Life cycle assessment of rapeseed oil and palm oil

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Ph.D. thesis, Part 1: Summary report

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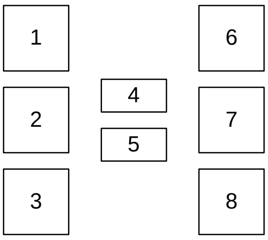

1) Jannick H Schmidt, Rapeseed field near Aalborg, May 2007
2) Calle Schmidt, Rapeseed field in Northern Jutland, May 2007
3) Picture obtained from: http://jyndevad.okologgen.dk (Accessed May 2007)
4) Jannick H Schmidt, Rapeseed oil, June 2007
5) Jannick H Schmidt, Palm oil, May 2007
6) Jannick H Schmidt, United Plantations Berhad, Malaysia, November 2006
7) Jannick H Schmidt, United Plantations Berhad, Malaysia, November 2006
8) Jannick H Schmidt, United Plantations Berhad, Malaysia, August 2005

Preface

This report is published as part of the Ph.D. thesis: Life cycle assessment of rapeseed oil and palm oil. The thesis consists of three parts:

1. **Part 1: Summary report**
   This summary report describes the overall problem of the Ph.D. project, the research outline, summaries of the research articles and the perspectives and recommendations.
2. **Part 2: Article collection (6 scientific articles)**
   The article collection presents the core of the scientific output of the Ph.D. project.
3. **Part 3: Life cycle inventory of rapeseed oil and palm oil**
   The life cycle inventory report provides and documents the background material for the scientific article: Comparative life cycle assessment of rapeseed oil and palm oil. The inventory report has character of an appendix report to the life cycle assessment

The Ph.D. thesis was carried out at the Department of Development and Planning at Aalborg University. The project was initiated under the framework of the DUCED - I&UA project which is a Danish university consortium for environment and development. The thesis was supervised by professor Per Christensen and associate professor Eskild Holm Nielsen, Department of Development and Planning, Aalborg University.

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Peter Shonfield, LCA Team Leader, Chemistry & Environmental Protection Department, Safety and Environmental Assurance Centre, Unilever

Jannick Hoejrup Schmidt, June 2007

Summary

The Ph.D. thesis ‘Life cycle assessment of rapeseed oil and palm oil’ is published in three reports:

- **Part 1: Summary report**
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  The life cycle inventory report provides and documents the background material for the scientific article: Comparative life cycle assessment of rapeseed oil and palm oil. The inventory report has character of an appendix report to the life cycle assessment

The Ph.D. thesis takes its point of departure in the overall question: what is the environmental effect of globalisation? In this respect the main focus has been on an assessment of the environmental impacts from a local versus a global product alternative for supplying the EU with vegetable oil for food purposes, i.e. rapeseed oil from Denmark and palm oil from Malaysia and Indonesia respectively. Due to present lack in crucial life cycle assessment (LCA) methodology, a large part of the LCA work has been focussed on development of methodology. Attention has also been paid to the issue of how to manage undesirable effects of globalisation. Here the focus has been on the capacity for environmental governance regarding some identified improvement options in the product chains of rapeseed oil and palm oil.

The problem area and research questions

The summary report (part 1 of the thesis) describes the problem areas of globalisation and the environment, life cycle assessment and capacity for environmental governance, and their inter-linkage.

In the section on globalisation and environment, it is shown that a large part of a nation’s production and consumption takes place in other countries and other parts of the world. Since traditional environmental regulation does not include the production processes associated with imported products, countries with a high level of environmental protection may continue to increase its pollution by shifting from local to global supply of the polluting commodities. According to EEA (2003), this is what has actually taken place in the EU. It is chosen to centre the analyses upon the empirical case of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia as the local and global alternatives for supplying the EU with vegetable oils respectively. The commodity ‘vegetable oils’ is chosen for several reasons: 1) rapeseed oil and palm oil are the two largest vegetable oils used in the EU, 2) rapeseed oil and palm oil represent a ‘local’ and a ‘global’ alternative of the supply, 3) the total supply as well as the import share of vegetable oils to the EU is increasing, and 4) the production of food represents a significant contribution to the overall environmental impacts (and the production of vegetable oil is significant in terms of impact per product as well as the overall impact).

In the section on life cycle assessment the LCA methodology is described and two crucial lacks in LCA methodology are identified; system delimitation in the agricultural stage and methods for impact assessment of land use. A large part of the LCA work in this Ph.D. thesis has been focussed on development of methodology. The work on LCA is carried out in accordance with the ISO 14040 and 14044 standards and the consequential approach for system delimitation has been used.

In the section on capacity for environmental governance, the theoretical basis of the capacity analysis is outlined. The capacity study is based on the theory of Jänicke (1997).

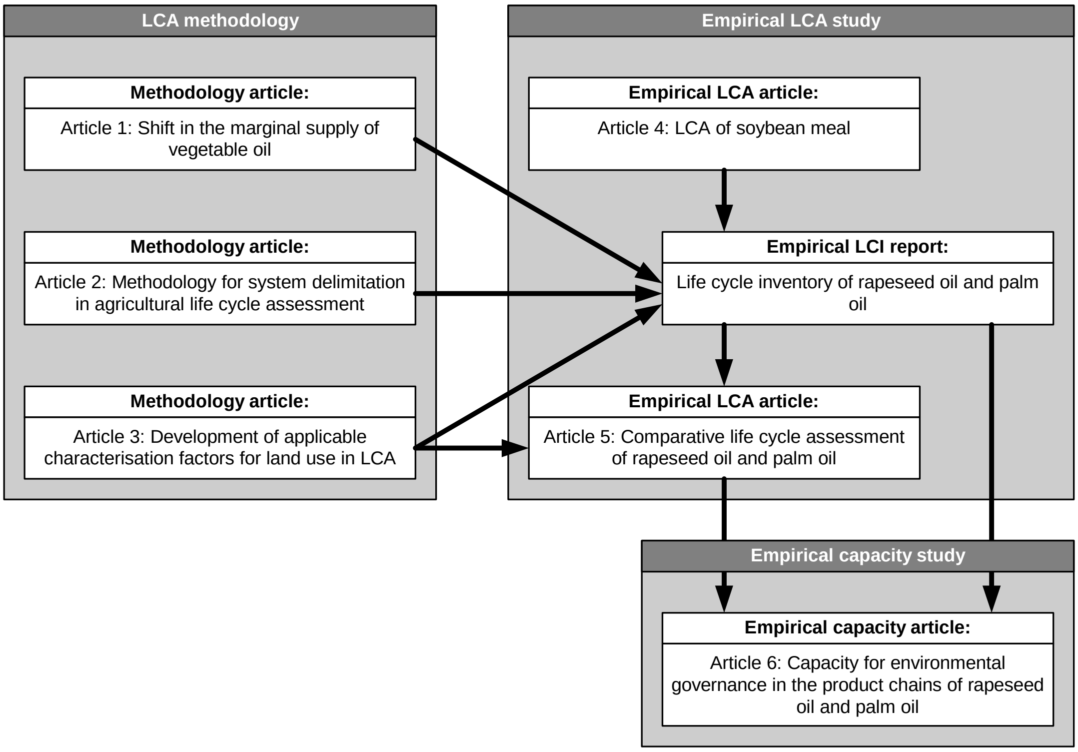
In total five research questions, upon which the research activities are centred, are defined. These fall within three clusters of research:

1. LCA methodology (research question 1, 2 and 3)
2. Empirical LCA study: LCA of rapeseed oil and palm oil (research question 4)
3. Empirical capacity study: Capacity analysis of environmental governance regarding implementation of improvement options in the product chains of rapeseed oil and palm oil (research question 5)

The research questions are presented below.

RESEARCH QUESTION 1: LCA METHODOLOGY
The output from oil mills is constituted by three important products: vegetable oil and oil meal which functions as fodder protein and fodder energy. How can co-product allocation be avoided/handled appropriately in a consequential LCA of rapeseed oil and palm oil?
RESEARCH QUESTION 2: LCA METHODOLOGY
The affected land and the associated affected crops from increased production of a certain crop is not necessarily the land under the crop of interest. How can the affected crops and land be identified and how can the means of increased production (increased land or increased yield) be predicted in a consequential agricultural LCA?
RESEARCH QUESTION 3: LCA METHODOLOGY
How can the impacts on biodiversity from occupation and from transformation of land be included in LCIA?
RESEARCH QUESTION 4: EMPIRICAL LCA STUDY
What characterises the environmental impact from the supply of rapeseed oil from Denmark and palm oil from Malaysia/Indonesia to the European market and what are the most essential options for improving the environmental performance of these two oils?
RESEARCH QUESTION 5: EMPIRICAL CAPACITY STUDY
What characterises the capacity for environmental governance for implementing identified options for improving the environmental performance of the product chains of rapeseed oil and palm oil?

The research questions are addressed in 6 scientific articles (part 2 of the thesis) and a life cycle inventory report (part 3 of the thesis). The linkages between the 6 articles and the inventory report are illustrated in the figure below.



The research is summarised in the following.

Development of LCA methodology

In the following the three articles on development of LCA methodology are described.

Article 1: Shift in marginal supply of vegetable oil

The consequential approach to system delimitation in LCA requires that the technologies and suppliers included are "marginal", i.e. that they are actually affected by a change in demand. Furthermore, co-product allocation must be avoided by system expansion. Vegetable oils constitute a significant product group included in many LCAs intended for use in decision support. This article argues that the vegetable oil market has faced major changes around the turn of the century, which have resulted in a shift in the marginal vegetable oil source from rapeseed oil to palm oil.

The major vegetable oils are soybean oil, palm oil, rapeseed oil and sunflower oil. These oils are substitutable within the most common applications. Based on market trends, a shift from rapeseed oil to palm oil as the marginal supply of vegetable oil is identified around year 2000, when palm oil turned out to be the most competitive oil. It is recommended to regard palm oil and its dependent co-product palm kernel oil as the marginal vegetable oil. The analysis of the product system shows that the demand for 1 kg palm oil requires 4.49 kg FFB (oil palm fruit) and the displacement of 0.035 kg soybeans (marginal source of fodder protein) and 0.066 kg barley (marginal source of fodder energy).

The identification of the marginal vegetable oil and the avoidance of co-product allocation by system expansion showed that several commodities may be affected when using the consequential approach. Hence, the product system for vegetable oils is relatively complex compared to traditional LCAs in which average technologies and suppliers are applied and in which co-product allocation is carried out by applying an allocation factor. This article presents how the marginal vegetable oil can be identified and that co-product allocation between oils and meal can be avoided by system expansion, by considering the energy and protein content in the meal, which displaces a mix of the marginal sources of energy and protein for animal fodder (barley and soybean meal, respectively). The implication of a shift in the marginal vegetable oil is significant. Many LCAs on rapeseed oil have been conducted and are being used as decision support in the bio energy field. Thus, based on consequential LCA methodology, it is argued that these LCAs need to be revised, since they no longer focus on the oil actually affected.

Article 2: Methodology for system delimitation in agricultural LCA

When dealing with system delimitation in an LCA, two methodologies are typically referred to; consequential LCA and attributional LCA. The consequential approach uses marginal data and avoids co-product allocation by system expansion. The attributional approach uses average or supplier-specific data and treats co-product allocation by applying allocation factors. Agricultural LCAs typically regard local production as affected and they only include the interventions related to the harvested area. However, since changes in demand may affect foreign production, yields, and the displacement of other crops in regions where the agricultural area is constrained, there is a need for incorporating the actual affected processes in agricultural consequential LCA. This paper presents a framework for defining system boundaries in consequential agricultural LCA. The framework is applied to an illustrative case study; LCA of increased demand for wheat in Denmark. The aim of the LCA screening is to assess the environmental impact from different ways of meeting increased demand for wheat in Denmark.

The proposed framework mainly builds on the work of Ekvall and Weidema (2004), agricultural statistics (FAOSTAT, 2006), and agricultural outlook (FAPRI 2006a). The framework and accompanying guidelines concern the suppliers affected, the achievement of increased production (area or yield), and the substitutions between crops. The framework, which is presented as a decision tree, proposes four possible systems that may be affected as a result of the increased demand of a certain crop in a certain area.

The sensitivity of the results of system delimitation and the implementation of the framework are tested through an empirical study on how to meet increased demand for wheat in Denmark. Different scenarios of how increased demand can be met show significant differences in emission levels as well as land use. The great differences in potential environmental impacts of the analysed results underpin the importance of system delimitation. The consequential approach is appointed as providing a more complete and accurate but also less precise result, while the attributional approach provides a more precise result but with inherent blind spots, i.e. a less accurate result. The main features of the proposed framework and case study are 1) an identification of significant sensitivity on results of system delimitation and 2) a formalised way of identifying blind spots in attributional agricultural LCAs. It is recommended to include considerations on the basis of the framework presented in agricultural LCAs if relevant. This may be done either by full quantification or as qualitative identification of the most likely ways in which the agricultural product system will respond to change in demand. Hereby, it will be possible to make reservations to the conclusions drawn on the basis of an attributional LCA.

Article 3: Development of applicable characterisation factors for land use in LCA

The UNEP/SETAC life cycle initiative has recently proposed a framework for life cycle impact assessment (LCIA) of land use (Milá i Canals et al. 2006). Still, a lack of appropriate LCIA-methods for assessing land use impacts exist in Life cycle assessment (LCA). Most existing methods are either too coarse-grained regarding the differentiation between different land use types (e.g. conventional farming versus organic farming), or they are too narrow regarding spatial coverage (e.g. only part of Europe). This article proposes a method for land use impact assessment on biodiversity at the midpoint level.

The framework for the method developed is coherent with the UNEP/SETAC life cycle initiative (Milá i Canals et al. 2006). The method is based on Köllner (2000) and Weidema and Lindeijer (2001). The proposed LCIA-method assumes that characterisation factors are possible to determine for any land use type in any region without the need for overwhelming data and data manipulation requirements.

The developed method for LCIA of biodiversity focuses on species richness of vascular plants which can be determined from species-area curves. Data accessibility of species surveys is quite good for most regions and land use types. The category indicator is calculated as the multiplication of occupied and transformed area, the number of species affected per standard area (100 m^2), the duration of occupation and renaturalisation from transformation, and a factor for ecosystem vulnerability. The main uncertainties of the method are related to the absence of weighting between species and the determination of renaturalisation times. Also uncertainties in establishing species-area curves have proven to be significant. This article proposes a midpoint level method for LCIA for biodiversity from land use. The intention, i.e. to develop an applicable model with global coverage and no constraints on resolution regarding spatial and land use type differentiation, has widely been met. The limiting factor for applicability is the access to species richness surveys for the relevant regions and land use types. But still, the method shows that, with limited efforts, it is possible to calculate characterisation factors for a large range of land use types in different parts of the world. In order to facilitate future data collection, a common accessible databank is suggested for this reason. Another important effort in the future is better determination of renaturalisation times.

Empirical LCA study

In the following, the life cycle inventory report and the two articles relating to the comparative LCA of rapeseed oil and palm oil are described. The inventory report and the article on soybean meal function as data input to article 5: Comparative LCA of rapeseed oil and palm oil.

Report: Life cycle inventory of rapeseed oil and palm oil

In order to provide the needed data for a detailed comparative life cycle assessment of rapeseed oil and palm oil, this report documents the most work intensive part of the LCA, namely the second phase of an LCA; the life cycle inventory (LCI). In addition, various sensitivity analyses are carried out and the data are evaluated in order to ensure confidence in LCA results. Existing LCAs on rapeseed oil and palm oil do not represent the level of detail intended for this study and they do not incorporate the state of the art regarding modelling in LCI in particular in the agricultural stage, the oil mill stage, and the refinery stage. The aim of this report is therefore to carry out the LCI modelling and the detailed data collection for all relevant processes in the product systems of rapeseed oil and palm oil. As a part of the data collection, improvement options for improving the environmental performance of the products are identified. The identified improvement options are evaluated in sensitivity analyses.

