr. and aquatic)	-	Yes	-	Quantitative - EDIP method No distinction between terr. and aquatic
Ph. ozone formation	-	Yes	-	Quantitative - EDIP method
Eco-toxicity (Terrestrial, fresh- and marine water)	-	Yes	-	Quantitative - EDIP method. No distinction between freshwater and marine eco-toxicity, or sediment.
Land use	-	-	(Yes)	Semi quantitative - Modeling by Ecoindicator 99 and qualitative assessment
Impacts on the seabed	Yes	-	Yes	Qualitative – detailed
---- Abiotic resources ----				
Fossil fuel (deposit)	-	-	Yes	Both EDIP and Ecoindicator 99
Minerals (deposit)	-	-	Yes	Ecoindicator 99
Ground water (fund)	Yes	(Yes)	Yes	Not included as resource depletion in chapter 8-9. Qualitative assessment
Sand, gravel etc. fund)	-	-	-	*Assessed to be not relevant!!
Rivers etc. (flow)	-	-	(Yes)	Assessed in relation to ground water
---- Biotic resources ----				
Agriculture, fish farms etc. (Man-controlled)	-	-	-	*Assessed to be not relevant!!
Wild fish etc. (Nature)	Yes	-	Yes	Qualitative assessment
Discard (Nature)	Yes	-	Yes	Semi-quantitative assessment
By-catch (Nature)	Yes	-	Yes	Qualitative assessment
---- Human health and welfare related impacts ----				
Human toxicity/health	-	-	Yes	Semi quantitative - Modeling by Ecoindicator 99 and qualitative assessment
Occupational health & safety	Yes	-	Yes	Semi quantitative – only selected life cycle stages
Carcinogenic	-	-	(Yes)	Ecoindicator 99 (see human tox./health)
Radiation	-	-	(Yes)	Ecoindicator 99 (see human tox./health)
Animal welfare	-	-	Yes	Qualitative
Noise, odour, accidents, visual aspects (not work related)	-	-	(Yes)	Qualitative – only as brief description

As it appears there is a long list of effect types and it should be stressed that some effects are only assessed very roughly – these are marked with brackets. This is especially the case for noise, odour, accidents and visual aspects, at the bottom of the list.

It should be stressed that the impacts from the category environmental impacts also have an effect on the category “human health and welfare related impacts”. This is obviously the case for impacts such as global warming, ozone depletion, and ozone formation – which are all related to human health in the Ecoindicator 99 method. However, we are mainly talking about an indirect effect on human health and a large effect on the external environment as well.

Even though the list is long, there are still several effects that are not included. This includes transgenic effects, carcinogenic effects, hormone disruption etc. Transgenic effects are not included at all, while hormone disruption is discussed in relation to anti-fouling agents.

Assessment approach

Although methods are being developed that can provide some sort of quantitative assessments for most of the impact categories described in this chapter, the international LCA community have still not reached consensus about the best methods in most cases (Ude de Haes et al. 2002).

Thus, I have chosen to use a qualitative approach to assess the impact potential for most of the impact categories considered in this chapter. The weakness of the qualitative approach is that it is difficult to compare the importance for different impact categories, but an attempt is made based on examples for technical criteria in Wenzel et al. (1997) and importance criteria used within Strategic Impact Assessment (SEA) according to Schmidt (2004). In this regard, attention is given to:

- Size of area affected.
- Seriousness of impact with respect to humans, animals and the environment.
- The level of reversibility.
- The certainty that the effects will actually occur.

For some impact categories, the importance has been fully or partially assessed according to LCIA methods available in Simapro. In this case, I have

not paid separate attention to the items listed above. In this regard, it should be emphasized that the assessment is qualitative and fundamentally based on a common sense combined with “hard” facts to the fullest extent possible.

Grouping of impact categories

The impact categories included in this chapter are illustrated together with categories assessed in chapter 8-9, in table 2 where they are grouped according to spatial range and impact type - inspired by Wenzel et al. (1997).

Table 2: Environmental impact categories included in this chapter (black) and categories included in chapter 8-9 (grey) grouped according to spatial range and impact type. (*) The immediate exchange is described in the MECO analysis.

	Environmental impact	Resources consumption	Human health and welfare related impacts
Global	<ul style="list-style-type: none"> • Global warming (GWP) • Ozone depletion (ODP) 	<ul style="list-style-type: none"> • *Depletion of fossil fuel and minerals (Ch. 10.4) 	
Regional	<ul style="list-style-type: none"> • Photoch. ozone formation • Acidification • Nutrient enrichment • Eco-toxicity (persistent) 		
Local	<ul style="list-style-type: none"> • Eco-toxicity (non-persist.) • *Impacts on the seabed (Ch. 10.1) • Land use (Ch. 10.2) • Waste (Ch. 10.3) 	<ul style="list-style-type: none"> • *Exploitation of fish stocks (Ch. 10.5) • By-catch and discard (related to the above)* (Ch. 10.6) • *Ground water exploitation (Ch. 10.7) 	<ul style="list-style-type: none"> • Human toxicity/health (Ch. 10.8) • *Occupational H&S (Ch. 10.9) • Animal welfare (Ch. 10.9) • Noise, odour, accidents and visual aspects (Ch. 10.9)

As illustrated, the impact categories considered in this chapter can be divided into four groups according to their spatial range and type of impact. It should be noticed that human toxicity, exploitation of fish (biotic resource extraction) as well as by-catch and discard also could be considered regional impacts. By-catch and discard are strongly related to exploitation of fish resources, and it could be argued that all three aspects should be considered as one category. The four groups of impact categories will be separately described in the following sections.

10.2 Impacts on the seabed

Active bottom tending fishing gear, such as beam and bottom trawl, inflict damage to the seabed. Large areas of seabed (partly in the North Sea) are swept every year and some areas are swept several times each year – as described in the MECO analysis. While the MECO analysis focused on the magnitude of the exchange, this section addresses the type and magnitude of damage that occurs as a result. Obviously, the fishery is the hot-spot for this impact category, but a damage assessment is important to elucidate as to whether or not this should be taken seriously.

It is important to stress that disturbance of the seabed only occurs when fishing gear is in contact with the seabed. This main concern is bottom dragged fishing gear such as beam-, bottom- and bobbin trawl (Hall, 1999 p. 49). However, other bottom tending fishing gears such as Danish seine, can probably also inflict damage – especially if ropes with a large diameter are used. For further descriptions of fishing gear, their use and environmental characteristics - see appendix 1.

Methodological aspects

In chapter 4 it was mentioned that the immediate exchange depends on variables such as surface area swept, frequency of fishing and the vertical pressure from fishing gear. These variables describe the size of the physical impact, but the actual damage depends on another set of variables.

In this respect, there are a number of site-specific aspects that should be taken into account. Inspired by Kaiser and de Groot (2000), Jennings et al. (2001), Hall (1999) and Dorsey and Pederson (1998), I have listed some of the important factors that determine the degree of disturbance related to a given intervention.

- *Level and type of background disturbance.* All things being equal, a higher background disturbance will result in a lower impact potential because the benthic communities accommodate disturbance)
- *History of human activity.* The marginal effects will be smaller in areas with a long history of human activity, because the ecosystems are already modified.
- *Sediment structure.* Seabed consisting of reefs (especially living reefs), stones and mud/clay are typically more sensitive to seabed

impacts than a flat seabed of sand or gravel with a relatively low biodiversity (e.g. most areas in the central of the North Sea).

- *Type of benthos.* The most vulnerable areas are characterized by long-lived benthos, while areas with short-lived opportunistic species are more robust to disturbance. These species will be more frequent in areas with low background disturbance, low degree of human activity and diverse sediment structure (around reefs and stones/boulders)
- *Depth.* Impacts that are inflicted at large depth will typically cause greater damage. This is because the background disturbance is lower and due to lower growth rates of the organisms resulting in longer recovery rates.

As one can imagine, it is very difficult to estimate the precise effects from a given type of fishing, as there are many effects and many variables. It is complex because there are many interdependent variables. For example, the consequences of re-suspension caused by trawling depend on variables such as the amount of nutrient in the sediment, exposure of anoxic layers, release of contaminants, smothering of feeding and respiratory organs (Jennings et al. 2001).

Observed effects from bottom trawling

Research on the physical effects on the aquatic ecosystem has been conducted in a variety of seabed types differing in depths, substrate type, benthic fauna and the degree of human and natural disturbance. Furthermore, different types of fishing gear have been analyzed. The conclusion is that fishing activities (especially bottom trawling) may lead to the following effects, considering the impact on the seabed (Jennings et al. 2001; ICES, 1999; Nielsen and Møllgaard, 1999; Nielsen et al. 1997; Ball et al. 2000):

- Removal of physical features on the seabed¹
- Short term alteration in benthic fauna structures
- Long term changes in populations of vulnerable species

¹ It should be noticed that areas of the seabed with a uniform nature have the smallest fauna diversity. As an example the central part of the North Sea is characterized by a relatively low species diversity and a uniform seabed (Jennings et al. 2001 p. 248)

- Re-suspension of sedimentary material, with chemicals (TBT and other biocides) and nutrients that may contribute to oxygen depletion
- Reductions of habitat complexity

These effects are only some of the effects that are mentioned most frequently in the literature, but there are others. Indirect discard of fish and benthos (that is fish and benthos which are damaged or killed in the trawl path) is described separately in chapter 4 and in a separate section in this chapter.

The effects are documented in a great number of studies and also documented in terms of more generally applied indicators such as biodiversity indexes – for example the Shannon–Weaver diversity index (Ball et al. 2000; Collie et al. 2000)

The importance of seabed impacts

One study that scientists often refer to is the “Impact II assessment”. This is a Dutch study of the effects from bottom dragged fishing gear in the Southern North Sea. The study concludes that bottom and beam trawl cause a “*significant*” disturbance of the seabed. The disturbance includes changes in the sediment structure, re-suspension of nutrients and changes in the benthos communities. Even though words such as “significant” indicate that it is important, we may ask how significant and important to whom or what ?

How important?

Area affected. As explained in chapter 4, Swedish studies suggest that the area affected is around 1,7 hectare per kg of caught cod in the Baltic. This is considerable if we compare this to farmed products, but the question is also: How much are they affected?

Seriousness of impact and reversibility. Preliminary LCA results conducted at SINTEF in Norway, suggest that the seabed impacts are considerable. According to Ellingsen and Pedersen (2003), the sea floor impact is dominating in the life cycle of cod filet – even if it is assumed that only 10% of the swept seafloor is affected with a recovery rate of 1 week. The results are obtained by the EcoIndicator 99 (H/A) method, which is supposed to be used for land use impacts. Still, the results are remarkable because the average recovery rate is estimated to be around 100 days in the North Sea according to Collie et al. (2000).

Studies of the effects of fishing on the seabed have been limited to immediate or short-term changes. Furthermore, the studies have been hampered by the lack of suitable undisturbed reference areas (Jennings et al. 2001). However, there is clear evidence that some damage has occurred and for instance whelks have been absent from the Dutch Wadden Sea for many years. So far, all studies suggest that bottom trawling is almost certainly responsible. (Kaiser and de Groot, 2000 p. 385).

According to Ball et al. (2000), there is strong evidence that chronic fishing disturbance has altered the benthic communities in studies where shipwrecks are used as reference sites. He also refers to another study in the Scottish Sea (Loch Gareloch) where an area that has been closed to fishing for over 25 years is used as a reference. This study reached the same conclusions and showed that that trawl door tracks were still visible from side-scan sonar records 18 months after fishing. Finally, the paper refers to studies that measure the penetration depths of commercial otter trawling in the Kiel Bay. Here it is measured that the penetration depth is 8-17 cm in mud and 0-5 cm in sand. Furthermore bobbins and ground rope marks were measured to 2-5 cm.

According to Nielsen & Møllgaard (1999), studies also show that the density of long lived organisms such as Sea stars and different types of shellfish increased after the area (Rødspættekassen) was closed to flatfish fishing.

A widely known meta study (Collie et al. 2000) speculates about the level of physical disturbance that is sustainable for a particular type of habitat. The study suggests that sandy sediment communities are able to recover within 100 days, which implies that they can withstand 2-3 incidents of physical disturbance per year without changing markedly in character. This is the average predicted rate of disturbance for parts of the southern North Sea (Collie et al. 2000). If this is true, many areas in the North Sea are held in a permanently altered state². Some areas are actually visited more than 400 times a year and some types of seabed are more sensitive to disturbance than sandy sediments³.(Jennings et al. 2001).

² According to Nielsen et al. (1997) some of the most fished areas are also areas that experience oxygen depletion and the authors suggest that the contribution to oxygen deficiency may be significant in the most fished areas.

³ This includes muddy sediments and especially habitats constructed by or composed of living organisms such as meadow grounds (Hall-Spencer and Moore, 2000)

Important to whom?

The seabed is hidden and the immediate effects on biodiversity and physical structures are not visible to most of us. However, the long term effects from oxygen depletion, re-suspension of nutrients and chemicals may eventually affect the consumers in terms of less fish, fish with a higher content of chemicals and a less diverse marine ecosystem. In this regard, it should also be considered that the fishing methods that are most problematic in terms of seabed impacts also represent the most fuel consuming fishing methods, e.g. beam trawl.

It is worth stressing that there is a wide spread concern among Danish coastal vessels that certain active fishing methods (beam-, bottom-, bobbin- and rock hopper trawl) destroys the seabed and reduces the biodiversity and nursing grounds for the fish. This is described in a study about sustainable fishery, conducted by the Danish Society for a Living Sea in 1999. The study included interviews with 77 coastal fishermen. Several fishermen expressed their concern for the use of bottom trawls in areas with reef formations. Concern was also expressed about the use of bobbin trawl and rock hoppers that were able to enter previously unfished areas⁴ (Andersen and Andersen, 1999; Andersen, 2002a).

Uncertainty

From one point of view, the effects on the seabed from bottom tending fishing gear are well analyzed and documented. From another point of view, it has only been possible to analyze and document the short-term impacts. Thus, the wider and long-term impacts on the marine ecosystem and the food web are still relatively unknown. If we consider the large number of different potential impacts and the risk of creating irreversible damage to reefs etc., I would consider this impact to be relatively important. The large uncertainties that exist and our limited understanding of marine eco-system functioning could also be seen as an argument for using the precautionary approach.

Hot-spots

It is only the fishing stage that causes impacts on the sea floor, but it should be noted that this only applies to demersal and shellfish caught by bottom tending fishing gear. Bottom- and beam trawl catch most of these fish, but

⁴ It is possible that this development is a consequence of declining stocks that forces the fishermen to exploit new areas.

for many species alternative-fishing methods can be used as well. This applies to flatfish, which can be caught with Danish seine, and codfish that can be caught with long line or gill-net. For shellfish, the opportunities for substitutions of fishing gear are maybe less obvious, but for lobster fishing cages could be considered an alternative. Seabed impacts for different fish species were also discussed in chapter 4, and will not be elaborated here.

10.3 Land use

Land use was one of the exchanges that were not included in the MECO analysis. However, preliminary results obtained from Weidema (2003c) suggest that agriculture products represent around 75% of all land use - related to activities operated by Danish economic concerns. Other important sectors are forestry products, which represent 14% and finally we have different types of transport operations, which represent less than 1% of the land use.

For fish products transport processes are probably important for land use, but land use is also involved in production of ancillaries (especially those based on agriculture), extraction of fossil fuels used for energy production etc. However, there are several methodological challenges in an overall assessment of hot-spots.

Methodological aspects

Apart from the basic data on areas occupied, the data from Weidema (2003c) includes preliminary results where simple utilization factors have been used. The utilization factors reflect two variables. The first illustrates the assumed change in biodiversity compared to the initial situation and the second reflects the estimated time before the biodiversity is restored to the level before the occupation. Weidema argues that the time of occupation is by far the most important indicator – see figure 1:

$$S_B = \Delta Q * (area \times time)_{FU} * FU^{-1}$$

Figure 1: The impact potential (S_b) for land use per functional unit (FU^{-1}) as the product of the change in biodiversity (delta Q), the area occupied (area) and the time it takes to restore the initial level of biodiversity (time). The red arrows indicate magnitude of variation.

According to Weidema (2003b) the utilization factors emphasize the importance of soybean production in South America, because this involves occupation of previously unoccupied areas (at least in many cases) and because it is estimated that it will take a relatively long time (roughly estimated to 510 years) to restore the initial level of biodiversity.

Thus, when utilization factors are applied soy bean production will become even more important, as soy bean production to a large degree reflects occupation of new land.

Land use for agriculture based ancillaries

Referring to the figures for land use in the Danish economy, it must be assumed that land use is important for agricultural based ancillaries used at the processing stage for some fish products (e.g. grain for breaded flatfish or sugar for pickled herring). If we assume that, a change in demand for agricultural based products in Europe will affect, not the European agriculture, but moreover soybean production in South America, the impact potential will be even greater⁵.

⁵ Obviously, we could also discuss a number of unwanted side effects related to land use in Europe. However, I would argue that this is somewhat irrelevant. Basically large areas suited for agriculture in Europe are already utilized, and it is not likely that there will be allocated more areas to agriculture in the future. Thus, the increasing need for food that the world will experience in the future must come from “new” agricultural areas. In this respect, Weidema (2003a) suggests that the marginal

I have not included land use in the quantitative LCA, but nutrient enrichment related to agriculture can be used as a rough indicator of the areas occupied. If this is done, it appears that the avoided land use related to the avoided production of soy protein at the processing stage is a very important factor. This would suggest an overall negative contribution to land use, caused by the substitution of soy protein at the processing stage.

Soybean production in South America and Argentina, often involves the clear cutting of rain forest or pampas with a high biodiversity (Pengue, 2003; Vidal, 2003). Apparently clearing land for industrial soy farming is becoming the major driver of forest loss in some regions. This development, which mainly happens in the south, has been promoted by European consumers who have rejected GM soya from the US in favor of the conventional crops from Brazil. (Vidal, 2003)

Thus, it appears that we have a large negative impact potential for land use. Still, it should be stressed that there is a positive contribution related to consumption of ancillaries. In the previous chapter, it was concluded that breaded fish products reflected a smaller impact potential compared to ordinary flatfish filets, except from nutrient enrichment – partly caused by larger use of ancillaries for the breeding. In this regard, land use would be yet another impact category where the breaded products turned out worse – and we therefore have a situation where it is highly questionable whether breaded flatfish are more environmentally sound than ordinary flatfish.

Land use for other processes and products

As mentioned, transport is also potentially important for land use due to the infrastructure. The biodiversity is significantly reduced on the roads, but additionally the roads perform a barrier effect that reduces the biodiversity in the surrounding areas (Goedkoop and Spriensma, 2000). According to the EcoIndicator 99 (H/A) method, which describes land use in terms of lost biodiversity according to principles similar to figure 1, the use stage has the highest land use impact for ordinary flatfish filets, followed by the fishery,

source of proteins is soy protein from South America. Thus, a change in demand for food products will eventually not affect food production in Europe, but instead soy protein production in South America.

processing and transport stages. The most dominant process of all is transport, followed by energy consumption.

However, it should be noted that the Ecoindicator 99 method has only included land use for data obtained from the ETH-ESU 96 database. Hence, ancillaries based on agricultural products which have been obtained from the LCAfood database – are excluded from the assessment.

The importance of land use

The importance of land use aspects are discussed in the following.

How important?

According to Goodkoop and Speriensma (2000), landuse is often one of the most important impact categories for eco-systems, measured in terms of biodiversity. However, it obviously depends on the product. According to the Ecoindicator 99 (H/A) method, the land use impact potential is insignificant compared to other impact categories for flatfish products. Due to the lack of data, no further assessments have been conducted here.

Important for whom?

Landuse will affect animals and plants through reduced biodiversity, but also humans. The loss of biodiversity will make the earth a “poorer place” to inhabit, some would argue. This could be regarded as an indirect effect. Still, there is also a direct effect. When a highway is built, it will affect people living in the vicinity. They will be subjected to increased noise levels, pollution etc. Similarly, clear cutting of rainforests in Brazil will affect the chances of survival for indigenous people representing ancient cultures etc.

Uncertainties

It should be stressed that the results from the LCAfood project as well as results from the Norwegian study are preliminary, and that the methodological uncertainties are large – especially in the Norwegian study where a methodology developed for land use is applied to assess seafloor impacts.

Hot-spots

Considering the magnitude and importance of land use related to soy production, I would assume that this is one of the most important factors together with transport and energy consumption. As soy protein is an avoided product from the processing stage, I would assume that processing generally is of

relatively little importance – even though it includes some transport between harbour and processing. I would therefore suggest that the hot-spots are the use and fishing stages. If we disregard the avoided land use for soy production, it is also possible that the processing stage is among the hot-spots - due to the consumption of ancillaries and some types of packaging material.

10.4 Waste

LCA studies often include waste in terms of emissions caused by incineration or treatment of chemical waste. This was also the case for the LCA in chapters 8 and 9, where I included chemical waste from the fishing stage (lead and biocides from the slipway) as well as waste from the processing and use stage. However, waste can also be treated as a separate impact category.

Methodological aspects

The EDIP method includes four sub-categories of waste: Bulk waste, hazardous waste, radioactive waste and slag & ashes – all measured in volume (Wenzel et al. 1997).

In this project, it has not been possible to make a precise estimate of these categories in the assessment in chapter 8-9, because of inconsistencies between the EDIP method and the databases applied, mainly ETH-ESU-96. To compensate I have made a more qualitative oriented assessment, which also address littering. In the following, I will begin with a description of the immediate contribution to waste in the different stages.

Waste from the fishing stage

As described in chapter 4, fishing gear is often lost in the fishery and the LCA suggests that even lead pollution from lost fishing gear is a relatively insignificant problem for eco-toxicity. However, loss of fishing gear could also be perceived as a kind of littering.

A project funded by the Nordic Council of Ministers termed “Save the North Sea” is currently addressing the problem of littering in the North Sea. It has been concluded that waste is generated by a variety of sources including shipping, off-shore activities, fishing vessels and private boats. The waste generated by fishing vessels include lost fishing gear-, and different types of plastic containers, pallets etc. (Jacobsen, 2003)

According to (Jacobsen, 2003) the problem is that the waste ends up on the shore or in the stomach of birds⁶ and other animals. As described in chapter 4, gillnets can also contribute to “Ghost fishing” where the fishing gear continues to fish, long after being lost.

However, it should be emphasized that the vessels also “catch” a lot of waste generated by non-fishermen. In a Dutch study the average trawler caught 12 tons of waste per year. Still, the problem is that the fishermen have to pay to get rid of the waste in some harbours. Therefore some fishermen get rid of the waste by dumping it in the sea again. Skagen harbour in Northern Jutland have developed a machine that can granulate the waste, which can be re-used in the plastic industry, but obviously the fishermen should be able to bring it back without fees or even with a bonus if the situation should be changed (Jacobsen, 2003)

⁶ The bird “petrel” eats a lot of the waste dumped in the sea and that the stomach is full of trawl-, plastic- and aluminum waste. Considering the small size of the birds the amount would be comparable to if our human stomachs contained 2 liter of waste. Considering the waste that ends up on the shore it is assessed that 6.000 cubic meter ends up on the Swedish west coast of which 80-90% is plastic that may remain imperishable for up till 450 years. (Jacobsen, 2003)

Waste from other stages

Obviously, waste is also generated in other lifecycle stages – as an immediate exchange or indirectly through related product systems.

Immediate exchanges

Based on the MECO analysis, it can be established that the use stage contributes with the largest amount of waste, regarding the immediate exchanges. However, the waste is typically incinerated and the emissions that occur are already included in the LCA in chapter 9. This is also the case for other types of waste generated at other lifecycle stages. Obviously, there will still exist a fraction of the waste that ends up in landfill, but I assume that this amount is insignificant.

At the processing stage, even larger amounts of by-products occur. However, these by-products substitute other food products or “sand and gravel” for mussels – as documented in chapter 5.

Indirect generation of waste

With respect to the indirect waste generation, it is important to notice that large amounts of “bulk waste” are generated in relation to the extraction of coal used for the production of electricity (Anon, 2000). This points towards the retail and use stages as the hot-spots, but it can be debated whether “bulk waste” is a serious problem. Furthermore, the study has used Danish normalization references for bulk waste occurring in other parts of the world where mining activities probably are more common than in Denmark. Thus, the estimate of the impact potential in terms of PE could be overestimated.

There are also produced significant amounts of “slag and ashes” at coal-powered power plants, but according to Anon (2000) the impact potential is insignificant. In this regard, it should also be emphasized that the avoided environmental impacts from substitution of other building materials have not been included. Thus, I have chosen to disregard this subcategory.

The production of other materials and chemicals may also imply generation of large amounts of waste. In this regard, the processing stage includes large exchanges of materials for packaging and ancillaries used in the fish products. Thus, a rough estimate points towards the processing, retail- and use stages as the potential hot-spots for indirect generation of waste.

The importance of waste

The importance of environmental impacts related to waste generation are discussed in the following.

How important?

Area affected. The magnitude of the littering problem in the fishery influence large coastlines, especially in Sweden where 6.000 cubic meters of waste ends up on the shore each year. However, it is not clear to what extent the fishery is a net contributor to this problem.

Seriousness of impact. Littering in the fishery is a serious visual and environmental problem and it also a problem related to animal welfare.

It is also difficult to assess the importance of waste generation through indirect exchanges related to production of energy and materials. The analysis points towards coal fired power plants as the most important process, which direct the attention towards the retail and use stage, but the processing stage could also be important. Still, the impact potential for “bulk waste” could be overestimated and is not necessarily a serious problem in any case.

Important for whom?

The waste littering problem in the fishery is a problem that concerns people who appreciate clean beaches – pretty much all of us. However, the problem will probably also concern animal welfare organizations as well as the fishermen themselves because lost fishing gear may continue to fish and reduce the catch potential.

Uncertainties

The results presented here, should be perceived more like a discussion and do not include any absolute statements.

Hot-spots

It must be concluded that the fishery-, processing-, retail- and use stage all are potential hot-spots for the “waste” impact category. Still, if one hot-spot should be selected, I would suggest the fishing stage. Obviously, it could be argued that the fishery could turn out to be a net remover of waste from the sea. On the other hand, it could be argued that the fishermen are indeed responsible for the handling for everything they catch - also waste. In this re-

gard, the waste could be perceived as by-product of the production – also if it is caught together with the fish.

10.5 Depletion of non-renewable resources

As it appeared in chapter 8 and 9, I have not previously included the impact category “depletion of non-renewable resources” (abiotic deposit resources) such as fossil fuels and metals, which are included in the EDIP method. This is partly due to the lack of methodological consensus among researchers in the international LCA community and partly due to methodological inconsistencies between the EDIP method and the databases used in this project. Some researchers even argue that consumption of non-renewable resources isn't a problem in itself – see Weidema (2000).

Resource depletion according to EDIP

The EDIP 96 method⁷ includes two categories for depletion of non-renewable resources, fossil fuels, and metals.

Methodological approach in the EDIP method

In the EDIP method, resource consumption is considered to be a global problem and the normalization reference is therefore the average resource consumption for a global citizen per year. However, the weighting step is not performed according to the distance to target method. Instead the weighting factor reflects the remaining resources available per person. Thus, the weighted result can be obtained by dividing the resource consumption of a given material, related to the product in question, with the remaining resources available per person of the given resource.

However, the EDIP method was not developed to be used together with foreign databases. This is particularly a problem for the metal-category in resource consumption. The reason is that different names for the various resources are used in a number of cases. To avoid uncertainties, I have therefore not applied the EDIP method for the metal category.

⁷ Resource consumption has not been integrated in the EDIP 97 update available in Simapro and edited by 2.-0 LCA consultants.

Results for fossil fuel

The weighted results for the category resource consumption of fossil fuels obtained by the EDIP-96, for one kg ordinary flatfish filet are illustrated in figure 1.

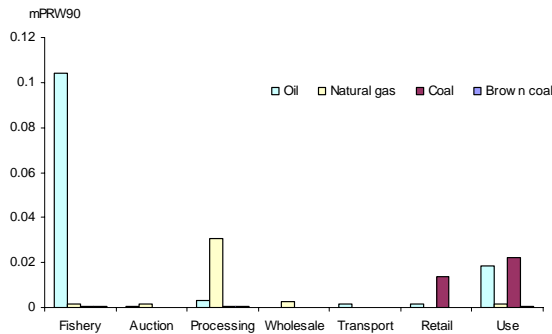


Figure 1. Weighted results for fossil fuel for one kg consumed ordinary flatfish filets –according to the EDIP 96.

As it appears, the fishing stage represents the largest impact potential in terms of weighted person reserves. The most important aspects are coal and oil consumption. However, the use stage is also quite important due to consumption of lead, coal, and oil. Coal is also important for the retail stage, while processing is dominated by natural gas, because it is assumed that gas is the marginal electricity source in Denmark.

Figure 1 only shows one example of a fish product. In this regard, it is relevant to consider canned mackerel, which represents an extreme case⁸. The weighted results for one kg of consumed canned mackerel with 0% recycled aluminum are illustrated in figure 2.

⁸ By extreme, I mean that the exchanges at the fishery- and use stages are relatively small compared to the processing stage, where the consumption of energy and packaging is somewhat larger than for flatfish

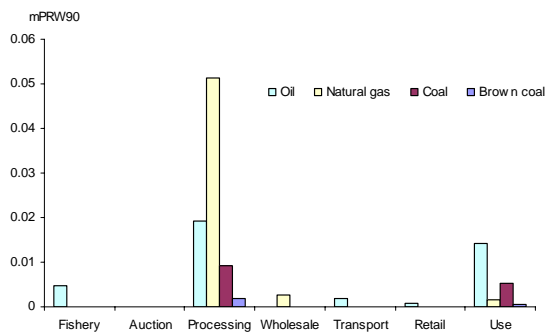


Figure 2. Weighted results for depletion of fossil fuel for one kg consumed canned mackerel (0% re-cycled aluminum) - based on EDIP 96.

It appears that the processing stage becomes relatively more important – partly due to the consumption of natural gas in mackerel production and partly because of the consumption of aluminum. Nevertheless, it should be noted that the main reason for the changing picture is the low energy consumption at the fishing stage. Furthermore, it should be noted that it is assumed that virgin aluminum is used thus, emphasizing the importance of the processing stage.

If we consider pickled herring in virgin glass, the fishing stage becomes considerably more important, even though this is a fuel-efficient fishery as well⁹ – see figure 3.

⁹ For instance the fuel consumption is only half of that for the average edible fish – see chapter 4.

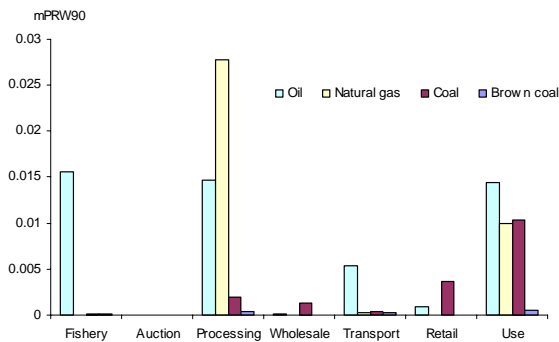


Figure 3. Weighted results for depletion of fossil fuel for one kg consumed pickled herring (virgin glass)- based on EDIP 96.

As it appears, the fishery becomes much more important (the fuel consumption is 0,18 liter per kg of caught herring). The use and retail stages also have significant contributions related to coal consumption due to electricity consumption, which is somewhat larger than for canned mackerel because of cold storage.

All things considered, the picture is roughly the same as for the assessment of emissions related impact potentials in chapter 8 and 9. However, the main difference is that the processing stage appears to be somewhat more important for resource consumption, which is mainly due to the relatively short supply horizon for natural gas.

Results obtained with EcoIndicator 99 (H/A)

Due to the lack of consensus on how resource consumption should be treated in an LCA, I have used the EcoIndicator 99 for verification. This method also models fossil fuel and mineral resources.

Methodological approach in the EcoIndicator 99 method

In the description of the Ecoindicator 99 (Goedkoop and Spriensma, 2000) it is argued that it is very difficult to estimate the remaining accessible resources and that the result becomes arbitrary. Even very low concentration

ores can be exploited, -if the need is large enough in the future. Furthermore, extraction technologies change very fast – at least that has been the case, so far. Finally, we may continue to discover new high-grade ores.

Therefore, the EcoIndicator 99 uses a different approach. It is argued, that exploitation of non-renewable resources leaves future generations to deal with lower concentration ores, which is the real problem. The method therefore suggests that future generations will use more energy and land to extract the remaining resources. It has therefore been chosen to measure the damage in terms of the expected increase in extraction energy per kg of extracted material, so called surplus energy¹⁰.

The weighted results for ordinary flatfish filet and canned mackerel, according to the Ecoindicator 99 (H/A), are illustrated in figure 4.

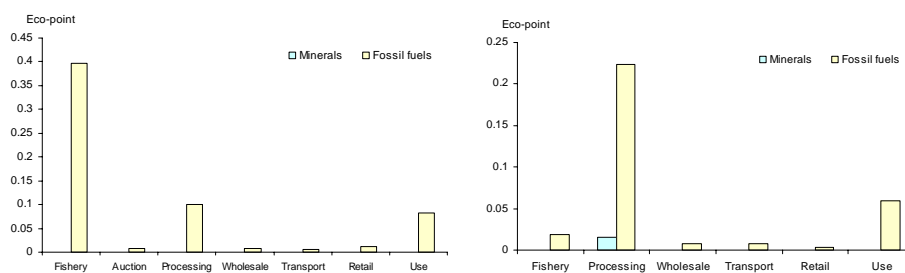


Figure 4. Weighted results for fossil fuel and minerals for one kg consumed ordinary flatfish filets and one kg canned mackerel – according to the EcoIndicator 99 (H/A) method.

As it appears, the results for fossil fuel are very similar to the results obtained by the EDIP method. The additional information we obtain is that minerals apparently are of very small importance, even for canned mackerel, where relatively large amounts of aluminum/bauxite is involved.

¹⁰ If the damage factor is one, this means that due to a certain current extraction, further extraction of this resource in the “future” will require one additional MJ of energy. The point in the future has been chosen at the time at which five times the cumulative extraction of the resource before 1990 is extracted. The factor five is arbitrary, but after normalization this has no further influence on the results (Goedkoop and Spruiensma, 2000)

However, the weighting step is not performed according to the distance to target method. Instead, the weighting factor reflects the remaining resources available per person. Thus, the weighted result can be obtained by dividing the resource consumption of a given material, related to the product in question, with the remaining resources available per person of the given resource.

The importance of resource depletion

The importance of aspects related to resource depletion are discussed below.

How important?

It is very difficult to assess the importance of resource depletion, and in the EDIP method it doesn't make much sense to compare resource consumption with other impact categories, as the weighted results are obtained with a completely different approach (not distance to target in this case).

However, comparison is possible in the Ecoindicator 99 (H/A) where it appears that resource consumption for flatfish products has a relatively high importance. The damage potential for resource consumption is assessed to be of the same magnitude as the total damage potential for human health, which reflect the human health damage caused by global warming, ozone depletion and respiratory effects, radiation and carcinogens.

The eco-indicator 99 (H/A) method uses a panel procedure for weighting. Thus, a panel has been asked to rank and apply weighting factor for the three damage categories. Obviously, the method can be criticized for the relatively low number of answers to the questionnaire (82 out of 365), but I would argue that the *main problem* is that resource consumption is treated in a separate category (as an end point) on the same level as ecosystem quality and human health. As suggested by Weidema (2000) it can be argued that resource consumption, especially when related to energy carriers, cannot be regarded as an endpoint. Thus, he suggests that there only exists a maximum of two end point categories: Ecosystem quality and Human health.

The reason is that energy carriers can be substituted and will be substituted (it is just a matter of time). As mentioned previously, it can also be argued that metals are not an end point, as they can be retrieved in most cases.

In my opinion, the ideal solution would be to “translate” the surplus energy requirements into emissions, land use and other midpoint categories that

subsequently could be assessed in the context of damage to eco-system quality.

All this suggests that the results obtained above are very uncertain. The results, which suggest that resource consumption is as important as the two other end-point categories is especially uncertain. When resource consumption gets its own end point category – it obviously gets a relatively high weighting score, when presented to a weighting panel.

Important for whom?

Consumption of fossil fuels and metals/minerals is mainly a problem for future generations. Still, it can be argued that the problem will be limited – at least when we focus on fossil fuels, which can and will be substituted.

Uncertainties

The results for fossil fuels are surprisingly similar in the two methods, which suggest that the results are quite reliable, but it should be stressed that the methodological approach in both methods remains problematic – see Weidema (2000). According the EcoIndicator 99 (H/A), mineral resources have a relatively small importance. It is difficult to assess whether this is reliable, but for both impact categories it is most likely that very different results can be obtained by different methods. There is no consensus among researchers as to how to best describe this impact category. Some of the problems are (Goedkoop and Spriensma, 2000):

- A difficulty in determining the available resources, as it depends on many variables and assumptions about the future extraction potentials etc.
- Difficulties in determining the essential property of various resources and why depletion of such a resource should be a problem. As we know many resources can also substitute each other.
- Finally, a mineral resource doesn't disappear after use. Minerals can be retrieved after use e.g. in dumpsites or from re-cycling of products and materials.

Thus, it must be realized that the results presented here are somewhat uncertain in the sense that different methodological assumptions could lead to different results.

Finally, it should be stressed that there are other abiotic deposit resources, such as sand and gravel but these have not been considered here. Biotic re-

sources such as fish and groundwater are treated separately in the following sections.

Hot-spots

If we consider the average edible fish with a fuel consumption of 0,32 liter per kg caught fish, the resource consumption at the fishery, processing and use stages is roughly similar, according to the EDIP method as well as Ecoindicator 99. Considering the importance of different processes – the resource consumption also points towards fishery, transport, and cold storage as the most important (this was also the conclusion in chapter 9).

However, the difference is that the consumption of energy at the processing stage is more important for resource consumption, due to the consumption of natural gas, which has a relatively short supply horizon. Thus, for some products characterized by a low energy consumption at the fishery and relatively high exchanges at the processing stage (e.g. canned mackerel) – the processing stage will be the hot-spot.