The consequential approach for modelling in LCI is applied. The consequential approach requires that the actual affected processes are included and that co-product allocation is avoided by system expansion. Therefore an important part of the LCI modelling is to identify marginal suppliers of the affected agricultural crops and carry out system expansion in order to avoid co-product allocation. Another aspect of the modelling is the system delimitation in the agricultural stage. Here the first problem is to determine how increased agricultural production is achieved, i.e. by increased area and by increased yield. Secondly, the affected land is to be identified when cultivating in regions with land constraints. In Denmark, the agricultural land has been slightly decreasing the last several decades. Thus, when increasing rapeseed cultivation, other crops are displaced, and consequentially these crops have to be cultivated somewhere else. The data collection for the agricultural stage includes collection of primary as well as secondary data and modelling of nutrient balances. The data collection for the oil mill stage and refinery is mainly based on collection of primary data.

The LCI modelling shows that the crops; rapeseed, oil palm, soybean and barley are inter-linked by the co-products of the oil mill and refinery. In addition, the following oil mills are affected; rapeseed oil mill, palm oil mill, palm kernel oil mill and soybean oil mill. For each of the vegetables oils, rapeseed oil, palm oil, palm kernel oil and soybean oil there is an oil refinery process as well. The LCI results are presented as detailed data sheets for each of the affected crops, oil mills and refineries. In total, 21 sensitivity analyses are carried out. These sensitivity analyses have identified the most significant uncertainties in system delimitation, data and LCIA-methods as well as the most significant improvement options. The collected data regarding land use and emissions related to energy use and the nitrogen cycle are regarded as very robust. The data collected for pesticides and heavy metals are more uncertain. In the LCIA results, these characteristics will be further intensified because the LCIA methods are in general relatively certain regarding the emissions relating to energy and nitrogen cycle while toxicities caused by pesticides and heavy metals are less certain. This report presents detailed LCI results for the product systems of rapeseed oil and palm oil. The LCI results are presented at a disaggregated level per main stage which facilitates large flexibility in the further use of the collected data. The data collected and presented in this report mainly serves as an input to a comparative LCA of rapeseed oil and palm oil. However, the collected process specific data for the agricultural stage and oil mill stage represent some of the most detailed data available. Therefore, the data may serve as an important data input for other LCAs in the area of rapeseed, oil palm, soybean, and barley cultivation as well as rapeseed oil, palm oil, palm kernel oil, and soybean oil milling.

Article 4: LCA of soybean meal

Soybean meal is an important protein input to the European livestock production, with Argentina being an important supplier. The area cultivated with soybeans is still increasing globally, and so are the numbers of LCAs where the production of soybean meal is part of the product chain. In recent years, there has been increasing focus on how soybean production affects the environment. The purpose of the study was to estimate the environmental consequences of soybean meal consumption using a consequential LCA approach. The functional unit is ‘one kg of soybean meal produced in Argentina and delivered to Rotterdam Harbor’. The LCA of soybean meal is presented as an individual LCA with no relations to the LCA of rapeseed oil and palm oil. The inventory data on soybean cultivation and soybean milling are used as input to the life cycle inventory of rapeseed oil and palm oil.

Soybean meal has the co-product of soybean oil. In this study, the consequential LCA method is applied, and co-product allocation is thereby avoided through system expansion. In this context, system expansion implies that the inputs and outputs are entirely ascribed to soybean meal, and the product system is subsequently expanded to include the avoided production of palm oil. Presently, the marginal vegetable oil on the world market is palm oil but, to be prepared for fluctuations in market demands, an alternative product system with rapeseed oil as the marginal vegetable oil has been established. EDIP97 (updated version 2.3) is used for LCIA and the following impact categories are included: Global warming, eutrophication, acidification, ozone depletion and photochemical smog.

Two soybean loops are established to demonstrate how an increased demand for soybean meal affects the palm oil and rapeseed oil production, respectively. The characterized results from LCA on soybean meal (with palm oil as marginal oil) are 721 g CO_2 eq. for global warming potential, 0.3 mg CFC11 eq. for ozone depletion potential, 3.1 g SO_2 eq. for acidification potential, -2 g NO_3 eq. for eutrophication potential and 0.4 g ethene eq. for photochemical smog potential per kg soybean meal. The average area per kg soybean meal consumed is

3.6 m^2year. Attributional results, calculated by economic and mass allocation, are also presented. Normalised results show that the most dominating impact categories are: global warming, eutrophication and acidification. The 'hot spot' in relation to global warming, was 'soybean cultivation', dominated by N_2O emissions from degradation of crop residues (e.g., straw) and during biological nitrogen fixation. In relation to eutrophication and acidification, the transport of soybeans by truck is important, and sensitivity analyses show that the acidification potential is very sensitive to the increased transport distance by truck. The potential environmental impacts (except photochemical smog) are lower when using rapeseed oil as the marginal vegetable oil, because the avoided production of rapeseed contributes more negatively compared with the avoided production of palm oil. Identification of the marginal vegetable oil (palm oil or rapeseed oil) turns out to be important for the result, and this shows how crucial it is in consequential LCA to identify the right marginal product system (e.g. marginal vegetable oil). Consequential LCAs are successfully performed on soybean meal and LCA data on soybean meal are now available for consequential (or attributional) LCAs on livestock products. The study clearly shows that consequential LCAs are quite easy to handle, even though it has been necessary to include production of palm oil, rapeseed and spring barley, as these production systems are affected by the soybean oil co-product. It would be desirable if the International Journal of Life Cycle Assessment had articles on the developments on, for example, marginal protein, marginal vegetable oil, marginal electricity (related to relevant markets), marginal heat, marginal cereals and, likewise, on metals and other basic commodities. This would not only facilitate the work with consequential LCAs, but would also increase the quality of LCAs.

Article 5: Comparative life cycle assessment of rapeseed oil and palm oil

The environmental effect of globalisation has been debated intensively over the last decades. Only few well documented analyses of global versus local product alternatives exist while recommendations on buying local are vast. At the same time the European Environmental Agency's Third Assessment concludes that the resource use within the EU is stabilising at the expense of increased resource use for import of products to the EU. Taking its point of departure in vegetable oils, this article compares rapeseed oil and palm oil as a local and a global alternative for meeting the increasing demand for these products in the EU. Little environmental information on local versus global product alternatives exists as well as there is no policy or strategy on how to decrease the increasing environmental impact outside the EU associated with EUs consumption. Therefore, by using detailed life cycle assessment (LCA), this study compares the environmental impacts and identifies alternative ways of producing rapeseed oil and palm oil to the EU market in order to reduce environmental impacts.

The consequential approach for system delimitation is applied (Ekvall and Weidema 2004; Weidema 2003; Schmidt 2007b; Schmidt and Weidema 2007). This approach differs from the attributional approach in the way that the actual affected suppliers and technologies are modelled instead of averages. In addition, co-product allocation is avoided by system expansion. The method for life cycle impact assessment (LCIA) is EDIP97 updated (LCA-Center 2007). In addition, land use and the associated impacts on biodiversity are assessed using the LCIA method described in Schmidt (2007c).

The characterised results of the comparative LCA show that palm oil is environmentally preferable to rapeseed oil within ozone depletion, acidification, eutrophication, photochemical smog and land use, while the difference within global warming and biodiversity is less clear. The most significant process contributing to global warming from rapeseed oil is the cultivation of rapeseed while the oil palm cultivation and the palm oil mill are equally important. Regarding land use and biodiversity for rapeseed oil, the avoided production caused by system expansion has a major role, while system expansion does not affect the results of palm oil to the same extent.

Alternative cultivation practises and technologies are assessed. The findings for rapeseed oil are that local expansions of the cultivated area on set-aside area is preferable to displacement of crops which are compensated for by increased agricultural production abroad, and that the full press technology in the oil mill is preferable to solvent extraction. Concerning palm oil, cultivation on peat increases the contribution to global warming significantly with a factor of 4-5 compared to cultivation on the current mix of soils types. Another hotspot related to global warming can be markedly reduced by installation of digester tanks and subsequent utilisation of biogas as treatment of palm oil mill effluent. The results of the scenarios show that the approach to system delimitation matter. When the consequential approach to system delimitation is applied in the agricultural stage, uncertainties show to be significant. Overall palm oil tends to be environmentally preferable to rapeseed oil within all impact categories except global warming, biodiversity and ecotoxicity where the difference is less pronounced. However, changes in technology and cultivation practises may significantly make the one oil environmentally preferable to the other. The supply of rapeseed oil to the EU can be environmentally improved if; i) the full press technology for oil milling is used instead of the solvent extraction technology, ii) prioritising land use transformation of agricultural land to take place on sandy soils rather than on clay soils, and iii) it is ensured that increases in production causes total net increase in the EU cultivated area rather than pushing out the marginal crop which then is compensated for somewhere else in the world. Correspondingly, demands to the supplying countries of palm oil can improve the environmental performance if biogas utilisation is required and cultivation of peat soils is avoided.

Empirical capacity study

In the following the article on the capacity study is described.

Article 6: Capacity for environmental governance in the product chains of rapeseed oil and palm oil

Several studies show that a considerable share of the environmental impacts related to a country's consumption is located in other countries and that there is a tendency that the share is increasing. Consequently, a significant share of the environmental impacts is becoming out of reach of the nation state's capability for environmental regulation. This article analyses the capacity for implementing six identified improvement options of the environmental performance of the product chains of rapeseed oil from Denmark and palm oil from Malaysia. These two commodities represent a local and a global alternative for supplying the EU with vegetable oils. The improvement options include technical changes as well as more management oriented changes of land use administration.

The applied analytical approach is a capacity analysis based on Jänicke (1997) but with focus on product chains instead of capacity building for national environmental protection. Thus, the included actors and institutions are determined by the system boundaries of the product system instead of national borders. The six improvement options are identified through a detailed life cycle assessment of rapeseed oil and palm oil. The data for the analysis are primarily obtained from international and national environmental conventions, protocols, action plans and legislation as well as key documents from other important actors (non governmental organisations). For each improvement option, the relevant actors, knowledge about the option/problem among relevant actors, regulation and economic-technological conditions are analysed. Together these elements constitute the existing capacity for implementing the improvement options. The utilisation of the capacity is determined by the strategy, skill and will of the proponents and of the variable conditions of action, e.g. public awareness or strong opponents.

The analysed improvement options are 1) applying best available techniques in N-fertiliser production (fertiliser used in rapeseed cultivation, Denmark), 2) prioritising the most fertile soils when agricultural land is reclaimed for other purposes (rapeseed cultivation, Denmark), 3) Avoiding cultivation on peat in order to avoid significant CO_2 emissions (oil palm cultivation, Malaysia), 4) Expanding the agricultural area on grassland and avoiding transformation of forests (oil palm cultivation, Malaysia), 5) yield increases by additional fertiliser (oil palm cultivation, Malaysia) and 6) Installation of digester tank and utilisation of biogas instead of anaerobic ponds for treatment of palm oil mill effluent (palm oil production, Malaysia). All improvement options focus on reducing either the impact on climate change or biodiversity. In general, governments play a larger role as proponents of implementing improvement options in Denmark then in Malaysia were NGOs and industry have a larger role. No remarkable differences in the strength of capacity in Denmark and Malaysia were identified. Normally, the capacity for environmental governance in Denmark would be expected to be stronger than in Malaysia. The reason why it is not the case here is that climate change and biodiversity generally fall out of the scope of traditional environmental regulation (command and control). The analysis shows that legal capacity is lacking for most improvement options. Consequently, the implementation of improvement options relies on voluntary efforts mainly driven by economic incentives. The analysis also shows that the proponents of improvements in Denmark are primarily national bodies and industry while they are constituted by non-governmental and multi-national bodies in Malaysia where the capacity of government regulation is general weaker than in Denmark. The strongest capacity for governing the environmental problems related to globalisation is primarily found within different non-governmental organisations driven by green market mechanisms. The analysis showed to provide a good overview of the capacity for implementing different improvement options in different contexts. The analysis is regarded as a fruitful input to the process of developing integrated product policy (IPP) for different product groups. Hence, using capacity analysis as presented in this article, a formalised coordinated IPP can contribute significantly to capacity building in achieving improved collaboration between actors, strengthened framework conditions, and maximised utilisation of the capacity for implementing improvement options in product chains.

Conclusions and perspectives

Characteristics of the environmental impacts from local versus global agricultural products

The findings of above mentioned research issues have been presented in the previous section. In this section, attention is paid to the general overall question: 'what is the environmental effect of globalisation?' without focussing on the specific case of rapeseed oil and palm oil.

The research process has led to some recognition of what is significant regarding the environmental effect of globalisation and agricultural products. The characteristics are important to be aware of in comparative studies of local versus global agricultural products. Examples of these significant characteristics are given below:

- Increasing cultivation in the developed part of the world often lead to displacement of other crops which has to be grown in other countries. In most of the developed part of the world (e.g. Europe, USA, Canada and Japan) the area covered with annual and permanent crops has been constant or declining the last decade (FAOSTAT 2007). At the same time, the global agricultural area has been increasing. Therefore, it is likely that increased demand for a crop grown in the developed part of the world will lead to an increase of the total cultivated area in the developing part of the world.
- Crop yields are typically considerably higher in developing countries (in the tropical countries) than in the developed part of the world (in the temperate countries)
- Cultivating peat soils causes significant greenhouse gas emissions. Tropical peat swamps in especially Indonesia are rapidly being transformed into agricultural land.

- Transport from remote countries does not have a significant impact in a life cycle perspective. This is because local transportation with lorry is many times less efficient per tkm than long distance transport with transoceanic freight ship.
- Greenhouse gas emissions from agriculture mainly comes from dinitrogen oxide emissions from the field (denitrification of surplus nitrogen in the field) and from the production of N-fertiliser. Carbon dioxide emissions from traction are less significant. However, when cultivating on peat, the most significant greenhouse gas emissions are carbon dioxide from the mineralisation of the organic material.
- Depending on the crop and the agricultural practises and regulation in the affected region, increased production can be achieved by either increased cultivated area or by intensification, e.g. by additional fertiliser input. The environmental impact from the two different ways of increasing agricultural production may differ significantly.

Based on the empirical LCA study in this project and the recognition of significant characteristics, it is not possible to say whether local or global product alternatives are the best from an environmental point of view. Several factors determine the environmental performance of agricultural products. And in the case of cultivation in regions with constrained land, the actual affected crops and land may be located in another part of the world. Hence, local production may have effects on the global agricultural system. Therefore, the issue of globalisation is not limited to a choice between local and global product alternatives. The associated product system to local products is globally inter-linked. Hence, the environmental performance of the supply of agricultural products may be difficult to improve just by choosing one crop alternative over another.

The empirical LCA study of rapeseed oil and palm oil showed that the ranking of the two oils could be changed both ways by implementing improvement options in the product chains of the two commodities. Therefore, the greening of the supply of agricultural products should be based on implementing improvement options by imposing criteria for the production processes in the product chains. Based on the empirical LCA study, the following examples of general criteria can be defined. Such criteria could be a starting point for a development towards integrated product policy for products from the agricultural sector.

- Avoid cultivation on peat soil and restore cultivated peat to natural peat swamp
- Extensively cultivated land should be checked for environmentally sound intensification in order to minimise the environmental impact per product
- Increased utilisation of crop residues, but without sub-optimising caused by negative effects on the carbon stock and soil fertility from the removal of organic material
- Use N-fertiliser produced with best available techniques for minimising dinitrogen oxide emissions from the fertiliser production
- When expanding the agricultural area, priority should be given to transformation of already degraded land, e.g. alang-alang grassland (mainly in SE-Asia) or set-aside/idle agricultural land
- Requirements to a minimum standard of cultivation practise and land utilisation in order to maximise yields. This is especially relevant in the case of smallholders who are often characterised by poor cultivation standards and low yields

Challenges for governing a globalised agricultural product system

It appears that if the supply of agricultural products to the EU is to be greened, the way to go is not to ban imports and rely on local supply. Instead, criteria for the production processes and the environmental governance system in the supplying countries should be introduced. These criteria could be based on the characteristics mentioned above. The analysis of capacity for environmental governance regarding the identified improvement options showed that legal capacity were lacking in general. This means that the traditional national environmental regulating institutions in general have weak capacity for implementing the identified improvement options. But led by NGOs and industry and driven by voluntary efforts and economic incentives some promising initiatives have been started, e.g. the Roundtable on Sustainable Palm Oil (RSPO) and the Round Table on Responsible Soy (RTRS). These initiatives have members from most stages of the product chains, and in order to be certified, the members must comply with an agreed on set of criteria.

A relevant question to be answered is then: Can we rely on voluntary efforts alone to provide a desirable management of the undesirable environmental effects of globalisation. Here the term ‘globalisation’ refers to the fact that a growing share of the environmental impacts from agricultural products takes place in other countries than in the consuming country. Hereby, the governance of the environmental impacts from a country’s supply of commodities falls out of reach of the traditional environmental regulation system (nation state based command and control and EIA). I argue that voluntary efforts do not ensure that all relevant polluters are committed to reduce their environmental impact, and that voluntary efforts do not ensure that all relevant products are included (e.g. there only exist a round table on sustainable palm oil even though rapeseed oil is likely to have a more significant environmental impact within many impact categories). Important polluters are overseen and the definition, monitoring and achievement of overall environmental goals are not ensured. However, the same weaknesses may be present if the efforts were left in the hands of national environmental agencies and international bodies. But the advantages of these institutions are that they normally have a broader focus than only one single product (e.g. palm oil or soybean), and they may have the power to put into force legal requirements to the production. Hereby, completeness in terms of products (e.g. all vegetables oils) and all polluters (not only the actors who have joined the voluntary initiative) could be ensured. Thus, the relevant national and international institutions should follow up on the initiated voluntary efforts as part of the development of integrated product policy and this should be supplemented with legal requirements.

The European Commission started the work on integrated product policy (IPP) in 1998. Though the development of IPP is still in its infancy, it could be seen as a compensating factor for the lacking of legal capacity in environmental governance. However, the integrated product policy in the EU has only focussed on voluntary participation and industry’s voluntary commitments of implementing environmental improvement options. Hence, initiatives led by the EU have not shown to be more promising than the round tables on palm oil and soybean in terms of including a broader range of products and polluters and in terms of providing more legal capacity. Only two pilot products have been included in the IPP programme so far and the inclusion of polluters relies only on the voluntary commitment of the polluter.

Hence I argue, that if integrated product policy has to have a significant impact, it should be supplemented by legal requirements. My suggestion in this respect is to include an analysis of the capacity for environmental governance regarding the identified improvement options in the development of IPP for each product or product group. This would point at existing strong capacities for implementing the improvement options and at actors and institutions that need capacity building.

Contents

1 Introduction

The environmental effect of globalisation has been discussed broadly in the last decades. Based on Mol (2000), two major issues in this respect have been identified: 1) How does globalisation affect the environment? And 2) what characterises the transformation of governance systems in order to manage undesirable effects of globalisation? Relating to the first of the two above mentioned issues, the European Environmental Agency's third assessment of Europe's Environment concludes that increasing import of resources to the EU is resulting in a shift of the environmental burden from inside the EU to outside the EU (EEA 2003). Weidema et al. (2005a) show that the foreign environmental impacts related to activities (production and consumption) in Denmark in many cases are as large as the domestic impacts. In addition, Peters and Hertwich (2006) show that the environmental impacts from products produced in developing countries are typically of greater magnitude than the products produced in the developed part of the world. Regarding the second mentioned issue on the transformation of governance systems, the interesting questions are; what is the capacity for environmental governance? And which transformations contribute to environmental reform? Since most traditional environmental regulation is the nation-state based, the above mentioned processes of globalisation challenge the existing governance regimes that manage the environment. An example of nation-state's poor capability of regulating environmental effects of imported products is the EU and WTO ban on regulating the processes with which products are made (Moellendorf 2005). Nation-states only have the authority to regulate processes that are taking place within their own borders.

The empirical focus of this project is mainly on how globalisation affects the environment. This encompasses an environmental assessment of environmental effects of a globalised product system, and an analysis of how the environment is governed along global product chains. The environmental assessment constitutes the major part of the project. Point of departure is taken in a specific comparative case: Rapeseed oil from Denmark and palm oil from Malaysia and Indonesia. These two commodities can be considered as a 'local' and a 'global' product system that can supply the EU with oils and fat. Secondary, the project deals with how the governance regime related to the product chains of rapeseed oil and palm oil can transform in order to contribute to environmental reform. The focus of this analysis is on the capacity for environmental governance regarding implementation of environmental improvements along the product chains of rapeseed oil and palm oil.

The environmental effect of globalisation consists, according to Mol (2000), of two elements. Firstly, there is the most obvious relation between globalisation and environmental degradation which includes that trade, investment, economic decision-making, financial markets etc. directly result in environmental degradation. This includes 'normal' environment risks such as air and water pollution and waste disposal e.g. from increased transport around the globe and loss of biodiversity by economic development in developing countries, where the bulk of biodiversity is situated. These environmental effects of globalisation are often related to the globalisation of economic production and consumption (Mol 2000). Secondly, there is an increasing global (unequal) distribution of environmental effects. Only the first element of the above-mentioned environmental effects of globalisation is included in this study. The environmental effects of rapeseed oil and palm oil representing the 'local' and the 'global' supply of vegetable oils to the EU will be quantified and assessed using life cycle assessment (LCA).

The analysis of how the environment is managed along global product chains will follow the same path in terms of stages in the product chains as in the LCA. When combining the LCA and capacity-analysis several advantages are achieved. Recognising the complexity of product chains, several countries have launched integrated product policies (IPP) to deal with these problems (Scheer and Rubik 2006), however, the policies are still in their infancy and at a development stage. The common definition of IPP in the EU is: ”*Public policy which aims at or is suitable for continuous improvement in the environmental performance of products and services within a life-cycle context*” (Scheer 2006, p 47). According to Scheer (2006), IPP is a conceptual approach based on three essential principles: life-cycle orientation, multi-stakeholder approach and policy mix. Thus, IPP contain the elements of the life cycle assessment as well as governance (the actors and the policy mix). In this respect the LCA is used for identifying significant environmental hotspots and improvement options through out the product chains of palm oil and rapeseed oil. This then serves as an input to the capacity analysis of environmental governance. The use of the LCA in this respect ensures that the analysed improvement options represent significant improvements in a life cycle perspective. The capacity analysis focuses on the capacity for implementing the proposed improvement options in the framework of IPP.

2 The discussion of globalisation and the environment

Since the 1980s, the use of the notion of globalisation has emerged and has been quite popular. The concept of globalisation could hardly be found neither in academic studies nor in magazines and newspapers before 1980 (Mol 2000). However, neither transnational trade nor older concepts on related issues to globalisation are new. According to Mol (2000), analyses of globalisation processes are often made with reference to the environment. Traditionally, environmental problems have been seen as one of the driving forces of global awareness. More recently, environmental degradation has been interpreted as one of the negative effects of globalisation in the economic sphere of production and consumption.

2.1 Globalisation: Definition and research

Globalisation is often defined in very broad terms and with other purposes than analysing the relations between globalisation and the environment. Therefore, the term has to be clarified further. Globalisation includes aspects that are both intentional and reflexive (Waters 2001, p 2). An example of intentional aspects is business planning for global marketing and an example of a reflexive aspect is environmentalists efforts to save the planet. Both aspects are reflected in Waters' definition of globalisation: "*A social process in which the constraints of geography on economic, political, social and cultural arrangements recede, in which people become increasingly aware that they are receding and in which people act accordingly.*" (Waters 2001, p 5). The essences of the definition are 1) that a change is taking place and constraints recede and 2) people are aware of it and act according to it. When referring to the environmental effects of globalisation in this study, reference is not meant in the very broad terms as in the definition. Thus, in the use of the term '*globalisation*', the intentional aspects include increased international trade causing 1) that a decreasing part of the product chains are situated in the country/countries of processing or end-use, and 2) that an increasing part of the supply in developed countries comes from developing countries where environmental governance is less developed and where most of the world's biodiversity is situated. The reflexive aspects include the reactions on the intentional aspects encompassing efforts in environmental governance at the national and international level undertaken by public as well as private institutions. In the analysis of the effects of globalisation focus will be concentrated more on the intentional aspects than on the reflexive. This is because the aim of the study is to analyse the environmental effects of globalisation and what can be done in order to avoid and minimise these effects. The reflexive aspects would include an analysis of how and why institutions react to globalisation which falls out of the scope of the study. Thus, the analysis of environmental governance will be centralised more on how environmental effects from different stages of product chains are managed than on identifying the reflexive changes triggered by globalisation processes.

According to Mol (2000), research of globalisation and the environment include two dimensions, these are; 1) how do the changing institutions (by the processes of globalisation) affect the environment and 2) the synchronization of globalisation and transformation of institutions on the one hand and environmental reform on the other. The first dimension covers the direct environmental effect of changed institutions. The change of institutions may e.g. be change in financial markets that provides consumers with goods produced thousands of kilometres away. The environmental effects include both 'normal' environment risks such as air and water pollution, waste disposal and loss of biodiversity and an increasing global (unequal) distribution of environmental effects. Furthermore, Mol emphasizes, that the traditional institutional arrangements for environmental management systems' (most notably nation-state) diminishing ability to manage the environmental effects of products is included under the first dimension. The second dimension covers how environmental reform follows the changing institutions (driven by the processes of globalisation) or visa versa. According to Mol

(2000), ecological concern is to some extent a driving force behind globalisation. In a similar way, globalisation processes can enhance environmental reform as they generate e.g. harmonisation of national environmental practices, transfer environmental technologies, accelerate environmental information around the globe etc. Examples of this are vertical institutionalism; when multinational enterprises harmonize their environmental standards in their branches around the globe, and when environmental considerations increasingly are adopted by global and regional economical organizations (e.g. World Bank, OECD and the EU), and horizontal dispersion; when global environmental protection is dispersed through national frontrunners (Biermann and Dingwerth 2004).

2.2 Product chains and the role of the nation-state

It appears from the previous section that the role of nation-state is receding regarding its ability to manage environmental protection. Therefore, this section briefly points at some causes of that tendency, and the underlying assumption of that is evaluated, i.e. that an increasingly share of the environmental impacts related to a nation's production and consumption take place outside the nation.

According to Mol (2000) some of the causes of the receding role and importance of the nation-state in environmental regulation are:

- Diminishing sovereignty via different economic and political mechanisms reduces the capability to intervene in economic activities that affect the environment (e.g. declining authority on restrictions on import)
- Growing organisational and technical complexity of production and consumption systems
- Growing international competition
- Increasing request for environmental standardisation and harmonisation
- Environmental problems are becoming global and cannot be dealt with on the nation-state level (global warming, ozone layer depletion and biodiversity)

To some extend most of the above reasons for the receding role of the nation-state are based on the assumption that a still greater part of the product chains is situated outside the nation in which consumption of the products takes place. Here two important questions need to be answered; 1) is the share of environmental effects related to domestic activities increasingly taking place abroad? And 2) what is the distribution between domestic and foreign effects related to domestic activities? In order to answer these questions a literature review has been carried out. The relevant studies identified are given in **Table 2.1**.

Method	Features analysed	Studies
IO-LCA[1]	Domestic and foreign shares of impacts from Denmark's production and consumption	Weidema et al. (2005a, p 34-47)
IO-LCA	Domestic and foreign shares of impacts from Sweden's agriculture	Engström et al. (2004, p 19, 33)
IO-LCA	Impacts from consumption in the Netherlands distributed among domestic impacts and impacts in Europe, other OECD and non-OECD	Goedkoop and Nijdam (2003)
IO-LCA	CO_2 emissions embodied in imports to Norway compared to domestic CO_2 emissions	Peters and Hertwich (2006)
TMR[2]	Domestic and foreign shares of material supply to the EU	EEA (2003, p 20-21)
TMR	Import share of DK's material requirement	Weidema et al. (2005a, p 161)

Table 2.1: Identified studies on distribution between domestic and foreign shares of nations (and unions of nation's) environmental impacts.

[1] IO-LCA: Input-output LCA. LCA-data on sector level combined with national input-output trade statistics (Weidema et al., 2005).

[2] TMR: Total material requirement. The total extraction of materials (both used flows and hidden flows such as minedust) related to a national economy (Eurostat, 2001).

According to the identified studies on foreign and domestic shares of environmental impacts in **Table 2.1**, environmental impacts from import constitute a considerable share of the total national production and consumption and furthermore, this tendency seems to increase. In Weidema et al. (2005a) the share of foreign and domestic environmental impacts are shown for Danish production and consumption. For different categories of environmental impacts the import share constitutes between 26% and 86% (average 52%). Peters and Hertwich (2006) show that CO_2 emissions embodied in imported products to Norway correspond to 67% of Norways domestic CO_2 emissions. In a similar way Engström et al. (2004) show that the foreign impacts from Swedish agriculture amount to between 23% and 84% for different categories (average 47%). In Goedkoop and Nijdam (2003) it is shown that between approximately 22% and 83% (average 51%) of different environmental impacts from consumption in the Netherlands take place abroad. And between 23% and 59% (average 44%) of the foreign impacts take place in non-OECD countries, especially land-use and acidification. EEA (2003) shows that the domestic extraction of raw materials in the EU is decreasing, while the import is increasing. In EEA (2003), it is argued that this may cause a better state of the environment in the EU, while environmental pressures related to raw materials are moved to other parts of the world. The material extraction, which includes both direct and hidden flows in the EU, has decreased from 38 tonnes per capita in the late 1980s to around 32 tonnes per capita in the late 1990s. During the same period imports have increased from around 17 to 20 tonnes per capita. It is also argued that the trend for increased import is likely to continue the years to come. In Weidema et al. (2005a) domestic and foreign shares of the total material requirement in Denmark are compared for 1997 and 1999, and the comparison shows increased import share. However, due to different methodologies in 1997 and 1999, this comparison does not provide sufficient information to conclude whether the import share of the total TMR has been increasing.

It is evident from the studies described above that a significant share of the environmental impacts related to a nation’s production and consumption take place outside the nation. Furthermore, there are some indications that this tendency is increasing. The significant share of environmental impacts taking place outside the country of consumption and the indication that this share increases underpin Mol’s argument that the role of the nation-state in the case of environmental regulation is diminishing. It also indicates that product chains are becoming longer and more spread out all over the world. An obvious consequence of this is that the traditional nation-state based environmental regulation captures a still smaller part of the product chains of the products produced and consumed inside the country.