10.6 Exploitation of fish stocks

Exploitation of fish resources (or biotic resource extraction) was described in terms of the degree of over-exploitation for different stocks in the MECO analysis in chapter 4. Thus, for this particular exchange, the MECO actually included some type of impact assessment.

Even though the analysis in chapter 4 considered the magnitude of overexploitation for different stocks, the seriousness of the over-exploitation was not further analyzed. This is compensated for in the following section.

The effects of exploitation of fish resources are closely connected to species diversity. Aspects of biodiversity has been described previously (in relation to seabed impacts and land use), but it has been found necessary to further elaborate on the concept of biodiversity with particular focus on exploitation of fish resources.

The concept of biodiversity

Biodiversity is not an easily definable concept and extinction rates tell only a part of the story. The biologist Hanne Stensen Christensen puts it this way (Christensen, 2002):

“Extinction rate is a grossly over simplified concept – it can only say something about species that have become extinct and nothing about the situation of all other species. Nor has the global extinction rate anything to tell us as to how the animals and plants are thriving in individual continents or countries”.

Often biodiversity is defined in terms of three factors genetic diversity, species diversity and ecosystem diversity. These three factors are interrelated in such a way that a reduction in the diversity in one factor is likely to affect the diversity in the remaining two factors (Weidema and Lindeijer, 2001).

Both the temporal and spatial dimension is essential in the discussion of biodiversity. The diversity of species, ecosystems and genetic resources can be reduced locally, regionally or even globally. Furthermore the diversity can be reduced for a limited period of time, for a longer period or even for eternity, depending on the type and scale of impact. A total extinction of a certain species would reflect a situation where the temporal dimension is eternity or at least a very long time, and where the spatial dimension is global, see figure 5.

	Local / regional	Global
Temporary	Reduced local abundance	Reduced abundance
Eternity	Extirpation	Extinction

Figure 5. *Temporal and spatial scale of biodiversity reduction.*

A quantification of the effects on the seabed as well as on the food-web could be done in terms of a biodiversity indicator such as the Shannon Wiener index. The latter measures the number of species for a given number of

of individuals or indexes, and considers the taxonomic diversity as well. The taxonomic diversity incorporates the idea that a community with three distantly related species, say cod, herring and skate are more diverse than a community with three species of anchovy (Jennings et al. 2001).

Effects on fish populations and communities

The OSPAR Commission¹¹ presented its status report about the Northeast Atlantic, the 30th of June, 2000. The aim was to determine the status of and the causes behind pollution of the Northeast Atlantic. In spite of improvements in some areas, it is argued that there are still serious problems. Among the most important problems are over-fishing, by-catch, discard of fish, disturbance of seafloors, and emission of biocides. The disturbance of sea floors is dealt with separately while the TBT emissions were considered in chapter 8 and 9.

Changes in the food web

The magnitude of the exploitation of different fish stocks was described in section 4.1 about materials, but this section focuses more on the qualitative effects of over-exploitation.

Any exploitation of fish stocks and over-exploitation in particular, will result in changes in the species composition. These changes will eventually affect the whole food web – to some degree. Most fishing methods are size selective and fishing activities therefore tends to change the size and age structure of fish populations. This means that mean body size and mean age decreases, which may have negative effects on spawning potential. The reason for this is that smaller and younger individuals are less fecund. Size selective fishing can also affect the sex-ratio, the genetic structure, growth rates (promotes individuals with high growth rates) and age at maturity and length at maturity. Such changes are well documented and are also the effect of fishing in our part of the North Sea (Jennings et al. 2001).

¹¹ The OSPAR Commission is an inter-ministerial co-operation, concerning prevention of sea pollution and measurement of the state of the environment in the Northeast Atlantic. The participating countries are most European countries including Denmark.

Extirpation

In some cases certain fish stocks may be exploited to the extent of extirpation, which refers to losses of “local” stocks or populations. According to Jennings et al. (2001), fishing has extirpated many fished species on scales of tens to hundreds of square kilometers. This includes giant clams on many of the Pacific Islands, and the Indo Pacific “Bumphead parrotfish”, the Giant sea bass in California and skate in the Iris Sea.

Extirpation results in reduced species and genetic diversity. There are a number of different methods to measure the species diversity. They range from methods that measure the total number of species (species richness) to methods that measure the way in which the total number of individuals are divided among the total number of species (equitability). According to the latter, a community with a high evenness and low dominance is considered more diverse than one with the same number of species but low evenness and where a few species are dominant.(Jennings et al. 2101).

Trawl surveys of the North Sea demersal fish community shows that the diversity among the whole community has declined between 1929 and 1953 and 1980-83 measured by methods that take into account equitability. During the same period, no change in the non-target community was observed (Jennings et al. 2001).

Extinction

Total extinction of species as a result of fishing, is also a theoretical risk but far more rare than extirpation. For the major target species the probability of their extinction is very low because economic extinction will occur first. Stephen J. Hall (1999) puts it this way:

“With respect to the exploited species themselves, a stock collapse is often viewed in the eyes of the popular press and many others as a small step from extinction. This is a falsehood that needs to be put to rest. With a collapse, animal abundance falls to low levels where fishing becomes uneconomical, or controls on fishing become imperative”

Hall argues that biological extinction of exploited species is rarely an issue¹². There are exceptions such as the great whales and some species, which are

¹² It should be mentioned that it is always extremely difficult to measure extinction rates of species. One of the problems is that we simply don't know the total number of species. For instance, it is assumed that only around 60 % of all species of fresh

caught as by-catch, and may also be threatened, e.g. certain birds, mammals and turtles (Hall, 1999 p. 203). As a function of by-catch, four of the North Sea Skates and Rays are currently being fished down to very critical levels (Jennings et al. 2001; ICES, 1999).

As illustrated, fishery activities have effects on the populations and may lead to extirpation or extinction of species. However, it should be stressed that species may become vulnerable and may miss-thrive long before it materializes in extirpation or extinction (Christensen, 2002).

In this regard, it is also worth considering the risks of inbreeding and reductions of genetic diversity. Inbreeding and reductions in genetic diversity makes the species more vulnerable to changes due to fluctuating population levels, disasters, climate changes, human exploitation etc.¹³ (Christensen, 2002).

The importance of the exploitation of fish

The importance of aspects related to exploitation of fish resources are discussed in the following.

How important?

Area affected. Obviously, the area affected can vary from very local effects to global affects – e.g. in the case of global extinction. Still, the latter is very seldom the case and in most cases, the effects will be on a local or regional scale.

Seriousness and reversibility. The effects of exploitation and not least over-exploitation are not merely a question of jeopardizing short or medium term economic gain. Some of the effects can be irreversible changes of the ecosystem, such as extinction of species taken as by-catch and changes in genetic diversity. It can be discussed whether extirpation is an irreversible ef-

water fish in South America have been described. The same reference estimates that the total number of fish that we know has become extinct over the last 50 years is approximately 80. The number of extinct mammals is estimated to be 38, the number of mollusks is 60 and finally the number of plants which have become extinct is approximately 371. (Fog, 2002)

¹³ A small population, with little variation in their gene pool will be far less likely to have individuals able to cope with the changes in their environment. (Christensen, 2002)

fect. Theoretically, it will be possible to re-introduce the extirpated species from other areas, but at least the consequences are serious.

Among the other effects are changes of species composition, age distribution and reduced fertility, which may affect future potential for reproduction.

Obviously, exploitation and over-exploitation contribute to a reduction of biodiversity, and species may become vulnerable and may miss-thrive long before it results in extirpation or extinction. Furthermore, over-exploitation leads to lower yields that result in two things: 1) larger environmental impacts per kg caught fish and 2) the need for increased food production somewhere else. Concerning the latter, it has previously been argued that a global increase in food production may involve clear-cutting of rain forest.

Thus, it is assessed that the over-exploitation of demersal fish and especially cod fish (see chapter 4) is a very serious environmental problem.

Important for whom?

Exploitation and especially over-exploitation of fish stocks is a problem that affects the fishermen, but the advantages of over-exploitation belongs to the single fishermen, while the disadvantages (in terms of stock depletion) is distributed among a larger group of fishermen.

Over-exploitation also affects the consumers that will be faced with higher prices and a smaller selection of fish. Besides, if nature is believed to have an intrinsic value, it is obviously a problem for the eco-system as such. In some cases, over-exploitation may also lead to hunger or mal-nutrition, but this is not likely to be the case for the Danish fishery.

Uncertainties

Fish stock assessment is a relatively old science based on extensive empirical studies in all parts of the world. Thus, it is assessed that the uncertainty is relatively small compared to the other impact categories described in this chapter.

Hot-spots

It is obviously the fishery which is the hot-spot in this case.

10.7 By-catch and discard

The term by-catch is used to describe the catch of non-target species (including marine mammals etc¹⁴), while discard is used to describe species (fish and other species) that are caught but returned to the sea thus, not landed. Discard may consist of by-catch as well as target fish.

Methodological aspects

Currently, no methods exist to describe and quantify the impact potential for by-catch and discard in a lifecycle assessment context (Udo de Haes et al. 2002). Chapter 4 included a quantitative assessment of the amount of discard in different vessel segments and mentioned some of the problems concerning by-catch. However, this section will elaborate on the seriousness of by-catch and discard in the fishery.

By-catch

By-catch is often mentioned as a problem, but in many cases this is not necessarily the case. It is basically impossible to conduct a fishery that only catches one single species. Other species will always be caught as well. By-catch can in fact contribute to a more fuel-efficient fishery, if the by-catch consists of species that would require larger energy consumption to catch separately.

By-catch of overexploited species

Obviously, by-catch can be a problem if it consists of fish species that are overexploited, such as Skates in the North Sea. It can also be a problem if the amount of by-catch is so significant that it becomes illegal for the fishermen to land it. This may lead to discard, described in the following section.

By-catch of marine mammals and birds

By-catch is also a problem if it consists of marine mammals and birds. As mentioned in chapter 4, the problem that has caused most attention in Denmark is the by-catch of sea-porpoises in bottom set gillnet fisheries – especially in fisheries targeting Turbot. In year 2001 it was estimated that the total by-catch was just below 4.000 individuals. (Miljøstyrelsen, 2003)

¹⁴ Actually, by-catch may also consist of waste as described in the previous section.

According to Jennings et al. (2001), the public interest in by-catch of marine mammals is highly motivated by sentimental factors. This may be true in most cases, but by-catch of marine porpoises is actually believed to be among the most important factors currently threatening the community of sea porpoises in the Baltic Sea. In this regard, a special Danish version of gillnets (bottom set gillnets) used in demersal fishery, is believed to be the main cause of the problem (Danmarks Naturfredningsforening, 2003).

Discard

Discard is fish and other species (benthos, marine reptiles, birds and marine mammals¹⁵) that are caught but not retained and landed.

Different types of discarding

Obviously, discard would happen seldom in fisheries where the main purpose is to gather enough protein for daily survival. However, modern fisheries, in our part of the world, focus on economic gain and are often restricted through fish quota. Thus, in some cases fishermen perform “high grading” where less valuable fish are discarded to reserve room or quota for more valuable fish. In other cases discard is simply necessary because limited quota on the given by-catch makes it illegal for the fishermen to land it.

Norway is the first country where high grading has been outlawed and fishermen shall land all fish above the minimum landing size (Jennings et al. 2001). However, I have not been able to obtain information to assess the efficiency of these measures. Another solution are quotas that address the number of sea days the fishermen are allowed to fish - instead of the amount of fish they are allowed to catch. This would reduce the amount of by-catch that is related to quota, but would still not prevent high-grading caused by limited fish holding capacity. However, in the study by Denmark’s Fiskeriundersøgelser (2001) limited fish holding capacity was not mentioned as a typical reason to discard in the Danish fishery.

What are the effects?

As documented in chapter 9, discard is probably not a problem in terms of contribution to eutrophication, but is obviously an ethical problem in relation to food. An estimate by Alversen et al. (1994) suggest that 27 million tones

¹⁵ This could also include waste.

of material are discarded each year while the total catch is around 100 million tons. It should also be considered that discard inflicts damage to the fish (or other species). In this respect we talk about discard mortality, which can be close to 100% in some cases. Thus, discard will cause some of the same effects as exploitation of fish stocks in terms of changes to species composition, biodiversity etc. Finally, it will obviously reduce the catch opportunities in the future.

The importance of by-catch and discard

The importance of environmental aspects related to by-catch and discard are discussed in the following.

How important?

Area affected. By-catch and discard happens all over the world, but in Denmark by-catch of marine mammals is a problem that mainly concerns some areas.

Seriousness. It can be concluded that by-catch can have a negative impact on some stocks of marine mammals, but is also a problem for animal welfare (what Jennings refer to as “sentimental reasons”). The latter is treated separately in the following sections.

For discard, it can be concluded that this is an ethical problem as well as a problem in parallel with exploitation of fish resources. Thus, I would argue that exploitation of fish, by-catch and discard should be considered as one impact category - when compared to other impact categories. Considering the amounts of discard that occurs in some types of fisheries (especially for Norway lobster) it could be argued that it is a serious problem - see chapter 4.

In some sense discard is already reflected in the LCA in chapter 8 and 9, because the exchanges per kg retained catch will grow proportionally with the amount of discard – all things being equal. Thus, energy consumption may be an indicator for discard as well as seafloor impacts, as earlier suggested.

Important for whom?

As argued, by-catch and discard are closely related to over-exploitation of fish resources and therefore important for the same stakeholders.

Uncertainties

Generally, large data uncertainties exist concerning discard and by-catch in single fisheries, but I assume that the overall trends have a relatively large certainty.

Hot-spots

Considering hot-spots, it is obviously the fishery that is most important for this impact category.

10.8 Consumption of ground water

Water consumption, which belongs to the category “abiotic fund resources” has only been considered in terms of energy needed to extract, treat and distribute the water in the LCA in chapter 8 and 9. However, depletion of ground water¹⁶ resources could also be considered as an impact category in itself.

Methodological aspects

Depletion of fund resources such as groundwater only occurs if the natural replenishment rate is smaller than the extraction rate. There exist methods to include ground water depletion in LCIA, but currently they do not include effects on life support systems such as rivers (Udo de Haes et al. 2002).

When the ground water level falls, it will affect other life support systems such as watercourses and therefore other life support systems. In addition, a higher extraction rate tends to increase the risk of groundwater pollution as well. (NOVA, 2003). As mentioned earlier, LCIA methods to assess such effects have not yet been developed and I have therefore chosen to use a more qualitative approach to describe this impact category.

¹⁶ In Denmark – clean drinking water is mainly obtained from groundwater reserves, but part of the drinking water used in Copenhagen derives from surface water reserves as well. The latter is also the case in other European countries.

The ground water resources in Denmark

The ground water resource in Denmark is relevant to consider in relation to the first lifecycle stages (fishery, landing, processing and wholesale) – within the scope of the present study. It is clearly the fish processing stage that represents the largest water consumption – but the water resource may not be overexploited in all areas. The Geological Survey of Denmark and Greenland (GEUS) have recently published a comprehensive assessment of the ground water potential in different parts of Denmark. In this study, effects on rivers and risk of pollution have been included in the assessment of sustainable ground water potential (safe yield). More precisely the following parameters are included in the assessment:

- Reduction of the ground water reservoir
- Quality reduction of groundwater due to of over-exploitation
- Salt-water penetration
- Impacts of existing water exploitation
- Reductions of the water volume in rivers
- Impacts on other parts of the freshwater eco-system

According to the study, parts of Jutland have sufficient groundwater resources, while over-exploitation is a widespread problem in most other parts of the country. However, the situation can vary locally – see figure 6.

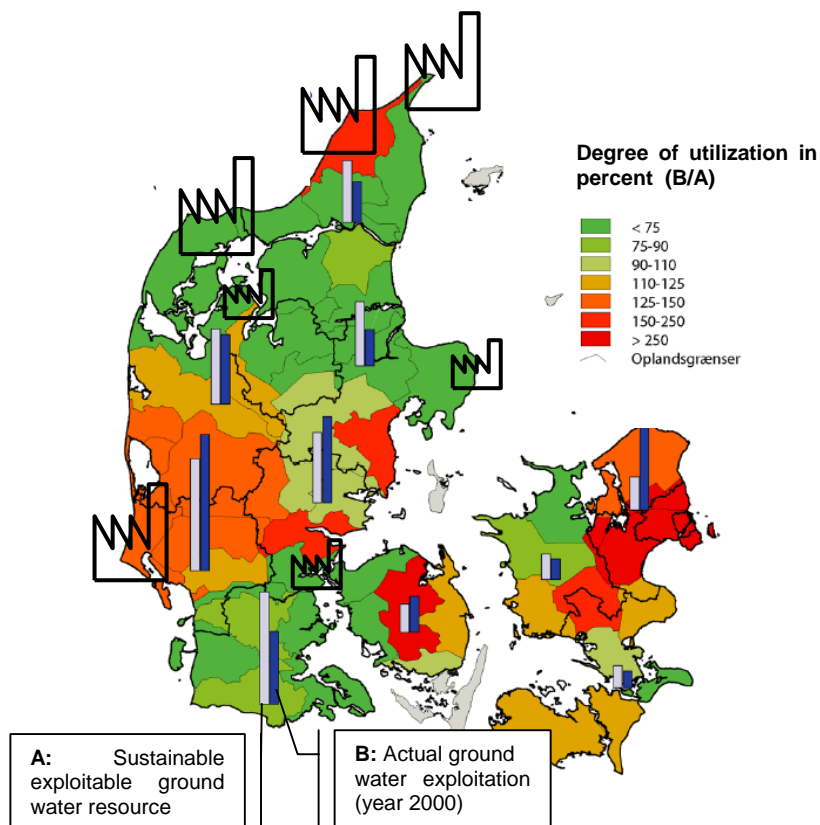


Figure 6: Illustration of the water consumption (blue columns) in Denmark year 2000 compared to the estimated sustainable resource potential, gray columns (NOVA, 2003). Large plants illustrates grouping of many fish industries (five or more) while small plants illustrates small grouping of fish industries (less than five)

A crude estimate is that half of the fish processing industry is situated in areas where the ground water resource is overexploited (red colors), while the other half is localized in areas with sufficient ground water resources (green colors). The island of Bornholm is not included in the assessment but a large grouping of fish industries is also situated here.

Skagen is a good example of an area with local problems. The problem has not been a lack of water, but mainly pollution of the water with organic substances. According to Østergård (2003), the problem is not necessarily caused by over-exploitation or other human activities. The local problem has

been solved by the establishment of a water supply line from Aalbaek (25 km south of Skagen), but it may become necessary to establish some sort of cleaning of the local groundwater in the future.

The ground water resources in Europe

Over-exploitation of water resources should also be considered for the retail and use stage in central and southern Europe. The Third assessment of Europe's Environment (European Environmental Agency, 2003b) states:

“..31 % of Europe's population lives in countries that experience high water stress, particularly during droughts or periods of low river flow. Water shortages also continue to occur in parts of southern Europe where there is a combination of low water availability and high demand, particularly from agriculture”

Besides, the assessment shows that central and southern European countries generally experience problems with pollution of drinking water reserves with nitrates and pesticides – a problem that tends to increase as a function of over-exploitation.

The importance of ground water exploitation

The importance of environmental aspects related to groundwater exploitation are discussed in the following.

How important?

Area affected. Utilization of ground water in most parts of Denmark is indeed a problem, but the over-exploitation is definitely much worse in some areas than others. In Denmark, the over-exploitation is less pronounced in Northern and Western Jutland where most of the fish processing industry is localized.

Seriousness. The study of the Danish water resources (NOVA) concludes that the situation in Denmark is serious, and that we only have around half of the ground water potential that we expected to have just a few years ago. It is concluded that over-exploitation in most cases is due to the impacts on rivers and the risk of increased pollution such as nitrate and pesticides. The main reason why the situation is characterized as "serious" is that the upper ground water reservoirs are polluted with pesticides and nitrates. (NOVA,

2003). In the period from 1987-99 around 600 water-works closed due to pollution caused by human activity (DMU, 2001).

Compared to the situation in many other European countries, the groundwater situation in Denmark is “relatively” good (European Environmental Agency, 2003b). Thus, for the retail and use stage, the situation is probably as bad as or even worse than in Denmark.

It is difficult to compare the importance of ground water exploitation – especially if we compare it to other types of environmental impacts. However, over-exploitation and pollution of groundwater is generally a problem that receives a lot of public attention in Denmark and something that the politicians have given a high priority.

Important for whom?

Over-exploitation of the groundwater is a problem that affects the consumers that will have to pay more for clean water. Ultimately, it can be necessary to buy drinking water in the store or to clean the ground water. However, the problem also affects people who use rivers for recreation and obviously the animals and plants living in and around rivers.

Uncertainties

The Danish NOVA research project is the most comprehensive assessment of the Danish fresh water resources conducted so far. Therefore, I assume that the results have a high validity. As regards the situation in central and southern Europe, I have only included very general descriptions, and it should be stressed that the situation varies considerably from country to country and region to region.

Hot-spots

From a quantitative point of view, the potential hot-spots are the processing-followed by the use stage. Generally, the ground water resources are not overexploited in Northern Jutland, where most of the fish processing industry is situated, but locally there are indeed problems.

The groundwater resource is overexploited in most parts of central and southern Europe¹⁷, and it is therefore possible that the use stage becomes the real hot-spot when site-specific aspects are included in the assessment. Still, the analysis is not detailed enough to distinguish between the two stages.

10.9 Human toxicity

Although human-toxicity is included as a separate impact category in the EDIP method, it was disregarded in the quantitative LCA in chapters 8 and 9, due to several methodological shortcomings.

Methodological aspects

The EDIP method includes three subcategories: human toxicity soil and water (chronic) and human toxicity air (acute).

According to the EDIP method, air emissions of benzene and lead are the most important aspects contributing to human toxicity – which mainly address transport in the use stage. However, these results have been disregarded because:

- Benzene and lead emissions from transport processes have been greatly reduced due to cleaner fuel and catalytic converters used in modern cars¹⁸ (Hansen, 2003b; European Environmental Agency, 2003a; Olsen, 2003).

¹⁷ According to the European Environmental Agency, Denmark has no reported problems concerning key indicators such as microbiology, nitrates, toxins, and metals. This is not the case for most of the other European countries. For instance, problems with nitrates appear in most other countries. This indicates that the problems are more serious in other countries, but it is important to note that the assessment only speaks about countries and not particular areas in these countries. (European Environmental Agency, 2003b). According to NOVA, Denmark had sufficient groundwater resources if we consider it as one big region without local considerations (NOVA, 2003).

¹⁸ As previously mentioned, I have used databases such as ETH-ESU 96, which represent the situation in the early 1990s. During the last 10-15 years the development of toxic emissions has changed considerably – especially for transport. First of all, the fuels have become cleaner and the content of sulfur, lead and benzene has

- Benzene and lead emissions are not included in the data for combustion processes at the fishing stage.
- The EDIP method does not include characterization values for human toxicity related to TBT.
- The EDIP method does not include characterization factors for fine and ultra fine particles (< PM 2,5¹⁹) and the characterization factor for large particles (<PM 10) is only based on WHO emission limits and not recent studies reflecting the real impact potential (Olsen, 2003).

First, it is questionable whether benzene and lead are still important emission parameters (data quality problem). The exclusion of these parameters in the data for the fishing stage contributes to inconsistency and risk of biased results (underestimation of the fishing stage). The lack of a characterization factor for human toxicity for TBT, may add to this underestimation of the fishing stage.

Secondly, I would argue that particle pollution is greatly underestimated in the EDIP method. According to the EDIP method, particle pollution has a very low importance for the category human toxicity air and this especially contributes to an underestimation of health impacts from combustion processes – e.g. transport.

The following sections include a qualitative assessment of human toxicity related to particles and TBT.

The importance of particle pollution

I have assessed the importance of particle pollution by referring to epidemiological studies of the general problem, and by a quantitative assessment of the life cycle of flatfish filets according to the Ecoindicator 99 method.

been reduced considerably. Furthermore, catalytic converters have been installed and today development is moving towards particle filters as well. The development has partly been driven by the EU emission regulations, typically referred to as Euro 1 to 3 (Dieselnet, 2003; Hansen, 2003b).

¹⁹ Obviously, the databases do not include 2,5 PM either, but this just emphasizes the limitations.

Epidemiological studies

According to Nielsen (2002c), particle pollution from traffic is believed to increase mortality and to cause chronic bronchitis, acute bronchitis, asthma and hospitalization. It is suggested that the total particulate pollution, of which man-made particles constitute around 2/3, contribute to 5.000 deaths, about 5.000 hospital admissions, 5.000 cases of bronchitis, about 17.000 cases of acute bronchitis, about 200.000 asthma attacks and about three million restricted activity days in Denmark per year²⁰. It is estimated that the health related gains from installing particle filters on all heavy-duty vehicles in Denmark ranges from 22 to 1.250 human lives per year, depending on the assumptions.

Hence, it appears that particle pollution induces a very serious health risk countrywide, but it is obviously necessary to relate it directly to fish products before we can draw any conclusions – especially regarding hot-spots in the lifecycle. This is done in the following.

Importance of particles according to Ecoindicator 99 (H/A)

The Eco-indicator 99 method includes recently updated characterization factors for particles (including fine particles < PM 2,5). Furthermore, the method uses a different approach²¹, which is more likely to grasp the human health impacts related to particulate matter.

According to the Ecoindicator-99 (H/A) method, particulate matter (or substances such as NO_x and SO_x contributing to fine particles²²) is by far the

²⁰ Obviously, photochemical ozone formation (summer smog) contributes to some of the same effects, but ozone formation is not caused by particle pollution. Volatile organic compounds (gases) mainly cause photochemical ozone formation.

²¹ The EDIP uses a bottom up approach where characterization factors are derived from toxicological experiments. Some of the weaknesses of this method are that test organisms are not necessarily representative for the populations affected and that a non-linear dose-response curve is not considered in the modeling. For toxicity and respiratory effects, the Eco-indicator method uses a top-down approach. Here point of departure is epidemiological studies, linking several non-organic substances and dust to respiratory effects in humans. The approach mainly suffers from limited possibilities to prove causalities, but on the other hand the approach makes it possible to apply a larger amount of studies. Finally, the method is used together with a number of criteria for causation that increase the validity of the results. (Goedkoop and Spriensma, 2000)

²² There is typically distinguished between three size categories of particles. Large particles (<PM 10), fine particles (<PM2,5) and very fine particles (<0,2 PM). Me-

most important emissions considering the potential damage to human health (measured in DALY²³) –related to the lifecycle of one kg consumed flatfish filets.

In the Ecoindicator 99 method, particle pollution is included in a separate category termed “respiratory inorganics” as opposed to “respiratory organics” which are somewhat similar to photochemical ozone formation in the EDIP method²⁴. The method suggests that the fishing stage²⁵ is the most important due to combustion of diesel oil, followed by use and retail. For use and retail, the most important process is electricity consumption based on coal; though at the use stage, transport also plays an important role.

Considering site-specific aspects (exposure), I would assume that transport is the most important process, especially in the use stage where shopping often takes place in urban areas. Transport is also involved in the processing and transport stages, but the contribution is still relatively small according to the Ecoindicator (H/A) method.

The importance of biocides (TBT and Sea Nine)

The EDIP method includes a characterization factor for human toxicity for copper, but not for the two other biocides included in my study: TBT and Sea Nine. This is also the case for other LCIA methods available in the SimaPro PC tool – thus, it has not been possible to quantify the impact potential. Instead, I have chosen to refer to an epidemiological study, which may help to elucidate the size of the problem.

chanical processes produce the large particles, while chemical processes such as transformation of NO_x and SO_x create the fine particles. The very fine particles are a result of very high temperatures in relation to combustion processes. In this regard, studies suggest that the health impacts increase as a function of decreasing particle size (DMU, 2001).

²³ DALY: Disability adjusted life years – further explained in chapter 9.4

²⁴ The category, respiratory inorganics is also equivalent to “winter smog”, while respiratory organics sometimes is referred to as “summer smog”.

²⁵ The data for the fishing stage does not include particles, but the method estimates the particle pollution based on the NO_x and SO_x emissions (Goedkoop and Spriensma, 2000)

Epidemiological studies

According to Belfroid et al (2000) the levels of organotin compounds such as TBT in seafood is relatively high. In a study involving 22 countries - the tolerable average residue intake (TARL²⁶) was exceeded in one or more samples, for one third of the countries. In Italy the TARL value was exceeded with a factor 2,5 for mussels and when DBT²⁷ was included up to a factor 25.

This indicates that the emissions of biocides in anti-fouling agents can be a human health problem, but according to my knowledge, there are no epidemiological studies suggesting human deaths or chronic diseases inflicted by these compounds, contained in fish and shellfish²⁸. Furthermore organotin compounds are currently being phased out due to international regulation from the International Maritime Organization (IMO).

Copper can still be used, but the amounts are also being reduced – at least in Denmark. Finally, the EDIP method suggests that copper has a relatively low human toxicity potential. I have therefore concluded that human toxicity for antifouling paints is a limited problem – at least compared to particle pollution from traffic.

The importance of human-toxicity

The importance of health aspects related to human toxicity are discussed in the following.

How important?

Area affected. The most important human health impacts related to particle pollution mainly occur on a local scale, but as the emissions mainly come from mobile sources, the effects are not site-specific.

Seriousness. According to the Eco-indicator 99 (H/A) particle pollution makes up the largest part of the damage to human health. Thus, the method suggests that the effect on human health is far larger than other impact potentials such as global warming (the next most important), ozone depletion,

²⁶ TARL is defined as the (Tolerable Daily Intake * 60 kg body weight) / (average daily seafood consumption).

²⁷ When TBT is released into the sea, it breaks down into dibutyltin oxide (DBT)

²⁸ In this respect it should also be noted that the damage oriented method Ecoindicator 99 does not even include TBT in any of the human health related categories.

radiation and carcinogenic effects. The three latter effects have very small impact potentials.

Other studies confirm that particle pollution generally has a large impact potential for human health. Thus, I would argue that human health impact is one of the most important impacts considered in this study – including impact categories considered in chapter 8-9.

Important to whom?

Obviously human health impacts are important for humans and especially humans exposed to traffic pollution. Generally, environmental impacts with impacts on human health have a high priority.

Uncertainties

As mentioned previously, the Ecoindicator 99 method suggests that particle pollution has a much greater impact potential than the greenhouse effect and other impact potentials. However, it should be stressed that large uncertainties exist in the modeling. Still, for particle pollution a large number of studies have emerged during the last decade and it is relatively easier to establish a correlation between cause and effect for this impact compared to human health impacts from global warming, where the time horizon is several hundred years. Thus, the question is not so much whether particle pollution is important or not, but whether other impacts such as global warming may have been relatively underestimated.

Hot-spots

All things considered, I have assessed that particle pollution from combustion processes probably is the most important factor contributing to human toxicity. Even if the emissions of benzene and heavy metals were considered more important, this would point in the same direction. It is assessed that the contribution to human toxicity from anti-fouling agents are marginal.

Hot-spots in the lifecycle

The potential hot-spots for human toxicity are assessed to be transport (shopping) at the use stage and electricity consumption at the retail and use stage. This conclusion applies not only to flatfish but edible fish as such. Considering the risk of human exposure, it can be argued that the transport during shopping probably is the most important, because it takes place in urban areas, but transport at the processing and transport stages should also be

be considered. It must be assumed that particle pollution from fishing vessels and power plants is relatively insignificant due to low human exposure.

As for other impact categories, large uncertainties still exist. However, nothing suggests that the landing-, processing- (except for the transport) and wholesale stage are important concerning human toxicity

10.10 Other types of impacts

This section includes an assessment of the impacts related to Occupational health & safety, animal welfare, noise, odour, accidents and visual aspects. These impact categories are generally rather difficult to assess, especially quantitatively.

Occupational health & safety

A quantitative assessment of occupational health & safety was included in the MECO analysis in part two.

Data from the MECO study

Even though data were not available for all stages, it was assessed that the H&S hot-spots are the fishery and processing stage followed by the wholesale stage (see chapter 7).

My data suggests that small vessels have a slightly higher number of accidents and injuries per kg caught fish, but not per employee. Still, the data in the MECO analysis only provide a crude estimate and it must be expected that some level of underreporting occurs – especially in the fisheries.

Qualitative aspects of H&S

I have only discussed a few aspects of the type of H&S problems that occur at the various life cycle stages. One of them is the number of fatal accidents that clearly appear to be highest at the fishing stage.

Ideally, I should have done more research about the type of accidents, their seriousness, as well as psychological factors. For instance, it could be considered a psychological stress factor to work in rough weather, and to be without your family for several weeks at a time. From another point of view, some fishermen are probably fishermen at heart and would never consider

changing profession – partly because they enjoy the freedom and the sea. Thus, large uncertainties exist and are basically difficult to avoid, unless a very detailed analysis is conducted.

Animal welfare

Fish do not scream when they are caught, and they do not have facial expression or arms to signal pain and stress. Furthermore, they are cold-blooded animals that live a secret life in the dark waters. Therefore, humans tend to focus more on animal welfare among mammals: domestic animals, cows, pigs, chickens, horses, etc. However, do we need to consider animal welfare among fish - can they feel pain and stress at all?

British animal rights organizations suggest that animal welfare should indeed be considered also for fish. However, one of the most comprehensive scientific studies that have been made so far suggest that fish are too primitive to register and feel pain and stress “consciously”.

Results from a recent American study

The American professor James D. Rose from University of Wyoming concludes that behavioral responses to noxious stimuli are separate from the psychological experience of pain and that awareness of pain in humans depends on functions of specific regions of the brain called “cerebral cortex”. Finally, he remarks that fish lack these essential brain regions or any functional equivalent, making it unlikely that they can experience pain. (Rose, 2002). Rose writes:

“Because the experience of fear, similar to pain, depends on cerebral cortical structures that are absent from fish brains, it is concluded that awareness of fear is impossible for fish. Although it is implausible that fish can experience pain or emotions, they display robust, non-conscious, neuroendocrine, and physiological stress responses to noxious stimuli” (Rose, 2002)

When other researchers have concluded the opposite, it is because they have mistaken pain and the ability to register noxious stimuli, he states²⁹. It is comparable to humans that are anaesthetized during an operation. The person may react to external physical noxious stimuli, but the patient cannot

²⁹ Results from other researchers are also discussed at www.cambridgefpas.co.uk/national_news.htm

feel the pain. It is also commonly known that a chicken can move and react on pain after its head has been cut off. (Rose, 2002)

Acknowledging that research in neurological behavior and consciousness is a new and very difficult field of research, it is difficult to conclude anything decisive on the matter. However, based on the knowledge we have today, there are strong indications that animal welfare related to fish is not a matter of fish feeling pain and stress. For marine mammals such as sea porpoises the matter is more complicated. According to Prof. Rose marine mammals may have the ability to feel some kind of pain and stress. Thus, marine mammal entanglement in gill nets may also be an issue related to animal welfare.

Noise, odour, accidents and visual aspects

Finally, I briefly consider non-work related noise, odour, accidents, and visual aspects. These aspects have not been included in the quantitative LCA, nor have data for immediate exchanges been included in the MECO analysis. However, I assume that transport is the largest contributor to all four categories as the following argumentation will demonstrate.

Noise

According to Ohm et al. (2003) a rough estimate is that 200-500 people experience a premature death in Denmark, because of traffic noise.

For non-work related noise, traffic is clearly one of the main contributors to this problem in Denmark – especially in urban areas (Miljø og Energiministeriet, 1999; DMU, 2001). Another potential source of noise is the fish processing industry. Still, most of the Danish processing industry is situated in rural areas – mainly harbours. Thus, considering the relatively large amount of transport that is involved in the export and distribution of fish products, I assume that traffic related noise is the main problem for fish products. As traffic related noise mainly is a problem in urban areas and because the use stage is the most transport-intensive stage, I assume that the use stage is the hot-spot in this case.

Odour

If we consider the fish processing industry, problems with odour exist within fishmeal production, but fishmeal production has not been in focus in this dissertation. Thus, I would argue that exhaust from transport is one of the main contributors to this impact potential, but no further analysis has been

conducted. Still, I would argue that the most likely hot-spot is the use stage, for the same reasons as mentioned in relation to noise.

Accidents and visual aspects

The number of traffic related fatal accidents is around 500 per year in Denmark (Danmarks statistik, 2003). Considering non-work related accidents and visual aspects, I also argue that traffic is one of the most important factors. According to Lomborg (2001 p. 86) transport including walking, cycling, MC and cars is by far the main cause for fatal accidents. In this respect, it must be assumed that transport in urban areas is particularly dangerous. Thus, again it is probably the use stage which is the hot-spot.

Common sense tells me that traffic, and the infrastructure required in this respect, is the most important process with regard to negative influence on visual aspects – considering the life cycle of fish products. Still, this is only a rough “personal” assessment and not a statement based on any analysis.

Importance of other impacts

The importance of “other” types of environmental aspects are discussed in the following.

How important?

Area affected. All the “other” impact categories considered here have a local scale of impact.

Seriousness. Based on the tentative assessment in this section, I assess that animal welfare represents a “less” insignificant impact potential – mainly related to by-catch of marine mammals. The impact categories “accidents, noise and visual aspects” are all considered to be relatively significant – at least when considered as one group of impacts. It should be acknowledged that noise is believed to reduce the quality of life for many people all over Europe, and that noise and traffic accidents, all in all, are believed to cause around 700-1000 deaths per year in Denmark (European Environment Agency, 2003b).

Important for whom?

All the impacts described here, have a direct effect on humans. As most impacts are related to transport it mainly influences people that use the roads or live adjacent to the road network.

Uncertainties

The impact categories treated here are only described tentatively but there is only little uncertainty that the impacts occur and that it has negative impacts on human health

Hot-spots

As transport is assessed to be the most important process for all impact categories in this section (accidents, noise, odour and visual aspects), the hot-spots are probably the use-, transport- and processing stage in this order.

10.11 Summary & final comments

The qualitative LCA addresses a number of other relevant impact categories that have not previously been addressed in the LCA in chapter 8 and 9. As mentioned, the purpose has been to elucidate as to whether other conclusions could have been obtained by an alternative choice of impact categories.