2.3 What is the environmental effect of globalisation? Some existing findings

Focussing on globalisation and the environment, one of the most important questions arising is how globalisation affects the environment. Since the focus of this project is on food (vegetable oils) and since most existing scientific findings of the environmental effect of globalisation are on food commodities, this section will also focus on food. It is evident from the previous section that a considerable share of the environmental impact from domestic activities is situated abroad. Furthermore, there are indications that point in the direction that this share is increasing. Apart from that, it is relevant to answer whether the impact from imported products are more or less environmentally sound than locally produced products. It has not been possible to identify any general research on that. However, it tends to be a common perception that local, small-scale and organic food is good and that global and big-scale food is bad. Such arguments can be found with several NGOs as well as researchers. Examples where such arguments on ‘buy local’ are put forward by NGO campaigns are CAFF (2001), GRACE (2005), FoE (2005), Sustain (2005) and FoodRoutes (2005). An example of scientific work on ‘global’ versus ‘local’ supply is Carlsson-Kanyama (1997). The most common environmental oriented argument for buying local in these campaigns and scientific works is related to transportation. In the light of the debate on food miles in the UK, Professor Jules Pretty is cited for saying: “… *buying local is even more impor-*

tant than buying green…" (Planet Ark 2005). The concept of food miles is further described in Paxton (1994) and Hird et al. (1999). Besides the impact from increased transport distances, Carlsson-Kanyama (1997) and Mol (2000) argue that global food supply often causes loss of biodiversity when development in developing countries accelerates. In addition, it is sometimes stated that local food preserves open space and biodiversity and that it has a positive effect on global warming, clean water, erosion, and material input in terms of fertilisers (CAFF 2001). However, in all identified campaigns it is taken for granted that increased transport distances causes an overall harm to the environment and in addition, none of the studies compare the environmental impact of locally produced products with globally produced products. Thus, I argue that a more holistic approach must be taken into account when assessing the environmental effect of globalisation. In particular, I argue that focussing only on the transport stage in the product chain is too narrow. Factors such as emissions, the use of fertilisers, pesticides and other resources, waste disposal/recycling, energy for traction and processing and land use should also be taken into consideration. Besides the impact from agriculture, it is also worth mentioning the relevance of upstream processes, i.e. emissions etc. from production of agricultural inputs (fertiliser, pesticides, fuels, buildings, machinery etc.) as well as the emissions etc. from the further processing of the agricultural crops into food products in the food industry (energy use, waste water, use of chemicals, waste, by-products etc.). Such more holistic approaches are found in LCA-studies and to some extent in energy balances. Identified LCA-studies and energy balances comparing single products in terms of 'global' versus 'local' supply are given in **Table 2.2**.

Method	Features analysed	Studies
Energy balances	Fruit juice from Brazil, EU and Germany	Schlich and Fleissner (2005)
Energy balances	Lamb from New Zealand and Germany	Schlich and Fleissner (2005)
LCA	Pork production in Denmark, the Netherlands, Spain, US and Brazil	Weidema et al. (2005b)
LCA	Milk production in Denmark, France, Germany and the Netherlands	Weidema et al. (2005b)
LCA	Impacts of land-use from oil crops: rapeseed in Sweden, soybean in Brazil and oil palm in Malaysia.	Mattson et al. (2000)
IO-LCA	Environmental impacts from products imported to Norway from different regions of the world	Peters and Hertwich (2006)

Table 2.2: Identified studies on the environmental effect of globalisation: single products compared in terms of 'global' and 'local' supply.

In Schlich and Fleissner (2005) energy use for production of fruit juice from Brazil, Europe and German is compared. They conclude that juice from 'global' supply from Brazil to Europe does not change the advantage of global business to a disadvantage because of global transport. Furthermore, they show that the energy use per litre of juice decreases with increasing size of production units. Another case, also in Schlich and Fleissner (2005) concerns a comparison of energy use related to production of lamb in New Zealand with lamb in Germany. The conclusion here is quite similar to the one on fruit juice; energy use is smaller for lamb from New Zealand even though the meat is shipped under strict cooling conditions to Europe, and energy use decreases with increasing size of production units. Weidema et al. (2005b) compares pig production and milk production in different countries using LCA. For most of the included categories of environmental impacts it is shown that Danish pig production is doing quite well compared to the Netherlands, Spain, US and Brazil. However, when looking into occupation of nature, Danish pig production falls short, which is especially due to lower yields of locally produced fodder in Denmark (barley and wheat) than in Brazil and US (maize). Milk production is compared for Denmark, France, Germany and the Netherlands. The main difference here is that Danish milk has a greater contribution to eutrophication than the other countries, and that Danish and French milk causes greater nature occupation than German and Dutch milk. Mattson et al. (2000) compare three oil crops; rapeseed from Sweden, soybean from Brazil and oil palm from Malaysia. However, this study only focuses on one single category of impacts; land-use related impacts, and only on one stage of the life cycle of the oil crops; the agricultural stage. In Mattson et al., it is concluded that with respect to several aspects of land-use rapeseed in Sweden is preferable to Soybean in Brazil. Oil palm is not directly compared to rapeseed and soybean but is discussed with respect to how to include land transformation in LCA. Peters and Hertwich (2006) show that half of the CO_2 emissions embodied in imports to Norway come from developing countries which only represent 10% of the value of the import. Thus, Peters and Hertwich indicate that the environmental performance of products from developing countries is considerably worse than the performance of the products produced in the developed part of the world.

As it appears from the previous section, the identified studies do not provide a clear picture on global versus local product alternatives. There are cases where global alternatives tend to be preferable (fruit juice, lamb and to some extent milk) and cases where the local alternatives tend to be preferable (pig meat and rape).

As described in the beginning of this section, there tend to be a general perception among many NGOs as well as researchers that locally produced food is more environmentally friendly than global food. However, taking the above given product comparisons into account, this link does not seem to be true in all cases - at least not when looking at simple comparisons of global versus local product supply. Furthermore, the referred studies seem to rely on either relatively simplified assessments or only focus on one single type of impact. Schlich and Fleissner (2005) only take energy use into account. Weidema et al. (2005b) are somehow more holistic, taking four environmental categories into account and in addition, site-dependant factors such as environmental vulnerability are accounted for. But still, only four categories of impacts (global warming, eutrophication, acidification and nature occupation) are included and the effects on biodiversity are only dealt with in terms of occupied square meters and the effects from use of pesticides are not included. Mattson et al. (2000) only take the effects of land-use into account. In addition, the consequences of increasing agricultural production of a certain crop in a certain country are taken for granted in all studies. E.g. when Mattson et al. (2000) analyse rapeseed cultivation in Sweden, only the impacts from cultivation of a piece of agricultural land in Sweden are considered. However, it is likely that increased production of rapeseed in Sweden will not cause any impacts in Sweden. It is more likely that the agricultural area is constrained and that increased rapeseed production then will lead to decreased production of alternative crops. This will then lead to increased production of these missing crops in other parts of the World. Thus, I argue that the field of environmental effects of globalisation is not very well investigated, and that the studies which exist are based on relatively simplified assessments.

2.4 Globalisation and the focus of the study

This project takes its point of departure in recognising:

- the problems of globalisation as described by Mol and others
- the lack of empirical studies on local versus global product alternatives
- the lack of holistic approaches to environmental assessment of globalisation and the environment

The project aims at describing the environmental impact of global versus local product alternatives having different product chains, identifying options of environmental improvements throughout the products chains, and analysing the environmental governance regime's capacity for ensuring environmental reform. The description of environmental impacts and the identification of options of environmental improvements is carried out using LCA (see section 4), and the analysis of environmental governance uses the capacity analysis (see section 5).

Even though, this project has a global outlook in the sense that environmental governance is analysed along global product chains, the aim is more normative in its approach to globalisation than the conceptual description of globalisation in section 2.1. Hence, the aim is not to provide an analytical approach to the explanation of the environmental effects of globalisation and the corresponding transformation of institutions. Instead this project focuses on assessment of the actual impacts and on the capacity for improving the environmental performance of global product chains.

As mentioned, an important issue of globalisation research is the role of the nation-state and its receding ability to manage environmental impacts. The analysis of environmental governance in this project includes several influential actors, policy mixes and governing levels (international, national, industry, NGO etc.) (this is further described in section 5). Hence, the role of the nation-state will not be the nodal point of the analysis of environmental governance; its role and capacity will be dealt with as one among several other elements of a broader governance regime.

The next section describes the case chosen for the empirical study; rapeseed oil and palm oil, while section 4 and 5 deal with the applied methods and methodological developments used in the empirical study.

3 The case: Rapeseed oil and palm oil

Analysing the environment and globalisation, it has been chosen to focus on a case study on rapeseed oil from Denmark and palm oil from Malaysia and Indonesia. It is regarded as relevant to focus on vegetable oils as a food commodity for several reasons; 1) Food constitutes a significant share of the environmental impact from consumption, 2) There is an increasing consumption of food commodities – both for food purposes and for biofuel purposes, 3) Food is highly 'globalised' in terms of international trade, and 4) The consumption and production pattern can be arranged in different ways, i.e. based on locally or globally produced commodities. These general characteristics for food have shown to be especially significant in the case of vegetable oils. This is further dealt with in the following.

Furthermore, it is regarded as relevant to focus on vegetable oils and specifically rapeseed oil from Denmark and palm oil from Malaysia and Indonesia because 1) oil and fats make up one of the basic components in food (the other basic components are carbon hydrate and protein), 2) the demand for vegetable oils for biodiesel purposes is increasing, 3) vegetable oils are the most traded food commodity group, and 4) vegetable oils turns out to be one of the significant contributors to the total environmental impact from consumption. Rapeseed oil from the EU and palm oil from Malaysia and Indonesia are chosen because these oils are the two most important oils supplying the EU market.

3.1 Food commodities as an environmental hotspot

Numerous studies on different product groups' contribution to the overall impact from activities and consumption in a society have been carried out (Tukker et al. 2006). Several of these studies show that food turns out to be on the top three list of the most environmental burdening product groups related to consumption (Tukker et al. 2006; Weidema et al. 2005a; Dall et al. 2002). This is not only valid in terms of total environmental impacts from consumption, but environmental intensity measured as environmental impact per monetary unit also shows to be significant for food (Weidema et al. 2005a; Tukker et al. 2006). Other burdening product groups are housing and transportation. The analyses in Weidema et al. (2005a) and Tukker et al. (2006) show that vegetable oils/edible oils are on the top-lists of the overall product groups in economy with the largest total environmental impact as well as the largest impact per monetary unit. Other product groups with high impacts are meat, sugar, bread/cereals and dairy products.

Thus, food production is regarded as a major contributor to the overall environmental degradation. Vegetable oils have been identified as one of the most important product groups within food commodities.

3.2 The production of food commodities is increasing

The world's production of food has been increasing for decades. **Table 3.1** shows the world's production of the major food commodities (annual production > 1Mn t) from 1990 to 2003. During this period, the production of these crops has been increasing with 6 – 84%. The most significant increases are identified for vegetables, vegetable oils, meat and fruits, while increases of the production of cereals, milk have been more moderate.

Commodity	World production (Mn t):				Increase from 1990 to 2003
	1990	1995	2000	2003	
Vegetables	462	564	747	848	84%
Vegetable oils	64	78	95	107	68%
Meat	180	206	235	253	41%
Fruits (excluding wine)	352	408	469	489	39%
Sugar	111	119	132	150	35%
Fish, Seafood	98	115	129	128	31%
Starchy roots	573	629	700	692	21%
Alcoholic beverages	179	191	205	215	20%
Milk (excluding butter)	542	539	579	615	13%
Cereals total (excluding beer)	1779	1715	1861	1886	6%

Table 3.1: World production of the major food commodities 1990-2003 and average annual increase. Only commodity groups for which world production >100 Mn t are shown. Based on food balance sheets obtained from FAOSTAT (2007)

It appears that vegetable oils belong to the most increasing food commodities. In 2003, the world's production of vegetable oils was 107 Mn t where the major oils are palm oil[3] (29%), soybean oil (28%), rapeseed oil (11%) and sunflower oil (9%). Other important oils are groundnut oil (5%), cottonseed oil (4%), olive oil (3%) and coconut oil (3%). **Figure 3.1** shows the world's production of the major vegetable oils 1980 – 2003.

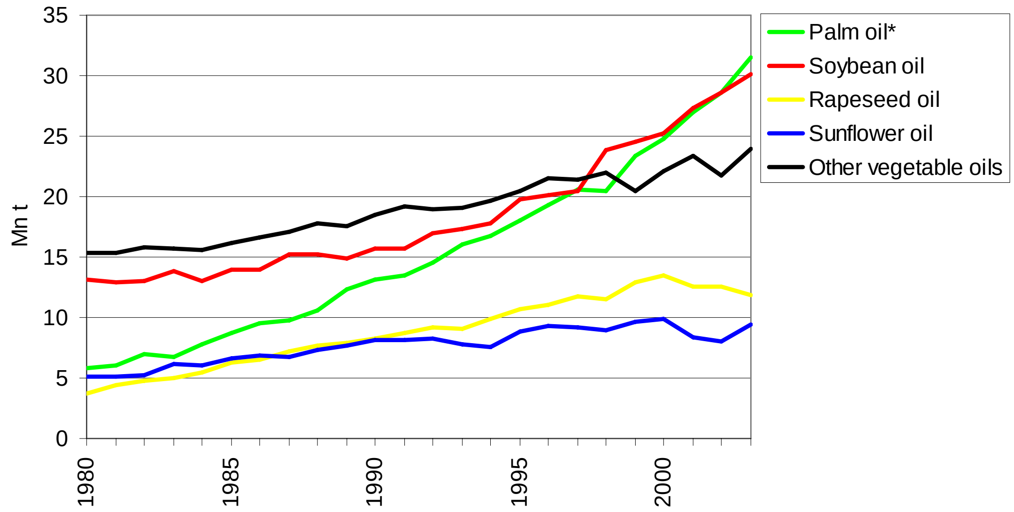


Figure 3.1: World's production of vegetable oils 1980 – 2003. Palm oil is shown as the sum of palm oil and palm kernel oil. Based on FAOSTAT (2007).

It appears from **Figure 3.1** that palm oil is the fastest increasing vegetable oil followed by soybean oil. The production of rapeseed oil, sunflower oil and other vegetable oils have increased more moderately. The declining tendency of rapeseed oil during 2000 – 2003 is according to Oil World (2005) balanced out in 2004 where the production were at the same level as in 2000. Soybean oil is a dependant co-product of soybean meal production which accounts for approximately 65% of the economic output of soybean processing in soybean mills (based on Oil World 2005). Therefore, the increasing tendency of soybean oil is due to increased demand for soybean meal. Consequently, this makes soybean oil less relevant in a comparable study of globalisation and the environment because the demand for soybean oil does not affect the production of soybean oil. Instead the

[3] Palm oil is given as the sum of palm oil (26%) and palm kernel oil (3%). Palm oil is extracted from the pressing of the fruits while palm kernel oil is extracted in a separate process from the pressing of the kernels. The kernel is a by-product of the processing of the fruits.

production of other oils will change (Weidema 2003). Thus, palm oil and rapeseed oil are the two major oils in the world market that are able to respond to changes in demand.

The use of vegetable oils for energy purposes such as biofuel has been on the rise the last years. Thus, the demand for biofuel has affected the prices and the use significantly in the EU. In 1999/00 approximately 15% of the rapeseed consumption in the EU25 was used as biofuel. In 2005/05 this had increased to around 45% (Oil World 2005). The EU directive on biofuels for transport sets targets of 2% market shares of biofuel in 2005 and 5.75% in 2010 (The European Parliament and Council 2003). The European strategy for biofuels puts forward several means of promoting the production of biofuels which includes subsidies for growing rapeseed for energy purposes on set-aside areas (The European Commission 2006). Parallel to this, the Malaysian government has also put forward efforts in order to promote biodiesel produced from palm oil for domestic use as well as for export (Ministry of Plantation Industries and Commodities 2006). Oil World (2005) predicts that the growing demand for biofuel will boost the prices and global production of vegetable oils further in the years to come.

3.3 Food as a highly globalised commodity

Food is often crossing national borders before it is consumed. However, some food commodities are more ‘global’ than others and consequently the most ‘global’ commodities are more relevant for a study on environment and globalisation. The share of the world production of food that crosses national borders before it is consumed is used as an indicator of how ‘global’ food commodities are. **Table 3.2** shows the export share of world production of various crops.

Commodity	World production 2003 (Mn t)	Export share of world production
Vegetable oils	107	48%
Fish, Seafood	128	37%
Sugar	150	31%
Fruits (excluding wine)	489	19%
Cereals total (excluding beer)	1,886	16%
Milk (excluding butter)	615	13%
Meat	253	12%
Alcoholic beverages	215	9%
Vegetables	848	6%
Starchy roots	692	6%

Table 3.2: World production and export share for major food commodities. Only commodity groups for which world production >100 Mn t are shown. Based on food balance sheets obtained from FAOSTAT (2007)

Table 3.2 shows that a considerable share of some food commodities is used in another country than the one in which they are produced. Especially vegetable oils, fish, sugar and fruits are commodities characterised by being widely exported. However, **Table 3.2** does not distinguish between trade between continents and between neighbour countries. But still, it provides an indication of which commodity groups that are ‘global’.

3.4 EU-supply: Local and global alternatives

Numerous major basic food commodities are made up by a range of different substitutable alternatives. E.g. several different vegetable oils are suitable for same purposes, sugar can be based on canes or beet, beef and animal fodder may come from a range of different countries all over the world. These substitutable commodities represent production using different technologies and production in different climate and regions.

Focussing on the supply of vegetable oils to the EU, it appears that rapeseed oil and palm oil constitute the two most important vegetable oils. **Figure 3.2** shows the supply (production + import) of vegetable oils to the EU15.

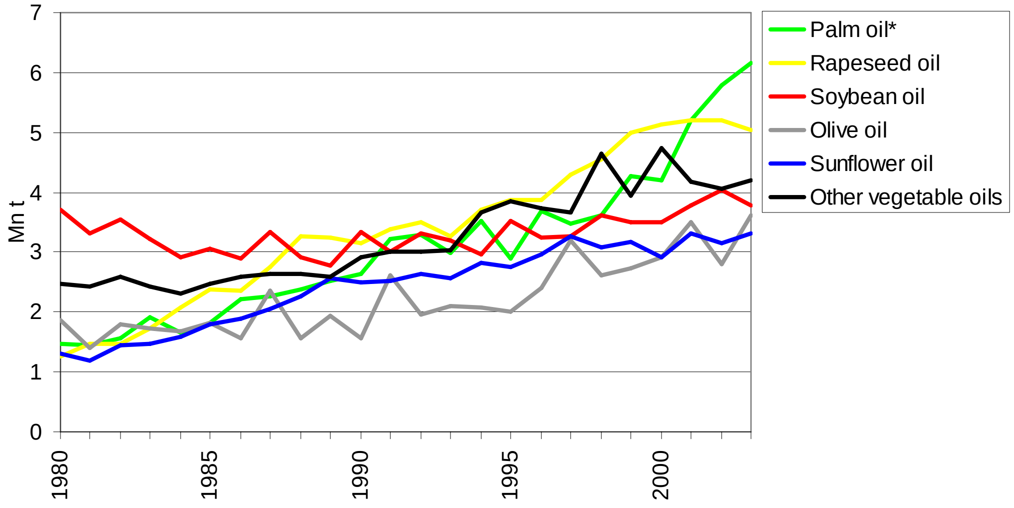


Figure 3.2: EU15's supply (production + import) of vegetable oils 1980 – 2003. Based on (FAOSTAT 2007). * Palm oil is shown as the sum of palm oil and palm kernel oil.

It appears from **Figure 3.2** that palm oil and rapeseed oil are the largest oils supplying the EU15. In 1998, palm oil turned out to be more important than soybean oil and in 2000 palm oil turned out to be the largest vegetable oil in the EU15. In 2003, the EU15's supply of vegetable oils were composed of 24% palm oil (palm oil + palm kernel oil), 19% rapeseed oil, 14% soybean oil, 14% olive oil, 13% sunflower oil, and 16% other vegetable oils.

According to Oil World (2005), the import share of the EU25 supply of rapeseed oil in 2004 was <1% while the import share of palm oil was 100%. Since palm oil is the fastest increasing oil supplying the EU, it seems like there is a shift towards more import of vegetable oils to the EU and consequently export of environmental impacts related to the EU-supply. This tendency is illustrated in **Figure 3.3** which shows the supply (production + import) and production of 17 oils and fats in the EU25.

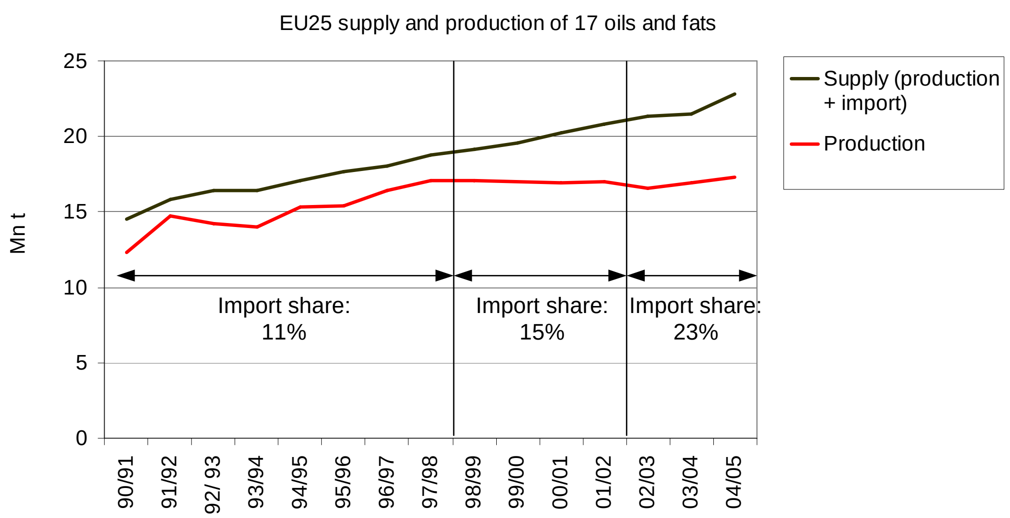


Figure 3.3: Supply and production of 17 oils and fats 1990/91 to 2004/05 in the EU25. Based on (Oil World 2005)

It appears from **Figure 3.3** that the import share of the supply of vegetable oils[4] to the EU25 has increased from an average of 11% during 1990-97 to 23% in 2002-05. Palm oil is the most important contributor to the increase in import share of the supply. Thus, import of palm oil from third world countries to EU25 has increased from 1.6 million tonne in 1991/92 to 4.4 million tonne in 2004/05. During the same period palm oil's share of the total import has increased from around 38% to around 60% (Oil World 2005). Thus, the case of vegetable oils in the EU fits very well into the introducing description of the environmental impacts of the EU which are tending to stabilise within the EU at the expanse of increased import and consequently impacts outside the EU.

It appears from the previous sections that using rapeseed oil and palm oil as the local and the global alternatives respectively of supplying the EU with vegetable oils is a good case when analysing globalisation and the environment. It has been documented that this case is environmentally significant, that the tendency shows increasing production, that the chosen oils are highly traded, and that they are the most important oils regarding the EU supply.

In order to keep the study and the data collection manageable, the case is limited to rapeseed oil from Denmark and palm oil from Malaysia and Indonesia. The primary reasons for choosing Denmark and Malaysia are that this PhD study was initiated under the framework of the DUCED - I&UA project which is a Danish university consortium for environment and development. Beside Danish universities, universities from Malaysia, Thailand and South Africa are in the consortium. Thus, in the case of rapeseed oil and palm oil, Denmark and Malaysia are the obvious countries to focus on. Another reason is very good data availability and good contacts within the agricultural sector and the vegetable oil industry in Denmark and Malaysia. Beside these practical reasons for choosing Denmark and Malaysia, these countries also show to represent European rapeseed oil and 'global' palm oil. In this regard, a good representative of European rapeseed is regarded as a country which is relative close to the European average because the EU is regarded as relatively uniform and that changes in demand are met by uniform changes through out the EU. A good representative of the global supply of palm oil is regarded as the major producers of palm oil and the producers having the greatest growth. This is because these are regarded as the suppliers that are most likely to respond to changes in demand. **Table 3.3** shows the characteristics of the major rapeseed producing countries in the EU25. It appears from **Table 3.3** that Denmark is very close to represent EU25 average cultivation of rapeseed – measured in terms of yield and share of agricultural land covered with rapeseed. **Table 3.4** shows the characteristics of the world's major palm oil producing countries. It appears from **Table 3.4** that Malaysia and Indonesia are the lead countries of palm oil regarding production volume, yield and growth.

[4] The import share of the supply is calculated as the import divided with EU production plus import.

Country	Area cultivated with rapeseed (1000 ha)	Annual yield (t/ha)	Rapeseed share of agr. land
Germany	1,344	3.8	7.9%
France	1,231	3.7	4.2%
United Kingdom	593	3.2	3.5%
Poland	550	2.6	3.5%
Czech Republic	267	2.9	6.3%
Hungary	122	2.3	2.1%
Denmark	**112**	**3.1**	**4.3%**
Lithuania	109	1.8	3.9%
Slovakia	106	2.2	5.5%
Sweden	82	2.4	2.6%
Remaining EU25 countries	249	2.0	0.4%
Total EU25	**4,517**	**3.2**	**3.0%**

Table 3.3: Characteristics of the rapeseed producing countries in the EU25 in 2005. Based on FAOSTAT (2007)

Country	FFB production (Mn t)	Cultivated area (1000 ha)	Annual FFB yield (t/ha)	Annual increase in palm oil production 2000 – 2005 (1000 t)
Malaysia	75.6	3,620	20.9	816
Indonesia	64.3	3,600	17.8	1,433
Nigeria	8.9	3,320	2.7	57
Thailand	5.0	324	15.4	28
Colombia	3.3	170	19.3	28
Remaining world	16.3	1,671	9.8	68
Total World	**173**	**12,705**	**13.6**	**2,429**

Table 3.4: Characteristics of the major oil palm countries in 2005. Based on FAOSTAT (2007). (1) FFB: Fresh fruit bunches, i.e. the harvested oil palm fruits.

Thus, the empirical study of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia used in this project for analysing globalisation and the environment is regarded as a good representative case. The case has environmental significance which is increasing, the commodities of interest are the most important regarding the EU supply of vegetable oils, and they are widely traded globally.

3.5 The case and the focus of the study

The empirical case study of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia is used in an environmental assessment of local versus global product alternatives (see section 4) as well as in the analysis of environmental governance of global commodities (see section 5).

The case is chosen in order to be a good representative of the problems related to globalisation and the environment. The case is used to provide an illustrative example of 1) a comparative environmental assessment of local versus global products and 2) an analysis of environmental governance of global commodities with special focus on the promotion of potential environmental improvements. The specific results and conclusions are intended for use only related to vegetable oils. Hence, the intension is not to draw general conclusions on whether to choose local or global products and how to solve the environmental problems of globalisation in general.

4 Life cycle assessment (LCA) – methodological framework

In section 2 it is described how the analysis deals with globalisation and the environment. It appears that the analysis in this project consists of two elements; an environmental assessment of the effect of globalisation (LCA of rapeseed oil and palm oil) and an analysis of environmental governance along the stages in the product chains. In this section, the methodological framework for LCA is described further and methodological challenges are identified in order to focus on which part of the LCA methodology this project will contribute to.

4.1 Tools for environmental assessment

As described in section 2.3, the few identified existing studies on global versus local product alternatives are based on relatively simplified assessments. Especially the identified NGO campaigns on 'buy local' are based on some taken for granted assumptions, and they only consider the transportation stage in the product chain. Therefore, this approach is considered too blunt. The identified energy balances and LCAs are more holistic in the way that they include more stages of the product chain than only the transport. However, for assessing the environmental effect from rapeseed oil and palm oil as a global and a local alternative several methods are available. **Table 4.1** provides an overview of these available methods. The tools are described in more detail below the table.

Method	Features	Key references
LCA	Measures potential environmental impacts related to a product/service in a life cycle perspective. This includes extraction of raw materials, emissions and waste from all activities related to production, use and disposal of a product/service.	ISO 14040 (2006) and ISO 14044 (2006)
Energy balance	An energy balance may be a simplified LCA only focussing on energy as an impact category	
MIPS (Material input per unit of service)	Measures the mass of materials needed for providing a specified product/service in a life cycle perspective. The material input is made up of five categories: biotic, abiotic, earth movements, water and air. MIPS equals the product's own weight plus the ecological rucksack, i.e. the materials affected which are not part of the product.	Schmidt-Bleek (1993) Hintberger and Schmidt-Bleek (1999)
Ecological footprints	Measures resource use and waste assimilation related to a defined human population or economy in terms of required land. The required land encompasses direct land use (e.g. by crop cultivation) and land needed for assimilation of waste (e.g. needed land area for carbon sink required to absorb CO_2-emissions).	Wackernagel and Rees (1996)

Table 4.1: Available potential methods for assessing the environmental impacts from rapeseed oil and palm oil.

Life cycle assessment (LCA)

LCA is a tool with which the potential environmental effect from a product or a service can be assessed. In an LCA it is attempted to make up all environmental exchanges[5] related to the functional unit. The functional unit is a quantified performance of a product system (ISO 14040 1997). An example of a functional unit is; one kg of non-refined rapeseed oil for food purposes. The product system includes the different stages in the product's life cycle from extraction of raw materials over processing and use to final disposal. The number of different

[5] Environmental Exchange: Physical or immaterial input or output between the environment and the products system. The most common exchanges are: Resources, emissions, land-use and waste.

environmental exchanges included in an LCA often covers several hundred emissions (Schmidt and Thrane, 2006). The several exchanges are translated into a limited number of impact categories, e.g. global warming, acidification and eco-toxicity. Typically, the number of impact categories available in life cycle impact assessment methods varies from 9 to 30 different categories of environmental impacts and several resources (Bengt 1999a and 1999b; Braunschweig et al. 1998; Guinée et al. 2002; Hauschild and Potting 2005, Goedkoop and Spriensma 2001; Wenzel et al. 1997).

Energy balances

Energy balances may be holistic in the way that it captures energy use in all stages of the life cycle of a product. However, it does not capture non-energy related environmental effects such as e.g. land use, toxicity and eutrophication. Thus, I argue that this method is not sufficient when comparing two product alternatives in a holistic way.

MIPS

MIPS is a concept that in many cases is quite similar to LCA. MIPS is, like LCA, based on an inventory of (some) environmental exchanges and a functional unit. But instead of translating the environmental exchanges into impact categories, the weight of the exchanges within the five categories are added. These five measures are used as indicators when assessing the products' environmental profile. As LCA focuses on both inputs from nature (resources) and outputs from the product system (environmental impacts), MIPS only focuses on the input side.

Ecological footprint

It is debatable whether ecological footprint can be used for comparison of two single product alternatives such as rapeseed oil and palm oil. Ecological footprint is developed in order to measure to which degree human populations live within the carrying capacity of the ecosphere (Wackernagel and Rees, 1996, p 11). I argue that when it comes to comparison of two single products the aggregate level of the measurement in ecological footprint becomes too high. The measurement is only given in terms of one indicator – needed productive land. Furthermore, the translation of different human activities, such as emissions of CO_2, into required productive land is often difficult to deal with in a consistent way.

Food miles

'Food miles' is not shown in **Table 4.1**. The concept of food miles, which is used by some NGOs, does not capture other differences in the two product systems than transport distances. Thus, I argue that this concept is not sufficient when comparing product alternatives – even not in the case when applied processing technologies are identical for the two products. This is because it is still not possible to monitor the relative importance of transport compared to the effects from all stages in the life cycle of the product chains.

LCA is chosen as the tool in this study

It appears from the above brief description of different methods for environmental assessment that LCA is the most comprehensive and holistic method. Firstly, the advantages of using LCA include that the environmental assessment may encompass all elements from the other methods. Secondly, LCA ideally includes all affected processes and emissions in a life cycle perspective. Thirdly, the advantages include that LCA can be used for assessing potential environmental effects rather than proxies or aggregate indicators (energy, mass flow, needed productive land etc.) of the environmental impacts as in the other methods. Fourthly, the method of LCA is more developed and widespread than any of the others. During 1997 to 2000, the first version of the ISO-standards on LCA was published (ISO 14040 1997; ISO 14041 1998; ISO 14042, 2000; ISO 14043, 2000). This has recently been updated with ISO 14040 (2006) and ISO 14044 (2006) which replace the old standards. No formalized standards have been developed for any of the other methods. Fifthly, there is an increased use of LCA in policy decisions. This includes both direct use of LCA-studies as decision support (e.g. Schmidt 2005; Kromann et al. 2004) and more general developments through the use of the life cycle perspective in environmental policy (e.g. EU's waste strategy (The European Commission 2003b) and the development of integrated product policy, IPP (The European Commission 2003a). The issue of IPP will be dealt with in more detail in section 5.4 'Capacity for environmental governance in product chains and integrated product policy (IPP)'. Hence, among the described methods, LCA is the most holistic and comprehensive method as well as it is the most used as decision support in policy decisions.