Importance of the impact categories (grouping)

The study includes an individual assessment of the importance of the different impact categories, but the assessment cannot be used as a basis for a detailed ranking of the categories. Still, I would argue that it is possible to make a grouping in three levels:

- 1) Impact categories which are very important
- 2) Impact categories which are important
- 3) Impact categories which are less important

It should be noted that the assessment of importance should be seen in this particular context, which is an environmental analysis of fish products. More precisely, the grouping is not universal in the sense that it can be applied on all product types. It should also be emphasized that the grouping is subjective even though it refers to “hard” facts as well.

Group 1) Very important impact categories

I have assessed that the following fishery specific impact categories are very important for fish products as the following argumentation demonstrates.

- Exploitation of fish stocks.

- Discard and by-catch (closely related to the above).
- Seabed impacts.

Exploitation of fish. The fishery represents a considerable extraction of biological resources, with well-documented effects on biodiversity and ecosystem functioning. In this respect, it is characterized by a large and direct intervention with the marine eco-system – involving animals, plants, and the seabed. I argue that only few other products, even food products, match this magnitude of intervention with a natural eco-system, and it should be noted that agriculture is characterized by an intervention with a “man-controlled” ecosystem, not a natural eco-system.

*Discard and by-catch*³⁰. Discard and by-catch is a serious problem from an ethical point of view. Large amounts of food, roughly 25% of all catches, are wasted. For certain fisheries the discard is much larger. This is the case for Norway lobster fisheries where the discard makes up more than 2/3 of the catches. A large percentage of the discard die, which influence the stocks, their species composition and the biodiversity in the whole eco-system. It should also be stressed that the discarded fish potentially could have contributed to the reduction of hunger problems or could have substituted other food products. By-catch is mainly a problem when involving entanglement of rare fish species (e.g. some types of rays) or marine mammals such as sea porpoises.

Damage to the seabed. The fishery is one of the most important human activities with respect to damage inflicted on the seabed. A large area of seabed is swept every year and effects such as removal of reef formations, are probably irreversible in praxis. As described earlier, there is a limited knowledge about the wider consequences of seabed impacts and it depends on the locality and the sediment structure etc. Still, several studies suggest that it is indeed something to worry about, and that the damage, in terms of reductions in biodiversity can be significant when bottom-dragged fishing gears are applied to sensitive habitats.

Group 2) important impact categories

The second level reflects “important” impact categories that include:

³⁰ It could be argued to consider exploitation of fish and discard/by-catch as one impact category, because the effects are similar in many ways (effects on species composition, biodiversity etc.).

- Land use
- Consumption of non-renewable resources.
- Human toxicity.
- Occupational health & safety.
- Noise and accidents (plus odour and visual aspects).

Landuse. Landuse is often a very important impact category and often underestimated according to Goodkoop and Speriensma (2000). Still it is not assessed to be among the most important impact types for fish products. However, results obtained with Ecoindicator 99 suggest that this relatively insignificant for flatfish products and it is generally assessed that land use is not a key issue for fish products – opposite to food products based on agriculture.

Non-renewable resources. The use of non-renewable resources is often assessed to be relatively important in LCAs. There actually exist environmental assessment tools that only address material consumption such as the “ecological rucksack” approach, developed at the Wuppertal Institute in Germany.

In the EDIP method, resource consumption cannot be compared to other impact categories, but this is possible in the Ecoindicator 99 because it uses the damage approach (an end-point method). According to this method, the importance of resource consumption for flatfish products is of the same magnitude as the damage to “ecosystem quality” and “human health”. This would suggest that it is a *very* important category (group one). Still, there are a number of methodological problems related to the handling of resource consumption in the Ecoindicator method (see chapter 10.4). As fossil fuels can be substituted and as minerals typically can be retrieved, I therefore assign this impact category to the second group, representing important, but not very important, types of impacts.

Human toxicity. I have also assessed that human toxicity is among the “important” impact types. According to the Ecoindicator 99 particle pollution, is by far the most important contribution to damage to human health for one kg consumed flatfish filet. As this impact category makes up at least on third of the total impact potential from all impact categories in the method, it is assessed to be important. Furthermore, epidemiological studies suggest that the number of people seriously affected by particle pollution is considerable.

Occupational health & safety. Occupational health & safety is assessed to be an important impact category as well. A large number of people are directly affected at the fishery-, processing-, and wholesale stage. Furthermore, the consequences involve around seven fatal accidents in the fishery alone per year.

Noise, odour, accidents and visual aspects. Finally, the “noise, odour, accidents and visual aspects” are also considered to be important. It is assessed that between 700 and 1000 people die of traffic related noise and accidents per year in Denmark. This is of the same magnitude as the data for particle pollution, and as both effects are related to traffic, it must be assessed that this impact category is as important as human toxicity for fish products.

Group 3) Less important impact categories

The third level reflects “less important” impact categories which include:

- Waste
- Animal welfare
- Ground water consumption

Waste. As described it can be debated whether “bulk waste” is a serious problem in relation to energy production. The “littering problem” in the fishery is indeed a problem, but as the fishery also removes litter, it is difficult to establish whether it is a net contributor or net remover of litter. Thus, in this context it is assessed that waste is a “less” serious problem compared to the other impact types – but obviously, this depends on the perspective.

Animal welfare. For animal welfare, studies have shown that fish cannot feel pain or stress – at least it is very unlikely. Thus, with respect to these aspects of animal welfare, it is probably only a potential problem among marine mammals taken as by-catch in some gill net fisheries. Obviously, this is regarded as a serious problem, especially among some NGOs, but as described earlier in this chapter, there is a lot of focus on the problem and fishing gear is being developed to avoid this kind of by-catch.

It could be argued that animal welfare with respect to fish remains an important issue, not least for ethical reasons. However, I assess this problem to be of limited importance compared to the other impacts considered here.

Groundwater consumption. I have also assessed that groundwater consumption is less important. The reason is that over utilization mainly is a problem

on Sjælland and particularly around Copenhagen. Most of the Danish fish processing industry is situated in northern and western Jutland where the groundwater resources are generally not overexploited. Obviously, there are local problems, but often they can be solved by transport of water from other areas or cleaning. Water use is also an issue at the use stage, which is assumed to take place in central and southern Europe. As explained in chapter 10.7, the problems of over-exploitation are probably larger compared to Denmark. It could therefore be argued that water consumption is indeed an important problem in particular for the use stage. Still, as part of an overall assessment, where I also notice that the processing stage is the most important with respect to water consumption, I have assessed that the impact category generally is less important.

The fishing stage is still the overall hot-pot

Based on the analysis in this chapter, the fishing stage is the dominating factor for a large number of the most important impact categories.

Fishery dominates for “group 1” impact categories

The fishery is the dominating factor for impacts such as seabed impact, exploitation of biological resources (fish), by-catch and discard. These impacts are all assessed to be among the most important in terms of seriousness.

Fishing is dominant for “group 2 and 3” categories

The fishing stage is also dominant for non-renewable resources and among the most important stages together with processing for Occupational health & safety. If we consider the number of fatal accidents, fishing is completely dominating.

The fishing stage is also dominant for human toxicity (due to particle pollution), but I have argued that site-specific aspects probably reduce this impact potential considerably.

With respect to “group 3” impact categories, fishing fishery is still assessed to be the most important for two out of three impact types. This includes waste generation and animal welfare.

Processing – increased importance

Compared to the results from the LCA in chapter 8-9, the importance of the processing stage increases when the “alternative” variables (impact catego-

ries) are investigated. The processing stage is not completely dominant for any categories, but it is among the most important for occupational health & safety (group 2) and groundwater consumption (group 3). Apart from that, it is somewhat important with respect to consumption of non-renewable resources (group 2: partly due to gas) and land use (group 2: partly due to transport).

Use – probably still the second most important stage

It is assessed that the use stage remains the second most important stage – based on the qualitative LCA. The use stage is assessed to be dominating for land use (group 2), human toxicity (group 2) and “noise, accidents, odour and visual effects” (group 2) – due to the large transport load for shopping activities. Furthermore, the use stage is among the most important stages for ground water consumption (group 3) and consumption of non-renewable resources (groups 2).

With respect to the variables investigated in this chapter, fishing and transport appears to be the overall most important processes.

Overview of results

The results from the assessment in this chapter can be summarized in a matrix – reflecting the importance of life cycle stages for different species groups as well as the importance of the impact categories - see table 3.

Table 3: Results from the qualitative LCA grouped in impact types.

		Environment			Resources				Welfare			
		Sea-use	Land-use		Abiotic	Biotic		Human		Animal		
		Seabed impacts	Land use	Waste ³¹	Non-renewable resources	Ground water	Exploitation of fish	By-catch and discard	Human toxicity	Occupational health & safety.	Noise and accidents	Animal welfare
Fishery	D	+++	+	++	+++	~0	+++	++	(+++)	+++	(+)	+++
	S	+++	+	++	+++	~0	++	+++	(+++)	+++	(+)	+
	P	~0	+	++	++	~0	++	+	(+) ³²	+++	(+)	+
Land-ing	D	0	~0	~0	~0	~0	0	0	~0	~0	~0	0
	S	0	~0	~0	~0	~0	0	0	~0	~0	~0	0
	P	0	~0	~0	~0	~0	0	0	~0	~0	~0	0
Proc-essing	D	0	++	*	++	++	0	0	+	+++	+	0
	S	0	++	*	++	+++	0	0	+	+++	+	0
	P	0	++	*	++	++	0	0	+	+++	+	0
Whole-sale	D	0	~0	~0	~0	~0	0	0	~0	+	~0	0
	S	0	~0	~0	~0	~0	0	0	~0	+	~0	0
	P	0	~0	~0	~0	~0	0	0	~0	+	~0	0
Trans- port	D	0	++	~0	~0	~0	0	0	+		++	0
	S	0	++	~0	~0	~0	0	0	+	No data	++	0
	P	0	++	~0	~0	~0	0	0	+		++	0
Retail	D	0	+	*	+	~0	0	0	~0		~0	0
	S	0	+	*	+	~0	0	0	~0	No data	~0	0
	P	0	+	*	+	~0	0	0	~0		~0	0
Con- sumer	D	0	+++	*	++	++	0	0	++		+++	0
	S	0	+++	*	++	++	0	0	++	No data	+++	0
	P	0	+++	*	++	++	0	0	++		+++	0

Impact potential compared to other life cycle stages:

+++) Large, ++ medium, + small, ~0) very small, 0) no. *) potential problem.

Species: D) Demersal fish, S) Shellfish, P) Pelagic fish

Red cells/columns: Very important (group 1)

Yellow cells/columns: Important (group 2)

White cells/columns: Less important (group 3)

³¹ I have considered waste to belong to the impact category land use, because waste considered here mainly consists of lost fishing gear that ends up on beaches or as waste for landfill.

³² Brackets mean that this impact is considered insignificant due to site-specific aspects.

Generally, it is still the fishing stage that dominates for most categories, but the processing stage is more important at the expense of the retail stage, if we compare it to the quantitative LCA results obtained in chapters 8 and 9.

However, it is also clear that a different view on “important” impact categories could provide other results.

Different perspectives on what is most important

There are different schools within environmental management. Other methods within environmental assessment have a tradition of focusing on material consumption/flow such as the “ecological rucksack” approach developed at the Wuppertal Institute in Germany or land use such as the “ecological footprint analysis” developed at University of British Columbia. Obviously, we should also consider NGOs that may focus on animal welfare, noise, visual aspects etc.

The ecological rucksack perspective

It is most likely that an ecological rucksack approach would have suggested that the processing stage is the most important stage, if the focus had been abiotic resources. Still, if we included biotic resources, it would most likely still be the fishing stage that was chosen as the hot spot – see table 1.

The ecological footprint perspective

If I had applied the “ecological footprint” approach, it is possible that the use stage would turn out to be the overall hot-spot, followed by transport and processing, due to land use related to transport processes. Still, if we include seabed impacts, the fishery would probably remain the hot-spot. At least this is what preliminary results from Norway suggest.

It is also relevant to mention that a Canadian PhD dissertation from University of British Columbia, comparing wild salmon versus farmed salmon, suggests that the fishing is indeed the hot-spot from an ecological footprint approach (Tyedmers, 2000b).

A human welfare perspective (consumers)

Finally, a human welfare perspective – often shared by people directly affected, public movements and NGO’s – would either stress the importance of transport or the health value of the products (mainly fishery). If we consider the results in table 1, my studies suggest that a human welfare perspective should focus on “transport heavy” life cycle stages, because it probably is

the most important factor for human toxicity/health as well as noise, odour, accidents and visual aspects.

Still, there is a difference between perceived seriousness and actual seriousness. In this regard, it must be assumed that most consumers will be more focused on the health effects of the products themselves, but this has not been included in the analysis (besides anti-fouling agents contained in the fish). Even though I have focused on environmental impacts generated from the production of fish products, it could be argued that I should have included this aspect. If this had been the case, the fishing stage could turn out as the hot-spot, because this stage influence where the fish are caught and therefore also the content of chemicals and heavy metals in the fish products.

A human welfare perspective (trade-unions, employees)

From a somewhat different perspective, namely the welfare of the people who work in the fish processing industry, the main issue is probably Occupational health & safety. In this regard, the fishery and processing stage are both candidates to be hot-spots.

An animal rights perspective

Finally, an animal rights perspective would mainly address the fishing stage. In this regards the catch of fish but also by-catch of marine mammals are the important issues.

Overall, it is interesting that the processing stage could turn out as quite important from a combined “ecological rucksack” and “human welfare” perspective.

New impact categories – new trade-offs?

When we increase the number of environmental effects there is a chance that new trade-off situations appear. This is the case for H&S impacts where Norwegian studies suggest that small vessels generally have a higher percentage of work related injuries and accidents per crew member compared to large vessels. This indicates that Danish seine and gill net vessels (which typically are relatively small in Denmark) perform worse than beam trawl with respect to H&S, but the Danish data cannot confirm this tendency. Thus, it is not possible to confirm that this difference exists in Denmark and whether the difference would be significant – also considering the qualitative aspects of H&S.

Another example is by-catch of marine mammals, which mainly is a problem among certain gill net vessels. Thus, we may expect beam trawlers to perform better in this respect – when comparing gill-net with beam trawl. This, is truly a new trade-off situation, apart from the trade-off situation related to eco-toxicity from anti fouling agents in the present scenario.

However, it can hardly be argued that active fishing gear provide sounder fish products compared to passive fishing methods such as gill-net and Danish seine – especially not if we consider the future development.

Future development and regulation

Just as we saw for the impact categories considered in chapters 8-9, change is likely to occur considering the impact potential over the next 10-15 years. In the following, I argue that significant changes in the impact potentials analyzed in this chapter will mainly occur for waste and by-catch of marine mammals in the fishing stage as well as for human toxicity in transport processes. In all three cases, a reduction is expected.

Reduction in waste from fishery

Considering waste, we already see a development where lead is substituted with iron in fishing gear. Furthermore, some harbours have initiated waste collection arrangement and reuse of the waste brought to land by the fishermen. I therefore assume that we can expect a tendency where more fishermen bring the waste back to land. Obviously fishing vessels still loose fishing gear and other materials, but it should be considered that the vessels collect waste from other fishermen and other marine activities as well. Therefore, it is even possible that fishing vessels become net collectors of waste. In this regard, a recent study from the Baltic Sea suggest that the fishery may contribute to clean the Sea for certain chemicals such as dioxin and PCB if the fishermen store the fish guts and bring them to land. A considerable effect can be reached if the cod liver brought to land, because the chemicals accumulate in to food chain and end up in the large concentrations in the cod liver (MacKenzie, 2004).

As mentioned in chapter 4, similar “cleaning” effects are possibly related to the removal of fish as such, because large amounts of nutrients are removed from the sea. Thus, an interesting conclusion is that fishery maybe serves to “clean” the ocean for waste, nutrients as well as certain chemicals that tend to accumulate in the food chain.

Reduction in by-catch

In the period 1994 to 2001 the number of sea porpoises caught as by-catch in Danish fisheries reduced from 7.300 to 3.900 individuals - a reduction of roughly 40%. The reason is probably reductions in gillnet fisheries after turbot, but also the introduction of sound emitting devices applied to scare the porpoises. (Miljøstyrelsen, 2003; Dyrenes Beskyttelse, 2003)

Effective devices also exist to avoid birds as by-catch in long-line fisheries, but it has not been possible to establish whether a significant reduction has occurred in Denmark.

Considering discard, trawl gear is being developed which should be more selective due to selection panels etc. Still, it is unknown whether an improvement has occurred here, as well. Basically, the discard depends on many other variables than the fishing gear, and the fishing gear can be used in many different ways. Thus, one thing is theory – another is practice. As described in chapter 4, I wouldn't expect large changes in this area.

Reductions in human toxicity from transport

With respect to human toxicity, we can expect a development towards cleaner fuels, better engines and filter solutions – partly enforced by public regulation as described in chapters 8-9. Still, I assume that transport processes remain the most important factor contributing to human toxicity in the next 10-15 years, due to its dominant role in current scenarios.

Developments for other impact types

It is also possible that we will see a significant reduction in over-exploitation and seabed impacts as a result of new types of fishing gear or a reduction in the over-capacity in the EU fishing fleet. Still, I would argue that it is just as likely that the opposite will happen – at least no signs of improvements have occurred yet. Considering seabed impacts, it should also be considered that the development, so far, has been characterized by an increase in the trawler capacity on behalf of the capacity among smaller vessels applying passive fishing gear (Lassen, 2000).

All things considered, I do not expect the overall conclusions to change considerably – considering the development tendencies over the next 10-15 years.

Limitations of the analysis

The limitations of the qualitative life cycle assessment are discussed in the following.

Exchanges not included

My studies have not included indoor particle pollution as a result of cooking practices. Recently published research results from the Danish building and Urban Research center suggest that indoor particle pollution reflect a serious damage potential for human health; in this respect cooking and especially frying processes on gas stoves figure among the largest indoor contributors to particle pollution. (Danish building and Urban Research, 2003).

If particle pollution from cooking had been included it would just emphasize the importance of the use stage, and I would therefore not expect any change in previous conclusions, unless the use stage turned out to be more important than the fishing stage.

Uncertainties

As mentioned, the assessments in this chapter are less detailed and the approach has been more qualitative oriented. Thus, large uncertainties exist, especially for some impact types, such as waste and noise, odour, accidents and visual aspects where the amount of data has been most limited.

11

Regulation and Policies

The previous chapters in part three focused on the environmental impacts from fish products, while the following chapters in part four focuses on “regulation and policies” addressing environmental burdens from sea to table. This is done in the attempt to put the results in perspective and discuss the effectiveness of current regulations. Rarely LCA studies are combined with a discussion of environmental regulation and often it appears that environmental regulation remains sector oriented and may create sub-optimization (Miljø- og Energiministeriet, 1999).

The purpose of the following chapter is to describe existing policies addressing environmental impacts for fish products – from sea to table. The analysis is mainly retrospective, but current and planned initiatives are also described. Chapter 12 deals with potentials and barriers for development towards cleaner products and consequently draws attention to possible solutions.

As a basis for the analysis, the first section presents a short introduction of different approaches and concepts within environmental regulation. This can be perceived as a conceptual framework. The main reference in section 11.1 is Sminck (2002) unless else is stated. Also as a theoretical basis for the analysis, a short introduction to implementation theory is provided in section 11.2. The analysis refers to different organizations that are involved in the regulations of the sector. For readers that want to obtain an overview of the different organizations and their respective goals and interests, the analysis presented in chapter 3.2 can be recommended.

11.1 Conceptual framework

Studies of environmental policies and regulations often distinguish between three “archetypes” these being: Public regulation, Market based regulation and Self regulation. The three regulatory approaches are often discussed in an industrial perspective, but the distinctions can be used for all life cycle stages. Figure 1 illustrates the three archetypes:

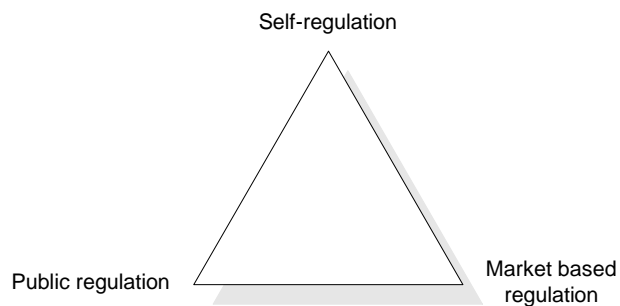


Figure 1: Illustration of three archetypes of environmental regulation.

In practice regulations are often placed somewhere inside the triangle, instead of at the extremes. The three approaches are further elaborated in the following text together with their strengths and weaknesses, as well as examples.

Public Regulation

Public regulation encompasses a large variety of instruments – both the more traditional command and control approach as well as types of regulation, which are, developed to increase market- and self regulation. I have chosen to describe the latter as “market-oriented public regulation” and “voluntary-oriented public regulation.”

Command and Control

Command and control regulation is characterized by environmental standards, which can be performance based or technology based. With respect to the industry (that is industrial companies such as fish processing) performance based standards typically focus on emissions such as wastewater effluents, while the technology based standards points the attention to the technologies that are used. In practice it is typically, a mix of performance and technology based standards that are applied.

In Denmark, the command and control regulation has been focused on emission limits. Thus, the focus has mainly been the (outputs) rather than resource consumption³³ (that is inputs) – see figure 2.

³³ For companies that are subjected to the IPPC regulation (only a small fraction of the “listed” companies in Denmark) energy efficiency should also be considered. In Denmark the BAT level is reflected in “Brancheorienteringer” established by the Danish EPA. In the EU these lists are called BREF documents and in both cases the documents are made in cooperation with industrial organizations, authorities and relevant NGOs. (Nielsen and Remmen, 2002)

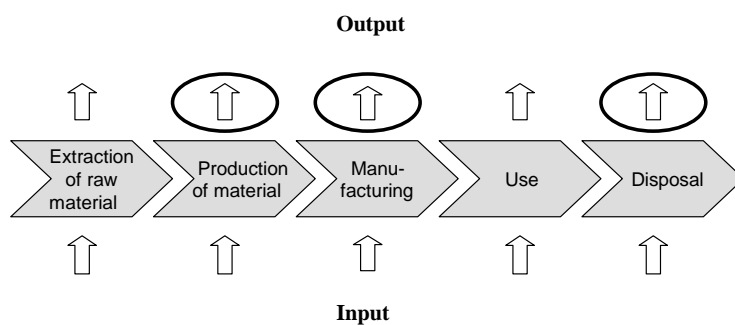


Figure 2. Traditional environmental focus (circles) in Denmark and other industrialized countries (Wenzel et al. 1997)

Theoretically the emission limits should reflect the Best Available Technology in Denmark but according to Miljøstyrelsen (2002b) this is not always the case in practice.

Examples. The most obvious example of “command and control” regulation in Denmark is the environmental permit systems used to regulate the industry.

Strengths and weaknesses. Command and control regulation was the first type of regulation that was implemented in Denmark in the early 1970s, and it has produced concrete and significant results, especially for the industry. According to Wenzel et al. (1997) the content of organic matter, toxic chemicals, and heavy metals from industrial wastewater has been reduced considerably over the last few decades. The strength of command and control regulation is also that it is relatively easy to predict in terms of future impacts and easy to articulate and understand for the companies or actors that are subjected to the regulations.

The weaknesses are mainly that traditional command and control regulation is expensive to enforce and easily becomes too static. First, the standards are seldom updated at the same pace as technological development and secondly, the regulation does not motivate companies or actors to make continual improvements - beyond legal requirements.

Economic Instruments

Economic instruments provide incentives for environmentally friendly behavior and to punish the opposite through price signals. Economic instruments intervene with the market and can be perceived as “market oriented” public regulation. In Denmark, we have a number of green taxes, which can be seen as an alternative to income tax where the intention is to change behavioral patterns of industries and consumers.

Examples. Carter (2001) defines economic instruments as instruments aimed at preventing market failure³⁴ by applying the polluter-pays-principle. He argues that this regulation may include:

- Green taxes (user charges, emission charges, product charges e.g. pesticide charges),
- Tradable permits (e.g. ITQ fish quota) or
- Deposit funds (e.g. charge on re-usable beverage containers).

Economic instruments may also involve government expenditure where the government for example subsidizes cleaner technology, insulation of private homes etc. (Carter, 2001)

Strengths and weaknesses. The strengths of economic instruments are that they can promote economically efficient and less bureaucratic solutions. Companies are given a greater flexibility to determine the level of improvement and the way in which the improvements are achieved. Economic instruments are in accordance with the polluter-pays-principle and create an incentive for continuous improvements beyond the legal requirements. Finally, economic instruments are relatively easy to implement, according to Winter (2003).

One of the weaknesses is that the economic instruments may have unwanted side effects. One example is when companies start to clean their own wastewater and consequently create overcapacity on the public wastewater treatment plants. This increases the tariff for the remaining companies and promotes inefficient solutions from a macro-economical perspective.

³⁴ According to Carter (2001) market failure occurs when the market price does not incorporate the external costs of using the environmental resources.

Informative instruments

Informative instruments do not prescribe a certain behavior, but are intended to influence the behavior of producers or consumers by means of information.

Examples. Informative instruments may include information about the costs of electricity consumption in private households related to stand-by functions or traditional light bulbs. It may also involve eco-labeling such as the Nordic Swan for the Ø-label for organic food products.

Eco-labeling may influence the functioning of the market, while being voluntary at the same time. Thus, eco-labeling promoted by the authorities can be described as a mix of “market based” and “voluntary” oriented public regulation.

Strengths and weaknesses. Informative instruments stress the responsibility of the actors being regulated, and are likely to promote environmental awareness and a higher degree of self/market regulation. Still, it could be argued that the effects from informative instruments are difficult to predict and that the worst polluters and/or reactive companies (as opposed to proactive companies), remain unaffected by this type of regulation.

Market Based Regulation.

According to Smink (2002) market regulation can be defined as:

“The way, in which market actors exert pressure upon companies with regard to their environmental performance”

This definition emphasizes the importance of the business network and mutual regulation between actors in the product chain. These are mainly green demands to suppliers (upstream pressure) but may also include demands from the suppliers to buyers or consumers (downstream pressure). Apart from agents in the product chain, the market regulation encompasses actors such as financial institutions, owners, shareholders, and consultants etc.

Examples. An example of market regulation is supplier demands, but it may also include information exchange and co-operations in the product chain. This can spark innovation and the development of cleaner products.

Strengths and weaknesses. Interactions between actors in the product chain and other parts of the business network have the advantage of addressing the product chain and therefore the products, ideally in a life cycle perspective. It is possible that companies perceive market regulation as more serious, because the companies risk being out of business if they cannot comply with the customer demands. It can be argued that environmental questions “to a greater degree” become a part of the “business reality”, thus linking economy and environment. The government’s role to promote market regulation can be to stimulate environmental management systems, eco-labeling, and innovation of cleaner products on a sectoral level.

Self Regulation

According to Smink (2002) self-regulation is regulation where:

“...government and industry jointly prepare regulatory or standard settings. Industry is enabled to control itself - albeit government will exercise an oversight role - which involves a periodic review of the results of company’s internal controls”

However, it is stressed that self-regulation is not a precise concept, but common for all definitions of self-regulation is that the actor or groups of actors commit themselves to pursue environmental targets on a voluntary basis.

Examples of Self Regulation.

Self-regulation may include voluntary agreements, which are negotiated agreements between government and an individual company or organization. Voluntary agreements will typically be enforced by a permit mechanism, implemented as part of the traditional command and control regulation regime and can therefore also be regarded as an innovative form of command and control regulation.

Another example is environmental management systems (EMS) where companies commit themselves to continual improvements beyond the normative environmental standards. There exists one international standard (ISO 14001) and one European standard (EMAS II) which is somewhat more demanding with respect to initial environmental review, documentation/information and product focus (Jørgensen, 2001).

Strengths and Weaknesses

Self-regulation may promote flexible and efficient solutions, and is more likely to lead to continual improvements, especially if we consider EMS. In addition, it may provide a regulatory relief for the authorities as well as the regulated part. In this regard, authorities can even become a sparring partner, which can be used to create further improvements.

One of the weaknesses of self-regulation is that this type of regulation does “not necessarily” lead to large environmental improvements³⁵. As an example, the ISO and EMAS standard do not have any specific requirements for environmental performance, beyond the legal requirements (Jørgensen, 2001). Another weakness is the short-term economic interests among industries, which may be in conflict with investments in cleaner technologies that sometimes have a relatively long payback time.

Changing roles of State and the Non-State Actors

Another perspective on regulation is to focus on the different roles of the government and the actors that are subjected to regulation.

Since the 1970s, public regulation has gradually developed from being focused on command and control regulation towards new types of regulation, which includes economic and informational instruments. Partly initiated by these new and more market oriented public regulations a development has occurred towards increased market and self-regulation.

In this process, the problem focus has moved from local ad-hoc problems towards global problems while the solutions have moved from a dilution and end-of-pipe approach, towards more preventive solutions addressing the technology factor e.g. cleaner production and cleaner products.(Remmen, 2001)

³⁵ Recently, a comprehensive study of the effects from EMS was published. The conclusion was that EMS is “probably” a relatively small driver for environmental improvements. Even though other studies may have concluded differently, this study must be taken seriously as it is based on data from 280 companies and 430 production sites in 6 manufacturing sectors in 6 EU countries (Hertin et al. 2003). Obviously, the study does not necessarily reflect long-term effects, but it indicates that self-regulation can hardly stand alone.

The role of the government or the authorities has gradually changed from being focused on control and enforcement towards a focus on co-operation – vis-à-vis the most proactive companies. In addition, there has been a tendency towards increased involvement of representatives from industry in the development of new regulations, especially for self-regulation and market-based regulation. (Remmen, 2001)

As several problems, concerning the existing fishery and environmental regulation have turned out to be related to problems in the implementation process, it is also chosen to provide a quick introduction to implementation theory as a basis for the analysis. The model presented in the following deals with the implementation process of public policies and is developed by S. Winter (2003).

11.2 Implementation theory

According to Winter (2003) insufficient implementation is a general problem in the public administration – especially for environmental regulation. Winter has made a model of the implementation process that illustrates how policies are formulated and transformed into certain policy designs, which reflect certain measures and objectives aimed at fulfilling the overall goals. The policy design is then transformed in an implementation process involving various organizations, street level bureaucrats,³⁶ and finally the target group – in this case the fishermen. The implementation results include performance and the outcome. The performance focuses on what is “delivered” by the street level bureaucrats, while the outcome focuses on the effects, for example, reduced overexploitation or reduced energy consumption per kg caught fish.

A simple version of Winters implementation model is illustrated in figure 1; it shows all the phases from policy formulation (left) to outcome (right):

³⁶ These are typical people in governmental institutions, which are in direct contact with target groups and responsible for “delivering” the policies to the target groups.

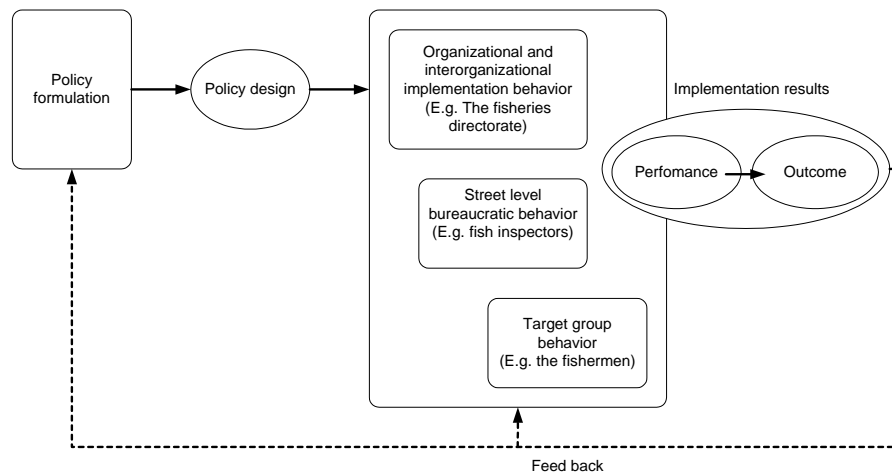


Figure 1: Main elements in the implementation process of governmental policies, according Winter (2003). The model should be read from left to right.

Winters model also include a fifth variable – that is the socio economical context. Obviously, the socioeconomic context, as well as other types of context, will influence all the phases and actors in the process but this is not separately discussed here.

Policy formulation and design

The implementation process can be hampered already in the policy formulation and design phase, due to the use of wrong causal theories, conflicts between different interest groups and inconsistencies between goals and measures. The latter may create a situation where the goals never will be reached despite well functioning implementation processes. (Winter, 1994)

Organizational Behavior

Winters model also address the organizational and not least inter-organizational behavior. He argues that one or several organizations are involved in the implementation of nearly all types of laws and politics, and the these organizations behavior and mutual influence, has an impact on the results of the results (Winter, 2003).

Street level bureaucrats and target group

The model also address the behavior of the street level bureaucrats and the target group (citizens, industries etc.). Also here, the behavior and the interests may significantly influence the implementation results. The street level bureaucrat often has to make an assessment/judgment, which depends on the competencies, resources, and interests. Often, motivations exist within organizations, which promotes a behavior among street level bureaucrats that contradicts goal fulfillment.(Winter, 1994)

Finally, the behavior of the target groups will influence the results as well, and also here, interests, motivations, and resources are important variables. For instance, it is common knowledge that fishermen often find quota regulations unfair and irrelevant in certain cases and that this may influence the effectiveness of the regulations.(Winter, 1994)

Performance, outcome and feed back

Winter argues that one of the problems is that the implementation results are often measured in terms of “performance” instead of “outcome”.

In this regard, it is also worth directing the attention to the feedback. The feedback is the information flow back to the decision makers and actors involved in the implementation process. Ideally, this feedback should ensure that policies and implementation behaviors are continuously adjusted to remain or become effective. However, if the feedback only focuses on the performance and/or theoretical calculations of the outcome instead of real measurements, this may never happened. (Winter, 1994)

With a focus on the fishing stage, the following section will describe existing and planned policies and regulations, which are related to environmental aspects.

11.3 Policies and Regulation - the Fishing Stage

This section includes an analysis of traditional fishery regulation as well as new incentives aimed at integrating the environmental dimension into fishery policies. The analysis is based on the conceptual framework established in the previous section.

Traditional Fishery Policies

As mentioned in chapter 2, the production output from the fishery in Denmark is mainly restricted through quotas for different species - nearly all commercially interesting species are currently embraced by quotas in the EU (European Commission, 2001a). This type of regulation can be categorized as “command and control” regulation, but it differs from traditional environmental regulation by restricting the production volume rather than the emissions.

The Common Fishery Policy in the EU (traditional elements)

The fishery management in Denmark is based on the Common Fishery Policy (CFP) of the EU – first established in 1983 and renegotiated in 2003. The CFP can be divided into three focus areas (European Commission, 2001a; European Communities, 2002a; European Communities, 2002b):

- 1) Resource and conservation policies are aimed at protecting the fish resource by regulating the amount of fish caught – with considerations of fish species, size and fishing ground (country). The most important instrument is the quota or total allowable catch (TAC) divided among the member states, and based on historical catch records. Apart from quota the policies include technical measures used to regulate mesh size and areas restricted or closed for fishery. A key organization is the International Council for the Exploration of the Sea (ICES) that provide scientific advice. Quota limitations and the national handling and distribution of quota were described in chapter 2.
- 2) Structural policies are the second focus area, with the purpose of adapting the fishing capacity to resource availability and the market situation. The measures include economic support for reducing surplus capacity, modernization of vessels, experimental fishery, and facilities for the landing and processing of fish.
- 3) Market policies are the third area aimed at obtaining a common organization of the market for fish products and to match supply and demand for the benefit of producers and consumers. EU is a net importer of fishery products and the import tariffs are a part of the market policy.

As it stands, the traditional fishery policies include some aspects that address the environmental dimension. Examples are quota regulation, minimum

mess sizes, areas closed for fishery and fleet reduction programs that reduce the pressure on the stocks. However, the environmental dimension has not been considered as a separate goal or policy area and therefore under prioritized compared to traditional stock management (European Commission 2001a).

Integration of Environmental Aspects in the CFP

The commission has now increased the focus on environmental aspects inspired by the so-called Ecosystem Based Fishery Management approach (EBFM)³⁷. Thus, environmental aspects (or at least some) are being incorporated in the new CFP.

A Greening of the CFP

According to the “Community Action Plan to integrate environmental protection into the CFP”, the objectives with highest priority are (European communities, 2002b):

- To ensure reduction of target fishing activities having adverse effects both on the sustainability of target fish, non-commercial species and habitats.
- To improve fishing methods with a view to reducing discard, incidental by-catch and impacts on habitats.
- To eliminate public aid to modernization or renewal of the fishing fleet except for aid to improve safety or product quality not likely to increase fishing capacity.

Thus, the environmental dimension will encompass non-target species, sea-floor considerations, by-catch, discard and a reduction in the fishing capacity. A relatively large number of specific management measures are planned. This include:

- Marine areas/habitats protected against bottom dragged fishing gear

³⁷ EBFM was recently discussed at an international conference in Reykjavik and organized by FAO. Instead of a narrow focus on economically interesting fish stocks - the concept of EBFM address multi-species considerations, by-catch, discards and impacts on the sea floor. (International Institute for Sustainable Development, 2001)

- Measures against discard (for example selective fishing gears)
- Technical conservation measures designed to reduce by-catch of cetaceans?
- Action plans to manage sharks and protect seabirds etc.

Within the 6th framework program for community research, the commission will aim to stimulate a better understanding of the marine ecosystems such as the effects on marine habitats, with the purpose to progressively implement ecosystem-based fishery management (European Communities, 2002b).

Eco-labeling and Polluter-pays-principle

Eco-labeling is also mentioned among the possible measures and further debate about both eco-labeling and integration of the polluter-pays-principle (PPP) is planned (European Communities, 2002b). In the Green Paper “The future of the common fisheries policy”, it is stated:

“The Commission supports the objectives of eco-labeling schemes in the fishery sector, namely to stimulate consumer awareness of the environmental dimension of fishing and thereby to encourage environmental responsibility of both managers and fishermen (European Commission 2001a, p. 25)

So far, the EU has chosen a strategy where it is up to the individual countries or regions to establish their own labels. However, the commission has developed a recommended framework for eco-labeling (European Commission, 2001b). A similar framework has been developed among the Nordic countries, but specific criteria have not been developed in any of the cases. Furthermore, it is worth noticing that energy aspects are left out of the discussion in both cases, while traditional stock management gets a high priority even though this is something that already is, or at least should be, regulated (Nordic Council or Ministers, 2000b).