4.2 Life cycle assessment

In the previous section, LCA is regarded as being the most comprehensive and holistic method for carrying out a comparative environmental assessment for the purpose of this study. Notwithstanding the advances of LCA, there is also a number of product specific factors and general inherent problems within the method that have to be addressed. But before going more into detail with these aspects, the general framework of an LCA will be described. The general framework for an LCA is described in ISO 14040 (2006) where an LCA is defined as: "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*" (ISO 14040 2006, p 2). The term 'life cycle' refers to the stages in a product system from raw materials to final disposal. A product system is a collection of connected processes which together perform one or more services. A simplified example is the product system of rapeseed oil production which consists of use of fertilisers, pesticides and traction in the agricultural stage and use of energy and ancillary materials in the milling stage. Inputs and outputs describe both material and energy flows between processes (intermediate flows) and between the environment and the product system (elementary flows). Even though not referred to in the ISO-standards, there are several examples on included inputs and outputs in LCA-studies that are not characterized by being either a material or energy flow. On the input side, we have land use that in some LCAs are considered as resource use on the same level as the use of metals and mineral oil ores, for an example see ecoinvent (2004). On the output side there are noise and aesthetics. However, these outputs are usually not included in LCAs. Finally, there are some aspects which can be described as neither inputs nor outputs. These are the causes that contribute to a certain level of working environment. Again, these aspects are seldom included in LCAs. However, some recent guidelines on how to include working environment in LCA have been published by the Danish EPA, see Schmidt et al. (2004). Thus, indicating that inputs and outputs may include material/energy as well as non-material/energy flows, I use the term 'interventions' which is also used in Udo de Haes et al. (2002). In the ISO definition of LCA, environmental impacts are referred to as potential environmental impacts. The reason for that is that the indicator results of the included impact categories do not consider detailed site-specific conditions such as actual intake of emitted hazardous substances and the sensitivity of the specific recipients (ecosystems) of the emissions.

According to the ISO standards, an LCA includes four phases; Phase 1: Definition of goal and scope, Phase 2: Life cycle inventory (LCI), Phase 3: Life cycle impact assessment (LCIA) and Phase 4: Life cycle interpretation. The four phases are briefly described in the following.

Phase 1: Definition of goal and scope

The first phase of an LCA covers definition of goal and scope. Two important elements of the first phase are the functional unit and system delimitation[6]. The functional unit is a quantified service, to which all interven-

[6] System delimitation: The overall boundary conditions and the approach to system delimitation are defined in the first phase while the actually modelling, which is also part of system delimitation, is carried out in the second phase.

tions are related. The system delimitation includes a geographical, technological and temporal delimitation in LCA. In recent years, the approach to system delimitation has turned from the attributional approach towards the consequential approach. However, proponents of the attributional approach and opponents of the consequential approach still exist (Ekvall et al. 2005).

The attributional approach to system delimitation represents the traditional way of identifying affected processes[7] and to handle co-product allocation in LCA. In attributional modelling in LCI, the included processes are often represented by average data and co-product allocation is handled by using allocation factors. An example of an attributional LCA is a life cycle assessment of Danish electricity and heat (Eltra et al. 2000). In Eltra et al. (2000) the affected processes are assumed to be an average of the used technologies producing electric power in Denmark, which is a mix of coal, natural gas, waste incineration and wind power. For several of the technologies (central and de-central coal and natural gas plants and waste incineration plants) electricity is co-produced with heat. Co-product allocation is handled by application of allocation factors (obtained by either energy or exergy content). Another example is the ecoinvent LCI database which consists of more than 2500 processes (Ecoinvent 2004). Again, material and energy inputs are applied as averages and co-product allocation is handled by application of allocation factors obtained either by mass or energy content.

Initiated by the Danish environmental protection agency, a project on LCA methodology and consensus has been carried out during the period from 1997 to 2003 (Hansen 2004). The Danish Methodology and Consensus Project advocates using the consequential approach. The specific arguments for the consequential approach are to be found in Weidema (2003). Here, the basic argument against the attributional approach is that it does not give a causal explanation of consequences of past and future actions. Weidema argues that only the actually affected processes should be included, i.e. the marginal processes. Using the consequential approach on the above mentioned example on electricity, the affected technology is coal or gas since all other technologies are constrained or determined by other factors than the marginal demand for electricity. Furthermore, the consequential approach implies that co-product allocation is avoided by system expansion (Weidema 2003). The problems related to the use of allocation factors in the attributional approach are, that the various co-products are ascribed to a certain share of the total environmental impact from a process. In most cases this approach does not describe the actual cause-effect mechanisms when changing the demand for one of the co-products. An example is a rapeseed oil mill which produces rapeseed oil as well as rapeseed meal (used for fodder purposes). When increasing the demand for rapeseed oil, the whole rapeseed oil mill will be affected (and not only a fraction defined as the allocation factor as prescribed in the attributional approach). Then the co-product, rapeseed meal, will displace the alternative production of animal fodder. This is what is taken into account in consequential LCA. Basically, consequential LCA strives towards predicting the consequences of a change in demand/production of a product or service, while the attributional approach describes how production is taking place today.

Schmidt (2004) and Villanueva et al. (2004) argue that in the cases of vegetable oils and pulp and paper respectively, the outcome of LCA studies heavily depends on assumptions related to system delimitation.

It has been chosen to use the consequential approach to system delimitation as the default approach. Results of attributional modelling are only included at the level of sensitivity analyses. There are several arguments for using the consequential approach: 1) Since the purpose of the LCA is to assess and compare different product alternatives and improvement potentials and then use this in a governance and capacity analysis, the study can be characterised as a change oriented study aiming at supporting future decisions. Therefore, it is regarded as

[7] Processes: This may be in terms of technologies or suppliers

essential that the results reflect the consequences of future actions, which is what the consequential approach strives towards. 2) The production of vegetable oils is characterised by having two significant product outputs, i.e. the vegetable oil and the oil meal[8]. This makes the issue of co-product allocation relevant and according to Schmidt (2004), also very significant for the results. As described in the previous, numerous different allocation factors exist, i.e. they may be obtained by mass, energy content, fodder value, economic value etc. Hence, the choice of allocation factor may be more or less randomly chosen and the choice is founded in more subjective arguments rather than founded in the cause-effect chain. Therefore, as the consequential approach prescribes, avoiding co-product allocation by system expansion is regarded as more consistent and more rationally founded. 3) As referred to in the previous, the marginal source of electricity and other inputs to the system may be different from the average technology/supplier used. The consequential approach prescribes that the marginal source should be identified. Since decisions relating to the product chain of rapeseed oil and palm oil will not affect average technologies/suppliers as default, the consequential approach is again regarded as more consistent and rationally founded. An example of where the attributional approach does not reflect actual cause-effect chains is in the case when average electricity is used as default (including wind power, hydro power and power from waste incineration). It is obvious that a change in the use of electricity in the oil mill will not affect these technologies: wind and hydro power are determined by political decisions on renewable energy and on natural resources (wind and rainfall) and power from waste incineration is determined by the amount of waste.

Phase 2: Life cycle inventory (LCI)

The second phase of an LCA is the life cycle inventory analysis (LCI). In this phase quantitative and qualitative data on environmental interventions for each process are collected. The collected data are then related to the functional unit.

The main work of an LCA is normally in the LCI phase where the key activities are data collection and modelling of affected processes (identification of marginal processes and avoiding co-product allocation by system expansion).

The quantitative outcome of the inventory analysis is a list of interventions related to the functional unit and possible qualitative descriptions of the environmental impact from the different stages. This part of the LCI outcome is illustrated in **Figure 4.1** as the interventions between the environment and the product system. It is possible to assess the results based only on the inventory analysis. However, difficulties may arise because the outcome of the inventory phase often consist of several hundreds interventions (mainly emissions). Hence, the results are normally assessed and interpreted based on the third phase, see next section.

Phase 3: Life cycle impact assessment (LCIA)

The third phase of an LCA is the life cycle impacts assessment (LCIA). In the LCIA the outcome from the LCI is compiled into a limited number of impact categories; e.g. global warming, acidification and ecotoxicity. There are impact categories both related to inputs interventions and to output interventions from the system. Global warming and ecotoxicity are examples of impact categories that are linked to outputs (emissions) from the system while use of crude oil and aluminium are examples of categories that are related to inputs to the system. In LCIA there are two main elements; characterisation and valuation. Characterisation includes assessment of the magnitude of the impacts, and valuation covers assessment of the importance of impacts (Hertwich et al. 2002). In the ISO standards, the valuation elements are referred to as 'Optional Elements'. In the characterisation, connections from the stressors (interventions) found in the LCI are drawn to valued items,

[8] Oil meal: The residual after the oil seeds are pressed in the oil mill. Oil meal is rich in protein content and energy and is used for animal fodder.

such as ecosystems and human health etc. These connections are expressed in cause-effect chains, describing environmental mechanisms (Hertwich et al. 2002). The traditional approach to LCIA is in Hertwich et al. (2002) referred to as bottom-up. This reflects that the starting point of developing LCIA models is the stressors or interventions. These interventions are then via the characterisation compiled into magnitudes of potential impacts. Finally the importance and relative importance are assessed in the valuation part. An alternative approach to LCIA models is the top-down approach. Here point of departure is taken in the areas of protection which describe the end-points in cause-effects chains (e.g. lung cancer from different stressors). From there, the development of LCIA models draws the connections to the relevant interventions. The output from characterisation is expressed in a number of category indicators. These indicators may express the magnitude of impacts at different levels along the impact chain or cause-effect chain. Distinction is made between end-point and mid-point indicators. In the case of global warming, the global warming potential expressed as carbon dioxide equivalents is an example of a mid-point indicator. The corresponding end-point indicator could express the effects in terms of e.g. impacts on human health and ecosystems caused by an increased number of storms, changed precipitation distribution, increased sea level etc. The valuation may accordingly to the ISO standards include normalisation, grouping and/or weighting. Normalisation relates the magnitude of each impact to a reference, e.g. contribution per citizen per year of that specific impact category. Normalisation is used to give an impression of the importance of the different impacts. Grouping includes assigning of impacts into sets and may include ranking. Weighting is a conversion of indicator results using numerical factors which is based on value choices. Weighting is used for comparing across impact categories and for identifying the most significant impacts. The most common impact categories in LCIA are shown in **Figure 4.1**.

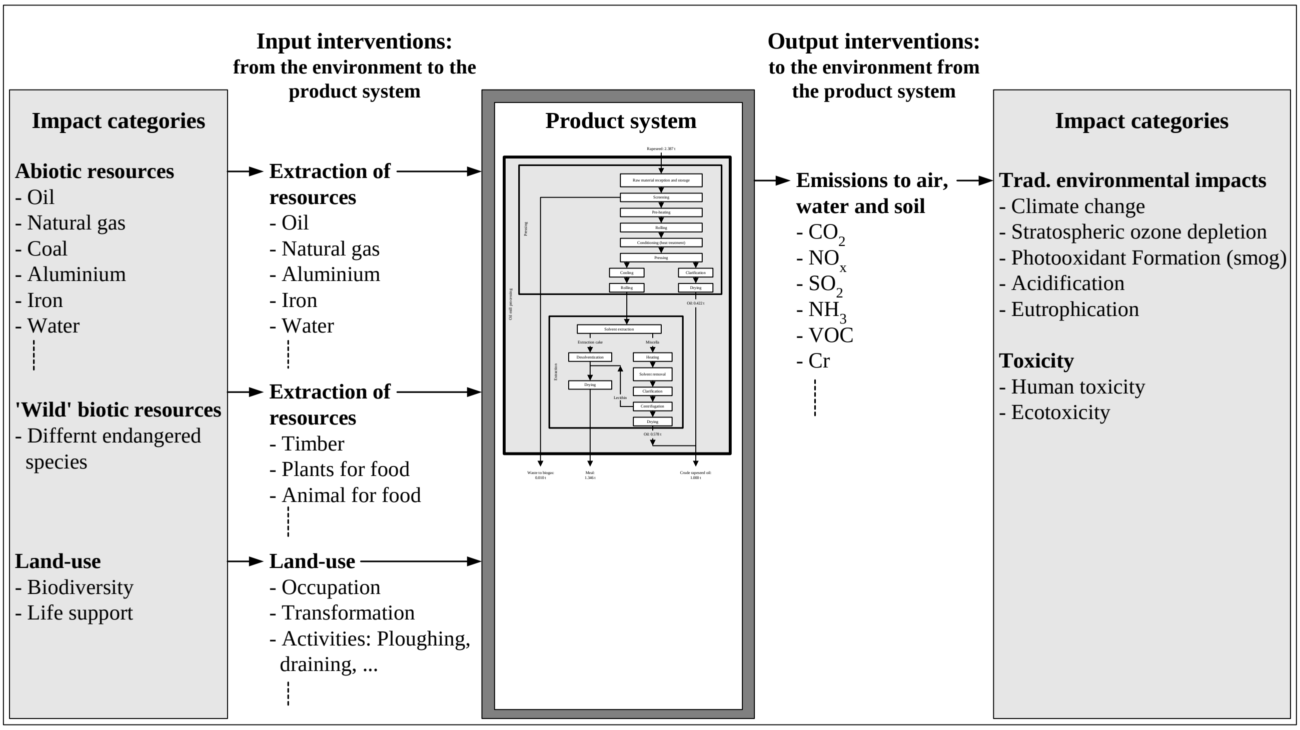


Figure 4.1: Overview of the most common impact categories. The identification of impact categories is based on Udo De Haes et al. (2002) and the figure as based on Schmidt (2005).

Udo De Haes et al. (2002) provides an overview of best practise within existing methods for LCIA in 2002. Here it appears that the least developed impact categories of the ones shown in **Figure 4.1** are the ones related to land use. The existing LCIA methods for land use are at a stage where there is a lack of agreed principles, definitions and objectives, and common for all LCIA methods related to land use are, that they are relatively new and untested (Lindeijer et al. 2002). In addition, existing methods for assessing ecotoxicity and human toxicity are appointed as impact categories that are encumbered with problems. LCIA methods for human toxicity have problems regarding environmental relevance, uncertainty, and the number of included substances (Krewitt et al. 2002). And LCIA methods for ecotoxicity have significant problems regarding uncertainties (Hauschild and Pennington 2002). As a result of the present lack of agreed LCIA methods for land use, LCAs ability to assess environmental impacts related to land use is often referred to; e.g. Koellner (2002), Mattson et al. (2000) and Schenck (2001). A consequence of the lack of agreed LCIA methods for land use is that impacts of land use are often excluded from LCA studies. Some examples of LCAs of agricultural products which do not include land use are: LCA of beer (Talve 2001), LCA of sugar (Ramjeawon 2004), LCA of vegetable products and meat (Jungbluth et al. 2000) and LCA of tomatoes and bread (Andersson 2000). And when land use is included, it is typically included in terms of square metres of occupied and possibly transformed land per functional unit, without considering the consequences of the activities (e.g. impacts on biodiversity and life support). Examples of up-to date and state of the art LCAs on agricultural products that only include land use in terms of square metres are Nielsen et al. (2003) and Weidema et al. (2005b). Since this project is centred upon agricultural production, I argue that land use is of particular importance. Another factor that stresses the importance of land use is that the two products (oil palm in Malaysia/Indonesia and rapeseed in Denmark) probably will have significantly different impacts regarding land use – both in terms of occupied and transformed land and in terms of biodiversity. Thus, this project will test and evaluate existing LCIA methods for land use, and based on that, develop a new improved method.