The EBFM and the greening of the CFP must still be categorized as “command and control” regulation, where the focus is extended to include by-catch, discard and non-flow related impacts on the seabed.

Other initiatives such as the framework for eco-labeling and the initiated debate about Polluter-pays-principle are examples that represent a development towards market-oriented public regulation. Still, it should be noted that it only includes recommendations – no actual regulations are planned.

Reflections about the CFP

The following includes a few reflections about some of the CFP and its implementation.

Lack of implementation

In spite of the CFP, which has existed since 1983, fishing is still not sustainable in the EU. In the EU Greenbook it is stated (European Commission 2001a, p. 4):

"Almost twenty years from its inception, the Common Fisheries Policy (CFP) is confronted with major challenges. The policy has not yet delivered sustainable exploitation of fisheries resources and will need to be changed if it is to do so"

"As far as conservation is concerned, many stocks are at present outside safe biological limits. They are too heavily exploited or have low quantities of mature fish or both. The situation is particularly serious for demersal fish stocks such as cod, hake and whiting. If current trends continue, many stocks will collapse. At the same time the available fishing capacity of the community fleets far exceeds that required to harvest fish in a sustainable manner"

It appears that the traditional CFP, so far, has worked insufficiently with respect to its main purpose - to avoid overexploitation of fish resources. This is important to realize and shows that implementational aspects are important – also with respect to the integration of the environmental dimension.

The implementation process will not be analyzed further here, but some of the reasons behind the lacking implementation is probably the conflicting interests in the policy formulation phase i.e. economical versus environmental interests (Holm et al. 1997), inconsistencies between quota regulations and management of fleet capacity and lacking acceptance of the regulations among fishermen (Vedsmann, 1998). In some EU countries, the lack of control and enforcement is also mentioned as a major problem (European Commission, 2001a).

Lack of Energy Aspects

As my analysis shows, the energy consumption is one of the most important environmental aspects for fish products – especially at the fishing stage. It is therefore worth noticing that energy is disregarded in the discussion of environmental protection and fishery management (European Commission, 2002b). The lack of energy considerations also applies to the concept of

ecosystem based fishery management, EBFM. In the conference in Reykjavik, energy was not mentioned in any of the presentations (International Institute for Sustainable Development, 2001)

The Environmental Dimension in Danish Fishery Policies

So far, the integration of the environmental dimension in Danish fishery policies has mainly been reflected in the selection of protected marine areas in the context of the Natura 2000 project. However, other types of regulations address the environmental dimension as well.

Marine Protected Areas (MPA)

According to Marine biologist S. Helmig from the Danish Forest and Nature Agency, Denmark has already selected sites "habitat areas" of which most are localized in coastal regions. However, there are also selected a few areas at Sea for instance certain stone reefs and sand banks. Helmig emphasizes that no decision has been made, concerning the activities that can be allowed within the protected areas. First, it has to be defined exactly what level of biodiversity Denmark wants to maintain within the sites. This is also termed the favourable conservation status. Helmig stresses that the level may include considerations about the natural state before human activities in the areas occurred (Helmig, 2003). After this, it will then be decided, which types of activities can be accepted in the protected areas, but so far, no decision has been made in this regard.

Helmig mentions that the Commission has prohibited bottom tending fishing gear on Darwin Mounds due to the occurrence of a cold water corals "Lophelia pertusa". A similar ban can possibly be launched for the nature type "reefs" that are included in 50 of the Danish habitat areas. (Helmig, 2004).

Fleet Reduction/Modernization

The individual countries are responsible for the distribution of quotas and licenses among fishermen. Thus, it is a national decision whether we want to promote the large or small vessel segments and whether we want to promote passive fishing or active gear.

If we consider the Danish fleet reduction programs that have been implemented in the period 1993 to 1999, it is mainly among smaller vessel seg-

ments employing passive fishing gear that the reductions have occurred³⁸. (Teknologisk Institut and IFM, 2003). As concluded in my previous analysis in part two and three, such a development is most likely to increase the contribution to important environmental impacts such as the greenhouse effect and damage to the seabed.

Modernization of Engines and Propulsion Systems

One of the intentions of the fleet reduction programs has been modernization and reductions in energy consumption. According to Fødevareministeriet (2000) subsidies have been given for new engines and propulsion systems in a number of cases in the period 1994-1999. This type of regulation can be categorized as economic instruments of the type “public funding”. It can be debated whether the example can be categorized “market oriented environmental regulation” as well – see the conceptual framework in chapter 11.1.

It is emphasized that no empirical data exist for the achieved energy reductions. Instead, theoretical estimates are calculated based on the efficiency improvements; if no changes are made with respect to other variables, number of sea days, catch volume, fishing gear, steaming speed etc. (Fødevareministeriet, 2000).

These theoretical estimates confirm that reductions in fuel consumption have occurred, but it has not been discussed whether an efficiency improvement may result in increased pull power,³⁹ which permits the use of heavier or

³⁸ From 1993-99, a total of 1370 vessels have received subsidies from the FIUP program of a total value of 300 million Dkr. (Teknologisk Institut and IFM, 2003). The programme includes subsidies for removal of fishing vessels as well as modernization and building of new vessels. (Fødevareministeriet, 2000). The number of vessels with passive fishing gear that have been removed was more than 1500 from 1996-1999 alone. The corresponding reduction was only 70 for the trawl segment. Obviously, this could reflect the same reduction measures in capacity, but this is not the case. The figures show the same tendency, with respect to tonnage and actually the tonnage for trawl vessel has increased in particular vessels over 35 meters. Among vessels applying purse seine, Danish seine and so called combination vessels³⁸ the tonnage is reduced by 5, 5% while vessels using passive fishing gear have been reduced by 26 % in tonnage from 1993 to 1999. Similar tendencies can be observed with respect to engine power for these segments (Teknologisk Institut and IFM, 2003).

³⁹ According to Tarvainen (2004) it has been allowed to change to an engine with the same effect or even larger effect if the engine is adjusted to run with a lower

more active fishing gear. The latter may lead to an increase in fuel consumption in practice as well as seabed impacts per caught fish, thus eroding the efficiency improvements.

As explained in chapter 4, the energy consumption per kg of caught fish has increased 20-30% over the last 30 years in Denmark. Hence, the development tendency – in terms of eco-efficiency – is clearly on the wrong track here. Several reasons probably exist, but based on the knowledge obtained in chapter 4, it can be argued that important reasons probably are over-exploitation, over-capacity, and a development towards fewer small vessels applying passive or semi-active fishing gear. It is obviously a benefit for the environment to change old two stroke engines with modern 4 stroke engines, with catalyst converters etc. Still, I would argue that the point of leverage⁴⁰ is more likely to be found among other variables⁴¹.

Horsepower Limitations

In Denmark, engines of over 300hp (221Kw) are not allowed for use on fishing vessels operating in the ICES fishing area 22 in the Eastern Baltic and the Belts. (BEK nr. 996, 2001). This restriction also concerns an area called “Rødspætte kassen,” which is restricted for plaice fishery. Finally, there is a general restriction against vessels with more than 170 hp within the 3 nautical miles from the coastline (BEK nr. 18, 1993; Jensen, 2004). This can be categorized as “command and control” regulation addressing the technology and the how and where it is used. From a theoretical point of view, these regulations should prevent larger vessels (beam- and bottom trawlers) from operating in the coastal zone, where they may disturb nursing grounds and where conflicts of interests may occur, vis-à-vis the coastal vessels.

effect. However, it is most likely that a new 300 hp engine results in a higher towing capacity. If additional improvements are made in the propulsion system, a considerable increase in towing capacity can be obtained.

⁴⁰ Within systems thinking – the point of leverage” or the leverage point refers to an area where small changes can yield large improvement in a system – in this example, the fishery. (Anderson and Johnson, 1997)

⁴¹ According to Tarvainen (2004), the subsidies to new engines under the FIUP programme has come to a halt because the subsidies to a wide extent were used to renew engines that had to be renewed anyway. Thus, instead of working as a subsidy to energy reduction it became a production subsidy according to Tarvainen (2004).

However, representatives from “The Danish society for a Living sea”, mainly representing a group of smaller and medium sized vessels, argue that many vessels have considerably larger engine power than allowed. According to Christensen (2001) the large vessels adjust their engines to 299 hp then get permission to operate in the restricted areas, and then readjust their engines to the initial power potential. He argues that there are several cases of fishing vessels officially registered as 299 hp, while applying fishing gear that is impossible to tow with only 299 hp. (Christensen, 2001)

The Danish maritime authority is responsible for verifying that the engine power is within a certain limit. In practice, this is done during registration and by tests performed with intervals of varying duration, sometimes several years. However, according to a representative from the Danish Maritime Authority, the tests are only performed when the vessels are in the harbour and with the previous notification of the owner. (Kristensen, 2003). A representative from the Danish fisheries directorate (Jensen, 2004) was aware that this represented a problem in some cases and according to Kristensen (2003) from the Danish Maritime Authority; it is technically possible to re-adjust the engines, sometimes electronically.

Thus, it cannot be proved that circumvention occurs, but it is possible and probably relatively easy. Furthermore, it appears that the authorities are somewhat aware of the problem.

Reflections on implementation

Both with respect to regulations aiming at reducing fuel consumption and regulations aiming at separating small and large vessels a lack of implementation appear to be a part of the problem.

The focus on performance instead of outcome is prevailing in both cases. The results appear to be positive in terms of performance (i.e. maximum allowed engine power for certain areas and more effective engines). Official reports go as far as establishing figures for fuel reductions based on rough theoretical assumptions, while the real results (the outcome) is hidden. This provides the wrong feedback to politicians. My studies in chapter 4 actually suggest that fuel consumption has increased over the last 3 decades.

Winter’s implementation model (figure 1) also addresses the policy formulation and the design as possible barriers for the implementation process. This shifts the attention to another aspect, namely that energy reduction only appears as a secondary goal, with respect to modernization, not an overall management objective. It can also be argued that the policy aimed at reduc-

ing fuel consumption by means of new engines, is an example of a wrong causal theory used in the policy formulation process.

Winter's model also addresses organizations involved in the implementation process. Concerning horsepower limitations, two organizations are apparently involved: The Fisheries Directorate and the Maritime authorities. Although my study does not include a separate analysis of the organizational behavior, conversations with representatives from both organizations suggested that co-operation and information flow could be significantly improved between these organizations.

Lack of Green Taxes

As mentioned, we have seen a development towards increased use of green taxes (market oriented public regulation) in other parts of society, but this does not encompass the fishing stage. The fishery is still exempted from paying sulfur tax, CO₂ tax and mineral oil tax – for all vessels over 5 GT. The same degree of tax exemption does not apply to agriculture, the fish processing industry, transport or for that matter private households (LBK 688, 1998; LBK 701, 1998 and LBK 643, 1998). Still, this regulation cannot be changed in Denmark alone, because we are subjected to the EU directives that do not allow the member states to use energy taxes in the fishery. (European Commission, 2003). According to Larsen (2004) one argument is that fishermen have access to oil without taxes in non-member states. (Larsen, 2004).

The European Union's Council of Ministers has just adopted a new directive concerning taxation on energy “Directive 2003/96/EC restructuring the community framework for the taxation of energy products and electricity”, on 27 October 2003. However, in this directive the fishery is still exempted from all types of energy tax⁴². (European Commission, 2003)

Other Aspects

As described in chapter 4, Danish regulations also address anti fouling agents for e.g TBT (subject to an international ban via IMO), lead in fishing gear (currently being substituted in the Danish fishery), HCFC and HFC cooling agents (currently being substituted by natural cooling agents). This can be categorized as traditional command and control regulation.

⁴² Denmark recently tried to change the formulations in the new directive, from a “shall” to a “can” include tax-exemption, but this was not possible according to Larsen (2004)

Furthermore, H&S aspects are regulated through the Danish Maritime Authority, which is responsible for standard setting (Søfartsstyrelsen, 2001). In addition we have the Danish Advisory Council for H&S in the fishery, that was established in 1995⁴³. The council provides advice to fishermen and helps with information and assessment of potential hazards on vessels. (Nielsen, 2003c). Thus we have a mix of command & control regulation as well as informative instruments in play with respect to H&S. As non-state actors establish the advisory council, it can also be perceived as a type of self-regulation.

Concluding remarks

As a concluding remark, it can be established that different types of regulation do exist which address at least some of the environmental impacts generated in the fishing stage. Command and control regulation is the most dominating approach, but economic instruments have been used as well. Still, the latter has mainly been in the form of governmental spending – not green taxes.

It appears that the implementation process is a hindrance for traditional fishery policies (see “reflections about the CFP”) as well as the more environmental oriented regulation - at least when we consider fuel consumption and horsepower limitations. The following presents an analysis of the environmental policies applied after the fishing stage.

⁴³ The Advisory council is supported by branch organizations such as the Danish Fishermen’s Association (DFA) and the Trade union for Skilled Workers, SID. (Nielsen, 2003c)

11.4 Environmental Policies – Post landing

As described in chapter 9 and 10, there are other important stages in terms of environmental impacts. This is mainly the use stage, but also processing, transport, and retail. This section presents a description of the most important environmental policies that apply to these stages.

The Processing Stage

A large number of environmental policies and regulatory instruments are at play at the processing stage. This includes the Danish environmental permit system, Green Accounts, green taxes, and subsidies for cleaner production and environmental management systems during the 1990s.

Environmental Permit System

In terms of command and control regulation, the industry is mainly regulated through environmental permits, where “listed” companies have to meet certain environmental requirements for a period of 8 years. The regulations are focused on site-specific point source emissions, and particularly in the fish processing industry, much attention has been given to the wastewater emissions (Andersen et al. 1994; Andersen et al. 1996 and Thrane, 2000b). Theoretically, the environmental requirements should be based on considerations about the best available technology, but in practice, the requirements seldom deviate from the minimum requirements set by the Danish EPA (Miljøstyrelsen, 2002). Generally, speaking the implementation of the principle of cleaner technology and BAT has not been very successful. The main reason is probably that the “street level bureaucrats” are left without tools and/or guidelines to really implement it, which also should be seen in the context of lacking resources in the Danish EPA. Originally, it was the intention that the Danish EPA should provide BAT reference documents (BREF) for 25 sectors, but so far, only 7 BREF’s has been published. Specifically for the fishery sector, no BREF has been officially published yet. (Nielsen and Remmen, 2002)

In Denmark it is nearly all larger fish processing industries that belong to the category of “listed companies”⁴⁴ and it is typically the county that is the environmental authority both for approval and enforcement (Moe, 1995; BEK nr 652, 2003). Today, nearly all fish processing industries are connected to wastewater treatment plants. The remaining fishing industries, less than 10, use separate wastewater treatment plants, which generally have to meet the same emission standards as public wastewater treatment plants⁴⁵ (Miljøstyrelsen and Skov & Naturstyrelsen, 2003).

Environmental Accounts

With effect from 1996 the Danish government introduced a requirement for the majority of the listed companies to produce environmental accounts – also termed green accounts⁴⁶. This type of regulation can also be termed public “command and control” regulation but it is also an instrument, which is developed to motivate self-regulation, because the intention is to increase the companies own awareness and trigger a process towards resource savings and implementation of environmental management systems.

Green Taxes and Subsidies

The environmental policies addressing industry encompass a number of market oriented public regulations, such as green taxes on:

- Energy (for example the CO₂ tax and a tax on sulfur).
- Certain types of chemicals (e.g chlorinated chemicals).
- Wastewater emissions and packaging.

⁴⁴ The Danish environmental approval system is continuously modernized and the result is often that the number of “listed” companies is reduced. This will probably also happen in the near future, but this is not likely to affect the fish processing industries (Miljøstyrelsen, 2002).

⁴⁵ It has been possible for companies to establish separate emissions of wastewater. During the 1990s a transition period has existed, in which these companies gradually had to live up to stricter emission limits. In the same period, subsidies have been given to promote cleaner technology, and thereby prevent the pollution as close to the source as possible (Thrane, 2000a). This can be perceived as a negotiated agreement between the government and the companies to live up to certain standards, and therefore include an element of self-regulation.

⁴⁶ The accounts must include information about consumption (input) of material, energy and chemicals as well as outputs in terms of products, wastewater emissions, air emissions and waste. (BEK 594, 2002). These types of measures increase the focus on consumption of energy and materials, while the traditional environmental approval tends to focus more on the emissions.

Concerning the fish processing industry, the CO₂ and the sulfur tax applies to all industries except the fish meal industry which is exempted for the CO₂ tax (Hansen, 2004)

Apart from green taxes, the policy instruments include subsidies for activities that can promote cleaner production practices. Details are left out here, but the general idea is to achieve both economical and environmental goals by introducing a tax system that motivates certain behaviors, instead of merely reducing the profit. (Danish Energy Authority, 2002; Regeringen, 2003; Miljø- og Energiministeriet, 1999)

Cleaner Production and Products

The Danish government has supported promotion of cleaner production for at least one decade. As previously mentioned, the implementation of the principle of cleaner production has generally not been very successful – at least not as an integrated part of the environmental permit system (command and control). Still, good results have been obtained in certain cases – such as for the pelagic fish processing industry in Northern Jutland, but it should be emphasized that these companies have received separate funding for implementation of cleaner production as well as environmental management systems during the period. This can be perceived as a mix of voluntary and market oriented public regulation (Thrane, 2000a, 2000b)

The pelagic fish processing industry is characterized by large emissions of organic material, nitrogen, and phosphorus through wastewater⁴⁷. As illustrated in chapter 5, large reductions in water consumption and wastewater emissions have been obtained, but energy consumption has remained relatively stable in the same period. It appears that the authorities primarily have focused on water issues, while energy as well as more product-oriented aspects has been less of a priority. (Thrane, 2000a, 2000b)

With respect to cleaner products, there has not been any co-coordinated effort to promote cleaner products within the fisheries sector, so far⁴⁸ (Thrane, 2000b).

⁴⁷ Two things characterize pelagic fish in this respect. The oil and fat content is high and the fish are not gutted before landing.

⁴⁸ According to Jørgensen and Thrane (2002), life cycle thinking is not widely adopted by the fish processing industry, but when confronted with specific questions about impacts in other stages, it appears that the companies are concerned about

Environmental Management Systems

Finally, the government has also initiated self-regulation. During the 1990s the Danish government supported promotion of environmental management systems (EMS⁴⁹) in the fish processing industry. According to Thrane (2000b) the most positive examples are from the pelagic fish processing industry in Skagen. There are currently 5-10 companies, which have implemented environmental management systems; and considerable improvements with respect to wastewater emissions and water consumption have been obtained⁵⁰. This indicates that self-regulation is indeed occurring at this stage of the life cycle process.

Other Stages

The following section includes an analysis of environmental regulations and policies addressing remaining processes taking place in Denmark or partly in Denmark (landing/auction, wholesale and transport) and abroad (retail and use).

environmental impacts in other stages and the product's environmental profile. The ISO 14000 series includes a number of other standards, which address eco-labeling, environmental communication, life cycle assessment and eco-design. Obviously, fish processing companies may use these standards or similar approaches as part of the voluntary action, but so far, this has not been used by the fish processing industry (Thrane, 2000b).

⁴⁹ EMS is a management system, which addresses the environmental aspects of a company, and includes the development of an environmental policy, goals and action plans, as well as procedures and instructions, which ensures the implementation of the system. Finally, the management systems include a phase of reviewing and maintenance of the environmental policy, which ensures continuous improvement. Companies can be certified according to the ISO 14001 standard or the EMAS standard. (Dansk Standard, 1996)

⁵⁰ It is always difficult to tell if these improvements would have been made anyway. Still, it can be established that companies that implemented EMS and worked with cleaner production technologies, had a remarkably high performance with regard to process innovation and innovative spirit. The same study illustrates that EMS is an advantage vis-à-vis the customers such as large British and German retail chains. In one case, a large fish processor got a considerable increase in prices due to the efforts made to obtain ISO 9000, 14001 and EMAS. The same company argued that the large retail chains have a rating system, where EMS is a precondition to obtain the higher rating. Finally, EMS appears to have a positive influence on the cooperation with customers, authorities, and the local community. (Thrane, 2000b).

Processes in Denmark (landing/auction, wholesale and transport)

Most of the processes in the rest of the product chain are regulated through green taxes (market oriented public regulation), but there are also emission norms for certain processes such as transport (command and control) and eco-labeling for white goods (market oriented informative instruments). This section does not include a detailed analysis of different types of policy instruments for all the remaining stages, but important types of regulations used in Denmark, are listed below (Miljø- og Energiministeriet, 1999; Regeringen, 2003):

- CO₂ tax and sulfur tax related to energy consumption⁵¹.
- Green taxes for wastewater emissions depending on the content of N, P, and organic substances.
- Norms for air-emissions – mainly addressing transport processes (applies to all EU countries, including trucks and private cars).
- Energy labeling – mainly addressing white goods for private households.

For green taxes, a general rule is that large energy consumers as well as export-oriented activities are subjected to relatively lower taxes to avoid reduced competitiveness of the most sensitive parts of the industry.

Apart from the green taxes mentioned above, a mineral oil tax also applies to transport processes. Thus both the transport and the use stage are subjected to this tax is relatively high, roughly 60-70 % of the fuel price (LBK 701, 1998). With respect to diesel, the price is kept on the same level as the price in Germany to avoid the purchasing of diesel fuel in Germany by Danish truck owners.

Processes that take place outside Denmark (retail and use)

The retail and use stage mainly takes place in other European countries where green taxes have been less prevalent.

However, emissions norms for transport are already harmonized. Furthermore, there has existed a community tax regulation on mineral oil (mini-

⁵¹ In Denmark, owners of private cars also have to pay a yearly tax which is highest for the most fuel consuming cars (Miljø- og Energiministeriet, 1999)

mum rate system) for many years⁵². A new directive “Directive 2003/96/EC” previously described, implies that the EU's minimum rate system for energy products, so far limited to mineral oils, will include all energy products including coal, natural gas and electricity in the future. The directive entered into force on 1st January 2004. Basically, the intention is to harmonize the tax on energy products, increase incentives to use energy more efficiently and allow member states to offer companies tax incentives in return for specific undertakings to reduce emissions.(European Commission, 2003)

As mentioned earlier, this report will not include a detailed analysis of different types of regulation, but the main point is that green taxes affect all life cycle stages and even energy consumption, except for the fishing stage.

11.5 Policies Addressing the Whole Product Chain

Product oriented environmental policies have generally not been promoted nor adopted in the fishery sector, but an eco-label for farmed fish has recently been developed.

Basic Aspects of Eco-Labeling

The most successful examples of eco-labeling in Denmark have been the reed Ø-label for organic food products, and the Nordic-swan for non-food products. In both cases, the Danish authorities approve the labels and especially in the case of the Ø-label intensive control and verification by public authorities have been important for its success.

The criteria for the Nordic Swan label are based on a life cycle screening, or at least life cycle considerations. Thus, the criteria should ideally address the hot-spots in the life cycle, but obviously practical considerations have to be made as well. The criteria for organic products are not based on a life cycle approach and do not address energy consumption, nor land-use. (Thrane, 2000c; Thrane, 2001).

⁵² A comparison of fuel prices between a large number of EU member countries shows relatively small variation. Thus, the tax-structure is roughly the same as in Denmark with respect to fuel used for transport. (Danish Energy Authority, 2002)

Eco-Labeling of Farmed Fish

So far it has not been possible to purchase eco-labeled fish products in Denmark; at least there has not existed a Danish eco-label⁵³. However, a Ø-label for farmed fish, similar to the red Ø-label for agricultural products has recently been developed.⁵⁴ (Pedersen and Larsen, 2003). Still, it is not quite clear whether the criteria currently are based on a life cycle assessment, but it is expressed as an intention (Strukturdirektoratet, 1999). The status for the Danish Ø-label for farmed fish is described on www.eco-aquafish.dk

Eco-Labeling of Wild Fish

So far, the Danish authorities have not planned to develop an Ø-label or an eco-label for wild fish⁵⁵. The barriers for an eco-label for wild fish include the lack of control and verification possibilities and the fact that the Ø-label was originally developed to handle farmed production. Furthermore, it is important to mention the conflicts of interest between different actors in the sector. It appears that the most important organization in the fishery, the Danish Fishermen's Association, is strongly against eco-labeling. They fear that it might cast suspicion over fishermen and their products. Furthermore, it is claimed that it might divide the fishermen into two conflicting groups (Thrane, 2000a).

The authorities have expressed a concern that the lack of eco-labeling for wild fish can be a problem because wild fish dominates the market. (Strukturdirektoratet, 1999). Furthermore, it can be added that the fodder for farmed fish is based on wild fish and that a substitution of wild fish with by-

⁵³ It should be mentioned that products with the international ecolabel from Marine Stewardship Council, are available in several countries, potentially also Denmark. Still this label focuses on overexploitation of fish stocks, by-catch and discard, aspects which are also the center of attention in traditional fishery regulation. Furthermore, it has only been a few fisheries around the world that has obtained the label, and so far, this does not include Danish fisheries (Thrane, 2001).

⁵⁴ In 1999 there was proposed a set of criteria for Ø-labeled farmed fish, and in 2001 a test project involving 4 production facilities was initiated. The project is expected to be finished in 2004 and the criteria have already been sent to the EU for final approval. (Pedersen and Larsen, 2003)

⁵⁵ In this respect, there are mainly two arguments used. First, it is argued that the Ø-label originally was developed for farmed products, and that a different type of criteria should apply to wild fish. Secondly, control and verification is considered to be very difficult for wild fish, because the production is not site-specific (Strukturdirektoratet, 1999)

products from the fish processing industry probably wouldn't have any environmental effects, as argued in chapter 2 (section 2.2). Finally, it must be assumed that most people consider wild fish as more natural than farmed fish, in this respect, consumers in Spain even perceive wild fish as more organic than farmed fish according to Søndergaard et al. (1998)

11.6 Summary & final comments

The environmental policy addressing Danish industry, including the fish processing industry, has developed from traditional “command and control” regulation towards the use of a wide range of economic and informative instruments, thus promoting self- and market based regulation – see figure 3.

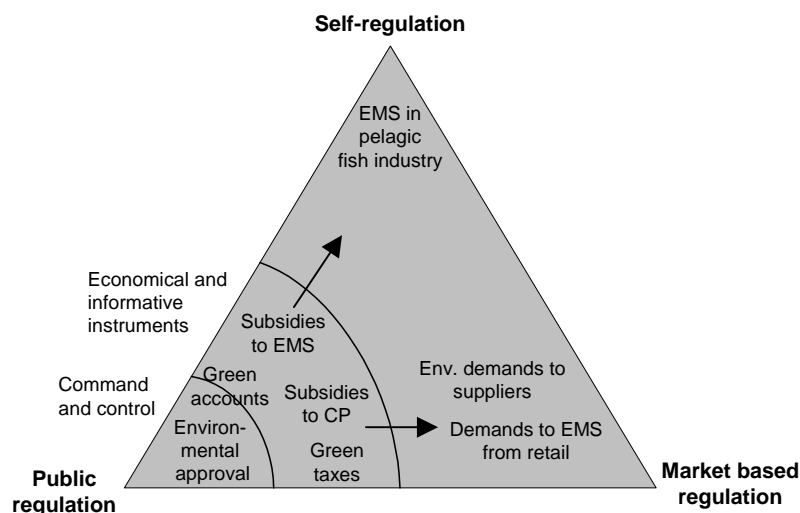


Figure 3. Examples of public regulations, self-regulation and market regulation at the processing stage.

Generally, the attention has moved from emissions and end-of-pipe solutions towards pollution prevention by means of cleaner production and cleaner products. This also reflect a shift of focus from only site-specific (point source) emissions to resource and energy consumption. The industry as well as the authorities has gone through a learning process where they have gradually gained experience and insight into environmental problems and pollution prevention. The understanding of environmental problems has

widened on both sides of the fence and in many cases the result has been a synergy between environmental and economic considerations (Remmen, 2001).

Regulation of the fishing stage versus the processing stage

As described previously, the environmental dimension is only partially integrated into the regulation at the fishing stage. In other words, there is still a great difference in the handling of environmental matters at the fishery stage and the processing stage, where the regulation includes a wide array of environmental regulations, including regulations that are intended to promote self- and market regulation.

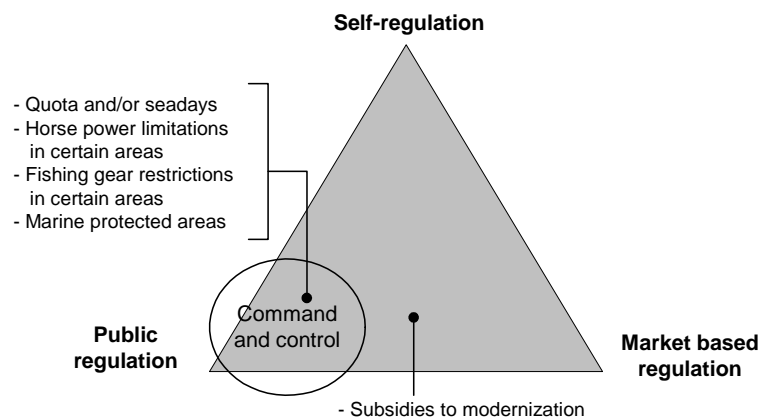


Figure 4. Regulations intended to reduce the environmental impacts at the fishing stage.

An important regulatory principle in Danish and European environmental regulation, is the Polluter-pays-principle (PPP). This principle has been the cornerstone in the development of modern regulation, but not in the fishery, where even fuel is exempted from green taxes. As mentioned, it is the Commission’s intention to start a debate about integration of the polluter-pays-principle in the fishery and fuel taxes would be a relevant focus area.

What can we learn from the regulation of the fish processing industry? Green taxes are one thing, but also green accounts could be a welcome idea in the fishery. Most important of all, the concept of cleaner production could very well be applied in the fishing stage as well. Still, it is important that the concept is applied as part of a more integrated approach to avoid isolated pro-

jects and sub-optimizations. In this regard, it is important to include considerations about improvement and not least substitution of fishing gear.

Reflections About Cooperation and Responsibility

It is worth noting that the regulation of the fish processing industry has moved towards increased cooperation and self-regulation. Proactive companies that have shown initiative and willingness to comply have increasingly been faced with the authorities as a partner instead of an inspector (Remmen, 2001; Thrane, 2000b).

In the fishery, we still see a focus on command and control strategy, even among the new initiatives aimed at integrating the environmental dimension. According to Vedsmand (1998) and Degnbol et al. (2003) increased cooperation between authorities and fishermen is much needed in the fishery. According to the authors, it is important that the fishermen are more involved in the design of regulations, partly because valuable knowledge from the fishermen can be used and because it will increase the commitment to actually implement the regulations. This is also called “co-management”.

The Life Cycle Perspective

The overall life cycle perspective is obviously important and it is necessary that the environmental regulation at each life cycle stage is based on life cycle considerations. As the fishing stage is generally a hot-spot, it is obvious that the effort must be strengthened here, but we also need to address the transport processes, retail and use. As described earlier, regulations exists both in terms of emission limits for transport and green taxes. However, an eco-label for wild fish would be a relevant (informative) instrument, which could enhance self- and market regulation in the whole product chain.

12

Barriers and Potentials

This chapter presents an analysis of the barriers and potentials for a development towards cleaner fish products. The analysis is mainly based on information from previous chapters – especially chapter 11. To ensure a broad perspective it is chosen to apply a natural science, a social science, and a human science perspective, respectively. With particular focus on energy reductions at the fishing stage, an analysis of specific solutions is presented in chapter 12.5

12.1 About research perspectives

It is important to be aware that a certain research perspective may lead to a certain problem understanding, which again may lead to a certain type of solution. This is illustrated in table 1, which is inspired by Arler (2002b).

Table 1: *The links between research perspective, problem understanding and typical solutions models, inspired by Arler (2002b)*

Research perspective	Problem understanding	Typical solution models
A) Natural science 1: Processes and technique	Focus on recipient and environmental mechanisms	Relatively “narrow” technical solutions such as filters and other “ad-on” solutions.
B) Natural science 2: Technological perspective	Focus on environmental consequences of technologies ¹ .	Technological solutions e.g. development of cleaner production or cleaner products.
C) Social science 1: Political / economic perspective	Focus on the economic infrastructure and the market.	Establishment or adjustment of taxes, subsidies and other market aspects
D) Social science 2: Political / administrative perspective	Focus on institutional set-ups and their ability to promote or prevent a certain type of development.	Establishment or adjustments of institutions and legal frameworks geared to promote certain activities and behaviors in society
E) Human science: Culture and value perspective	Focus on cultural aspects of modern consumers and our search for happiness through consumption of goods.	Reduction or modification of spending patterns among consumers and other groups in society.

The analysis in chapter 4-10 mainly represents a natural science perspective (item A and B), while the analysis of environmental policies and regulation in chapter 1-2 and 11, reflects a social science perspective (item C and D). Only little attention has been given to the human science perspective (E).

Potentials and barriers for a development towards cleaner fish products analyzed from the different research perspectives in table 1, are described in the following sections.

¹ In this regard, I distinguish between technique and technology. While technique concerns materials, tools and machinery, technology is perceived as a broader concept addressing not only technique but also organization, knowledge and product (Lorentzen, 1988).

12.2 Natural Science Perspective

The following presents an analysis of barriers and potentials for a development towards cleaner fish products from a natural science perspective. The first section focuses on key potentials and barriers related to knowledge and technical aspects.

Basic Science: Knowledge and Techniques

As illustrated in table 2 the lack of knowledge about ecosystem effects and difficulties in tracing the fish are among the key barriers for cleaner fish products, but a promising development in research and IT is occurring at the same time.

Table 2: Barriers and potentials for cleaner fish products, from a natural science perspective.

Barriers	Potentials
<ul style="list-style-type: none"> Lack of knowledge about eco-system effects from fishing activities such as the seriousness of seabed impacts. 	<ul style="list-style-type: none"> Promotion of research activities dealing with wider environmental aspects of fishery – also seabed impacts e.g. in auspices of ICES
<ul style="list-style-type: none"> Lack of traceability for fish products - with respect to fishing vessel, area, gear etc. 	<ul style="list-style-type: none"> IT and satellite surveillance increases the possibilities to document the history of the products.

Knowledge about Eco-system Effects and their Seriousness

Barriers. As described in chapters 4 and 10, there is still a lack of knowledge about the wider eco-system effects from fishery, especially concerning seabed impacts, but also concerning effects on multiple stocks. The lack of multi-species considerations in current fishery regulation is a direct result of this knowledge gap (Jennings et al. 2001).

Specifically, the lack of knowledge about seabed impact is a barrier for the development towards cleaner fish products, because it remains possible to argue that all types of bottom dragged fishing gears represents “insignificant” levels of damage.

The lack of multi-species consideration is a barrier because it could serve as a basis for adjustments in quota to obtain the maximum output of fish while

reducing the fuel input per kg caught fish – at least in theory. Obviously, multi-species considerations could also be used to avoid unwanted ecosystem effects from fisheries in general.

Potentials. On the positive side, a more eco-system oriented research approach is currently being developed, both in ICES and in various other national and international research bodies – see ICES (1999) and FAO (2003). Here the focus is not only on the fish stocks, but also on sea birds, sea mammals and impacts on the sea floor. This research perspective is relatively new, but it is indeed a step in the right direction.

Traceability

Barriers. The tracing of fish products with respect to fishing methods, fishing ground, vessels, time and place of catch can be used as a basis for an eco-labeling scheme. Still, tracing is not an easy task. One reason is that the fishery is difficult to control, partly because of its non site-specific nature² - see also chapter 2.

Potentials. There is a large potential in IT-technology that can register, store and send information about the catches directly from the vessels. Combined with satellite surveillance equipment this could compensate for some of the structural barriers mentioned (Thrane, 2000a). Still, it is difficult to predict when or how such measures will be implemented on ordinary fishing vessels.

Technology: Cleaner Production and Products

Focusing on barriers and potentials related to technological aspects (item B in table 1) it appears that one of the key barriers is a lacking interest for cleaner production at the fishing stage – see table 3.

² For farmed fish, which are based on site-specific production, this is not the case. However, the feed is still based on fishmeal and oil from wild fish as described in chapter 2.

Table 3: Barriers and potentials from a natural science perspective, with a focus on technological aspects.

Barriers	Potentials
<ul style="list-style-type: none"> • Lack of co-coordinated research in cleaner production at the fishing stage 	<ul style="list-style-type: none"> • Expressed intentions to increase focus on selective fishing gears in EU and DK.
<ul style="list-style-type: none"> • Little focus on environmental impacts from fish products - among authorities. 	<ul style="list-style-type: none"> • Current research activities concerning the environmental impacts from fish products

The items are elaborated further in the following.

Cleaner Production at the Fishing Stage

Barriers. As described in chapter 11, the absence of a holistic and integrated, cleaner production approach is one of the greatest barriers for development towards cleaner fish products. According to my knowledge, there are no studies that compare different fishing methods from a cleaner technology perspective – with focus on environmental performance and potentials for substitution in different contexts.

Potentials. On the positive side, there have been initiatives aimed at reducing energy consumption among Danish fishing vessels, but as mentioned in chapter 11 it is debatable whether measures such as public spending for new engines, have lead to “real” reductions in fuel consumption.

Another potential is the development of more selective fishing gears, which have a high priority in the EU as well as in Denmark (Fødevareministeriet, 2000). This is positive, but this type of research should ideally be a part of an overall cleaner production approach – if sub-optimization should be avoided. More precisely, there is a lack of an overall guiding principle towards cleaner production.

Environmental Impacts from Fish Products

The lack of research into cleaner production at the fishing stage, can also been seen as consequence of the lack of knowledge about impacts from fish products. However, the present dissertation as well as specific LCA studies performed in the Nordic countries³, obviously contributes to a change in this situation.