Regarding the other impact categories several sets of LCIA methods are available; EDIP97 (Wenzel et al. 1997), EDIP2003 (Hauschild and Potting 2005), Eco-indicator 99 (Goedkoop and Spriensma 2001), Impact 2002+ (Jolliet et al. 2003), CML 2 baseline 2000 (Guinée et al. 2002), Ecopoints 97 (Braunschweig et al. 1998), EPS 2000 (Bengt 1999a and 1999b), Stepwise 2006 (Weidema et al. 2007). Each of these sets of LCIA methods includes a number of LCIA methods for single impact categories and in addition most of them also include methods for normalisation and weighting. According to Dreyer et al. (2003) and Schmidt (2005), the choice of LCIA method can have significant influence on the results – especially within human toxicity and ecotoxicity. In this study, point of departure is taken in the Danish EDIP97 method. As the choice of LCIA method may influence the LCA-results other methods are also applied as a sensitivity analysis in order to minimize uncertainties related to LCIA. EDIP2003, which is the update of EDIP97, is not yet included in any LCA pc software and it only contains site dependant factors for Europe. Thus, EDIP2003 is not used in this study because; 1) EDIP2003 will be difficult to apply (not available in the used pc-software SimaPro) and 2) it is difficult to make it operational in an LCA of palm oil in Malaysia and Indonesia since site specific factors in the method only cover Europe.

Phase 4: Life cycle interpretation

The fourth phase of an LCA is the life cycle interpretation, which is described in ISO 14044 (2006). The interpretation phase includes three parts; 1) identification of significant issues, 2) evaluation of completeness, sensitivity and consistency and 3) conclusions and recommendations. Significant issues may be LCI categories such as energy or waste, impact categories such as global warming or land use, and essential contributions from stages in the life cycle. Sometimes the identification of significant issues is made in connection with the LCIA, e.g. Schmidt (2005), Thane (2004) and Kromann et al. (2004). Evaluation of completeness includes a review of the collected information considering if there is any missing or incomplete information. Sensitivity check includes an assessment of the results from sensitivity analyses and uncertainty analyses performed in the LCI and LCIA phases. In the consistency check methods, data and assumptions are assessed in relation to goal and scope.

4.3 Life cycle assessment and the focus of the study

The major part of the research of this project is related to the application of LCA on the empirical case study of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia. The first of the research issues is obviously the comparative LCA itself. However, some lacks in methodology for agricultural LCA are identified as well as the need for additional empirical inputs have been recognised. Therefore, in total five research issues related to LCA have been defined in this study. These are:

1. Comparative LCA of rapeseed oil and palm oil
2. Development of LCA methodology: System delimitation in the oil mill stage
3. Development of LCA methodology: System delimitation in the agricultural stage
4. Development of LCA methodology: LCIA method for land use related impacts on biodiversity
5. Empirical input to the comparative LCA of rapeseed oil and palm oil: LCA of soybean meal

Each of the single research issues represents a research article each and they are explained further in the following.

Research issue 1: Comparative LCA of rapeseed oil and palm oil

LCA is chosen as the most comprehensive and holistic approach for carrying out a comparative environmental assessment of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia. The comparative LCA is carried out in accordance with the ISO 14040 and 14044 standards. The consequential approach to system delimitation is used.

Detailed data collection and modelling for Danish rapeseed cultivation/Malaysian oil palm cultivation, oil mills and refineries is carried out. Data on rapeseed cultivation are collected and modelled in collaboration with the Faculty of Agricultural Science, Aarhus University (Randi Dalgaard), data on rapeseed oil milling and refining are primarily collected in cooperation with AarhusKarlshamn (Aarhus), and data on oil palm cultivation, and palm oil milling and refining are collected in cooperation with United Plantations Berhad (Malaysia) and the Malaysian Palm Oil Board (MPOB). Data on Indonesian palm oil production are assumed to be represented by Malaysian figures adjusted for FFB yield.

Research issue 2: System delimitation in the oil mill stage

Weidema (1999) was the first to deal with the problem of avoiding co-product allocation in the case of LCA of vegetable oils. Weidema (1999) presents a study on rapeseed oil. The co-product of rapeseed oil, rapeseed oil meal, displaces the marginal source of protein which is identified as soybean meal. The displaced soybean meal is co-produced with soybean oil. If the system expansion stopped here, the net output of vegetable oil from production of 1 t rapeseed oil would be less than 1 t because some soybean oil is displaced. This implies that the displaced soybean oil causes a corresponding increase in the production of the marginal source of vegetable oil, which Weidema identified as rapeseed oil. Then, again this rapeseed oil is associated with the co-product rapeseed meal, and the so called rapeseed-soybean loop is established. However, in Nielsen et al. (2005), it is realised that the ratio between the protein content and the fodder energy content is not equal for rapeseed meal and soybean meal. Therefore, the marginal source of fodder energy is also affected. This implies that production of vegetable oils is actually associated with three product outputs; vegetable oils, fodder protein and fodder energy. In addition, different oil crops are inter-connected as described above. This leads to some quite complex iterative calculations that, according to Thane (2004), should be solvable in much easier manageable matrix calculations. Thus, the management of the calculations in the system expansion related to the co-production of vegetable oils, meals and fodder energy is an issue that will be dealt with in this study.

Another important related issue is the identification of the marginal sources of vegetable oil, fodder protein and fodder energy which significantly affects the calculations.

Research issue 3: System delimitation in the agricultural stage

The consequential approach to system delimitation prescribes, that the actual affected processes should be included. Thus, e.g. when increasing the production of rapeseed in Denmark it should be considered how this increase is actually achieved. This means that it should be considered if the increased production is achieved by increased cultivated area or increased yield. And when increasing the cultivated area, it should be considered if this affects the cultivation of other crops in Denmark. Since the agricultural land have been slightly decreasing for more than 50 years in Denmark, it is not likely that increased cultivation of rapeseed in Denmark will affect the occupation of agricultural land nor the transformation of nature into agricultural land. Instead, increased cultivation of rapeseed will affect the area cultivated with other crops, e.g. barley. Thus, the land use effects of rapeseed cultivation in Denmark will probably take place outside Denmark. No LCA studies considering or incorporating this mechanism has been identified (Nielsen et al. 2005, Dalgaard et al. 2007, Cederberg and Stadig 2003, Ecoinvent 2004 and CenterNovem 2005). All identified agricultural LCAs implicitly presume that increased production of crops is achieved by increased cultivated area. However, this area has not been located in any LCA. In addition, the affected land is assumed to be the land under the crops of interest in all identified LCAs, i.e. nutrient balances and emissions are inventoried from the area under the crops of interest.

Based on the above reasoning, it is argued that existing agricultural LCAs do not take into account the actual affected processes, and therefore the development of a method for system delimitation in agricultural LCA will be a major research issue in this study.

Research issue 4: Assessment of land use related impacts in LCIA

It appears from section 4.2 that the present methods for LCIA of land use related impacts are lacking agreed principles, definitions and objectives, and common for all LCIA methods related to land use are, that they are relatively new and untested. In addition, the impacts of land use in existing agricultural LCAs are typically measured in terms of occupied land only, i.e. the impacts on biodiversity are not quantified. Therefore, a major research issue of this study is to develop an LCIA method for land use effects on biodiversity. Other land use effects such as life support (effects on water cycle and from erosion) could also be included. However, biodiversity is regarded as the most significant impact related to land use and therefore it has been chosen to focus on that.

Another significant issue that may be as relevant as land use is LCIA methods for toxicity – especially in relation to pesticides in agricultural LCA. However, more methods for assessing toxicity than land use exist, the existing methods for toxicity are more well tested and toxicity is included in most sets of LCIA methods; EDIP97 (Wenzel et al. 1997), EDIP2003 (Hauschild and Potting 2005), Eco-indicator 99 (Goedkoop and Spriensma 2001), Impact 2002+ (Jolliet et al. 2003), CML 2 baseline 2000 (Guinée et al. 2002), EPS 2000 (Bengt 1999a and 1999b) and Stepwise 2006 (Weidema et al. 2007). Therefore, the need for the development of LCIA methods for land use is regarded as more significant than the need for LCIA methods for toxicity.

The development of the LCIA method for land use related impacts takes its point in departure in recognising that the existing methods are either too coarse-grained regarding the differentiation between different land use types (e.g. conventional farming versus organic farming), or they are too narrow regarding spatial coverage (e.g. only part of Europe). Regarding the specific purpose of this study of comparing rapeseed oil with palm oil, these characteristics of existing LCIA methods poses a substantial limitation in the comparison exercise of the impacts on biodiversity. The developed LCIA method strives towards incorporating the strengths of the two types of existing LCIA methods in order to have a detailed model with global coverage.

Research issue 5: LCA of soybean meal

As described in ‘Research issue 2: System delimitation in the oil mill stage’ soybean meal is identified as the marginal source of fodder protein. Therefore the production of soybean meal may be significantly affected. The existing LCA data on soybean meal (soybean cultivation and processing of the soybeans in the oil mill) are of a relatively poor quality. The identified existing data are from Nielsen et al. (2005) and Ecoinvent (2004). Nielsen et al. (2005) is on the level of an LCA screening and Ecoinvent (2004) represents soybean cultivation in Switzerland. Swiss soybeans accounted for only 0.0019% of the world’s production in 2005 (FAOSTAT 2007). Thus, when considering the marginal supply of soybeans, Switzerland is completely irrelevant. According to Weidema (2003), the marginal supplier of fodder protein is either USA or Brazil while Nielsen et al. (2005) identify the marginal supplier as Argentina.

An LCA of soybean meal will be carried out. This will serve as a data input to the comparative LCA of rapeseed oil and palm oil.

5 Capacity for environmental governance – theoretical framework

A part of this study is an analysis of environmental governance along the stages in the product chains. In this section, the theoretical framework for analysing environmental governance is described. The aim of the analysis is to identify and characterise the capacity for environmental governance for some identified environmental improvement options for rapeseed oil and palm oil. The improvement options are identified through the comparative LCA of rapeseed oil and palm oil described in the previous section.

Ecological modernisation is used as an overall theoretical framework. The analysis takes its point of departure in the concept of governance. It is chosen to analyse governance rather than government regulation because the range of institutions and interventions affecting the environment is broader than just nation-state government environmental regulation (Jänicke 1997; Mol 2000; World Bank 2000). Analysing environmental governance, the concept of capacity for environmental protection described in Jänicke (1997) is found to be useful. The capacity problem is relevant especially in the case of new environmental problems where existing capacity tend to be out of scope and inadequate (Jänicke 1997). A good example of such 'new environmental problems' are the problems related to globalisation as described in section 2.

5.1 Ecological modernisation as an overall conceptual framework

Ecological modernisation is used as an overall conceptual framework for the analysis. Ecological modernisation is among others described in Mol and Sonnenfeld (2000), Carter (2001), Gouldson and Murphy (1998) and Dryzek (1997), and is referred to as: "*… a restructuring of the capitalist political economy along more environmentally sound lines*" (Dryzek 1997, p 141). Ecological modernisation perceives environmental degradation as a structural problem which can be dealt with by focussing on how the economy is organized. In that respect, ecological modernisation prescribes that environmental criteria must be built into a redesign of the system. Ecological modernisation may be analytically utilised in different ways. There are two main uses of the concept; 1) ecological modernisation as an analytical tool to understand the processes of environmental reform, and 2) ecological modernisation as both an analytical tool and as a normative description of desirable paths for environmental reform (Mol and Sonnenfeld 2000). Examples of other perspectives on the processes of environmental reform which ecological modernisation is demarcated from are 'deindustrialisation', 'small-is-beautiful' and 'radical (deep) ecology' (Mol and Sonnenfeld 2000). Operationalisation of the concept as an analytical tool can be done in several ways. According to Sonnenfeld (2000), operationalisation may include analysis of technological/materially transformations, processes of integration of ecology and economy and finally social and institutional transformations, which in particular focus on the transformation from nation-state based environmental regulation towards negotiation with industry, key role of NGOs and the supportive role of globalisation. Thus, ecological modernisation as an overall conceptual framework provides the focus point of the identification of environmental improvements (i.e. by restructuring the existing institutions[9]) and it provides some important and useful categories which the analysis may focus on.

The use of ecological modernisation as an overall conceptual framework implies that the main focus of the study is on the existing arrangement of the economy (institutions) and that solutions will be sought by changing these institutions. These changes encompass both technical and institutional changes.

[9] The term 'institutions' is to be interpreted broadly including e.g. regulation, actors and economy affecting the environmental performance of a system.

5.2 Definition of environmental governance

The focus point of the analysis is environmental governance. Environmental governance is a good expression of what is at stake in the concept of ecological modernisation. UNDP et al. (2003, p 2) define environmental governance as "*… the exercise of authority over natural resources and environment*". Thus, in popular terms environmental governance is the answer to the questions: "*Who let it happen?*" and "*Who is responsible for this mess?*" (UNDP et al. 2003, p 6). According to UNDP et al. (2003), environmental governance covers seven elements:

1. Institutions and laws
2. Participation rights and representation
3. Authority levels
4. Accountability and transparency
5. Property rights and tenure
6. Markets and financial flows
7. Science and risks

These elements together form the exercise over natural resources and the environment. The state of the environment is a result of the interplay between economic, physical and social forces, and these forces are affected by actors (governments, corporations, individuals etc.). Environmental governance describes these forces and actors. Defining the scope of the analysis of environmental governance, the definition implies that not only traditional nation-state environmental regulation is included, but also actions beyond these taken by government diplomats and regulators are included. These include decision-making in other sectors and with other purposes than environmental incentives and decision-making outside the government institutions. An example of decision-making in other sectors that influence the state of the environment is EU import duties and agricultural subsidies, which affect the relation between prices of locally produced commodities and imported commodities, which again affects the share of 'local' versus 'global' supply. And since the environmental impact from 'local' and 'global' supply probably differs, these kinds of decision-making indirectly affect the environment. An example of decision-making that occurs outside government institutions is Round Table on Sustainable Palm Oil (RSPO), which is a voluntary WWF initiated initiative on sustainable palm oil (RSPO 2007). Thus, the analysis of environmental governance strives towards including all relevant institutions which together form what I call a regulatory regime.

5.3 Environmental capacity

Analysing environmental governance, the concept of capacity for environmental protection is used as a theoretical framework. The aim of the analysis is to describe how the environmental problems along the product chains of rapeseed oil and palm oil are addressed and to analyse the capacity of environmental governance regarding implementation of improvement options. According to Jänicke (1997), the capacity problem is relevant especially in the case of new environmental problems where existing capacity tend to be irrelevant and inadequate. In his analytical framework for environmental capacity, Jänicke (1997) uses OECD's definition of environmental capacity; "*a society's ability to identify and solve environmental problems*" (Jänicke 1997, p 1). The concept points at the limitations and preconditions for managing a given environmental problem. Well known examples of such limitations are lack of knowledge, regulation, resources and weak institutions. As mentioned previously, a society's capacity for handling environmental problems is related to various structures and actors, described with the concept of environmental governance and not only government policy. Therefore, Jänicke (1997) uses the term 'capacity for environmental policy and management'. Relating to the previous section, I will use the term 'capacity for environmental governance' in this study. The meaning of the two terms is the same.

Jänicke (1997) points at four advantages of using the concept of environmental capacity. The first one is that the concept is not restricted to the wrong actions or “intervention failure” only. It also takes into account the structural characteristics which matter, e.g. resources and institutions. The second advantage is that the concept is closely related to development – political development or modernisation. The focus is to develop and increase the capacity for environmental governance and the starting point is the existing actors, resources and institutions. Thus, the concept of environmental capacity goes well in hand with the processes of sustainable development and the ecological modernisation which is used as the overall conceptual framework in this study. The third advantage is that the concept is practically oriented and it is realistic regarding the difficulties of not yet solved problems. Fourth, the concept of environmental capacity provides the opportunity for comparison of different countries’ capacity for environmental governance. The last mentioned advantage refers to the nature of most capacity analyses. Typically, the capacity for governing a specific environmental problem in different countries is compared and then, based on that, suggestions for the needs for capacity-building are given (Mertz 2006; Jänicke and Weidner 1997; Weidner and Jänicke 2002). However, this approach somehow contradicts the application of the capacity analysis in this study where the environmental capacity analysis is delimited by the boundary of product chains instead of country borders. This difference is not regarded as a limitation in the use of capacity analysis, but still attention will be given to this issue in the analysis.