³ This mainly include LCA studies of codfish in Island and Sweden – see Eyjólfsdóttir et al. (2003) and Ziegler et al. (2003)

12.3 Social Science Perspective

The analysis in chapter 11, unveiled that a number of barriers and potentials were related to a social science perspective, both in terms of socioeconomic factors and factors related to institutional aspects.

Political / economic perspective

This section describes key barriers and potentials from a social science perspective with focus on economic aspects (item C in table 1) – see table 4.

Table 4: Barriers and potentials from a social science perspective with a focus on socio-economic aspects.

Barriers	Potentials
<ul style="list-style-type: none"> The fishery is excluded from energy tax. 	<ul style="list-style-type: none"> EU express intentions to promote the polluter pay principle in the fishery.
<ul style="list-style-type: none"> Fleet reduction programs – largest reduction among the most eco-friendly vessel segments. 	<ul style="list-style-type: none"> Subsidies to promote energy reductions in terms of new engines.
<ul style="list-style-type: none"> Difficult to change the species composition in the fishery due to production limitations. 	<ul style="list-style-type: none"> Still possible to address the fishing methods and other aspects of how the fish products are produced.

Tax exemption at the fishing stage

Barriers. As mentioned in chapter 11, the fishery is exempted from energy taxes, including taxes on CO₂ and SO₂ emissions due to EU regulations. This can be perceived as an indirect subsidy to the most fuel consuming fisheries and is obviously a barrier for cleaner fish products (European Commission, 2001a).

Potentials. On the positive side the European Union and OECD perceives green taxes as key instruments for reducing the overall environmental burden. According to Dyck Madsen (2003), the OECD's recommends removing existing discounts and exemptions from environmental taxes.

Another potential mentioned in chapter 11, is that the European Commission intends to initiate a debate about the implementation of the polluter pays principle in the fishery (European Communities, 2002b). Still, it is a contradiction for the EU to adopt a regulation that provides the fishery with tax exemption for fuel consumption whilst arguing for the implementation of the polluter pays principle.

Subsidies in terms of the FIUP programme - fewer small vessels

Barriers. As described in chapter 11, subsidies have resulted in a significant reduction of the most environmental friendly vessels segments – small and medium sized vessels applying passive or semi active fishing gear. Meanwhile, the larger vessel segments have experienced an increase in capacity – particularly trawl vessels of over 35 meters, in the period 1993-99. (Teknologisk Institut and IFM, 2003). This is clearly not a step towards more eco-friendly fish products.

Potentials. The FIUP programme has also included subsidies for the development of more selective fishing gears. In the period 2000-2006 the intention is to increase the focus on selectivity, which is positive. (Fødevareministeriet, 2000). It should also be emphasized that the FIUP programme includes subsidies for the promotion of new technology, improvements in H&S conditions as well as product quality at the fishery and the processing stage. (Fødevareministeriet, 2000)

The market situation

Barriers. Unless there is a global boycott, as for the tuna fish, I would argue that it is unrealistic that the consumers can affect the “output” from the fishery sector significantly with respect to species composition. The fundamental reason is that the production volume isn’t man-controlled - see also chapter 7. This can be seen as a barrier for a consumer driven “green market” (market regulation) for fish species that represent a relatively low environmental burden.

If we turn to the industry and their possibilities to influence the fishing activities, the possibilities are also relatively small (Thrane, 2000b). Obviously, the industry cannot affect the species composition for the same reasons as the consumers, but even attempts to address the fishing methods are difficult because the market is characterized by a high demand and a limited supply because the system isn’t man-controlled. Thus, market regulation, which involves the fishing stage, is relatively difficult (Thrane, 2000b)

Potentials. An eco-label, which addresses the production methods in the fishery sector, including the fishery, is still highly relevant. There are signs that consumers are becoming more aware of the product’s history and the production methods. The success of the organic label for food products and the Nordic Swan for non-food products illustrates this tendency (Thrane, 2000a; 2000c).

Political – institutional perspective

Important barriers and potentials for the development towards cleaner fish products, from a political /institutional perspective (item D in table 1) are illustrated in table 5.

Table 5: Barriers and potentials from a social science perspective with focus on the institutional aspects.

Barriers	Potentials
<ul style="list-style-type: none"> • Energy aspects are not perceived as an integrated part of the ecosystem based fishery management approach (EBFM). 	<ul style="list-style-type: none"> • Promotion of EBFM, which represents a more holistic approach towards fishery management.
<ul style="list-style-type: none"> • Danish authorities reluctant to develop an eco-label for wild fish. • Fishery institutions such as the “Fishermen’s association” are negative towards eco-labeling of wild fish. 	<ul style="list-style-type: none"> • Emerging interest for eco-labeling among authorities in Scandinavia and EU. • Development of eco-labeling criteria for wild fish in Sweden. • Danish NGO support for sounder fishing practices and eco-labeling of wild fish.
<ul style="list-style-type: none"> • Life cycle thinking is generally not applied in the fishery sector. 	<ul style="list-style-type: none"> • Examples of self-regulation and market regulation among fish industries.

The table is elaborated further in the following.

Eco-system approach in fishery management

Potentials. As mentioned in chapter 11, there is an increasing focus on ecosystem based fishery management (EBFM) addressing the wider environmental impacts from fisheries, both nationally in Denmark and internationally by the FAO. This illustrates that the management approach gradually is becoming more holistic and will include more aspects than traditional stock assessment. This development can be seen as a potential for cleaner fish products (see chapter 4 and 10).

Barriers. The lack of energy considerations in the EBFM approach is a barrier because energy consumption in itself represents a great impact potential (see chapter 8 & 9) and because energy consumption appears to be proportional with other environmental impacts such as seafloor impacts and discard (see chapter 4 and 10). If we consider Norway lobster fishery, which is the most energy demanding of all Danish fisheries, it appears that this fishery is characterized by utilizing bottom dragged fishing gear and by the largest amount of discard per kg caught fish in the Danish fishery (see chapter 4). It

is also possible to perceive energy consumption as a cause to and an effect of overexploitation⁴. Thus, by addressing energy it is most likely that several other environmental problems are addressed at the same time. Opposite if energy consumption is not addressed – solutions, which represent sub-optimization, may be the result.

Eco-labeling

Barriers. As described in chapter 11, eco-labeling of farmed fish is emerging in Denmark, but the Danish authorities are reluctant to develop an eco-label for wild fish. An important barrier for labeling of wild fish is the interests conflicts in the fishery sector, but also the lack of possibilities for control and verification due to the non-site specific nature of wild fisheries (see chapter 11.4). Thus, we can speak of a “soft” actor related barrier (that is the interest conflicts) and a “hard” structural barrier, which is related to the nature of wild fisheries.

Potentials. Among the potentials are “The Danish Society for a Living Sea” that want to promote an eco-label representing products from environmentally sound fisheries. The NGO has developed a suggestion to an eco-label for wild fish, which includes considerations of maximum pull- power, energy consumption, seabed impacts, discard, by-catch etc. The criteria also address impacts in other life cycle stages⁵ and together with the Swedish KRAV label⁶, this is the most ambitious eco-label for wild fish I have seen, so far (see chapter 11).

⁴ As my studies indicated in chapter 4, the energy consumption per kg caught fish tends to increase when the quota or the amount of fish is low. Opposite, it could also be argued that highly energy intensive fisheries may be part of the reason that certain stocks are being overexploited. In this respect there may occur a vicious circle. When the stocks are depleted, the fishermen tend to stay longer on the sea, which increases the energy consumption; this means that the fishermen needs to catch even more fish, to generate the same revenue etc.

⁵ The criteria are available on: http://www.levendehav.dk/politik/oekologiske_fisk/regler-for-fiskeri.htm and http://www.levendehav.dk/politik/oekologiske_fisk/bemaerkninger.htm. The criteria are also discussed with other eco-labels for wild fish in Thrane (2001).

⁶ KRAV is the Swedish organization responsible for certification and control of organic food products. Since year 2000, KRAV has worked to develop an eco-label for wild fish – to supplement the existing label for farmed fish. KRAV has now proposed a standard, which focuses on overexploitation, selectivity and seabed impacts as well as traceability and credibility. However, the standard also addresses

The KRAV eco-label does not have any requirements for the maximum weight of fishing gear or maximum pull-power, such as the criteria suggested by the Danish Society for a living sea, but KRAV is more demanding with respect to other variables including credibility aspects⁷.

Environmental management systems (self regulation)

The implementation of environmental management systems (EMS) in the fish processing industry as an example of self regulation (see chapter 11.3). Currently there are 5-10 Danish fish industries that have implemented Environmental Management Systems according to ISO 14001 and/or EMAS. These industries represent companies that process pelagic fish, and have all received some degree of subsidies for cleaner production and EMS during the 1990s (Thrane, 2000a, 2000b)

EMS and cleaner production in these “first-mover” companies is theoretically a potential for cleaner products, but so far the main focus has been on-site activities – partly due to a limited awareness of life cycle thinking and partly because it is difficult to influence the fishing stage, as described in relation to table 4.

anti fouling agents, energy consumption, engine types, fuel types, catalyst converters, fishing gear and working environment. (KRAV, 2003).

⁷ For instance, the vessels must have GPS equipment, in order to be able to track the place and time of catch.

12.4 Human science perspective

This section reflects a human science perspective on barriers and potentials for development towards cleaner fish products (item E in table 1) – see table 5.

Table 5: Barriers and potentials from a human science perspective.

Barriers	Potentials
<ul style="list-style-type: none"> • Narrow understanding of sustainability in the fishery sector, especially at the fishing stage. • Lacking awareness/recognition of environmental problems generated by the fishery. 	<ul style="list-style-type: none"> • Growing awareness about broader ecosystem impacts in some segments of the fishery.
<ul style="list-style-type: none"> • Consumers focus on health aspects of food rather than the environment respects. • Consumers have limited knowledge about fishery and environmental aspects of fish products. 	<ul style="list-style-type: none"> • Growing market for “organic food products” • Increased awareness about immaterial quality aspects or the history of the products.
<ul style="list-style-type: none"> • Difficulties for the consumers to interpret and assess the environmental performance of products – especially fish products. 	<ul style="list-style-type: none"> • Increasing “responsibility” related to the role as consumers – appearance of the political consumer.

As it appears most of these aspects have an institutional cognitive character and have also been described from the political / institutional perspective.

Environmental understanding and problem awareness

Barriers. Ambiguous words such as “sustainability”, which addresses environmental, social and economic aspects of development, have been used in the fishery for decades. However, it has mainly been used to describe sustainability in relation to management of fish stocks, thus ignoring a number of other environmental aspects such as the contribution to global warming or eco-toxicity as well as the social and economic dimension. This relatively narrow understanding has not only been common among fishermen, but also authorities, researchers and consumers. (Nordic Council of Ministers, 2000a; Thrane, 2000b; Søndergaard et al. 1998)

It appear, there has been some inertia in the traditional “narrow” understanding of sustainability. Now, there is a tendency towards a wider environmental understanding, also within fishery management, but global warming

is still not mentioned in relation to emerging concepts such as EBFM only as a problem affecting the fishery. Previous statements from the Danish Fishermen's Association indicate that the fishermen direct the attention towards other activities such as agriculture, off-shore activities and industries influencing the fishery, while little attention is given to how the fishery influences the marine ecosystem and the climate (Thrane, 2000a). Together with the prevailing and relatively narrow understanding of sustainability, this could also be perceived as lacking problem awareness or problem recognition.

The "narrow" and sometimes fragmented problem understanding is a mental barrier, but it also appears to be a barrier for communication between different parts of the fishery sector. This became apparent during the discussion of a possible eco-label for wild fish in Denmark in the late 1990s. The chairman for the Fishermen's Association Bent Rulle argued that wild fish were "organic" by nature and was afraid that an eco-label would discredit non-labeled fish products that were caught legally. On the other hand, there was the "Danish Society for a Living Sea" representing the green segment of the small fishing vessels. They were positive and had a much broader understanding of sustainability especially with respect to the environmental aspects. Thus, it could be argued that the most basic preconditions for a good dialogue were missed and the result was that we could expect an eco-label for farmed fish as the only eco-label in Denmark.

Potentials. In 1999, the Danish Society for a Living Sea conducted 77 interviews with fishermen about their understanding or definition of a sustainable fishery. The interviews showed that fishermen mainly representing the smaller vessels, had a relatively wide understanding of the environmental problems in the fishery. Most fishermen were concerned with the damage inflicted upon the seabed and reefs, where the trawlers were blamed. Energy consumption was also mentioned and the interviews gave the impression that the fishermen are seriously concerned about the environmental impacts from certain fishing practices. A later study, conducted by the Institute of Fisheries Management, confirms that the fishermen are aware of many aspects of sustainability, and that most fishermen want to preserve heterogeneous fleets, also with room for small vessels. (IFM, 2003)

A market for green products – driven by values

Potentials. According to Nordisk Ministerråd (1998a), environmental parameters will become an important competitive parameter in the future market. Several references suggest that the future markets for green quality products will grow. Some authors even suggest that the product becomes the

by-product, while the history of the product will become the main/determining product (Jensen, 1999)

Thus, there appears to be a change in consumer behavior towards increased interest of and demand for immaterial quality aspects related to the history of the products. This development is also reflected in the parameters that are used by the supermarkets to attract costumers – see table 6:

Table 6. *Development in attraction parameters for a large Danish supermarket chain (Lauersen, 1999)*

1960s	1970s	1980s	1990s	2000-
Localization	Localization	Localization	Localization	Localization
	Product selection	Large selection	Larger selection	Differentiated selection
		Price	Lower price	Price
			Quality	Quality
			Environment	Environment
				Ethics, health etc.

Barriers. For fish products in particular, the consumers knowledge about environmental impacts is relatively small according to Søndergaard et al (1998). Furthermore, there is a tendency that some labels such as the read Ø-label for organic foods in Denmark, is being chosen because of health aspects rather than environmental aspects. (Husmer et al. 2003). If this turns out to be true for fish products as well, it will be a dilemma, because sound fishing practices such as passive fishing gear used in coastal areas, do not necessarily provide the fish with the lowest levels of heavy metals and other chemical components.

The political consumer

Potential. There seems to be a development towards increased awareness and responsibility taken by the consumers. Some authors argue that the supermarkets are and increasingly will become the democratic arena where the consumers “vote” on the preferred producers (Jensen, 1999). This is a potential for cleaner fish products, but only if the consumers are provided with alternatives and if they (we) are informed via some kind of labeling.

Barriers. This leads to the flip side of the coin. The number of different eco- and quality labels increases each day all over the world and the amount of information that the consumers have to understand and interpret increases each time. This does not fit into our daily lives that gradually become more hectic, with less time for shopping (Husmer et al. 2003). Too much respon-

sibility and too much information that can be difficult to interpret may lead to apathy and then we have achieved the total opposite of the intention. The polarization of the market in high quality products with an ethical dimension at one end and fast-food on the other, could be understood in this context.

12.5 Policy instruments – what can we do?

The previous chapters addressed the barriers and potentials for cleaner products, but specific solution models and suggestions for political instruments have not been further discussed. The purpose of the following section is to discuss solutions in terms of political instruments, which may contribute to a reduction of the energy consumption in the fishery. Solutions to other types of environmental problems in the fishery as well as other stages are not further analyzed here, but the conclusion in chapter 13 presents recommendations based on the analysis in chapters 11 and 12.

Key variables

As a basis for the analysis of specific solutions that can reduce fuel consumption, this section provides a description of key variables.

Important variables for fuel consumption

Several factors influence fuel consumption in the fishery. It is possible to direct the focus to the output of the fishery (the target species) just as in traditional fishery management. This may include considerations of quota, and how quota can be optimized with respect to maximum output of edible fish per fuel input.

An alternative to this kind of “output” regulation is “input” regulation, known also from traditional fishery management – see Frost (2001). If the concept of technology is applied as defined by Lorentzen (1988), it is possible to distinguish between three input variables: Technique, Knowledge and Organization. In this regard, the output variable becomes the product.

The technical variables may include considerations on the number and size of vessels, fishing gear etc. The knowledge variable addresses the behavior and skills of the fishermen. Finally, the last variable “organization” addresses the way we organize the fishery on a larger scale. As I will describe, all these variables are important and should ideally be assessed separately

and collectively, in the pursuit of fuel reductions. That is if sub-optimization should be avoided.

In between the input and output side of the “equation” we have the fish resources and related variables such as stock migration, weather etc. These factors are obviously difficult to influence and regulate.

The key variables that influence the fuel consumption in the fishery are illustrated in figure 1:

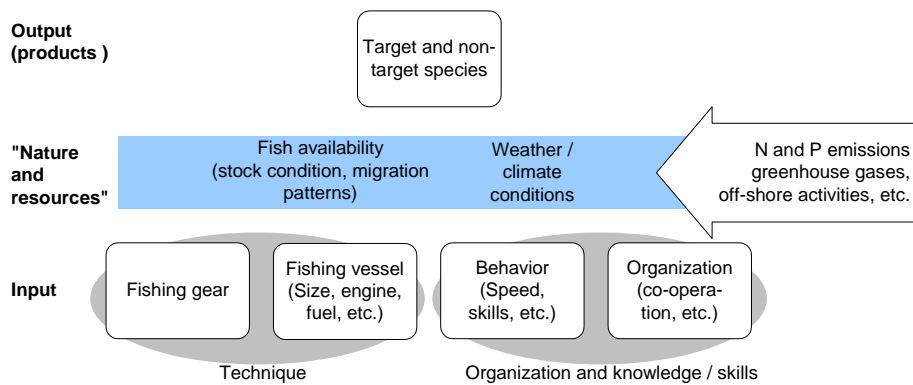


Figure 1. Illustration of the key variables for fuel consumption in the fishery – based on the concept technology as defined in Lorentzen (1988)

The model shows that previous initiatives taken by the authorities such as replacement of engines and propulsion systems is one out of many possible ways to obtain fuel reduction in the fishery.

A fix that fails!

As previously described, the authorities have primarily addressed fuel consumption in the fishery by supporting investments in new engines (Fødevareministeret, 2000). However, the fuel consumption per kg of landed fish has continued to rise and has increased around 30%⁸ from 1974 to 1998 – as explained in chapter 4.

⁸ The development in species composition in the same period, would suggest a decrease rather than an increase in fuel consumption.

One possible explanation is that new engines and new propulsion systems may lead to an increase in steaming speed and/or towing capacity. Thus, despite being more effective, they may not effectively reduce energy consumption. If this is the case, it can be regarded as an inadvertent subsidy⁹, leading to unwanted increases in fishing intensity and larger fuel consumption. Within “Systems Thinking” this is called a “fix that fails”. This can also be illustrated by a causal-loop-diagram – inspired by Senge (1994).



- +) Signifies that the interrelated variables changes in the same direction
-) Signifies that the interrelated variables changes in opposite directions

Figure 2: *Causal loop diagrams providing a possible explanation to why new engines (see proposed solution) not necessarily reduce the fuel consumption in the fishery, over time.*

The causal-loop-diagram provides one “possible” answer to why the solution of replacing engines appears to miss the goal. New engines probably contribute to fuel reductions in the short run – as they are more efficient (see the first loop in the low left corner). However, new engines “with the same effect” combined with better propulsion systems tend to increase the maximum

⁹ This applies to many types of subsidies to modernization in the fishing fleet (Vedsmann, 1998).

pull-power of the vessels (Tarvainen, 2004). This is likely to provide an increase in steaming/towing speed and /or an increase use of active fishing gear. Both things may cause an increase in fuel consumption according to the studies in chapter 4. However, there is also an indirect effect. Higher speeds and more use of active fishing gear may lead to an increase in fishing capacity, which after some delay (a matter of years) may contribute to further depletion¹⁰ of the fish stocks, which obviously lead to fewer fish and consequently a higher fuel consumption per kg caught fish – as described in chapter 4.

It is not possible to prove that this is really happening, the CLP diagram clearly shows that it is important to assess the impact of other variables when addressing one specific variable. The following sections present an analysis, and solution suggestions related to each of the key variables described in the model in figure 1.

Solutions addressing the fishing gear

Solutions, which address the fishing gear, can be divided into improvements of fishing gear and substitution of existing fishing gear.

Improvements of fishing gear

The fishing gear is an important factor for fuel consumption and some types are known to represent high fuel consumption per kg catch. The fuel consumption is mainly related to the water resistance with the net, but the sea-floor contact also plays an important role (Hansen, 1986b; Hansen 2002). Thus, the challenge is to develop fishing gear with little water resistance, minimum friction with the seafloor and high catch efficiency.

Promotion of passive or semi-active fishing gear

In the early part of the 20th century the Danish fishery was mainly based on passive and semi active fishing gear, but larger and more powerful vessels with trawl, have gradually substituted these types of vessels. This development has continued over the last three decades (Lassen, 2000). This is

¹⁰ Obviously, most of the target species are embraced by quota, but it is known that significant quantities of fish are landed as black (non reported catch) or grey fish (catch which is misreported as to area or species). High grading, where only the most valuable fish are retained, may also contribute to overexploitation – even though the catch is within the maximum quota. (Vedsmund, 1998)

probably one of the reasons behind the increase in fuel consumption per kg of caught fish in the last 30 years – see chapter 4.

The results presented in the MECO analysis (chapter 4) and the LCA in chapters 8-10 suggest that there is a considerable potential for energy savings by substituting beam and bottom trawl with passive and semi-active fishing gear. Large improvement potentials also exist in the pelagic fishery by substituting certain pelagic trawls with purse seine (see chapter 4).

Barriers. According to Hansen (2002), most of the edible fish in the world are caught with trawls today (~80%), and passive fishing gear can not provide the same amount of fish. He argues that it is unrealistic to assume that we can switch to passive and semi-active fishing methods. According to Hansen (2002) trawl can be used in a large variety of areas and for a wide range of target species. Thus, it has some unique characteristics.

Furthermore, trawl is sometimes less sensitive to seasonal changes. In the flatfish fishery, it is difficult to catch plaice in the winter because the fish adhere to the seabed, but beam- and bottom trawl is still capable of catching the fish in this period. Furthermore, large trawlers are less sensitive to weather conditions and can stay out fishing even in rough weather, while small vessels using passive fishing gear are much more dependent on the “nature”. The fish processing industry therefore depends on trawlers, according to Hansen (2002).

Potentials. As illustrated in chapter 4 (figure 6), the catch volumes were roughly of the same magnitude in the early 1970s as it is today. Furthermore, the amount of valuable demersal species was considerably higher than it is today. Opposite to the arguments presented by Hansen (2002), this suggest that it is possible to catch the same amount of fish, if we slowly and gradually increase or at least stabilizes the capacity of vessels that uses passive and semi-active fishing gear¹¹.

It is often mentioned that passive gear cannot utilize the same resources and this may be correct in some cases, but in the flatfish fishery, this is probably not the case. According to Andersen (2004) vessels applying Danish seine operate in the same areas as large beam and bottom trawlers targeting flat-

¹¹ Obviously, the species availability has decreased in the same period, but this can also be seen as a result of the development towards larger vessels with active fishing gear thus, the argument can be turned around.

fish, thus, roughly the same resource is exploited. The only difference is that the trawlers are able to catch flatfish more regularly (also in the winter), while the Danish seine vessels mainly catch flatfish and sole during the summer months, where the quality and price is highest. (Andersen, 2004a)

Economic aspects. According to Teknologisk Institute and IFM (2003) the largest improvement in profitability was among the Danish seine vessels (typically small or medium sized vessels) in the period 1994-1999. The study emphasizes that large trawlers (>200 GT) have experienced a turbulent period with a small profit in 1999. It is stressed that this segment is extremely sensitive to increasing fuel prices, which can be expected in the longer run, as oil is a limited resource. However, this development only tells something about the development in a certain period.

Since 2001 the account statistics for the Danish fishery has included detailed economic information for fishing vessels as a function of fishing gear and vessel size. If we only focus on the return rate¹², which tells us if the money invested in the given vessel type is a good investment (a micro economy perspective), it appears that small vessels generally have relatively low profitability compared to large vessels. If we maintain the focus on the fishing gear, it appear that passive and semi active fishing gear actually have the best economic performance compared to other types of fishing gear in the same size category (vessels under 24 meter) – see table 7.

¹² Rate of return calculated as operating profit deducted by owners remuneration, as a percentage of fishery assets at the beginning of the year (Fiskeriøkonomisk Institut, 2003)

Table 7: Return rates for different vessel sizes and fishing methods in years 2001 and 2002. Numbers in brackets in the two columns to the right, are the return rate for the particular fishing method Fødevareøkonomisk Institut, (2002a, 2003)

Vessel length	Average GT		Return rate [pct]		Best economical performance	
	2001	2002	2001	2002	2001	2002
<12m	8	8	-24	-23	Mixed (-5,4)	Trawl (-2,0)
12-14,9 m	19	19	-8	-8	Gillnet & hooks (-5,8)	Danish seine (-4,0)
15-17,9 m	28	29	-0,8	-1	Danish seine (6,3)	Danish seine (6,0)
18-23,9 m	69	63	0,5	3	Danish seine (6,9)	Gillnet & hooks (1,0)
24-39,9 m	257	246	2,3	9	Industrial trawl (4,1)	Industrial trawl (13,0)
40 + m	583	608	8,8	16	Purse seine (12,1)	Purse seine (20,0)
Average for all	64	65	2,3	7		

As it appears, passive and semi active fishing gear has the best performance among the small vessel segments, while trawl and purse seine performs best among the larger vessel segment.

Recommendations – fishing gear

From an environmental point of view, the maintenance of, or even increases in the capacity among vessels that apply passive or semi active fishing gear should be recommended; currently the opposite tendency prevails. The largest vessels in the pelagic fishery mainly use purse seine, but considering the high fuel efficiency of this fishery, it should be worthwhile investigating whether purse seine could be modified and adapted by smaller vessels in some types of demersal fisheries as well.

Factors other than environmental aspects should be assessed as well. In this respect, I have only conducted a tentative analysis, and it must be recommended to initiate more research of the strengths and weaknesses of different fishing methods with respect to economic and social aspects, as well as the practical possibilities for substitution. Within agriculture, studies have been made which analyze the environmental and socio-economic consequences of a reduction in pesticides, including organic production scenarios. Specifically, consequences have been assessed with respect to: Total production capacity, Economy, Legal aspects, Human health, Employment and the Environment (Bichel udvalget, 1999).

Similar studies of the consequences of different production scenarios in the fishery would be highly relevant, even on a European level. Still, the need for more research should not be a hindrance for some level of immediate action based on the knowledge we have today. As an example it would be relevant to stop further capacity reductions among Danish seine vessels, where the number of vessels is around 100 today. The number was around 300 vessels in 1990 and around 8.000 vessels in the 1950s, when Danish Seine was the most important fishing method in Denmark (Danmarks Fiskeriforening, 2001)

Solutions addressing fishing vessels

Referring to table 1, fishing vessels are another important variable with regard to energy consumption, both with respect to size, engine and propulsion system, fuel type, and the overall capacity of the fleet.

Size and shape

The MECO analysis suggested that fuel consumption increases as a function of vessel size, for the same target species and within the demersal fishery. However, I also mentioned that this was probably not the case in the pelagic fishery, where large purse seine vessels are able to catch mackerel and herring with very low fuel consumption.

I have not presented any explanations for the increase in fuel consumption as a function of increasing vessel size, but while large vessels typically exploit resources on the open sea while the small vessels tend to exploit resources in the coastal areas where the steaming distance is shorter. Other explanations are related to differences in engine power etc. It is therefore not necessarily a good idea to promote small vessels in all cases¹³.

Economic aspects. Referring to table 7, it appears that large vessels generally have the best economic performance. The average return rate for vessels under 18 meters is actually negative in 2001 and 2002. This is a fact, but small and large vessels can hardly be perceived as independent variables. If the large vessels catch a lot of fish – less remains to be caught by the small

¹³ Norwegian experiences show that regulations that address the length of the vessels may turn out to promote wide vessels with hydrodynamic properties that result in increased fuel consumption. (Huse et al. 2002)

vessels and opposite. Obviously, there is not a direct proportionality to the extent that the different vessel segments exploit different fish resources.

Another point is that the economic performance of different vessel types varies as a function of stocks and fuel prices etc. It must be assumed that periods with small stocks of flat-fish and codfish in the coastal areas, which has occurred in recent years, tend to reduce the profitability for small and medium sized vessels. (Fødevarerøkonomisk institut, 2002a and 2003; Fiskeridirektoratet, 2002a)

Socio-economic aspects. The socio-economic dimension is yet another factor. Small vessels applying passive fishing gear have proportionally larger labour costs, while large vessels have larger investments tied to fuel and technology – see figure 3:



Figure 3: Working days per landing value (white columns) and fuel consumption per landing value (blue columns) in year 2000 (Fødevarerøkonomisk Institut, 2001b)

Finally, it should be noted that the economic calculations presented here only focus on the micro-economics and that a macro level perspective could change the picture. From a societal perspective, it would be relevant to include parameters such as:

- External costs (i.e. costs related to environmental impacts such as overexploitation, seabed impacts, CO2 emissions etc.),
- Direct subsidies for modernization and the building of new vessels¹⁴
- Indirect subsidies (soft loans, exemption for fuel tax etc.)
- Costs related to effects on employment (large vessels employ a smaller crew per caught fish than small vessels)

In other words, one should be wary of reaching conclusions considering economic performances that are based only on the figures in table 7 – which represent a relatively narrow micro-economic perspective. According to FAO (1993) the world marine fisheries generates an economic deficit of around US \$54.000 million. Even though other economic studies have questioned these conclusions since, it illustrates that the results of economic calculations depend on the scope and the assumptions.

Engine and propulsion system

Apart from the vessel size, it is relevant to address the engine and the propulsion system. In this regard, it would be a solution to conduct modernization under the precondition that the maximum pull-power isn't increased. A solution would be to avoid new engines with larger potential power than allowed¹⁵. This could remove the possibility that fishermen re-adjust their engines to the original maximum pull-power.

Fuel type

Regulation could also address fuel types, but this is already being done within the framework of the EU. A more radical solution would be to use fuel taxes, which are used in other parts of the product chain and in other types of primary production in the food sector. As mentioned, economic instruments are often effective and ideally, fuel taxes could initiate self-regulation and innovation of sounder fishing practices.

¹⁴ 1.1 billion € of public money (Community and national) is injected into the fisheries sector each year in the EU (European Commission, 2001a).

¹⁵ In this regard, it is also worth stressing that engines with a high potential pull-power probably do not run as efficiently when the performance is reduced because the speed of rotation becomes too low (Christensen, 2001).

As mentioned in chapter 11, there still exist EU regulations that act as a barrier for this type of measure in the fishery. Quotas related to kW*sea days¹⁶ of fuel consumption could be another way to handle this. Thus, by distributing the fish resources/quota among EU countries based on kW*sea days, the countries and individual vessels would be more motivated to promote fuel-efficient fisheries.

The overall capacity

Finally, it is worth stressing solutions addressing the capacity of the fishing fleet. The capacity is not only reflected in the gross tonnage (GT), but also variables such as engine power, different types of technical equipment and fishing gear. The capacity is an important variable, not least because there is a surplus capacity in the fishing fleet, while the stocks are depleted in many cases. Fewer vessels and more fish would obviously contribute to a reduction in the fuel consumption, but probably also a reduction of other environmental impacts such as seabed impacts, as suggested in chapter 4.

According to Degnbol et al. (2003) the most important measure to reduce the environmental burden of fisheries in Europe is a reduction of the fleet capacity. However, it is also argued that we should consider the balance between vessel segments that have a relatively large and a relatively low impact potential (Degnbol et al. 2003):

“..it is worth considering whether environmental concerns may be integrated into the fleet reduction programs by a differentiated reduction scheme according to the environmental impact of the various fleet segments. It has, for instance, been argued that small scale coastal fleets have a relatively low environmental impact and to the extent that this can be documented, this may be a basis for integrating environmental concerns into fleet reduction programs“

The citation from P. Degnbol illustrates a growing awareness about the potentials in the small-scale coastal fisheries. However, it also indicates that even researchers dealing with these issues are not fully confident that the small vessels using passive fishing gear truly represent more environmentally friendly fishing practices.

¹⁶ According to Tyedmers (2001) the variable “kW*sea days” provides a relatively good estimate of the fuel consumption.

Recommendations – vessels

The most obvious recommendation is to continue with fleet reductions but avoid further decreases in the capacity among the small-scale coastal fisheries. Still, small vessels are not necessarily better with respect to fuel efficiency, for instance they can hardly compete with the low fuel consumption of the large-scale purse seine fishery.

More attention should be given to enforcement of horse power limitations in areas, with such restrictions and subsidies for modernization being given with careful consideration regarding the influence on capacity. Finally, a general recommendation is the use of fuel taxes, but unfortunately, this is hampered by EU regulations so far.

Solutions addressing behavior

As illustrated in figure 1, another important input variable is the behavior of the fishermen. Previous attempts to reduce fuel consumption in the Danish fishery in the early 1980s, focused on steaming speed, advantages in pair trawling and maintenance of engines, propulsion systems as well as the hull of the vessels. Large fuel reductions can indeed be obtained by reducing the steaming speed by just a few percent (Bak, 1994). However, other objectives motivate high speed. That is the objective for obtaining the best quality of landed fish and the objective for using a small percentage of the sea day quota (if the sea day regulation is used).

Green accounts would be another possibility that could initiate self-regulation, a type of regulation that was seldom used in the fishery according to the analysis in chapter 11. This could be used for vessels over a certain minimum size or vessels that represent fuel consumption over a certain threshold value. In this regard, I have developed a suggestion for a model that could be used for green accounts in the fishery. The model is available in app. 14 (only available in Danish language).

Besides information campaigns and green accounts, it must be recognized that education is important, as well. Skilled fishermen probably catch more fish per sea day and therefore have smaller fuel consumption per catch.

Recommendations

Information campaigns and education could initiate a more fuel-efficient behavior among fishermen, but it is questionable whether this will have a significant effect considering other motives, such as reduction of the time

gap between catch and landing of fish to optimize the quality of the landed fish and to reduce the number of sea days used.

Still, I would recommend green accounts, at least for some vessel segments. Green accounts require a continuous registration of data and therefore motivate a continuous awareness and self-regulation that is much needed in the fishery.

Solutions addressing organization of the fishery

As illustrated in figure 1, the organization of the fishery is also worthwhile addressing. The empirical studies of pelagic pair trawl fishery (two vessels towing one trawl) suggested that considerable amounts of energy can be saved when several fishing vessels co-operate in so-called “pool fishery” (Pelagic trawl, 2001)

The organization of the fishery may also deal with the separation of various vessel segments. As suggested by Andersen and Andersen (1999), small and large vessels are sometimes in conflict in certain areas. Some of the small vessels insist that the large trawlers destroy their gill or pound nets and catch the fish, which should be reserved for the coastal fishery vessels. To obtain lower fuel consumption separation is therefore necessary so as to ensure that sufficient resources are available for the most eco-friendly fisheries. Current horsepower limitations in the coastal zone could theoretically contribute to this separation; however, it is worth questioning the enforcement – as described in chapter 11.

As a rule, fishermen from all parts of the country can fish in all areas in Denmark (IFM, 2003). Thus, local fish resources are not necessarily reserved for local fishermen. In this respect, it could also be debated whether this is a barrier for a fuel-efficient fishery as, in some cases, it promotes longer steaming distances.

During the empirical studies of fuel consumption among the pelagic purse seine vessels, it was argued that the Danish authorities indirectly forced fuel-efficient vessels to fish in the international zone outside the coasts of Norway. Obviously, this resulted in a longer steaming distance and higher fuel consumption per caught fish. A fisherman representing three purse seine vessels argued that the Danish authorities had opened up the fishery in Skagerrak and the North Sea for other and less efficient vessels and therefore indirectly forced the purse seiners to fish in distant waters (Purse seine, 2001).

Obviously this could also be interpreted as a problem related to overcapacity, but it confirms that the organization of the fishery is yet another important parameter that should be addressed separately.

Recommendations

Co-operation between groups of fishermen should be promoted. Still, separation between small-scale coastal fishery and large-scale fishery remains important and one way to obtain this could be to improve the enforcement of horsepower limitations.

It is also worthwhile investigating if it is possible to deregulate certain groups of eco-friendly fisheries and to reserve local resources for local fishermen for longer periods. This would be a step towards self-regulation and could be implemented as part of a co-management strategy. Still, more research is needed for this type of more radical solution.

Solutions that address the output

With respect to the output in figure 1, it would be worthwhile investigating the whole Danish fishery and optimizing the output of fish while minimizing the input of fuel. This has also been mentioned in the MECO analysis, but this type of solution is hampered by the insufficient knowledge about fish population dynamics. As previously explained in chapter 4, most of the fishery regulation today is still based on single species assessments. The quota regulation, which can be seen as a result of this approach, is discussed in the following.

The current quota system

The current Quota system has several disadvantages concerning fuel consumption. In the last few years, the quota for codfish has been low and this has forced a lot of fishermen over into the Norway lobster fisheries, where the fuel consumption is very high. At the same time the prices on Norway lobster has decreased, and the risk of overexploitation of the resource obviously increases (IFM, 2003)

According to IFM (2003), a strict quota regulation is perceived as a political failure in all vessel segments and fisheries. The fishermen in the study argue that in their experience the quota system forces them in to short term opportunistic planning. The quota must be fully utilized because the quota may be reduced in the following period if this does not happen. The fishermen argue

that this phenomenon results in overexploitation, higher fuel consumption, and unnecessary wear on the fishing gear and crew.

Individual Transferable Quota

One of the most debated alternatives to the current quota system is a system where the quota becomes tradable, so called Individual Transferable Quota (ITQ). Some argue that this will result in a much more efficient fishery, but based on experiences from Island, it must be assumed that it may lead to a concentration of the fishing fleet on fewer and larger vessels. According to Tyedmers (2001), the ITQ system has not led to reductions in fuel consumption in Island, which similar to Denmark, has experienced increasing fuel consumption through the last decades in spite of ITQ¹⁷.

There exist a number of other alternative models besides ITQ, for example regulation of the maximum number of sea days per vessel and yearly quota. It is also possible that certain groups of fisheries can become self-regulating. It is certainly worthwhile investigating to what an extent these types of regulations will contribute to a reduction in fuel consumption, but this has not been further investigated here.

Eco-labeling or branding

Traditional eco-labeling. As described in relation to table 5, Eco-label's reflecting fish from fuel-efficient fisheries, could also be a solution addressing the output. As previously mentioned, eco-labeling of wild fish has met a lot of resistance in Denmark, both from the Danish Fishermen's Association and the authorities.

Branding. A suggestion by Weidema et al. (2002) of a relevant model – at least for agriculture products – would be to turn towards the branding of products as part of the retailer's own profile. Thus, supermarkets with a green profile could set up their own criteria for green fish products.

Another possibility is to relate the branding to Danish fish products, as such. This would maybe not exclude any vessels, at least not initially, and product

¹⁷ It is possible that an ITQ system could be modified to promote environmentally friendly fishing as well. A free market system can be a good idea – also from an environmental point of view. However, it presupposes that the market system reflects external costs, such as emissions of green house gases, seabed impacts etc. As previously explained the EU commission wishes to promote a debate about integration of the polluter pays principle in the fishery, and this could be one of the areas where such a debate would be highly relevant

declarations based on LCA could be a part of this strategy. It would probably be easier to involve the Danish Fishermen's Association and other actors in the fishery sector, but the question is if this strategy would be an efficient way of obtaining continual improvements¹⁸.

Recommendations

The current quota system obviously has limitations, also concerning the promotion of a fuel-efficient fishery. I have not been able to come up with any specific changes and certainly more research is needed.

The distribution of quota influences the efficiency of different vessel segments and therefore the economic return rates of different vessel segments. Therefore, it is important to address energy aspects, also with respect to quota regulation. Ideally, energy aspects should become an integrated part of discussions of future quota systems as well as the continuous adoptions.

With respect to eco-labeling, I would certainly recommend that the Danish authorities initiated a process towards eco-labeling of wild fish as well. The most important barrier is probably the lack of interest among actors within the sector, partly because the label could discredit other fish products. An alternative would be an environmental branding of Danish fish products where the environmental profile was established and marketed through an LCA approach. This type of benchmarking would probably meet with less resistance in the sector, but it would be rather difficult to argue that the consumer reduces their contribution to environmental impact through the purchase of these "Danish" products instead of fish products from other countries.

¹⁸ One argument that this would be the case, is that it would be in everybody's interest to isolate environmental hot-spots and reduce the environmental impacts at the most critical places. An argument against, is that the fishermen's mutual solidarity could become a barrier for significant changes.

12.6 Summary & final comments

It can be concluded that barriers for cleaner fish products exist on different levels, reaching from the lack of fundamental knowledge about environmental impacts on the seabed, to cognitive and institutional barriers in the fishery sector and among authorities and consumers. The most important factors are listed in table 8.

Table 8. Key barriers and potentials for a development towards cleaner fish products

Barriers	Potentials
----- Natural science perspective -----	
<ul style="list-style-type: none"> Lack of co-coordinated research in cleaner production at the fishing stage 	<ul style="list-style-type: none"> Expressed intentions to increase focus on selective fishing gears in EU and DK.
-----Social science perspective -----	
<ul style="list-style-type: none"> The fishery is excluded from energy tax. 	<ul style="list-style-type: none"> EU express intentions to promote the polluter pay principle in the fishery.
<ul style="list-style-type: none"> Fleet reduction programs – largest reduction among the most eco-friendly vessel segments. 	<ul style="list-style-type: none"> Subsidies to promote energy reductions in terms of new engines.
<ul style="list-style-type: none"> Energy aspects are not perceived as an integrated part of the ecosystem based fishery management approach (EBFM). 	<ul style="list-style-type: none"> Promotion of EBFM, which represents a more holistic approach towards fishery management.
<ul style="list-style-type: none"> Danish authorities reluctant to develop an eco-label for wild fish. Fishery institutions such as the “Fishermen’s association” are negative towards eco-labeling of wild fish (interest conflict with the Danish Society for a Living Sea). 	<ul style="list-style-type: none"> Emerging interest for eco-labeling among authorities in Scandinavia and EU. Development of eco-labeling criteria for wild fish in Sweden. Danish NGO support for sounder fishing practices and eco-labeling of wild fish.
-----Human science perspective -----	
<ul style="list-style-type: none"> Narrow understanding of sustainability in the fishery sector – especially the fishery. Lacking problem awareness/recognition in the fishery 	<ul style="list-style-type: none"> Growing awareness about broader ecosystem impacts in some segments of the fishery.

I would argue that relatively few barriers and potentials, are related to the lack of scientific knowledge about eco-system effects from fisheries. Obviously, we would like to now more about seabed impacts, the effects on the food chain and the green house effect, but I do not think that more research

would be the most efficient way to obtain improvements – at least it should not stand alone. Moreover, it is important to address cleaner production practices at the fishing stage, and increase the R&D activities in this area.

A key problem is the interest conflict between the Danish Fishermen's Association, and the NGO "The Danish Society for a Living Sea". The latter represents fishermen and citizens that are concerned with the environmental impacts generated by fisheries, while the Danish fishermen's Association (DFA) focus more on impacts generated by other parts of society. The lacking problem awareness and the lack of internal debate about environmental impacts in DFA is unfortunate, and it appears that important parts of the environmental discussion is externalized to NGOs with somewhat limited influence on decisions that affect the future of the fisheries.

As it appear in table 8, there are driving forces pulling in the other direction and the development of the EBFM approach together with initiatives to promote eco-labeling of wild fish in Sweden are promising initiatives. The EBFM approach could turn out to be a major step towards reductions in the environmental impacts in the fishery, but so far, even this concept has been centered around fish stocks and energy consumption are not discussed in this context.

Overall, I would argue that the most important barrier is related to the cognitive aspects, the lack of problem awareness as well as the narrow understanding of sustainability, which is closely connected to the focus on fish quotas and fish resources. Also, the lack of interest for environmental initiatives such as eco-labeling appears to be a barrier, both in the sector and among the authorities.

This situation is probably relatively difficult to change in a short time perspective. It must be recognized that the traditional fishery regulation already is quite demanding, both for the fishermen and the authorities. Thus, small resources are left for including new types of thinking and new goals and regulations. Still, I would argue that it is possible to promote cleaner fish products by small changes of fishery regulations, by introducing some of the elements known from environmental regulation of the industry and by promoting environmental regulation that address the products, such as eco-labeling.

Recommendations for fuel reductions in the fishery

Several recommendations are given to reduce the fuel consumption in the fishery. The recommendations address five key variables: fishing gear, fish-

ing vessels, behavior, and organization of the fishery as well as the output of the fishery (that is the target species). It is recommended to:

- Avoid a further reduction in capacity among the vessels that apply passive or semi active fishing gear
- To integrate environmental concerns in fleet reduction programs
- Initiate R&D activities in cleaner production practices
- Introduce fuel taxes
- Improve enforcement of horsepower limitations
- Provide information about possibilities to obtain fuel reductions by a change in steaming and towing speed
- Increase co-operation between certain segments of vessels
- Require green accounts for larger vessels
- Integrate environmental concerns in quota and seaday regulation
- Promote eco-labeling of wild fish

As it appear most recommendations reflect initiatives in the public regulation, but in fact it is only the enforcement of horsepower regulation that reflects a traditional “command and control” approach – see figure 2.

Other recommendations at the fishery stage

As described in chapter 11, a number of regulations exists, which address other environmental aspects in the fishery. This include regulation of occupational health & safety aspects, traditional fishery regulation (mainly quota), marine protected areas and regulation, which address anti fouling agents in the auspices of the International Maritime Organization (IMO). These regulations mainly have a character of command and control regulation, and are also illustrated in figure 2. Obviously, it can also be recommended to improve the implementation of these regulations, which is somewhat weak in a number of cases.

Also, new regulations can be recommended to create better incitements to return waste products to the land (e.g. subsidy to waste handling in harbours). Thus, all in all a number of recommendations are given which include more than just energy aspects – see figure 2.



Figure 2. *Suggestions for new types of regulation, which can reduce the fuel consumption at the fishing stage.*

An energy tax at the fishing stage would probably be an efficient economic instrument for promoting cleaner fish products, but so far this type of instrument cannot be used in Denmark, due to EU regulations.

Recommendations for other life cycle stages

The analysis in this chapter has mainly focused on the fishing stage, especially in the last section dealing with solutions addressing energy consumption in the fishery. Still, it is possible to suggest a number of regulations that address the other life cycle stages as well. For the processing stage in particular, the recommendations include:

- Continued support to cleaner production practices at the processing stage – but more focus on industries that process demersal and shellfish and more focus on the product perspective (that is life cycle thinking).

- Less focus on wastewater and more focus on energy aspects at the processing stage, also with respect to indirect energy consumption related to packaging materials such as aluminum and glass.
- Better utilization of the fish (increased filet yields) is obviously also a key area of improvement, which indirectly improves the environmental performance in previous life cycle stages as well. A higher yield means that less fish have to be caught to produce one kg of filet. In addition, it would be relevant to continue the effort to promote corporate environmental management (e.g. EMAS or ISO 14001) and adjust it to become more product oriented.

More generally, it would also be relevant to promote eco-labeling for wild fish. Some sort of branding and bench marking initiatives could also be an idea. The use stage is one of the hot-spots, but the political instruments already include a number of taxes. A reduction of the fuel consumption at the use stage would be most effectively promoted by a change in infrastructure, which reduces the need for transport. This would require reflections on localization of residential areas, work places and shopping centers etc., but this kind of development cannot be promoted through a focus on fish products alone. It needs to be addressed through urban planning (Næss, 2002).

Conclusion and Perspectives

The purpose of this dissertation has been to answer the following question.

How can authorities and actors within the Danish fishery sector effectively promote cleaner¹ fish products produced in Denmark?

Based on the related research questions, the report include an analysis of:

- 1) The environmental burden from fish products (chapter 4-10),
- 2) The existing environmental regulations and policies addressing different life cycle stages (chapter 11)
- 3) The potentials and barriers for development towards cleaner fish products (chapter 12).

The conclusion is divided into three sections:

- Hot-spots and improvement potentials.
- Methodological reflections.
- Environmental policies and regulation.

The main results from the MECO study and the LCA analysis is presented in the following.

¹ That is fish products, which represent a smaller environmental burden compared to initial/ reference situation.

13.1 Hot-spots and Improvement Potentials

The following section presents the main points concerning environmental hot-spots and improvement potentials for edible fish products caught and processed in Denmark but sold and consumed abroad (central and southern Europe).

Important life cycle stages for Danish fish products

The environmental hot-spots have been thoroughly described in chapters 7 & 10, but the main points are emphasized below.

Functional units

The analysis focuses on Individual Quickly Frozen (IQF) flatfish, where the functional unit is on kg of consumed fish based on consumer packaging of 300 gram in cardboard or plastic. The analysis includes LCA screenings of codfish (IQF), shrimp (IQF), prawn (IQF), blue mussels (IQF) as well as pickled herring in glass jar or plastic bucket and canned mackerel in oil and aluminum cans. A screening of fresh fish filets based on average edible fish exported to fresh fish markets in central Europe has also been conducted.

In all cases the functional unit has been 1 kg of consumed fish similar to the LCA of flatfish. Still, the data are not based on consumer packaging of 300 grams for mussels, herring and mackerel. For mussels it is based on consumer packaging of 1000 gram, while it is based on consumer packaging of 80 gram filet for mackerel and 205 gram for pickled herring.

The fishery: A dominant life cycle stage

Based on the MECO analysis (chapter 4-7) as well as the results from the LCA analysis (chapter 8-10), it can be concluded that the environmental impacts related to the fishing stage are *important* for all types of edible fish products analyzed in this project.

Except for mussels, herring and mackerel the fishing stage is completely dominant compared to other life cycle stages. The same conclusions apply to the fresh edible fish.

Process contribution

In a process perspective, it is especially the combustion of fossil fuel, which is important at the fishing stage, when we consider the impact categories assessed in the quantitative LCA.

The qualitative LCA (chapter 10) addresses several other impact categories and shows that the fishing stage is also important (or the most important) stage for exploitation of fish, by-catch and discard, seabed impacts (mainly demersal fish), use of non-renewable resources, human toxicity and Occupational health & safety.

It is worth emphasizing that most of the impact categories are correlated with the energy consumption, this includes global warming, eutrophication, ozone depletion, ozone formation, non-renewable resources, human toxicity and seabed impacts. Thus, by addressing the energy consumption at the fishing stage many other problems are likely to be addressed at the same time. In addition, it is plausible that a high energy consumption per kg caught fish can be the result of a high discard ratio. For instance, studies show that more than two-thirds of the total catch is discarded in the Danish Norway lobster fishery, which is also the highest fuel consuming. Thus, energy is indeed a key issue.

The use stage: An important life cycle stage as well

Next to the fishery stage, it is worth to emphasize the importance of the use stage, which also represents a very significant impact potential for all analyzed products. Except for herring and mackerel, the use stage represents the second most important life cycle stage, according to the quantitative LCA, and the MECO analysis as well as the qualitative LCA points in the same direction.

The impact potential is mainly related to shopping, which is relatively demanding with respect to energy consumption and land use, when conducted by car, as it frequently happens in Europe. Other important processes are cold storage, cooking, and dishwashing. In terms of energy consumption, these three processes represent roughly half of the energy consumption while shopping represents the other half.

The processing stage: Insignificant for most fish products

According to the quantitative LCA, the processing stage is relatively insignificant compared to the fishery and use stage for flatfish, codfish and shellfish. The qualitative LCA indicates that processing is indeed important in terms of water consumption, use of non-renewable resources (mainly gas)

and Occupational health & safety. Still, it can be debated whether water consumption represents a significant problem, as the Danish fish processing industry, generally is placed in areas with relatively plentiful water resources. With respect to non-renewable resources, it must also be assumed that there will be plenty of possibilities for substituting gas with other energy resources. Thus, except for occupational health & safety the processing stage is assessed to be relatively insignificant for flatfish, codfish, and shellfish.

For pickled herring and canned mackerel, processing is relatively important compared to other stages, according to the quantitative LCA. Glass and aluminum packaging plays an important role at this stage. It should also be noted that the energy consumption is relatively low for pelagic fishery and that canned mackerel doesn't require cooling at the retail and use stage. Finally, seabed impacts are not an issue for fisheries targeting pelagic fish such as herring and mackerel.

The retail stage: Important in most cases

Finally, it is worth emphasizing that the retail stage is somewhat important as well, except for canned mackerel where cooling is not required. Cold storing in the supermarkets represents a relatively large consumption of energy, especially for "specialty" products with a long storage time such as frozen blue mussels. For blue mussels (IQF), the quantitative LCA actually suggests that the retail stage is the overall hot-spot.

Concluding remarks

Hence, it is concluded that the fishing stage is overall the most important stage in terms of environmental impact for most or maybe even all fish products. Despite the fact that some fish products are caught by very fuel efficient fishing methods e.g. mussel and mackerel, the exploitation of fish resources including by-catch and discard represent an intervention with the natural ecosystem of a magnitude that is matched by few other products - see chapter 10. The effect on the food chain is significant and significant ecosystem effects such as changes in species composition, age distribution and age of maturity among fish stocks in the North Sea has been observed.

The impacts also include the seabed effects. Swedish studies suggest that the area affected is around 1, 7 hectare per kg of caught cod in the Baltic and LCA studies conducted at SINTEF in Norway suggest that the seabed impacts in the fishery are indeed the dominating environmental impact for the life cycle of cod filet. With respect to actual effects, there is evidence that whelks have been absent from the Dutch Wadden Sea, most likely due to bottom trawling. Specifically for the Danish sea territory, evidence exists

that the occurrence of long-lived organisms such as Sea stars and different types of shellfish increased after certain areas have been closed for flatfish fishery.

Future predictions (towards 2010-2015)

The LCA studies in chapters 8 to 10 suggest that the fishing stage generally remains an environmental hot spot for the next 10 to 15 years. The impact from cooling and anti-fouling agents will decrease significantly, but the energy consumption as well as the impacts on fish stocks and the seabed will probably remain stable or increase even further due to the increased use of trawl and rock-hopper trawl that can be used in areas not previously used for bottom tending fishing gear. In addition, energy consumption per kg caught fish is expected to increase further, as it has been the case during the last 30 years, due to depleted stocks and more powerful fishing vessels.

For the processing-, retail- and use stages it is predicted that the efficiency of cooling and heating processes will be improved, and that HCFC cooling agents will be replaced by natural cooling agents. It is also predicted that transport processes generally will become more efficient, but as the amount of transport needed is assumed to increase, it is assumed that the overall impact potential will remain stable.

Towards 2050 or 2100

With respect to the far more distant future (lets say year 2050-2100), it could be expected that some of the problems that we perceive as serious today would become insignificant. The emission of anti-fouling agents and the consumption of energy in the fishery could be such examples. In 50 or even 100 years time it could be expected that the traditional combustion engine will be replaced by fuel cells that transform hydrogen (or other fuels) into energy and water vapour (Hankin, 2001). In addition, anti-fouling agents may have become irrelevant due to self-repellant surfaces, or much less toxic.

Still, there are certain types of environmental impacts, which probably never will be completely removed (at least it is hard to imagine). This includes the impacts on the fish stocks, damage inflicted to the seabed as well as occupational health. These are aspects that are closely related to the fishing stage.

For the remaining life cycle stages, it can also be expected that fuel-cells will replace traditional combustion engines and that efficiency improvements will occur. Despite the technological development, it must be assumed that land use will become a growing problem in the future (see Weidema 2000). We

can improve efficiency and produce more per hectare of land, but there is a limit. Furthermore, it must be expected that land will become an increasingly sparse resource due to the predicted increase in populations and their levels of affluence, as described in chapter 1. A consequence will probably be that the environmental effects of a marginal change in land use will tend to increase.

All things considered, it can be expected that the fishing stage will remain one of the most important life cycle stages.

Reflections on the Results

Reflections on the results are presented in the following with focus on comparison with other studies and application of the results in other contexts.

Comparison with results from LCA studies in other countries

In parallel to this project, LCA studies have been conducted in Sweden and Island where the focus, in both cases, has been on codfish. The study from Island involved factory trawlers where the vessels also process and freeze the fish. The Swedish LCA involved traditional fishing vessels with trawl and gillnet – similar to the LCA in the present dissertation (Ziegler et al. 2003; Eyjólfsdóttir et al. 2003).

Both studies suggest that the fishing stage is the overall environmental hot-spot, and that the most important processes are fishery, transport and cooling. This supports the conclusion in the present study, but it should be noted that the Swedish study, unlike the present one, also points towards wastewater emissions from the processing stage as an important parameter.

Beyond Scandinavia, the only major study of environmental impacts from fish products, to the best of my knowledge, is a PhD dissertation from the University of Columbia in Canada. The Canadian study applies the “ecological footprint” approach, while addressing the environmental differences between farmed versus wild (caught) salmon. Here, it is also concluded that the fishing stage is the overall environmental hot-spot.

Comparison to studies of other meat products

For other meat products such as pork and cattle from agriculture, primary production is typically the hot-spot. Actually, the energy consumption for average edible fish appears to be lower than the energy consumption related to average meat products from agriculture. Nevertheless, the interesting as-

pect about fish products is the large differences in impact potentials between different species and between the same species caught by different fishing gear. The latter suggests that large improvement potentials exist at the fishing stage.

Application of the results in other countries

Even though a correlation exists in these studies, it is important to be aware that fish are caught and produced in different ways in different countries. It is particularly important to be aware of differences in industrialized countries and developing countries.

It could be expected that the energy consumption is considerably smaller for fisheries in developing countries, where access to fuel and technology is limited, however other types of impacts may be larger in some cases. Damage to coral reefs is a serious environmental impact and may be linked to the use of explosives or chemicals in the catch phase.

Differences also exist at other life cycle stages, for instance at the processing stage. It cannot be expected that countries in developing world typically have effective public wastewater treatment plants like those in Denmark. In addition, it should be noted that environmental impacts, which are important in Denmark might turn out to be (or be considered to be) less important in other parts of the world. Hence, it must be stressed that the conclusion in this study only applies to Denmark and that it cannot be directly applied to other countries.

Application of the results in other contexts

The production capacity in the fishery sector is limited by quota in Europe and many other parts of the world. Thus, it could be argued that a comparative LCA of beef and wild fish, wouldn't even involve fish as the marginal fish is chicken- or pork meat or maybe farmed fish. At least this would be the result of the consequential LCA approach is applied

Are the results trustworthy?

The present study shows that a LCA only can provide a rough assessment of environmental impacts from fish products (this is probably also the case for many other types of products). The tool is not, and cannot be, strictly scientific. Still, based on the conclusions in the MECO analysis combined with the quantitative and qualitative LCA as well as studies performed in other countries all things point towards the fishery as the overall environmental hot-spot for fish products as such. Nevertheless, there are many uncertainties

both methodologically and data related, which have been discussed – see for instance chapters 7 and 9.

It must be recognized that the uncertainties are large, especially those related to methodological aspects such as system delimitation and life cycle impact assessment (LCIA). The qualitative LCA was used as a separate LCA applied to verify the results, but it was also clear that a different weighting of the impact categories could have resulted in other types of results.

Still, considering the purpose of the present LCA it has been assessed that the level of uncertainty is low enough to justify the conclusions made. In this regard, it should also be emphasized that key exchanges, such as the fuel consumption in the fishery, has been thoroughly investigated and validated by information from databases, interviews and data obtained from several other countries (method triangulation), see for instance app. 5.

Potentials for Improvements in the Fishery

It is shown that there are great differences in the fuel consumption as function of the target species. The fuel consumption per kg caught fish is typically high for codfish, flatfish and shellfish (except mussels) while it is relative small for herring, mackerel and industrial fish such as sandeel.

The difference between the target species which represents the smallest and the largest fuel consumption is a factor 600 when system expansion is applied for co-product allocation. It only requires 0,01 liter diesel to catch one kg blue mussels, while it takes around 6 liter diesel per kg caught Norway lobster – that is if co-product allocation is handled by system expansion.

For various reasons, it is probably difficult to change the output in terms of species composition from the fishing stage, but it is obvious to search for efficiency improvements among the most fuel consuming fisheries. In this respect, the results show that the fuel consumption per kilogram (kg) of caught fish varies considerably as a function of fishing gear, even considering the same target species. Thus, by addressing the “production method” it is indeed possible to obtain improvements for most species categories.

Fuel reductions in the fishery

The most remarkable improvement potential addressed in this dissertation is the reduction in fuel consumption that can be obtained by substituting active fishing gear with passive and semi active fishing gear. The improvement is

most remarkable within the demersal fishery (mainly cod and flatfish – see chapter 4, figure 5). Still, large improvement potentials also exist within other types of fishery such as the herring and mackerel fishery where purse seine appears to be the most efficient fishing practice.

The fuel consumption in the flatfish fishery - which is one of the more energy consuming fisheries – can vary from 2,6 liter to 0,2 liter fuel per kg caught flatfish, where first represents beam trawl while the latter represents Danish seine. In this regard, it should be noticed that 2,6 liter per kg caught fish is around 8 liter fuel per kg consumed filet. If all flatfish were caught by Danish seine or passive fishing methods such as gillnet, it would theoretically be possible to save around 30.000 m³ fuel per year in the Danish fishery alone. This is 15% of the total fuel consumption in one year. Calculations and assumptions behind these figures are explained in chapter 7. It should be stressed that the figures are rather theoretical and do not consider whether this is obtainable in practice.

Other types of improvements in the fishing stage

As mentioned previously, the goal of fuel consumption appears to be consistent with other environmental goals in the fishery, such as reduced potential for global warming, ozone depletion, acidification, nutrient enrichment, ozone formation, and eco-toxicity. Furthermore, it is likely to address seafloor effects and discard at the same time. Still, the other environmental impacts can also be addressed separately. To reduce seafloor effects, it could be relevant to develop fishing gear which has a smaller friction with the seabed or gear that scare the fish up by sound, shock waves, or electric impulses.

If all guts were brought back to land, it is also possible that a large fraction could be used to produce fishmeal and oil, which substitutes for soy protein. Obviously, this would be difficult to implement, but economic incentives to bring back waste as well as guts would probably be a push in the right direction.

Improvement Potentials at other Life Cycle Stages

The MECO analysis, summarized in chapter 7, showed that there are considerable improvement potentials at the processing, retail and use stages as well. Transport and cooling processes are obvious areas of improvement, but it is also worth addressing packaging that involves aluminum and glass that can be substituted by plastic. The latter addresses the processing stage for canned mackerel, pickled herring and certain shellfish products.

At the use stage, it could be considered to switch to delivery services, internet shopping or simply to reorganize our cities and lifestyles in such a way that shopping by bi-cycle or foot can be performed more easily. At the processing stage, packaging represents a potential for large improvements for some products where glass or aluminum packaging is used. This applies to pickled herring, canned mackerel and a number of shellfish products, where different types of plastic containers can substitute glass and aluminum.

Is it possible to obtain factor 4 to 10 improvements?

In the LCA in chapters 8 and 9, it was shown that the aggregated weighted impact potential (five impact categories) for frozen flatfish could be reduced with a factor of 5, but only by substituting beam trawl with Danish seine in the fishing stage.

In future scenarios the improvement factor would amount to a factor of 9 due to substitution of chlorinated cooling agents and the expected increase in fuel consumption. For eco-toxicity the improvement potential only amounted to a factor of 3 to 5 depending on the scenario. These improvements could be obtained just by substituting beam trawl with Danish seine, and obviously further improvements could be obtained by cleaner production practices in other life cycle stages as well.

13.2 Methodological Reflections

The limitations of LCA approach and methodological reflections about the three pronged approach involving a MECO analysis, a quantitative and a qualitative LCA, is discussed in the following.

The use of both MECO and LCA

The MECO analysis established that the fishing stage was the hot-spot for the largest number of environmental exchanges, also for exchanges which often prove important in LCA studies, such as energy consumption. However, it was not possible to compare the importance of the different types of exchanges, e.g. emissions of anti-fouling agents, solid lead emissions from fishing gear and energy consumption.

Was the LCA necessary?

The LCA analysis included an assessment of the impact potential related to the various exchanges and therefore provided a basis for comparison between impact categories. This analysis confirmed that the fishing stage is indeed the hot-spot for most Danish fish products.

If the MECO study were the only analysis, it would not have been possible to distinguish between important and insignificant exchanges. For instance, it would not have been possible to establish that anti-fouling agents are a much greater problem than lead emission from fishing gear.

Was the MECO analysis necessary?

I would also argue that the MECO analysis had its own purpose – besides serving as input for the LCA inventory. First of all, it provides an overview of the exchanges for many different types of products, which is also accessible information for other LCA practitioners. Besides, it gives the practitioner or reader a “sense” of the magnitude of the data – also across product categories. This serves to avoid errors of a factor of 100 or 1000 – which tend to occur in some LCA studies. Finally, I have realized that the MECO approach is a good basis for improvement assessment and benchmarking, when comparing different production methods and product types.

Combining the Quantitative and Qualitative Approach

The separate qualitative LCA in chapter 10 includes a significant number of impact categories not previously addressed in the quantitative LCA (chapters 8 & 9). The purpose has been to elucidate to what extent other impact categories could possibly change or falsify the main conclusions from the qualitative LCA. This approach has been fruitful, and shows that different conclusion can be obtained by focusing separately on other impact categories such as consumption of abiotic resources (ecological rucksack perspective), land use (ecological footprint perspective) or human health (a welfare perspective). Still, it has not been assessed as to whether or not the overall result from the qualitative assessment falsifies the conclusions established through the quantitative LCA. Moreover, the overall results from the qualitative LCA appear to strengthen the previous conclusions and therefore serve as a validation of the main conclusions from the hot-spot analysis in chapters 8 & 9.

Considering the qualitative approach as such, one of the largest challenges is to compare the seriousness of different impact categories. The methodology applied in a quantitative LCA is more consistent and easy to apply in this

respect. Still, it could be argued that the qualitative approach tends to open a discussion rather than close it, as some traditional LCAs tend to do.

Limitations of LCA and future recommendations

A discussion of the most important weaknesses of the LCA approach is presented in the following. I have not only focused on the LCA, but also on how it is typically applied. Obviously, some of the weaknesses will reflect that the methodology is relatively new. Attention is therefore also given to current methodological improvements and recommendations to future research.

The lack of site-specific aspects in LCA

One of the weaknesses in the LCA presented in this dissertation is the lack of site-specific aspects (spatial differentiation). The latter is important for all types of local and regional impact categories. One example, could be the emission of nutrients (N and P), which may contribute to aquatic and terrestrial eutrophication. The emission of N and P derive from a variety of sources. However, there are great differences in the effects if we compare water emissions of bio-available nutrients to a sensitive lake or fiord with atmospheric emissions of NO_x occurring in the North Sea or in different parts of the world where aquatic and terrestrial eutrophication may be a very limited problem.

Current developments of the Danish EDIP method, which will result in a new version termed EDIP 2003, represents a great step towards including spatial differentiation. The method includes site-specific characterization factors at country or regional levels (at least for Europe) - developed based on knowledge about background levels and sensitivity of ecosystems. Furthermore, normalization and weighting factors will be available which can match this spatial differentiation. According to Hauchild and Potting (2003) the application of site-specific factors may change the results considerably. In a future update of the results in this dissertation, it would therefore be interesting to apply the EDIP 2003.

Limitations with respect to impact categories

As illustrated in chapter 9, another important weakness of current LCA methodologies is the relatively limited set of impact categories that are applied. In this project, it was chosen to conduct a more qualitative oriented LCA to compensate for this.

The inclusion of more impact categories in the EDIP method would be most welcome. These could be exploitation of biological resources (e.g. fish resources), water consumption, land use, seabed impacts, and noise. For LCA studies of food products, these types of impacts are particularly relevant.

Currently, research is being conducted to include seabed impacts in LCAs in Sweden as part of a PhD dissertation about the environmental impacts from codfish products – see Ziegler et al. (2003). This is surely a great challenge, not only with respect to modeling, but also with respect to data collection. Still, I would argue that it is important to be aware that quantification is not always strictly necessary. For instance, it was not strictly necessary to conduct a detailed quantification of seabed impacts in this report, as no tradeoff was identified between energy consumption and seabed impacts.

Challenges in the valuation step

Apart from the lack of site-specific aspects and impact categories, one of the largest weaknesses in current LCA methodologies is probably the valuation phase (normalization and weighting).

The EDIP method normalizes the results with person equivalents and uses the distance-to-target method in the weighting step (for further details see chapter 8). The method seeks to perform normalization and weighting on the same geographical scale as reflected by the impact.

The weighting should ideally reflect the “scientific” version of the seriousness as well as the perceived seriousness of the impact. Still, it is not a universally recognized method and LCA methods developed in other countries often use other approaches. For instance, it is common to normalize according to Dutch background levels for all impact categories in LCAs from Holland.

The weighting method suggested by the EDIP method (distance-to-target) is only one of several possible approaches such as panel weighting or monetization methods. LCA’s provide new insights and information can have a tendency to “hide” political questions. Personally, I would therefore prefer the use of different weighting methods – reflecting different approaches and different political standpoints.

Lacking considerations of socio-economic aspects

Finally, social aspects are yet another important research area. In chapter 12, it was concluded that small-scale fisheries employ considerably more workers than large-scale fisheries in Denmark. Still, from a national point of view

we also have to consider the related effects on the fishery etc; the latter has not been assessed. From an economic point of view, I have presented figures that indicate that small-scale fisheries are less economically efficient, but it is also argued that a macro economic perspective could change such conclusions, especially if externalities are considered. Thus, more research of the social and economic aspects would also be welcome.

If we return to the discussion of expensive versus inexpensive products, we could also argue that a cheap product from Asia is better from a social point of view. If we buy this type of product we contribute to improve the economy in poorer countries where an additional increase in GNP has a dramatic effect on the average life expectancy compared to the western world (Norris, 2002; Norris, 2004).

Thus, even though LCAs may serve to avoid sub-optimization with respect to environmental matters, economic and social aspects of sustainability ideally need to be addressed too, otherwise, we may risk a shift of burden phenomena in other areas. Obviously, life expectancy per GDP is only one element of the social aspects that could be considered in a LCA. Returning to fisheries, it is also a question of preservation of life forms, local fishing communities, employment, and even food security in the third world.

What is truly most sustainable is very difficult to answer and involves questions related to environmental, social and economic effects on a global scale. This makes one point very clear - an LCA does not provide the "right" answer – especially when we deal with ambiguous questions related to sustainability.

Reflections about Consequential LCA

Compared to attribution LCA, the consequential represents a radically different approach. Instead of perceiving the product systems as static and physically related via material flows, the consequential LCA represents a model of causal relationships. The market aspects have a more prominent position in consequential LCA and we persistently ask the question: what processes are most likely to be affected by a small change in demand in a given life cycle stage of for a given process? In addition, considerations of a change in supply are included e.g. for co-products.

Important conclusions obtained through the consequential approach

The benefits of using the consequential approach are that the LCA provides a more accurate picture of the environmental impacts from the analyzed products, as a consequence of a change in production volumes or production processes.

To me, the consequential approach has been an “eye opener” in several aspects. One of the characteristics of this approach is that it focuses on interactions and production limitations in various product systems. In chapter 2, it was shown how the interactions between the different product chains in the fishery sector meant that farmed fish are closely related to wild fish. The conclusion was that an eco-labeling scheme for farmed fish makes little sense without considering labeling of wild fish. In the Swedish criteria for farmed fish, the producers are restricted to mainly use fish offal from edible fish, but seen from a consequential perspective, this is hardly a solution in Denmark, where the by-products of edible fish already are fully utilized for other food purposes.

The consequential approach has also provided a solution for co-product allocation in the fishing stage where many types of fish are caught at the same time in nearly all fisheries. Compared to results obtained by mass and value allocation, the system expansion provided significantly different results for exchanges such as energy for different species group.

At the processing stage, the approach unveiled that by-products from the fish processing industry substituted other protein sources, which were isolated to be soy-protein from Argentina. This had a significant influence on the results, but it also exposed other limitations such as the lack of site-specific aspects for emissions taking place in Argentina and the lack of land use as an impact category in the EDIP method.

Still, the approach is indeed an “eye opener” and shows that physical or economic causal relationships from the local to the global level are indeed worthwhile to take into account.

Critique of consequential LCA

Even though the consequential approach is now being recommended in the new official recommendations for LCA conducted in Denmark (Weidema, 2003a), it doesn't mean that it is unproblematic.

It is rather unpleasant that the LCA practitioner has to consider market aspects, partly because people who typically conduct LCAs have a natural

science background, and partly because it is more time consuming (in some cases). In this respect, it could be argued that wrong assumptions concerning the market aspects may provide erroneous results. Wrong market assumptions in a consequential LCA can lead to results that are even more misleading than results obtained by attributional LCA, but in this case, a critique of the LCA practitioner is probably more justified than a critique of the consequential approach. However, it is possible that results obtained by consequential LCAs will not lead to more reliable results on average – considering the insufficiencies of the LCA practitioners. However, this has not proved to be true yet. Furthermore, it can hardly be an argument for disregarding the approach.

A consequential LCA only reflects a certain decision situation. It could therefore be argued that the chance of misuse is larger than for an attributional LCA, but again this can hardly be a critique of the method.

Finally, a consequential LCA typically disregards the possible effects on market constraints or other types of constraints. Ideally, this should be considered as well, but as argued by Ekvall and Weidema (2004) this is difficult to model in reality.

13.3 Environmental Policies and Regulation

This section addresses the political perspective and discusses how we can promote cleaner fish products based on the results from the hot-spot analysis, as well as the analysis of current policies and management from sea to table (in chapter 11-12).

Hot-spots versus Regulatory Focus

One of the most important conclusions is that there is a mismatch between the environmental policies (mainly addressing the processing stage) and the environmental hot-spots. Based on the analysis in parts two and three, it can be established that few arguments exist for the continued focus on wastewater emissions from the processing stage, which so far has been the regulatory focus with respect to environmental approvals and funding of cleaner production projects. The LCA studies in chapters 8 and 9 suggest that wastewater emissions from the fish processing industry generally are a small problem today, due to intensive wastewater treatment.

Contrary to wastewater emissions, energy consumption is one of the most important aspects, but only receives little attention, especially at the fishing stage.

Policies and regulations exist that address the environmental impacts at the fishing stage, but reductions in energy consumption have a relatively low priority. In addition, the few instruments that should ensure some level of improvement e.g. new engines, appear to have missed the goal because they did not address the point of leverage e.g. overcapacity, vessel and gear types. In this regard, it is also worth stressing that overcapacity not only results in larger energy consumption per caught fish but probably also means that the fishermen, to an increasing extent, include areas which have not previously experienced fishing activity. As these new areas previously have been left alone, it is most likely that this will lead to greater damage to the seabed and biodiversity loss.

What can we learn from the Processing Industry?

The regulation of the industry has developed from a “command and control” strategy towards increased self-regulation and pollution prevention by means of cleaner production practices. Several types of policy instruments have been brought into play including green taxes, subsidization of cleaner production methods and environmental management systems, and green accounts. Significant results have been obtained regarding water consumption and wastewater emissions.

Cleaner production and EMS have generated a basis for innovation and contributed to savings in resource consumption and more efficient use of the fish resources. Additionally, it has provided higher “ratings” in large retail chains and contributed to closer relationships between customers of strategic importance. Previous studies suggest that the demand for documentation concerning quality and the environment at the processing stage is high and the same type of demands and rating systems will most likely find their way to the fishing stage one day.

Thus, it can be argued that policies and regulations do work and that an effort to promote cleaner production, cleaner products, and self-regulation can be used to obtain environmental results in the fishery as well.

Integrating Environmental and Fishery Policies

The environmental dimension is currently being integrated into the fishery policies, but the lack of energy considerations can be a serious hindrance for results. There are two reasons for this; firstly, energy consumption at the fishing stage is one of the most important hot-spots in the life cycle of fish products. Secondly, the energy consumption is proportional or at least related to several other important types of impacts.

Among the new initiatives are marine protected areas. This could ensure some level of protection against seabed damage to sensitive recipients. Still, it remains a “command and control” regulation that does not address the root of the problem - overcapacity combined with a development towards larger bottom dragged fishing gears and gear that can be operated on rocks (rock hoppers). Another risk is that the regulatory focus is increased on a few new areas, while the largest parts of the seabed becomes the land of milk and honey, where all kinds of activities can continue without any kind of attention.

The present study suggests that the lack of implementation is one of the main causes for the failure of the traditional fishery regulations, and there is a potential risk that the same will happen with environmental regulation. There are already signs that initiatives aimed at reducing energy consumption are missing their goals.

Policy Recommendations and Outlook

Chapter 12 included a number of recommendations for policy instruments with particular focus on the energy consumption at the fishing stage.

Public “command and control” regulation

Recommendations for measures that can be defined as related to “public command and control” regulation as defined in chapter 11, include:

- Improvements in implementation practices with regard to *horsepower limitations* and areas restricted for certain types of fisheries.
- A regulation where $kW \cdot \text{Sea days}$ is included as a regulation parameter, should be considered.

Improvement of implementation practices would be welcomed for most types of fishery regulation, inclusive quota regulation, and capacity reduc-

tions, but here I have focused on horsepower limitations because a development towards improvement of implementation in other areas already has the attention of the authorities.

Public oriented regulation (governmental spending)

A number of recommendations that can be characterized as public market oriented regulation include.

- Introduction of *fuel taxes* in the fishery.
- Economic incentives should be given to *return waste* and maybe even fish guts to land.
- Fleet reduction programs, quota regulation etc. should be developed to *prevent a further reduction of the most energy efficient fisheries*.

With respect to fleet reduction, it is pivotal that the reduction really occurs and that the fleet is significantly reduced; this will partly reduce the risk of over fishing, but it will also create a basis for a more fuel-efficient fishery.

A fuel tax at the fishing stage would probably be an efficient instrument but this solution is hampered by EU regulations, at least in a short-term perspective. However, this is not a hindrance for a long pull towards a change in this type of regulation. This could be combined with a pull towards a more fundamental change of the tax system, where the tax related to pollution is increased, while the tax on labour is decreased – a green tax reform.

Public regulation to promote voluntary action

Finally, a number of recommendations have been given that can support a development towards more self-regulation in the fishery sector. These include:

- The initiation of research and development of *cleaner production practices in the fishing stage*.
- Demands for obligatory *green accounts* should be implemented at the fishing stage.
- Promotion of cleaner production / products at the fish processing stage with *more focus on optimization of the filet yield, energy and indirect environmental impacts* – such as consumption of aluminum and glass packaging.
- The cleaner production effort at the processing stage should be expanded to *include processing of demersal and shellfish*, but the focus should be removed from wastewater emissions towards energy as-

pects, aluminum and glass packaging and better utilization of the fish (increased filet yields).

- The effort to promote *corporate environmental management* (e.g. EMAS or ISO 14001) should be continued and developed to become more product oriented.
- An *eco-labeling scheme* for wild fish should be considered with inspiration from the Swedish initiatives. Alternatively, different kinds of branding and bench marking initiatives could be considered.

As it appears, few instruments address the use stage, even though this stage is one of the most important hot-spots. The reason is that the political instruments already include a number of taxes. A reduction of the consumption of fuel at the use stage would be most effectively promoted by a change in infrastructure that reduces the need for transport. This would require reflections about localization of residence areas, working places and shopping centers etc. but this kind of development cannot be promoted through a focus on fish products alone, but needs to be addressed in urban planning (Næss, 2002). Still, it could be argued that the conclusions which probably also reflect other types of food products, emphasize the importance of areas of urban planning which seek to reduce transport problems.

Is it realistic to promote passive and semi active fishing methods?

It would require a detailed analysis to assess the feasibility of substitution between different fishing methods, but this does not exist. Still, chapter 12 included a tentative analysis of the potentials and barriers for different fishing gears and vessel sizes.

The analysis in chapter 12, suggests that passive and semi active fishing gear typically have a better economic performance in terms of return rate, compared to trawl in the vessel segments representing small and medium sized vessels. For the largest vessel segment semi active fishing gear (purse seine) also have the best economic performance in terms of return rate compared to trawl. However, the analysis suggests that the return rate increases as a function of the vessel size, indicating that large vessels generally are the most profitable concerns. Nevertheless, several factors should be considered.

- The economic figures do not include considerations of economic consequences of the environmental impacts.
- The most fuel consuming fishing methods would most likely become much less profitable if the fuel price increases due to changes in the supply (which is limited) and demand (which increases).

- Effects on employment in the fishery are not included and it is shown that small vessels actually represent a larger employment potential than large vessels.

From a traditional micro-economic standpoint, we should promote larger vessels where active fishing gear typically is applied. Still, it should be considered that the economic performance of different vessel segments depend on the socio-economic context, which could be changed. One way to change this is to put more tax on fuel and less tax on labour and to allocate more quota or sea days to the small and medium sized vessels segments applying passive or semi active fishing gear.

Thus, is it realistic to promote a sounder fishery? Well, as illustrated above, the answer depends on the politicians, the socio-economic context, and the overall goals. It also depends on the consumers. If we take a specific example - comparison of beam trawl and Danish seine - the two fisheries exploit the same resource but at different times of the year. The vessels that apply Danish seine cannot catch the fish in the winter because the fish sticks close to the seabed. Thus, if we transfer capacity from beam trawl to Danish seine the result would most likely be that we would catch more fish in the summer and fewer fish in the winter.

Ideally, consumers should be better at adapting their eating habits to the natural cycle of product availability – at least if we want fresh fish. A parallel problem exists within other types of food production. For vegetables such as tomatoes, the most environmentally sound production takes place during summer while tomatoes during winter are produced in energy demanding green houses (I/S Økoanalyse, 1996).

Final remarks and outlook

As environmental policy becomes more product-oriented, there is an increasing need for seeing environmental impacts from a cradle to grave perspective. Traditional environmental regulation mainly focuses on the companies and their (on site) emissions, but frequently larger environmental impacts are found elsewhere in the life cycle.

The LCA presented in this dissertation provides new insights into the environmental impacts from fish products and gives a new perspective on the environmental regulation. It shows that LCA is a useful instrument for putting the size of environmental impacts through the life cycle of a product into perspective. It is possible to identify hot spots in other places than where traditional regulation has been put into action. The significant environmental

impacts at the fishery and use stages are examples, and it has been documented that significant improvement exist at the fishing stage.

It is most likely that these conclusions apply to most Western countries. In all cases, the conclusions provide reason for reconsiderations of the environmental regulation of the fishery sector in many other countries, as well. In this regard, it would be worthwhile to conduct a similar assessment on a European scale, and initiate a common European approach towards cleaner technology in the fishery. Both on a national and international level it should be relevant to ask: what kind of vessels and fishing practices do we want, and what kind of environmental impacts are we willing to live with in 20 or 30 years time and what should we do to obtain this?

References

- Aasjord, B. 1998. Hva er bærekraftige fiskerier; definisjon og avgrensning [What is sustainable fisheries – definition and delimitations]. In Nordisk Ministerråd (1998b)
- Allermann, K., I. Schneider, E. Walstrøm, B. H. Andersen, T.T. Andersen, H. Højevang, 2004. *Substitution af biocider i bundmaling til skibe med enzymer*. Miljøprojekt 910. Copenhagen: Miljøstyrelsen.
- Alverson, D. L., M.H. Freeberg, J.G. Pope, S.A. Murawski. 1994. *A global Assessment of Fisheries Discard and By-catch*. FAO fisheries technical paper nr. 339, Rome: FAO.
- Anable, J. 2002. *Picnics, Pets and Pleasant Places – The distinguishing Characteristics of Leisure Travel Demand*. In Black and Nijkamp (2002)
- Andersen, P. E. 1998. *Introduktion til Vore levnedsmidler – Animalske næringsmidler*. Århus: Polyteknisk forlag.
- Andersen, M. 2002a. *Perspektiver på en bæredygtig udvikling i fiskeriet. [Perspectives on a sustainable development of the fishery]*. Master thesis, TekSam – Roskilde Universitets Center, Roskilde, Denmark.
- Andersen, O., 2002b. Transport in the fish production chain: An industrial ecology perspective. *Journal of Cleaner Production* 10 (6): 581-588.
- Andersen, E. 2003. Personal communication with E. Andersen, Matcon - COWI, Lyngby, Denmark, Marts 2003.
- Andersen, M. S. 2004a. Personal communication with M. S. Andersen, PhD. student at the Danish Institute of Fishery Research, Lyngby, Denmark, 12. marts 2004.
- Andersen, K. 2004b. Personal communication with K. Andersen, Previously main responsible for a Danish eco-labelling for wild fish initiative established in regi of The Danish Society for a Living Sea (www.levendehav.dk)
- Andersen, M. S., M.G. Johansson, E.H. Nielsen, H. Riisgaard. 1994: *Spredning af renere teknologi i den danske fiskeindustri. [Diffusion of cleaner production in the Danish fish industry]*. Arbejdsrapport fra nr. 41. Copenhagen: Miljøstyrelsen.
- Andersen, E., A.V. Rasmussen, K. Rasmussen, and G. Jakobsen. 1996. *Oversigt over renere teknologi i fiskeindustrien. [Overview of cleaner production in the fish industry]*. Miljøprojekt nr. 317. København. Miljøstyrelsen.
- Andersen, M., and K. Andersen, 1999. *Fiskere om fisk og fiskeri - essensen af 77 samtaler med danske kystfiskere om økologisk fiskeri. [Fishermen about fish and fishery – the essential from 77 interviews about Danish coastal fishing and sustainable fishery]*. Landsforeningen Levende Hav. Grenaa: Grefta Tryk.
- Andersen, D. M., M. Mosgaard, J.M. Larsen, and J. Tröster. 2000. *Livscyklusscreening af frosne blåmuslinger - fra fjord til bord [Life cycle screening of frozen blue mussels – from sea to table]*. 6th semester student project, Department of Development and Planning, Aalborg University, Denmark.
- Anderson, V, and L. Johnson. 1997. *Systems Thinking Basics – From concepts to causal loops*. Massachusetts: Pegasus Communications Inc.
- Anon, 2000. *Livscyklusvurdering af dansk el og kraftvarme. [Life cycle assessment of Danish electricity and district heat systems]*. The LCA have been conducted in co-operation between Elfor, Elkraft System, Energi E2, Elsam og Eltra.

- Arbejdstilsynet, 1999. *Fjerkræslagterier, fiske- og fodder fabrikker. [Poultry slaughter houses, fish- and fodder industries]*. Vejviser nr. 39, København: Arbejdstilsynet.
- Arbejdstilsynet, 2001. *Dataudtræk fra arbejdstilsynets database vedrørende anmeldte arbejdsskader indenfor fiskerisektoren. [Data sample from occupational health and safety database concerning accidents in the fishery sector]*. Conducted by Jens Mondrup. Copenhagen: Arbejdstilsynet.
- Arler, F., 2002b: *Introduktion til humanøkologi [Introduction to human ecology]*. In Arler (2002).
- Bak, F.1994. *Brancheenergianalyse og standardløsninger for fiskeriet [Sector energy analysis and standard solutions for fishery]*. Århus: DTI Energi Motorteknik.
- Ball, B., Munday M., and I. Tuck. 2000. *Effects of otter trawling on the benthos and environment in muddy sediments*. In Kaiser and de Groot (2000)
- Beam trawl, 2001. Personal communication with the owner (Anonymous) of three beam trawlers, with an average tonnage of 178 GT, targeting European Plaice in the North Sea. Data available in app. 5: Interview with fishermen.
- BEK nr. 18, 1993. *Bekendtgørelse om trawl- og andet vodfiskeri. [Statement about trawl - and other dragnet fishery]*. Adopted 14/01/1993. www.retsinfo.dk. Accessed January 2004.
- BEK nr. 996, 2002. *Bekendtgørelse om regulering af fiskeriet i 2002 og visse vilkår for fiskeriet i 2003. [Statement about the regulation of the fishery in 2002 and certain conditions for the fishery in 2003]*. Adopted 07.12.01. Accessed January 2004.
- BEK nr 594, 2002. *Bekendtgørelse om visse listevirksomheders pligt til at udarbejde grønt regnskab. [Statement about certain companies obligation to make green accounts]*. Adopted 05/07/2002. Accessed January 2004.
- BEK nr 652, 2003: *Bekendtgørelse om godkendelse af listevirksomhed - godkendelsesbekendtgørelsen. [Statement about approval of certain companies]*. Adopted 03/07/2003. Accessed January 2004.
- Bertelsen, P., and K. Christensen. 2002. *Anvendelse af naturlige kølemidler i supermarkeder. [Use of natural cooling agents in supermarkets]*. Miljøprojekt nr. 658. Copenhagen: Miljøstyrelsen.
- Bichel udvalget, 1999. *Rapport fra hovedudvalget. [Report from the main committee]*. Udvalget til vurdering af de samlede konsekvenser af en afvikling af pesticidanvendelsen, Copenhagen.
- Binder, J. C., L. M. Nielsen, L. Kromann, S. H. Kragh, P. Christensen. 2003: *Service sektorens miljøbelastninger og forbedringspotentiale. [Environmental impacts and improvement potentials in the service sector]*. Arbejdsrapport nr. 1. Copenhagen: Miljøstyrelsen.
- Black, W. R. and P. Nijkamp. 2002. *Social change and sustainable transport*. Indiana: Indiana University Press.
- Buhl, J. 2003. Personal communication with the manager of Thyborøn harbour, Thyboreen, Denmark, November 2002.
- Busch, N. J. 2003. Calculation of weighting factors. In *LCA Guideline: Update on impact categories, normalisation and weighting in LCA. Selected EDIP97-data*, DRAFT report May 2003, edited by Stranddorf, H.K., L. Hoffmann, and A. Schmidt, Miljøstyrelsen, Copenhagen, Denmark.

- Buwal, 2001. Inventory of packaging materials made by the Swiss Packaging Institute (EMPA) and commissioned by BUWAL (The Swiss ministry of Environment, Forrests and Landscape) and EMPA. The inventory includes emissions from raw material production, energy production, production of semi-manufactures and auxiliary materials, transports and the production process of the materials. The data reflect the Swiss consumption of packaging materials. Energy systems are based on ETH data. Most data are from the mid 1990s, but the database is dated 2001 in the Simapro LCA PC tool.
- Carter, N. 2001. *The politics of the Environment – Ideas, Activism, Policy, Department of politics*. UK: University of York, Cambridge Press.
- Christensen, K. B. 2001. *Fiskefartøjer og deres motorer - redegørelse 2001. [Fishing vessels and their engines – statement 2001]*. www.levendehav.dk/politik/enkeltsager/motorkraft/indeks-motorkraft.htm. Accessed January 2004.
- Christensen, H. S. 2002. *Biodiversity is more than extinction rates*. In Ege and Christiansen (2002)
- Christensen, A., 2003: Personal communication with A. Christensen, Danske Fiskeres Forarbejdningsindustri A/S. [Danish fishermen's processing industry A/S]. August 2003.
- Christensen, P., J. Nordahl Madsen, and M. Thrane. 2001. LCA of Danish Fish products. International Conference on LCA in Foods in Gothenburg. *SIK-Dokument 143*. The Swedish Institute for Food and Biotechnology (SIK)
- Company codfish, 2002. Personal communication with chief of economical affairs (Anonymous), Data and information covers the calendar year 2000, Interview conducted June, 2002.
- Company flatfish, 2001. Documents for resource and water consumption as well as process descriptions for the calendar year 1999, Retrieved October 2001, Denmark.
- Company flatfish, 2002. Personal communication with quality manager (Anonymous) of a large Danish fish company mainly processing flatfish. Data and information cover the calendar year 1999. Interview conducted October 2001, Denmark.
- Company flatfish, 2003a. Personal communication with the production chief (Anonymous) of a large Danish fish company mainly processing flatfish. Data and information cover the calendar year 2000, but has been collected in 2003.
- Company flatfish, 2003b. Personal communication with the Transport manager (Anonymous) of a large Danish fish company mainly processing flatfish. Data and information cover the situation in recent years. Interview has been conducted may 2002.
- Dall, O. 2002. *Danske husholdningers miljøbelastning. [Environmental impacts from Danish households]*. Arbejdsrapport nr. 13. Copenhagen: Miljøstyrelsen.
- Danish Energy Authority, 2002. *Green Taxes in Trade and Industry - Danish Experiences*. www.ens.dk/graphics/publikationer/energibesparelser_uk/EnergyEfficiency/Green_taxes.pdf. Accessed december 2003.
- Danish NAMEA, 1999. National accounting matrices including environmental accounts. www.dst.dk.
- Danish Seine 1, 2001. Personal communication with the owner (Anonymous) of one 40 GT vessel applying Danish Seine, Esbjerg, Denmark, September 2001. Data available in app. 5: Interview with fishermen.

- Danish Seine 2, 2001. Personal communication with the owner (Anonymous) of one 50 GT vessel applying Danish Seine, Hirtshals, September 2001. Data available in app. 5: Interview with fishermen.
- Danish Seine 3, 2001. Personal communication with the owner (Anonymous) of one 49 GT vessel applying Danish Seine and fishing in the North Sea, Hirtshals, September 2001. Data available in app. 5: Interview with fishermen.
- Danmarks Fiskeriforening, 2001. *Snurrevodsfiskeri I Danmark. [Danish seine fishery in Denmark]*. Copenhagen: Danmarks Fiskeriforening.
- Danmarks Fiskeriundersøgelser, 2001. *Oversigt over discard af fisk og skaldyr I danske fiskerier I perioden 1995 til 2000. [Overview of discard of fish and shellfish in Danish fisheries 1995-2000]*. Afdelingen for Havfiskeri. Charlottenlund: Danmarks fiskeriundersøgelser (DFU).
- Danmarks Naturfredningsforening, 2003. *Marsvinet drukner i fiskegarnene. [Sea porpoises drown in the fishing net]*. www.dn.dk/sw1192.asp. Accessed October 2003.
- Danmarks Statistik, 1986. *Statistisk tiårsoversigt 1986. [Statistical 10 year review - 1986]*. Årgang 27. Copenhagen: Danmarks Statistik.
- Danmarks Statistik, 1992. *Statistisk tiårsoversigt 1992. [Statistical 10 year review - 1992]*. Årgang 22. Copenhagen: Danmarks Statistik.
- Danmarks Statistik, 1999. *Statistisk tiårsoversigt 1999. [Statistical 10 year review - 1999]*. Årgang 40. Copenhagen: Danmarks Statistik.
- Danmarks Statistik, 2003: Information available at the homepage of The Danish National Statistics. www.dst.dk. Accessed April 2003.
- Dansk Standard, 1996. *Environmental management systems – Specification with guidance for use*. DS/EN ISO 14001, 1 edition. Copenhagen: Dansk standard.
- Danske Elværkers Forening, 1998. *El-indkøbstips. [Green guide to purchase of electric equipment]*. Århus: Energicentret i Århus - Danske Elværkers Forening.
- Deere, C. 1999. *ECO-labelling and sustainable fisheries*. Washington: The World Conservation Union (IUCN).
- DEFU, 1999. *Køling. [Cooling]*. Håndbog I vejledning indenfor energirådgivning. Copenhagen: Danske Elværkers Forsknings og Udviklings center.
- Degnbol, P., A. Carlberg, H. Ellingsen, M. Tønder, R. Varjopuro and D. C. Wilson. 2003. *Integrating fisheries and environmental policies - Nordic experiences*. The Institute for Fisheries Management and Coastal Community Development (IFM). Hirtshals: TemaNord 2003:51, Nordic Council of Ministers.
- Demersal trawl 1, 2001. Personal communication with the owner (Anonymous) of a 12 GT bottom trawler, Hirtshals, Denmark, September 2001. Data available in app. 5: Interview with fishermen.
- Demersal trawl 2, 2001. Personal communication with the owner (Anonymous) of a 170 GT bottom trawler, Hirtshals, Denmark, September 2001. Data available in app. 5: Interview with fishermen.
- Dieselnet, 2003. Online information service on clean diesel engines and diesel emissions. www.dieselnet.com/standards/eu/ld.html. Accessed august 2003.
- DMU (Danmarks Miljø Undersøgelser), 2001. *Natur og Miljø 2001 – Påvirkninger og tilstand. [Nature and Environment 2001- impacts and state of the environment]*. Faglig rapport DMU nr. 385. Copenhagen: Danmarks Miljøundersøgelser.

- DOR Århus A/S, 2000a. *Miljøvurdering af EPS fiskekasse. [Environmental assessment of EPS fish boxes]*. Plastindustrien i Danmark - Sektionen for EPS producenter, Århus.
- DOR Århus A/S, 2000b. *Miljøvurdering af alternative grønsagskasser. [Environmental assessment of alternative vegetables boxes]*. Plastindustrien i Danmark - Sektionen for EPS producenter, Århus.
- Dorsey, E. M., and J. Pederson. 1998. *Effects of Fishing gear on the Sea Floor of New England*. Boston: Conservation Law Foundation.
- Drivsholm, T., M. H. Petersen, S. Skårup, N. Frees, and S. Olsen. 2002. *Produkters forbrug af transport – systemanalyse. [Products use of transport – system analysis]*. Arbejdsrapport nr. 44. Copenhagen: Miljøstyrelsen.
- Dyck Madsen, S. 2003. *Globale miljøproblemer - kan løses med økonomiske virkemidler. [Globale environmental problems – can be solved by economical measures]*. Copenhagen: Det Økologiske Råd.
- Ege, C. and J. L. Christiansen. 2002. *Sceptical questions and sustainable answers*. Copenhagen: The Danish Ecological Council.
- Ekvall, T., and B. P. Weidema, 2004. System boundaries and Input Data in Consequential Life Cycle Inventory Analysis. *International Journal of LCA*. OnlineFirst.
- Electrolux, 2002. Test of energy consumption for pan frying of breaded flatfish filets. Performed by Electrolux test kitchen. The test involved four fish filets – a total of 250g. Heating was performed on frying pan (Scanpan 21 cm) on heating zone pos. 4 at heat level 12 and 8. Test is available in app. 8.
- Ellingsen, H. 2001. Presentation by H. Ellingsen, Senior researcher at SINTEF – department of fishery technology. Trondheim: SINTEF, November 22nd-23rd.
- Ellingsen, H., and A. T. Pedersen. 2003. *Environmental effects of wild caught cod, farmed salmon and chicken – possible to compare?* In Yngvadóttir (2003).
- Endal, A. 1980. *Fuel Saving Potential in Norwegian Fisheries*. Trondheim: Institute of Fishery Technology Research.
- Energistyrelsen, 2002. *Energistatistik 2001. [Energy Statistics 2001]*. Copenhagen: Energistyrelsen.
- Ehrlich, P.R. and A. H. Ehrlich. 1991. *The Population Explosion*. New York: Simon and Schuster.
- ETH-ESU 96, 1996. Inventory data for Swiss and the Western European energy supply situation. Data include emissions from primary energy extraction and construction of infrastructures and energy conversion and transmission, The report and its database has been compiled, edited and revised by the ESU-group at ETH Zürich and the section of Comprehensive Systems Analysis at the PSI in Villigen.
- European Commission, 2001b. *A Community approach towards eco-labelling of fisheries*. Communication from the Commission to the Council and the European Parliament - DRAFT AT 01-02-2001, Brussels, Belgium.
- European Commission, 2001a: *Green Paper - The future of the common fisheries policy*. Bruxelles: European Commission.
- European Commission, 2003. *Energy taxation: Commission welcomes Council adoption of new EU rules*. Press release IP/03/1456, Brussels, 27th October 2003.
[http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&doc=IP/03/1456|RAPID&lg=EN&display,](http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&doc=IP/03/1456|RAPID&lg=EN&display)

- European Communities, 2002a. *Communication from the commission on the reform of the common fisheries policy – Roadmap*.
http://europa.eu.int/comm/fisheries/reform/roadmap_en.htm. Accessed 12. december 2003.
- European Communities, 2002b. *Communication from the Commission – setting out a Community Action Plan to integrate environmental protection requirements into the Common Fisheries Policy*.
http://europa.eu.int/comm/fisheries/doc_et_publ/factsheets/legal_texts/docscom/en/com_02_186_en.pdf. Accessed 15. december 2003.
- European Environment Agency, 2001. *EMEP/CORINAIR Emission Inventory Guidebook - 3rd edition*. Technical report No 30. (Group 8: Other mobile sources). Copenhagen: European Environment Agency
- European Environment Agency, 2003a. Transport emissions of air pollutants 2002.
http://themes.eea.eu.int/Sectors_and_activities/transport/indicators/consequences/air_pollutants/index.html. Accessed Marts 2004.
- European Environment Agency, 2003b. *Europe's environment: the third assessment Environmental assessment report No 10*. Copenhagen: European Environmental Agency (EEA).
- Eyjólfsson, H. R., E. Yngvadóttir, H. Jónsdóttir, and B. Skúladóttir. 2003. *Environmental effects of fish on the consumer's dish - Life cycle assessment of Icelandic frozen cod products*, Icelandic Fisheries Laboratories (IFL), Reykjavik, Island.
- FAO (Food and Agriculture Organization of the United Nations). 1993. *Marine Fisheries and The Law of The Sea: A decade of change*. Rome: FAO Fisheries Department.
- FAO (Food and Agriculture Organization of the United Nations). 2000. *The state of World Fisheries and Aquaculture 2000*. Rome: FAO Fisheries Department
- FAO (Food and Agriculture Organization of the United Nations). 2001. *Towards Ecosystem Based Fishery Management*. Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem.
- FAO (Food and Agriculture Organization of the United Nations). 2003. Report of the Expert Consultation on Ecosystem-based Fisheries Management. FAO Fisheries Report No. 690. <http://www.fao.org/DOCREP/005/Y4491T/y4491t01.htm>. Accessed May 2004
- FDB, 2001. *FDB's miljørapport 2001. [Environmental statement – FDB 2001]*. Afdeling for Miljø, Etik og Økologi, COOP Danmark.
- FIGIS, 2002. Fisheries Global Information System established by United Nations Food and Agriculture Programme (FAO). www.fao.org/fi/figis/tech/gears_1.jsp. Accessed November 2003.
- Fiskebranchen, 1997. *Fakta om fisk og skaldyr - hæfte nr. 1. [Facts about fish and shellfish – issue nr. 1]*. Århus: Foreningen Fiskebranchen F.M.B.A.
- Fiskebranchen, 1998. *Fakta om fisk og skaldyr 2 – Værd at vide om fisk og skaldyr som fødevarer. [Facts about fish and shellfish 2 – worth to know about fish and shellfish as foodproducts]*. Århus: Foreningen Fiskebranchen F.M.B.A.
- Fiskebranchen, 1999. *Fakta om fisk og skaldyr 4 – fra havn til forbruger. [Facts about fish and shellfish 4 – from harbour to consumer]*. Ministeriet for Fødevarer, Landbrug og Fiskeri og Danmarks Fiskeriundersøgelser. Aarhus: Foreningen Fiskebranchen F.M.B.A.

- Fiskeridirektoratet, 2000. *Fiskeristatistisk årbog 1999*. [Yearbook of fishery statistics 1999]. Copenhagen: Ministeriet for Fødevarer, Landbrug og Fiskeri.
- Fiskeridirektoratet, 2001a. *Fiskeristatistisk årbog 2000*. [Yearbook of fishery statistics 2000]. Copenhagen: Ministeriet for Fødevarer, Landbrug og Fiskeri.
- Fiskeridirektoratet, 2001b. *Skønnede fangstoplysninger for 1999 fordelt på tonnage og redskab* [Estimated catch for 1999 for different categories of Gross Tonnage and fishing gear]. Copenhagen: Fiskeridirektoratet 3. kontor (statistik sektionen)
- Fiskeridirektoratet, 2002a. *Fiskeristatistisk årbog 2001*. [Yearbook of fishery statistics 2001]. Copenhagen: Ministeriet for Fødevarer, Landbrug og Fiskeri.
- Fiskeridirektoratet, 2004a. *Vejledning om Indsatsregulering ved havdage I 2004*. [Guide about effort regulation by seadays in 2004]. Copenhagen: Fiskeridirektoratet.
- Fiskeridirektoratet, 2004b. *Individuelle overdragelige kvoteandele*. [Individual Transferable Quota]. www.fd.dk/info/sjle4/kvoteandele.htm. Accessed February 23th 2004.
- Fiskeritidende, 2002. Fiskeriet må bruge bly alligevel. *Fiskeritidende - week 33 2002*. Copenhagen: Danmarks Fiskeriforening.
- Fish-shop, 2003. Personal communication with the owner (Anonymous) of a large Danish fish shop, October, 2003.
- Fog, K. 2002. *How many species go extinct?*. In Ege and Christiansen (2002).
- Fonds, M. and S. Groenewold. 2000. *Food subsidies generated by the beam-trawl fishery in the southern North Sea*, in Kaiser and de Groot (2000).
- Fonteyne, R. 2000. Physical impact of beam trawls on seabed sediments. In *The effects of fishing on marine ecosystems*, edited by Jennings, S. and M. J. Kaiser. Advances in Marine Biology Vol. 34. Oxford: Blackwell Science Ltd.
- Foreningen af Danske Eksportvognmænd, 1995. *Fakta, sammenhænge og tendenser om miljø og færdselssikkerhed i forbindelse med godstransport*. [Facts, correlations and tendencies for environment and safety in freight transport]. www.transit.dk/sikkerhed/fakta/forside.htm. Accessed august 2003.
- Foreningen For Energi & Miljø, 2002. *Energihåndbogen - råd og vejledning*. [Energy handbook – advice and recommendations]. Copenhagen: Foreningen For Energi & Miljø.
- Foverskov, S. J. Strand, J. A. Jacobsen, B. Riemann, G. Pritzl, P.Ø. Nielsen, and A. Aagaard. 1999. *Bundmaling til skibe - et miljøproblem*. [Antifouling paint for ships – an environmental problem]. Tema rapport fra DMU. Copenhagen: Miljø- og Energiministeriet.
- From, L. 2003: Fed profit på tynde poser. [Large profit on light plastic backs]. *Morgenavisen Jyllandsposten* [Århus], 26 Juni.
- Frost, H., and F. Jensen. 2001. Effort management and economic incentives in view of the Danish management system its implementation and enforcement. Paper Presented at the XIIIth Annual EAFE Conference, 17-20 April, Salerno.
- Fødevareministeriet, 2000. *Fællesskabets strukturforanstaltninger i fiskerisektoren 2000-2006*. [The communities structural measures in the fishery sector 2000-2006]. FIUF sektorprogram. Copenhagen: Fødevareministeriet.
- Fødevareøkonomisk Institut, 2001a: *Fiskeriregnskabsstatistik 1999*. [Account Statistics for fishery 1999]. Serie F nr. 5. Copenhagen: Fødevareøkonomisk Institut.

- Fødevarøkonomisk Institut, 2001b: *Fiskeriregnskabsstatistik 2000 [Account Statistics for fishery 2000]*. Serie F nr. 6. Copenhagen: Fødevarøkonomisk Institut.
- Fødevarøkonomisk Institut, 2002a: *Fiskeriregnskabsstatistik 2001 [Account Statistics for fishery 2001]*. Serie F nr. 7. Copenhagen: Fødevarøkonomisk Institut.
- Fødevarøkonomisk Institut, 2002b: *Detaljerede fangstoplysninger fra forskellige fartøjskategorier i fiskeriregnskabsstatistikken gældende for 2000 [Detailed information on catch composition for the production categories in the account statistics for year 2000]*. This information is not publicly available and Based on data from database. Copenhagen: Fødevarøkonomisk Institut.
- Fødevarøkonomisk Institut, 2003: *Fiskeriregnskabsstatistik 2002. [Account Statistics for fishery 2002]*. Serie F nr. 8. Copenhagen: Fødevarøkonomisk Institut.
- Førby, T. 2004. Personal communication with T. Førby, Chairman in The Danish Fishermens Association (DFA), February 24th 2004.
- Gillnet, 2001. Personal communication with the owner (anonymous) of a 8GT gill net vessel. Hirtshals, Denmark, September 2001.
- Gislason H., and Kirkegaard E. 1998. Is the industrial fishery in the North Sea sustainable? In *Management Issues and Practice*, edited by D. Symes. Oxford: Fishing News Books.
- Goedkoop, M. and R. Spriensma, 2000. *Eco-indicator 99 - A damage oriented method for Life Cycle Assessment*. Amersfoort: Pré Consultants.
- Goedkoop, M. 2003. Personal communication with M. Goedkoop, Manager and owner of Pré Consultants B.V, Amersfoort, the Netherlands, September 2003.
- Gould, J. and T. F. Golob. 2002. *Consumer E-commerce, Virtual Accessibility, and sustainable Transport*, in: Black and Nijkamp (2002)
- Green Network, 2000. *Udarbejdelse af miljøredegørelser. [Preparation of environmental statements]*. Vejle: Green Network.
- Green Network, 2002. *Miljøvenlige storkøkkener. [Eco-friendly catering centers]*. Slutrapport, Green Network, Vejle, Denmark.
- Grunert, K.G., S. Bisp, L. Bredahl, E. Sørensen, N. A. Nielsen. 1995. *En undersøgelse af danskernes køb af fisk og skaldyr. [A study of the purchase of fish- and shellfish among Danish consumers]*. MAPP project paper. Aarhus: Handelshøjskolen.
- Grøn Information, 2001a. *Fakta om omvask. [Facts about dish washing]*. www.miljoeogsundhed.dk/artikel_disc.asp?artikelID=3607. Accessed February 2004.
- Grøn Information, 2001b. *Grønne råd om opvask. [Green advise about dishwashing]*. www.miljoeogsundhed.dk/artikel_disc.asp?artikelID=3606. Accessed February 2004.
- Guinée, J.B. et al. 2001. *Life Cycle Assessment - An operational guide to the ISO standards*, Final report May 2001. Leiden: Centre of Environmental Science - Leiden University (CML).
- Hall, S.J. 1999. *The effects of fishing on marine ecosystems and communities*, The Flinders University of South Australia. London: Blackwell science.
- Hall-Spencer. J.M., and P. G. Moore. 2000. *Impact of scallop dredging on maerl grounds*. In Kaiser and de Groot (2000).
- Hankin, D. 2001. *Iceland – The first hydrogen economy?*. www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/IndustryInformationDisplayArticle/0.1588.365.00.html. Accessed February 2004.

- Hansen, U. J. 1986b. *Fiskeri med Trawl.. [Fishery with trawl]. Hirtshals: Dansk Fiskeriteknologisk Institut og Nordsømuseum.*
- Hansen, U. J. 2002. Personal communication with U. J. Hansen. Seniorscientist at SINTEF department of Fishery Technology. Hirtshals, Denmark, 2002.
- Hansen, T. M. 2003a. Personal communication T. M. Hansen, Danish Technological Institute – Energy, Refrigeration and Heat Pump Technology, Tastrup, Denmark, April, 2003.
- Hansen, K. F., 2003b: Personal communication with K. F. Hansen, Centerchef, Forbrændings- og Motor teknik, Danish Technological Institute, Aarhus, Denmark.
- Hansen, J. H. H., 2004. Personal communication with chefkonsulent Jens Holger Helbo Hansen, Economical analysis sekretariat, The Danish Ministry of Taxation, May the 24th., 2004.
- Hanssen, O. J., A. Olsen, H. Møller and S. Rubach. 2002. *National Indicators for Material Efficiency and Waste Minimisation for the Norwegian Packaging Sector 1996-2001.* Working paper, Østfold Research Foundation, Frederikstad, Norway.
- Hassel, K., A. Farstad, and D. Standal. 2001. *Fiskerinæringens muligheter til å bidra til oppfyllelse av Kyoto-avtalen [The opportunities for the fishery to contribute to the fulfillment of the Kyoto agreement].* Trondheim: Rapport nr. 830011.00.SINTEF Fiskeri og havbruk AS.
- Hauschild, M. 1996. *Baggrund for miljøvurdering af produkter.. [Background for environmental assessment of products].* Lyngby: Institut for Produktudvikling, Danmarks Tekniske Universitet (DTU).
- Hauchild, M., and H. Wenzel. 1998. *Environmental Assessment of Products - Volume 2 - Scientific Background.* London: Chapman & Hall.
- Hauschild, M. and J. Potting. 2003. *Spatial differentiation in life cycle impact assessment – the EDIP2003 methodology.* Lyngby: Institute for Product Development, The Danish Technical University (DTU).
- Helmig, S. 2003. Personal communication with S. Helmig, The Danish Forest and Nature Agency, The Sea and Habitat departement, Copenhagen, Denmark, 15. December 2003.
- Helmig, S. 2004. Personal communication with S. Helmig, The Danish Forest and Nature Agency, The Sea and Habitat departement, Copenhagen, Denmark, 19. May 2004.
- Hertin, J. F. Berkhout, D. Tyteca, and W. Wehrmeyer. 2003. Are 'soft' policy instruments effective? Establishing the link between environmental management systems and the environmental performance of companies. Berlin Conference on the Human Dimension of Global Environmental Change 5 - 6 December 2003, Berlin.
- Hjerne, O. and S. Hansson, 2002. *The role of fish and fisheries in Baltic Sea nutrient dynamics.* Stockholm University, Department of Systems Ecology, Stockholm. Working paper.
- Holm, J., B. Kjærgård, and K. Pedersen. 1997. *Miljøregulering – Tværfaglige studier. [Environmental Regulation – multidisciplinary studies].* Roskilde: Roskilde Universitetsforlag.
- Huse, I., S. Aanonsen, H. Ellingsen, A. Engås, D. Furevik, N. Graham, B. Isaksen, T. Jørgensen, S. Løkkeborg, L. Nøttestad, and A.V.
- Husmer, L., M. L. Jensen, Poulsen, J., U. Hjelmar. 2003. *Miljø og forbrugeradfærd. [The environment and consumers attitudes].* Miljøprojekt nr. 870. Copenhagen: Miljøstyrelsen

- Højmann, J. O. 1997. *Fiskeriet ved en grænse. [The fishery at the edge]*. Oplæg til Teknologirådets konsensuskonference om fremtidens fiskeri i november 1996, København.
- ICES (International Council for Exploration of the Sea), 1999. *Report of the Working group on Ecosystem effects of fishing activities*. Copenhagen: ICES.
- IFM (Institute for Fisheries Management & Coastal Community Development), 2003. *Danske fiskeres holdninger til udnyttelse af havets ressourcer – herunder begreber som bæredygtighed. [Danish fishermen's attitudes towards exploitation of the marine resources – and concepts such as sustainability]*. Hirtshals: IFM.
- I/S Økoanalyse, 1996. *Miljøbelastningen ved familiens aktiviteter. [Environmental burdens related to activities in the family]*. Copenhagen: Forbrugerstyrelsen og Miljøstyrelsen.
- Institute of European Environmental Policy, 2002: *CFP reform 2002. Analysis of EU Fisheries Policy Reform proposals and communications*, Briefing No. 3. London: Institute of European Environmental Policy (IEEP).
- International Institute for Sustainable Development, 2001. Summary of the Reykjavik Conference on responsible fisheries in the marine eco-system. *The International Institute for Sustainable Development Vol 61, Number 1*.
- IRU & BGL, 2002. *Comparative Analysis of Energy Consumption and CO2 Emissions of Road Transport and Combined Transport Road/Rail*. Bundesverband Güterkraftverkehr Logistik und Entsorgung (BGL) e.V. and the International Road Transport Union (IRU).
- Jacobsen, C. 2003. Nordsøen er en losseplads og det ødelægger fiskeriet. [The North Sea is a dumpsite and it destroys the fishery]. *Nordfiskeri*. Nordisk arbejdsgruppe for fiskeriforskning (NAF)
- Jennings, S. et al. 1999. Fishing effects in northeast shelf seas: patterns in fishing effort, diversity and community structure. III. International trawling effort in the North Sea: an analysis of spatial and temporal trends. *ELSEVIER Fisheries Research 40 (1999): 125-134*.
- Jennings, S., M. J. Kaiser, and J. D. Reynolds. 2001. *Marine Fisheries Ecology, Centre for Environment, Fisheries and Aquaculture*. Lowestoft Laboratory. Oxford: Blackwell Science.
- Jensen, R. 1999. *The dream society*. Institut for Fremtidforskning. Viby: JP Bøger/Jyllands-Postens Erhvervsklub.
- Jensen, M. 2004. Personal communication with M. Jensen, Leading inspector at the O-section at the Fisheries Directorate, Copenhagen, Denmark, 22. January 2004.
- Jeremy, S. C., S. J. Hall, M. J. Kaiser, and I. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos, Meta analysis of 39 published fishing impact studies. *Journal of Animal Ecology 69 (5): 785-798*.
- Jerlang, J., K. Christiansen, B. Weidema, A. Astrup Jensen, and M. Hauschild. 2001. *Livscyklusvurderinger - en kommenteret oversættelse af ISO 14040-43. [Life Cycle Assessment an annotated translation of ISO 14040-43]*. Copenhagen: DS-Håndbog 126:2001, Danish Standards Association.
- Jespersen, E. 2001. Personal communication with E. Jespersen, Previous chairman for Hirtshals Fishery Association, Hirtshals, Denmark, week 38 2001.

- Jespersen, C., K. Christiansen, B. Hummelose. 1999. *Cleaner Production Assessment in Fish Processing*, Prepared by COWI Consulting Engineers and Planners AS. Paris: United Nations Environment Programme & Danish Environmental Protection Agency.
- Jungbluth, N. 2001. *Case Studies - Research groups and results of LCA's for Food Products*. Zürich: Swiss Federal Institute of Technology (ETH).
- Jørgensen, T. H. 2001. *Miljøledelse – systemer, standarder og praksis [Environmental Management – Systems, Standards and Practice]*. Ph. D dissertation, Skriftserie 277. Department of Development and Planning, Aalborg University, Denmark.
- Jørgensen, H. T. and M. Thrane. 2002. Life Cycle Based Environmental Approach in the Industry. Paper presented at the 2002 Corporate Social Responsibility and Environmental Management Conference, Leeds, UK.
- Kaenzig, J. 2003. *Input - Output Life Cycle Assessment of air transportation*. Master Thesis. Environmental Science and Engineering, Swiss Institute of Technology, Lausanne
- Kaiser, M.J. and S. J. de Groot. 2000. *Effects of fishing on non-target species and habitats*. United Kingdom: Blackwell Science.
- Klüwer, J. 2004. Personal communication with J. Klüwer (Manager), Bilka A/S. Tilst, Denmark, 26. January 2004.
- KRAV, 2003. *Standards for eco-labelling of fish and fishing – second draft for consideration*. www.krav.se/arkiv/internationellt/draft2-0.pdf. Accessed January 2004.
- Kristensen, P. 2003. Personal communication with P. Kristensen, shipinspector at the Danish Maritime Authority, Copenhagen, Denmark, December 2003.
- Krog, C. 2001. Personal communication with C. Krog, responsible for environmental aspects at the Danish Fishermens Association, Århus, Denmark, 2001.
- Kromann, L. 1996. *Livscyklusbaseret miljøvurdering af anvendelser af sildeafskær fra fiskeindustrien. [Lifecycle based environmental assessment of herring offal from the fish industry]*. Ph. D dissertation, Aalborg University, Aalborg, Denmark.
- Kuula, D., and L. From, 2004. 36.000 tons spisefisk smides ud hvert år, *Morgenavisen Jyllands-Posten* [Århus], Marts, 7.
- Københavns, E. 2002. *Opskrifter og energiforbrug. [recipies and energy consumption]*. Copenhagen: Københavns Energi.
- Larsen, H. J. 2004. Personal communication with H. J. Larsen from the Danish tax authority, Copenhagen, Denmark, January 2004.
- Lassen, J. 1996. *Forbrugerindflydelse i levnedsmiddelsektoren. [Consumer influence in the foodsector]*. Ph.D. dissertation, Roskilde Universitetscenter, Institut for miljø, teknologi og samfund, Denmark.
- Lassen, J. 2000. *Fiskeri, Natur og Miljø. [Fishery, Nature, and Environment]*. In *Dansk Naturpolitik - Viden og vurderinger*. Copenhagen: Naturrådet.
- Lassen, J. 2002. *Politisk forbrug: Miljøet mellem borger og forbruger. [Political consumption – the environment inbetween the citizens and the consumers]*. In Arler (2002a).
- Lassen, C., S. Vaaben, and E. Hansen, 1997. *Massestrømsanalyse for tin med særligt fokus på organotinforbindelser. [Substans flow analysis for tin with focus on organotincompounds]*. Arbejdsrapport nr. 7. Copenhagen: Miljøstyrelsen.

- Lassen, C., S. Skårup, S. H. Mikkelsen, J. Kjølholt., P. J. Nielsen, and L. Samsøe-Petersen. 2001: *Inventory of Biocides used in Denmark*. Environmental Project nr. 585. Copenhagen: The Danish Environmental Protection Agency.
- Lassen, L., C. L. Christensen, and S. Skårup. 2003: *Massestrømsanalyse for bly 2000*. [Substance flow analysis for lead]. Miljøprojekt nr. 789. Copenhagen: Miljøstyrelsen.
- Lauersen, T. 1999. Presentation by T. Lauersen, Fresh food manager at the Danish retail company FDB (COOP Denmark). Seminar about consumer oriented food production, Arranged by the Danish Engineer Society, Copenhagen.
- LBK 643, 1998. *Bekendtgørelse af lov om kuldioxidafgift af visse energiprodukter*. [Statement concerning law about CO₂ tax for certain energy products]. Adopted 27/08/1998. www.retsinfo.dk. Accessed december 2003.
- LBK 688, 1998. *Bekendtgørelse af lov om afgift af svovl*. [Statement concerning law about tax on sulfur]. Adopted 17/09/1998. www.retsinfo.dk. Accessed december 2003.
- LBK 701, 1998. *Bekendtgørelse af lov om energiafgift af mineralolieprodukter mv* [Statement concerning law about energy tax for mineral oil products etc.]. Adopted 28/09/1998. www.retsinfo.dk. Accessed december 2003.
- LCAfood, 2003. Data for basic food products produced and consumed in Denmark. Data have been established by the consequential LCA approach and are further described on www.lcafood.dk. The database has been developed by Nielsen, P.H., A. M. Nielsen, B. P. Weidema, R. Dalgaard, and N. Halberg.
- Lindeboom, H.J., and S.J. de Groot. 1999. *The effects of different types of fisheries on the North Sea and the Irish Sea bentic eco-systems – IMPACT II*. RIVO-DLO report, C0003/98. Den Burg: Netherlands Institute for Sea Research.
- Lomborg, B. 2001. *The Sceptical environmentalist – measuring the Real State of the World*. UK: Cambridge University Press.
- Longline, 2001. Personal communication with the owner (anonymous) of one 53 GT vessel applying longline. Data available in app. 5: Interview with fishermen.
- Lorentzen, A. 1988. *Technological Capacity*. Aalborg: Technology and Society Series no. 5, Aalborg University.
- Lutz W., W. Sanderson, and S. Scherbov. 2001: The end of the world population growth, *Nature* 412 (6846): pp 463-568
- Løkkegaard, J., J. Andersen, H. Frost, M. Jørgensen og E. Lindebo. 2001. *Udredning vedrørende anvendelse af individuelle omsættelige kvoter (IOK) i det danske fiskeri* [Elucidation of the use of Individual Transferable Quota (ITQ) in the Danish Fishery]. Rapport nr. 120. Copenhagen: Statens Jordbrugs- og fiskerøkonomiske Institut.
- MacKenzie, B. 2004. Kommercielt fiskeri kan fjerne farlig PCB fra Østersøen [Commercial fishery can remove PCB from the Baltics]. *Fødevareministeriets eksterne ugebrev, nr. 11, 10. marts 2004*.
- Madsen, J. N. 2001. *Livscyklusscreening af makrel*. [Lifecycle screening of canned mackerel]. Master theses, Department of Development and Planning, Aalborg University, Denmark.
- Matcon A/S and Dansk Energi Analyse A/S, 1995. *Brancheenergianalyse for fiskeindustrien*. [Sector energy analysis of the fish industry]. Copenhagen: Energistyrelsen.
- Matthiesen, J. 2003. Personal communication with J. Matthiesen, Manager of Quality, Hygiene and Environment, Neoplex A/S, Nyborg, Denmark, August 2003.

- Mattsson, B., and F. Ziegler, F. 2004. *Environmental Assessment of Sea Food products through LCA*. Final report of a Nordic Network project. Gothenburg: The Swedish Institute for Food and Biotechnology (SIK). In Press.
- Mikkelsen, B. 2001. Personal communication with B. Mikkelsen, Karlsson Skibs- og Stålservice Aps. Hirtshals, Denmark, Oktober 2001.
- Miljø- og Energiministeriet, 1999: *Natur- og Miljøpolitisk redegørelse 1999. [Statement about Nature- and Environmental politics 1999]*. Copenhagen: Miljø- og Energiministeriet.
- Miljø- og Planlægningsudvalget, 2000. *Miljø- og energiministerens besvarelse af spørgsmål nr. S 552 stillet af Henriette Kjær, KF.*
www.folketinget.dk/Samling/20001/udvtilag/MPU/Almdel_bilag320.htm. Accessed February 2004.
- Miljøstyrelsen, 1998a. *Redegørelse om den produktorienterede miljøindsats. [Statement about the Danish product oriented environmental effort]*. Copenhagen: Miljø- og Energiministeriet.
- Miljøstyrelsen, 1998b: *Organiske restprodukter i industrien. [Organic rest products from the industry]*. Copenhagen: Miljøprojekt nr. 397, Miljøstyrelsen.
- Miljøstyrelsen, 2002a. *Udkast til ændring af bekendtgørelse om bundmaling*, Kontoret for Biocid- og Kemikalievurdering, J.nr.M 7014-0053, Ref.: HPE/13. December 10th 2002.
- Miljøstyrelsen, 2002b. Status for arbejdet med forenkling og effektivisering af miljømyndighedernes regulering af industrivirksomheder. [Status for simplification and streamlining of regulation of industries]. Copenhagen: Miljøstyrelsen.*
- Miljøstyrelsen, 2003. *Indikatorrapport - Danmarks nationale strategi for bæredygtig udvikling [Indicator report – The Danish national strategy for a sustainable development]*. København: Miljøministeriet.
- Miljøstyrelsen, 2004. *Brancheorientering for Fiskeindustrien [Branchorientation for the fish industry]*. Copenhagen: Miljøstyrelsen. In review.
- Miljøstyrelsen og Skov & Naturstyrelsen, 2003. *Punktkilder 2002. [Point sources]*. Orientering fra Miljøstyrelsen Nr. 10 2003. Fagdatacenterrapport. Copenhagen: Miljøstyrelsen.
- Ministeriet for Fødevarer - Landbrug og Fiskeri, 1998. *Rapport fra reguleringsgruppen. [Report from the regulation group]*. Rapport fra arbejdsgruppe vedrørende beskrivelse og vurdering af nationale fiskerireguleringer (inkl. Bilag 1 og 2), København.
- Ministry of Food, Agriculture and Fisheries, 2001: *Facts on the Industrial Fisheries*. Copenhagen: Ministry of Food, Agriculture and Fisheries, Denmark
- Moe, M. 1995. *Environmental administration in Denmark*. Copenhagen: Danish Environmental Protection Agency.
- Muus, B. J., and J. G. Nielsen. 1998. *Havfisk og fiskeri i Nordvesteuropa. [Saltwater fishery in North West Europe]*. Copenhagen: Gads Forlag.
- Mussel fishery 1, 2001. Personal communication with the owner (anonymous) of one 15 GT vessel fishing in Limfjorden. Siltherslev, 5. October 2001. Data available in app. 5: Interview with fishermen.
- Mussel fishery 2, 2001. Personal communication with the owner (anonymous) of one 8 GT vessel fishing in Limfjorden. Jegenø, August 2001. Data available in app. 5: Interview with fishermen.

- Møller, T. 2003. Personal communication with T. Møller. Purchase coordinator at Nowaco A/S, Aalborg, Denmark, October 2003.
- Nielsen, E. H. 2000. *Nøgletalsanalyse af fiskeindustrien. [Benchmark analysis of the fish industry]*. Institut for Samfundsudvikling og Planlægning, Aalborg Universitet, Denmark. Not public available.
- Nielsen, J.R. 2000. *Danish Fisheries Management Policy*. Working paper. The ELSA-Peche project meeting in Brest, France.
- Nielsen, T. et al., 2001. *Markedsundersøgelse for afsætning af fisk fra natuskånsomt fiskeri i Danmark. [Market analysis concerning the demand for fish from environmentally sound fisheries in Denmark]*. Aarhus: Daycatch A/S og MAPP ved Handelshøjskolen i Århus. Not publicly available.
- Nielsen, E. W. 2002a. Personal communication with Environmental manager E. W. Nielsen, Esbjerg Fiskeindustri 999, Esbjerg, Denmark, 2002.
- Nielsen, R. 2002b. *Tal for gennemsnitligt brændstofforbrug fra forskellige fartøjskategorier og målarter gældende - år 2000 [Average fuel consumption for different production categories and target species - year 2000]*. Copenhagen: Fødevareøkonomisk Institut.
- Nielsen, R. 2003a. Personal communication with R. Nielsen, Danish Research Institute of Food Economics, Statistical Division, Copenhagen, 2003.
- Nielsen, N. A. 2003b. Niels Axel Niensens svar på Landsforeningen Levende Havs kritik af hans udtalelser om industrifiskeriet. www.dfu.min.dk/dk/aktuelt_fr.htm. Accessed February 2004.
- Nielsen, M. 2003c. Personal communication with Manager M. Nielsen, Fiskeriets Arbejds miljøråd [the fisheries H&S advisory Council], Esbjerg, Denmark, 19. December 2003.
- Nielsen, E, S. Møllergaard, and T.K. Hasselager. 1997. *Bomtrawlfiskeriets indflydelse på fisk og bunddyr (benthos). [Beam trawl influence on fish and benthos]*. DFU rapport nr 43-97. Copenhagen: Danmarks Fiskeriundersøgelser (DFU).
- Nielsen, E. and S. Møllergaard. 1999. *Bomtrawlfiskeriets indflydelse på fisk og bunddyr II. [The impacts on fish and seabed from bottom trawl]*. DFU rapport nr. 73-99. Charlottenlund: Danmarks Fiskeriundersøgelser (DFU).
- Nielsen, O. R., F. Palmgren, S. S. Jensen, P. Wåhlin, R. Berkowicz, O. Hertel, M. Vrang, and S. H. Loft. 2002c: *Helbredseffekter af partikulær luftforurening i Danmark - et forsøg på kvantificering, Ugeskrift for læger, 13.12.2002.*
- Nielsen, J. R., and C. Mathiesen. 2001. *Fiskernes holdning til og accept af fiskeriregulering. [The fishermen's attitudes to and accept of the fishery regulation]*. DFU-Rapport nr. 89-01. Hirtshals: Institut for Fiskeriforvaltning og Kystsamfundsudvikling (IFM)
- Nielsen, E., and A. Remmen, 2002. *Renere teknologi som miljøstrategi og virkemiddel. [Cleaner technology as environmental strategy and instrument]*. In Arler (2002).
- NIRAS A/S, 2000. *Livscyklus screening af renseteknologier indenfor fiskeindustrien. [Lifecycle screenings of filter technologies in the fish industry]*. Arbejdsrapport nr. 18. Copenhagen: Miljøstyrelsen.
- Nordea, 2003. Homepage of Nordea. www.Nordea.dk. Accessed April 2003.
- Nordic Council of Ministers, 2000a: *The Status of Fisheries and Related Environment of Northern Seas*. Prepared by ICES. Copenhagen: Nord 2000:10.

- Nordic Council of Ministers, 2000b: *An Arrangement for the Voluntary Certification of Products of Sustainable Fishing – final report*. Copenhagen: Nordic Technical Working Group on Fisheries Ecolabelling Criteria.
- Nordiske Jordbrugsforskeres Forening, 1985. *Nordisk Fodermedelstabel for Pälssdjur. [Nordic fodder product table for furred animals]*. Tabel for kemisk sammensætning og næringsindhold i fodermidler til mink. Nordiske Jordbrugsforskeres Forening - Sektion for pälssdyr.
- Nordisk Ministerråd, 1998a. *Fiskeriets nye markedsvirkelighed – nye udfordringer for det nordiske fiskeri. [The new market reality for fisheries – new challenges for the Nordic fisheries]*. Copenhagen: Mandag Morgen MicroNews.
- Nordisk Ministerråd, 1998b. *Fisk for framtida; hvordan sikre bærekraftige fiskerier. [Fish for the future – how to obtain sustainable fisheries]*. Consensus conferences. Copenhagen: TemaNord 1998:536.
- Norris, G. 2002. *LCA Application - Expanding Horizons Expanding Horizons*. Brisbane: 3rd Australian LCA Conference Australian LCA Conference. Life Cycle Decision Making for Sustainable Development Life Cycle Decision Making for Sustainable Development.
- Norris, G. 2004. Addressing the Health Impacts of Economic Development In Product Life Cycle Assessment. *Journal of Industrial Ecology*. In review.
- NOVA, 2003. *Ferskvandets Kredsløb. [The freshwater cycle]*. NOVA 2003 Temarapport. Copenhagen: GEUS.
- Næss, P. 2002. *Byplanlægning og energiforbrug. [Urban planning and energy consumption]*. In Arler (2002)
- Ohm, A., S. P. Lund, P. B. Poulsen, and S. Jakobsen. 2003. *Strategi for begrænsning af vejtrafikstøj. [Strategy for reduction of traffic noise]*. Arbejdsrapport nr. 53. Copenhagen: Miljøstyrelsen.
- Olsen, S.I. 2003. Personal communication with S. I. Olsen, Associate Professor, Danish Technological Institute, Institute for Production and Management, Lyngby, Denmark, August, 2003.
- Orremo, F., and C. Wallin. 1999. *IT, mat miljön- En miljökonsekvensanalys av elektronisk handel med dagligvarer. [IT, food and environment – a study of the consequences of E-trade with groceries]*. Lund: Institutionen för Designvetenskaper Förpackningslogistik, Lunds Tekniska Högskola.
- OSPAR, 2000. *OSPAR Quality Status Report 2000*. London: OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic.
- Pedersen, L. F and V. L. Larsen. 2003. *Status for økologisk akvakultur - mens vi venter på den danske bekendtgørelse. [Status for organic fish farming – while we are waiting for the Danish statement]*. www.eco-aquafish.dk/showpage.asp?ID=22. Accessed 22. December 2003.
- Pelagic trawl, 2001: Personal communication with the manager (Anonymous) of 5 pair-trawl vessels working together in a pool fishery in the North Sea and Skagerak, Esbjerg, Denmark, August, 2002. Data available in app. 5: Interview with fishermen.
- Pesonen, H. L., T. Ekvall, G. Fleisher, G. Huppel, C. Jahn, Z. S. Klos, G. Rebitzer, G. W. Sonnemann, A. Tintinelli, B.P. Weidema, H. Wenzel. 2000: Framework for Scenario Development in LCA. *International Journal of Life Cycle Assessment* 5(1):21-30.

- Pedersen, P. H. 2001. *Vurdering af mulighederne for at erstatte kraftige drivhusgasser. [Assessment of the possibilities for substituting strong greenhousegases]*. Taastrup: Teknologisk Institut – Energi.
- Pengue, W. A. 2003. *Soybean production in Argentina and South America*, Universidad de Buenos Aires, Landscape Ecology Group and Environemnt, Presentation at the International Conference on "Life Cycle Assessment in the Agri-food Sector", October 6-8, 2003, Horsens (Denmark).
- Petersen, S. M. 2001. *Fiskebestande og fiskeri 2002. [Fish stocks and fishery 2002]*. DFU rapport nr. 95-01. Charlottenlund: Danmarks Fiskeriundersøgelser (DFU).
- Petersen, S. M. 2002. *Fiskebestande og fiskeri 2003. [Fish stocks and fishery 2003]* DFU rapport nr. 115-02. Charlottenlund: Danmarks Fiskeriundersøgelser (DFU).
- Pihl, T. K. og G., Christensen. 1998. *Fiskerisektoren i Nordjylland og Hanstholm - Analyse af nuværende situation. [The fishery sector in Northern Jutland – analysis of the present situation]*. Hirtshals: Dansk Institut for Fiskeriteknologi og Akvakultur (DIFTA).
- PLS Consult, 1999. *Evaluering af Foreningen Fiskebranchens markedsføringskampagne. [Evaluation of "Foreningen Fiskebranchens" marketing campaign]*. København: Strukturdirektoratet.
- Pommer, K. 2000. *Miljøaspekter for rengøringsmidler*. Working paper, Teknologisk Institut, Miljø- og affaldsteknik, Taastrup, Denmark.
- Pommer, K., P. Bech, H. Wenzel, N. Caspersen, and S. I. Olsen. 2002. *Handbook in environmental assessment of products*. Environmental project nr. 813. Copenhagen: Danish Environmental Protection Agency.
- Porsbjerg, M. 2002. Personal communication with M. Porsbjerg, Environmental manager at Hempel's Marine Paints A/S J.C. Hempel's Skibsfarvefabrik A/S, Copenhagen, Denmark, May 2002.
- Purse seine, 2001. Personal communication with the owner (anonymous) of 3 modern purse seiners fishing in North sea and the Norwegian Sea, Hirtshals, Denmark, October 2001. Data available in app. 5: Interview with fishermen.
- Ranke, J. and B. Jastorff, 2000. Multidimensional Risk Analysis of Antifouling Biocides. *Environmental Science and Pollution Research* 7(2): 105 –114.
- Regeringen, 2003. *Grøn markedsøkonomi – mere miljø for pengene. [A green market economy – more environment for the money]*. Copenhagen: Miljøministeriet.
- Remmen, A. 2001. Greening of Danish Industry - changes in Concepts and Policies, *Technology Analysis & Strategic Management* 13 (1).
- Rendel, K. 2003. Personal communication with K. Rendel, Environmental Manager at Lynetten I/S. [waste water treatment plant]. Copenhagen, Denmark, October 2003.
- Ritter, E. 1997. *Livscyklus-screening for marineret sild i glas. [Lifecycle screening of pickled herring]*. Hirtshals: DTI Miljø og DIFTA.
- Rohmhaas, 2002. Environmental Impact Study: Sea-Nine 211 Antifouling agent. www.rohmhaas.com/seanine/hull/impact/index.html. Accessed Marts 2004.
- Rose, J.D. 2002. The neurobehavioral nature of fishes and the question of awareness and pain. *Reviews in Fisheries Science* 10(1), 1-38.
- SAS, 2003. *Tillæg til Miljøregnskab 2000. [Addendum to environmental account for year 2000]*. www.scandinavian.net/aci420/SAST00DK.pdf. Accessed August 2003.

- Schmidt, H. C. 2004. *Forslag til lov om miljøvurdering af planer og programmer. [Proposal to law about environmental assessment of plans and programs]*. L 147 (som fremsat), Copenhagen, Denmark.
- Senge, P. 1994. *The fifth discipline - The art and practice of The Learning Organization*. New York: Doubleday.
- SimaPro 5.1, 2003. *LCA software tool and database version 5.1*, Pré Consultants, Amersfort, Netherlands.
- Skov- og Naturstyrelsen, 2000. *Natur og Miljø 2000 – udvalgte indikatorer. [Nature and the environment 2000 – key indicators]*. Copenhagen: Miljø og Energiministeret.
- Skov- og Naturstyrelsen, 2004. *Vejrudsigten kan vende op og ned på dansk nature. [The weather forecast can change the Danish nature]*. Nyhedsbrevet "Skov og Natur" nr. 1, January 15th 2004. Miljøministeriet, Copenhagen.
- Skovmark, B. 2003. Personal communication with Bo Skovmark at the Northern Jutland county, Departement of Water Environment, Aalborg, Denmark, October 2003.
- Slipway, 2001. Personal communication with the owner a small slipway for woodships (anonymous), Hirtshals, Denmark, october 2001.
- Soldal. 2002. *A desk study of diverse methods of fishing when considered in perspective of responsible fishing, and the effect on the ecosystem caused by fishing activity*. TemaNord 2003:501. Bergen: Institute of Marine Research.
- Stamminger, R. 2002. *A European Comparison of cleaning dishes by hand*. University of Bonn, Section of Household and Appliance Technology, Institut für Landtechnik, Bonn, Germany.
- Strand, J., and J. A. Jacobsen. 2000. *Forekomst af organiske tinforbindelser i planter og dyr fra danske farvande. [Appearance of organic tin-compounds in plants and animals in Danish waters]*. Arbejdsrapport fra DMU nr. 135. Copenhagen. Danmarks Miljøundersøgelser.
- Stranddorf, H. K., L. Hoffmann, and A. Schmidt. 2001. *Normalisation and weighting – update of selected impact categories*. Copenhagen: Dk-teknik Energy & Environment. Draft.
- Strukturdirektoratet, 1999. *Rapport vedrørende udvikling af en mærkningsmodel for økologisk akvakulturproduktion. [Report about the development of a eco-labeling model for organic fish farming]*. Copenhagen: Ministeriet for Fødevarer, Landbrug og Fiskeri.
- Supermarket, 2002. Personal communication with employee in the purchasing department, Supermarket A (Anonymous: One of Denmark's largest supermarket chains), Århus, Marts 2002
- Supermarket, 2003a. Personal communication with manager of the meat departement in a small retail store, Århus, August 2003.
- Supermarket, 2003b. Personal communication with employee in the meat departement medium sized retail store, Århus, August 2003.
- Swedish National Chemicals Inspectorate, 2002. *Bekämpningsmedel and biocidprodukter*. www.kemi.se. Accessed November 2002.
- Søfartsstyrelsen, 2000. *Ulykker til søs 2000 – Statistik over ulykker og arbejdsskader til søs, Erhvervsministeriet. [Accidents at sea 2000 – statistics for acidents at Sea]*. København Ø: Søfartsstyrelsen.

- Søfartsstyrelsen, 2001. *Handlingsplan 2005 – Sikkerhed og sundhed til søs [Actionplan 2005 – Safety and Health at Sea]*. Copenhagen: Erhvervsministeriet.
- Søndergaard, H. A., K. G. Grunert, and S. O. Olsen. 1998. *Forbrugerholdninger til bæredygtigt fiskeri og økologiske fisk. [Consumer attitudes towards a sustainable fishery and organic fish products]*. Prepared for the Nordic Council of Ministers. Århus: The MAPP Center, Århus Business School.
- Taabel, 1997. *EMAS miljøredegørelse 1997. [EMAS environemntal statement]*. Erik Taabel Fiskeeksport A/S, Skagen, Denmark.
- Tarvainen, F. 2004. Personal communication with F. Tarvainen, Ekspeditionssekretær, Direktoratet for fødevarerhverv, Copenhagen, Denmark, 10. February 2004.
- Teknologisk Institut and IFM, 2003. *Evaluering af FIUF programmet. [Evaluation of the FIUF programme]*. Copenhagen: Teknologisk Institut and Institut for Fiskeriforvaltning og Kystsamfundsudvikling.
- TEMA, 2000. *Sammenligning med tidligere versioner og andre opgørelser. [Comparison with earlier version and other inventories]*. Bilagsrapport 1. Lyngby: Udarbejdet af COWI for trafikministeret.
- TemaNord, 2000. *Alternatives to HCFC as refrigerant in shipping vessels*. TemaNord 2000:573.
- The Danish Government, 2002. *A shared future - balanced development - Denmark's National Strategy for Sustainable Development*. Copenhagen: The Danish Environmental Protection Agency.
- Therkelsen, N. P. 2003. Personal communication with N. P. Therkelsen, Peter Hansen Transport A/S, Padborg, Denmark, January 2003.
- Thrane, M. 2000a. *Fiskerisektoren - sektorbeskrivelse, miljørelationer og regulering. [The Fishery sector – sector descriptions, environmental relations and regulation]*. Aalborg: Department of Development and Planning.
- Thrane, M. 2000b. *Innovation, Miljø og Kvalitet i Fiskeindustrien. [Innovation, Environment and Quality in the fish industry]*. Aalborg: Department of Development and Planning.
- Thrane, M. 2000c. *Den økologiske landbrugssektor - sektorbeskrivelse, miljørelationer og regulering. [The organic agriculture sector – sector description, environmental aspects and regulation]*. Aalborg: Department of Development and Planning.
- Thrane, M. 2001. Life Cycle Assessment as basis for eco-labelling of fish products. Proceedings. International Conference on LCA in Foods in Gothenburg. *SIK-Dokument 143*.
- Tyedmers, P.H. 2000a. *Average filet yield and protein content of seafood*, analysis of average filet yield, meat and protein content of more than 100 species, Working paper based on 14 references related to the dissertation Tyedmers (2000b). Not public available.
- Tyedmers, P. H. 2000b. *Salmon and Sustainability - The Biophysical Cost of Producing Salmon Through the Commercial Salmon Fishery and the Intensive Salmon Culture Industry*, Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, The University of British Columbia, Vancouver.
- Tyedmers, P.H. 2001. Energy Consumed by North Atlantic Fisheries. In *Fisheries Impacts on North Atlantic Ecosystems: Catch, effort and national/regional datasets*, edited by Zeller, D., R. Watson, and D. Pauly, Fisheries Center, Research reports, Volume 9

- number 3, Canada: University of British Columbia. Available at:
http://saup.fisheries.ubc.ca/report/datasets/Energy_Tyedmers1.pdf
- Tyedmers, P.H. 2002. Data provided by Peter Tyedmers but originally comprised of different Dutch references. It has not been possible to verify the data. Peter Tyedmers is Assistant Professor at the School for Resource and Environmental Studies, Dalhousie University, Canada.
- Udo de Haes, H.A., G. Finnveden, M. Goedkoop, M. Hauschild, E. Hertwich, P. Hofstetter, O. Jolliet, W. Klöpffer, W. Krewitt, E. Lindeijer, R. Mueller-Wenk, I. Mueller-Wenk, D. Pennington, J. Potting, and B. Steen. 2002. *Life-Cycle Impact Assessment – Striving towards best practice*. US: SETAC Press.
- UNEP, 2002. *Global Environmental Outlook 3*. London: United Nations Environment Programme, Earthscan publications Ltd.
- Ussing, B., C. Schmidt, and J. Kjeldgaard, 2001. *Brændt spinat. [Burned spinach]*. Forbruger magasinet Tænk og Test – 7. August 2001, Forbrugerinformationen, Forbrugerrådet, København. www.taenk.dk/tt/2001/tt16/opvask/artikel/
- Vedsmænd, T. 1998. *Fiskeriets regulering og erhvervsudvikling - i et institutionelt perspektiv [Regulation and corporate development of the fishery – in a institutional perspective]*. Ph.D. dissertation, Bornholms Udviklingscenter og Roskilde Universitetscenter, Institut for Geografi og Internationale udviklingsstudier, Denmark.
- Veterinær og Fødevarerdirektoratet, 2000. *Anbefalinger for den danske institutionskost. [Recommendations for diet in Danish public institutions]*. Copenhagen: Ministeriet for Fødevarer, Landbrug og Fiskeri.
- Viamichelin, 2003. *Routes in Europe*. www.viamichelin.com. Accessed April 2003.
- Vidal, J. 2003. Disappearance of Amazon rainforest brings pledge of emergency action. *Guardian* [UK], 28. June, 2003. <http://forests.org/articles/reader.asp?linkid=23918>
- Weidema, B. P. 1998. Multi-User Test of the Data Quality Matrix for Product Life Cycle Inventory. *The International Journal of Life Cycle Assessment*, (5):259-265.
- Weidema, B. P. 2000. *Can resource depletion be omitted from environmental impact assessment*. Text version of poster presented at the 3rd SETAC World Congress, Brighton, UK.
- Weidema, B. P. 2001a. *Systemafgrænsning - geografisk, teknologisk og tidsmæssig afgrænsning. [System delimitation – geographical, technological and temporal]*. LCA vejledning nr. 3 (endeligt udkast). Copenhagen: Miljøstyrelsen.
- Weidema, B. P. 2001b. Avoiding co-product allocation in life-cycle assessment, *Journal of Industrial Ecology* 4(3):11-33.
- Weidema, B. P. 2003a. *Market information in life cycle assessments*. Environmental project no. 863. Copenhagen: Danish Environmental Protection Agency.
- Weidema, B. P. 2003b. Personal communication with Bo Weidema (PhD), 2.-0 Consultants (www.lca.dk), Copenhagen, Denmark.
- Weidema, B. P. 2003c. Data obtained as part of the Danish Namea Project October 2003. Data have been delivered by B. P. Weidema, 2.-0 Consultants (www.lca.dk), Copenhagen, Denmark.
- Weidema, B., and B. Mortensen. 1995. *Projektinternt notat til projektet "Miljøbelastningen ved familiens aktiviteter" [Internal working paper about the environmental impacts from activities within the family]*, The Institute for Product development, The Technical University of Denmark, Lyngby.

- Weidema, B. P., and B. Mortensen. 1996 a. *Livscyklusvurdering af levnedsmidler - hvordan kommer vi i gang. [Lifecycle assessment of foodproducts – how to begin?]*. Lyngby: Akademiet for de tekniske videnskaber (ATV).
- Weidema, B. P., R. L. Pedersen, and T. S. Drivsholm. 1995. *Life Cycle Screening of Food Products - Two Examples and some Methodological Proposals*. Copenhagen: Akademiet for de Tekniske Videnskaber (ATV).
- Weidema, B. P. and E. Lindeijer, 2001. *Physical impact of land use in Product Life Cycle Assessment*, Final report of the Eurenvironlcagaps subproject on land use. Lyngby: Technical University of Denmark (DTU)
- Weidema, B. P., L. Thodberg, A. H. Nielsen, I. S. Kristensen, J. E. Hermansen, and S. K. Hvid. 2002: *Produktorienteret miljøindsats I landbrugets primærproduktion - Vurdering af virkemidler*, Arbejdsrapport fra Miljøstyrelsen Nr. 19 2002, Miljøstyrelsen, København.
- Weidema, B.P., E. H. Petersen, H. Øllgaard, and N. Frees. 2003c. *Reducing uncertainty in LCI*. Environmental project no. 862. Copenhagen: Danish Environmental Protection Agency.
- Weizsaecker, E. V., A. Lovins, and H. Lovins, 1998. *Factor 4 - Doubling Wealth Halving Resource Use*. London: Earthscan publications.
- Wenzel, H., 1998: Application Dependency of LCA Methodology: Key Variables and Their Mode of Influencing the Method. *Journal of Life Cycle Assessment* 3(5): 281-288.
- Wenzel, H, M. Hauschild, and L. Alting. 1997. *Environmental assessment of industrial products - Volume 1 - Tools and case studies*. London: Chapman & Hall.
- Winter, S. 1994. *Offentlig Forvaltning i Danmark - Implementering og effektivitet . [Public Adiministration in Denmark - Implementation and effectiveness]*. Herning: Systime A/S.
- Winter, S. 2003. Implementation – Introduction. In Peters, B. Guy and J. Pierre. 2003. *Handbook of Public Administration*. Sage publications ltd.
- World-Port distances, 2003. *World-Port distances*. www.distances.com. Accessed April 2003.
- Wrisberg, S., A. M. Eilersen, A. M. Nielsen, S. Balslev, K. Clemmesen, M. Henze. 2001. *Vurdering af muligheder og begrænsninger for recirkulering af næringsstoffer fra by til land. [Assessment of the possibilities and limitations for recirculation of nutrients from urban areas to the open land]*. Økologisk byfornyelse og spildevandsrensning nr. 14. Copenhagen: Miljøstyrelsen.
- Yngvadóttir, E. 2003. *Life Cycle Assessment of seafood 3rd workshop*. IFL project report 28-03, Reykjavik: Icelandic Fisheries Laboratories.
- Ziegler, F. 2002. *Environmental Assessment of a Swedish, frozen cod product with a life-cycle perspective*. SIK report 696. Gothenburg: The Swedish Institute for Food and Biotechnology (SIK).
- Ziegler, F., P. Nilsson, B. Mattsson, and Y. Walther. 2003. Life Cycle Assessment of Frozen Cod Fillets Including Fishery-Specific Environmental Impacts. *International Journal of Life Cycle Assessment* 8 (1) 39 – 47.
- Østergård, L. B. 2003. Personal communication with L. B. Østergård, Driftsleder vand & Spildevand, Skagen Kommune, Skagen, Denmark, August 2003.