The applied theoretical framework for the analysis of capacity for environmental governance is obtained from Jänicke (1997). The framework is described in the following. According to Jänicke (1997), the outcome of environmental protection is influenced by; 1) actors, 2) strategies, 3) systemic framework conditions, 4) situative context and 5) structure of the problems to be solved. And in addition, the structure of the problems to be solved as well as the capacity to respond to them are affected by economical performance of society (in general as well as related to the problem). **Figure 5.1** illustrates a model of policy explanation showing the interplay between above mentioned influencing factors.

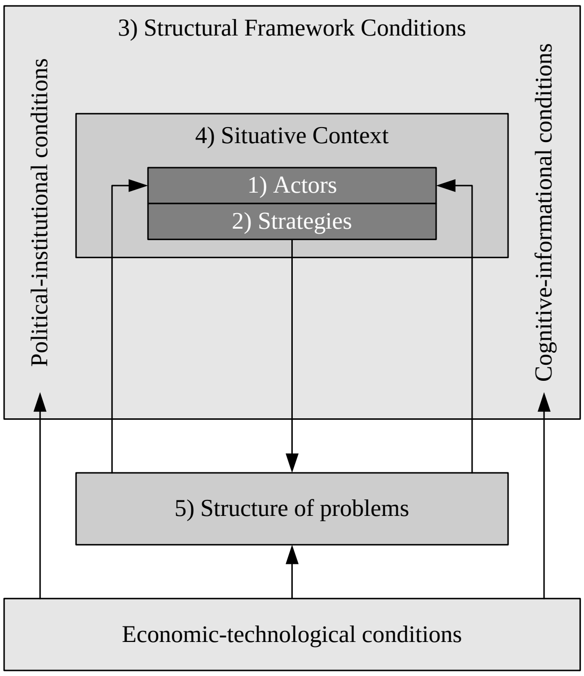


Figure 5.1: Influencing factors on a society’s capacity to respond to environmental problems and their interplay. The numbers refer to the explanation in the text in this section. Based on (Jänicke 1997, p 5)

The influencing factors and the interplay between factors in **Figure 5.1** are explained in the following. The explanation is based on Jänicke (1997).

The *actors* (1 in **Figure 5.1**) are defined as the proponents and opponents of a special issue, their support groups and third parties. Actors' capacity for action depends among other tings on their strength, power, competence, and constellation with other actors.

The *strategy* (2 in **Figure 5.1**) constitutes the general approach to the problem. More specifically it may be expressed as the purposeful use of instruments, capacities, and situative opportunities to achieve goals. The content of strategies may depend on knowledge and the possibility of action.

The *structural framework conditions* (3 in **Figure 5.1**) can be described as the opportunity structure of the relevant actors. The framework is made up by cognitive-informational, political-institutional and economic-technological framework conditions:

- *The cognitive-informational conditions* are the ones under which environmental information is produced, distributed, interpreted and applied. Knowledge is necessary to perceive a problem, to have public awareness, and a policy process targeting the problem. Available knowledge (threats and options) combined with environmental consciousness is an immediate resource for actors while culture is a background condition.
- *Political-institutional conditions* include the constitutional, institutional and legal structures and the rules and norms in and between the institutions. According to Jänicke (1997), special emphasis should be given to participation, integration and long-term action.
- *Economic-technological conditions* are defined as the performance, technological standard, sectoral composition, or general availability of raw materials. According to Jänicke (1997), these conditions are no easy target for environmental capacity building. However, factors such as price structures may be influenced by e.g. fiscal policy. In **Figure 5.1** it appears that the economic performance influences both the structure of problems and the structural framework conditions. Whereas influence on the problems is often of a direct character, the influence on the structural framework is more indirect.

The *situative context* (4 in **Figure 5.1**) is the short-term variable conditions of action which described the immediate driving forces for environmental incentives. Public debate and pressures on specific pollution problems are important situative conditions. Another important condition is discovery of win-win situations where both environmental and economic interests are supported.

The *structure of problems* (5 in **Figure 5.1**) describes whether it is easy or hard to solve. The character of an environmental problem may cause restrictions that can limit a given capacity. Here influencing factors are; Is the problem urgent or latent? Is the polluter economic relevant or not? Has the polluter a strong or weak influence on society? Is the target group weak or strong? And are any solutions available?

In order to utilise the presented analytical model of policy explanation for capacity analysis Jänicke (1997) reformulates the model as shown in **Figure 5.2**.

The capacities for the environment are constituted by:

a) Actors: the strength, competence and configuration of organised governmental and non-governmental proponents of environmental protection and

b) Structural framework conditions: the (i) congitive-informational, (ii) political-institutional and (iii) economic-technological conditions

The utilisation of existing capacity depends on:

c) Strategies and Actors: the strategy, will and skill of proponets and

d) Situative context: their situative opportunities

This has to be related to:

e) Structure of problems: the kind of the problem: its urgency as well as the power, resources and options of the target group (opponents)

Figure 5.2: Utilisation of the model for capacity analysis. The categories marked with bold refer the categories in the descriptions above and in **Figure 5.1**. Based on (Jänicke 1997, p 8)

The methodological framework shown in **Figure 5.2** provides categories and explanation in order to analyse capacity for environmental governance. There is one important change from **Figure 5.1** to **Figure 5.2**. It appears from **Figure 5.2** that the category 'actors' only includes proponents of environmental protection. The reason for only focussing on the proponents and not also the opponents as a part of the capacity for environmental governance is that the focus of the analysis of capacity is on the possibilities available to the active part in environmental protection (Jänicke 1997). The opponents are treated as a restricting factor and as a part of the structure of the problem.

5.4 Capacity for environmental governance in product chains and integrated product policy (IPP)

Recognising the complexity of product chains, several countries have launched integrated product policies (IPP) to deal with environmental problems related to products (Scheer and Rubik 2006). However, the policies are still conceptual rather than reflected in practice. According to the European Commission (2003a) some of the main reasons for introducing IPP are that products are traded on a global and regional scale, and that many different globally distributed actors are involved with a product throughout its life-cycle. Therefore, of particular relevance of this project, IPP can be seen as an approach for managing the undesirable effects of globalisation.

The aim of EU strategy on IPP is *"... to reduce the environmental impacts from products throughout their life-cycle, harnessing, where possible, a market driven approach, within which competitiveness concerns are integrated."* (The European Commission 2003a, p 5-6). Thus, IPP is an approach to environmental protection which seeks to reduce the environmental impacts from products in a life cycle perspective. That is to reduce the impacts from resource extraction/agriculture to production, distribution, use and disposal. The IPP approach intends to complement existing environmental policies using the unused potentials to improve product throughout their life cycle (Scheer and Rubik 2006). IPP compromises a broad mix of instruments and actors to be put into play.

The analysis of how the environment is managed along global product chains will follow the same path in terms of stages in the product chains as in the LCA. When combining the LCA and capacity-analysis several advantages are achieved. According to Scheer (2006), IPP is a conceptual approach based on three essential principles: life-cycle orientation, multi-stakeholder approach and policy mix. Thus, IPP contains the elements of the life cycle assessment as well as governance (the actors and the policy mix). In this respect the LCA (see research issue 1, p 22) is used for identifying significant environmental hotspots and improvement options through out the product chains of palm oil and rapeseed oil. Then, this serves as an input to the capacity analysis where it ensures to keep the focus on the significant problems and improvement options. The capacity analysis focuses on the capacity for implementing the proposed improvement options, and relating to IPP, it serves as an example of how capacity theory can be utilised in the field of IPP.

5.5 Capacity for environmental governance and the focus of the study

This section has outlined the theoretical framework for analysing capacity for environmental governance in the case of the product chains of rapeseed oil and palm oil. The capacity analysis is defined as the sixth and final research issue of this study.

Research issue 6: Capacity for environmental governance in the product chains of rapeseed oil and palm oil

The aim of the analysis is to describe how the environmental problems along the product chains of rapeseed oil and palm oil are addressed and to analyse the capacity of environmental governance regarding implementation of improvement options. Ecological modernisation is used as an overall conceptual framework. The focus of the analysis is environmental governance. When analysing environmental governance, the theoretical framework of capacity analysis as described in Jänicke (1997) is used. The comparative LCA of rapeseed oil and palm oil (see research issue 1, p 22) provides two essential inputs to the capacity analysis: 1) definition of the product systems, i.e. the system boundary of the analysis and 2) identification of the improvement options.

Relating to the life cycle assessment of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia, the capacity analysis of palm oil only focuses on Malaysia and not Indonesia. This delimitation is made because of lack of access to appropriate data on the governance system in Indonesia.

As mentioned previously in section 5.3, the analysis of capacity for environmental governance in this study differs from traditional capacity analyses in the way that the system is delimited by the boundaries of the product systems of rapeseed oil and palm oil instead of national borders. The boundaries of the product systems are defined in the LCA and as indicated in section 4 the affected processes relating to e.g. rapeseed oil may be located in various parts of the world, e.g. fertiliser production in Germany, rapeseed cultivation in Denmark, displaced soybean meal in Brazil and so forth. Normally, the focus (the problem) in capacity analyses is on one or several specific problems, e.g. aquatic environment, acidification etc. The focus of the capacity analysis in this study is also on one or several environmental problems. But since a product system itself does not constitute a regulatory unit such as a country, the focus is on both environmental problems and options for improvements for these environmental problems within the product system. The improvement options are identified through the comparative life cycle assessment of rapeseed oil and palm oil. The improvement options are not limited to include technical improvements such as e.g. elimination of GHG emissions from fertiliser production, but it also includes changes in terms of transformation of land, cultivation on different soil types etc.

6 Research questions

In the previous sections the focus of this study has been lined out. The study takes its point of departure in the overall question: what is the environmental effect of globalisation? Two major issues in this respect are identified: 1) How does globalisation affect the environment? And 2) what characterises the transformation of governance systems in order to manage undesirable effects of globalisation? The first one focuses on the environmental impacts of outsourcing supply of goods from local supply to global supply. The second issue deals with actions taken in order to manage undesirable effects of globalisation.

The analyses are centred upon the empirical case of rapeseed oil from Denmark and palm oil from Malaysia and Indonesia as the local and global alternatives for supplying the EU with vegetable oils respectively. It is chosen to deal with these issues on a very specific level rather than discussing on an aggregate level as in the overall questions above. Alternative, less detailed ways to go could be IO-LCA studies or to include more agricultural commodities than just rapeseed oil and palm oil. The choice of having a very detailed focus, makes it possible to carry out very detailed environmental assessments and capacity analysis rather than generalised studies that may not capture environmental mechanisms, improvement options and governance issues which are not already commonly known. On the other hand, an analysis of a specific case does not provide the optimal basis for generalizing. However, the analysis of environmental impacts from rapeseed oil and palm oil (the LCA) provides an example of how environmental impacts from different commodities in different contexts can be analysed and assessed, and furthermore the analysis of environmental governance provides an example of how different actors and institutions on different levels (global, national, company) may influence the environmental performance of global commodities.

Thus, referring to the overall question above, this study does not aim at answering the question directly. Instead emphasis is on a detailed assessment of the environmental impact from a ‘global’ and a ‘local’ product alternative for supplying the EU with vegetable oils. Based on that, potential options for improving the environmental performance of each product alternative will be identified. With these improvement options as a starting point, the capacity for environmental governance regarding these options will be analysed.

In total five research questions, upon which the research activities are centred, are defined. These are described in the following sections 6.1, 6.2 and 6.3. The research questions are defined based on the research issues identified in section 4.3 and 5.5. For each research question the approach or starting point for answering the question is described, i.e. the applied methods and the linkages with other research activities in this study. Section 6.4 provides an overview of the research outputs in terms of published articles and reports.

6.1 Research questions 1, 2 and 3: Development of LCA methodology

In order to carry out the LCA of rapeseed oil and palm oil adequately, some identified lacks in LCA methodology should be considered. Two major lacks in LCA methodology have been identified. The first one concerns system delimitation in LCA, which has potentially significant influence on the results. Therefore this study will contribute to the development of methodology for system delimitation, especially in terms of how to handle co-product allocation related to the oil mill process and how to carry out appropriate system delimitation in agricultural LCAs. The method for system delimitation in the oil mill stage as well as the agricultural stage is based on the consequential modelling in LCA. The reason for using the consequential approach instead of the attributional approach is, as described in section 4.2, that the consequential approach is regarded as being in better accordance with actual cause-effect mechanisms describing the relation between increased demand/production and the affected processes/suppliers.

The other challenge concerns inclusion of impacts on biodiversity from land use in the LCIA. I argue that land use is of certain importance of this study. Firstly, the impacts on land use and biodiversity from agricultural products are significantly larger of magnitude than from most other products. Secondly, the impacts on land use and biodiversity from the two vegetable oils are expected to differ significantly. In LCA, land use is normally not treated at the same level of detail (in terms of the environmental mechanisms in the cause-effect chain) as other impacts such as global warming and acidification. In addition, LCIA methods for assessing land use are less developed than the methods for other impacts.

Hence, the following three research questions relating to methodological development of the LCA method are formulated:

RESEARCH QUESTION 1
The output from oil mills constitutes three important products: vegetable oil and oil meal which functions as fodder protein and fodder energy. How can co-product allocation be avoided/handled appropriately in a consequential LCA of rapeseed oil and palm oil?

Box 6.1: Research question 1.

The approach for answering research question one takes its point of departure in the guidelines for consequential LCA which in line with the ISO standards on LCA prescribes that co-product allocation should be avoided by system expansion. The exercise in the system expansion is to identify the marginal suppliers of the co-products and model their displacement. However, as described in section 4.3, the marginal supplier of the co-product of fodder protein in the rapeseed meal is soybean meal. A co-product of soybean meal is soybean oil which then displaces the marginal source of oil. Thus, it appears that there may be interactions between the processing of e.g. rapeseed oil and soybean meal. This co-product allocation problem is solved by the use of mutual equations (matrices) as suggested by Thrane (2004).

RESEARCH QUESTION 2
The affected land and the associated affected crops from increased production of a certain crop is not necessarily the land under the crop of interest. How can the affected crops and land be identified and how can the means of increased production (increased land or increased yield) be predicted in a consequential agricultural LCA?

Box 6.2: Research question 2.

So far no LCAs has explicitly considered or incorporated the aspects of research question two. Therefore, the answer to research question two is a significant contribution to development of the consequential LCA methodology. The effort on system delimitation in agricultural LCA concerns the identification of the actual affected processes related to increased agricultural production, i.e. the identification of the means of increased agricultural production (increased area or increased yields), and the identification of which crops in what region of the world that are affected when cultivating in regions with constrained land. The approach for answering the research question takes its point of departure in the guidelines for consequential LCA (Weidema 2003) and the development of a decision tree which incorporates all the possible conceptual ways of increasing agricultural production, i.e. increased area, increased yield or by displacement of other crops. The proposed method is tested on a specific empirical case.

Research question 3
How can the impacts on biodiversity from occupation and from transformation of land be included in LCIA?

Box 6.3: Research question 3.

Though, existing LCAs typically do not include impacts on biodiversity, and though there is a lack of agreed principles, definitions and objectives for LCIA methods on biodiversity, some methods already exist and a few of them are used in LCA. Therefore, the approach for answering research question three is not to develop a new LCIA method from scratch. Instead, the approach is to develop a new improved method by using the best from the existing methods. 'The best' from existing methods is identified through reviews of methods (Lindeijer et al. 2002) and through checks of compliance with existing agreed-upon frameworks (Milá i Canals et al. 2006).

The main problems of the existing methods are that they are either too coarse-grained regarding the differentiation between different land use types (e.g. conventional farming versus organic farming), or that they are too narrow regarding spatial coverage (e.g. only part of Europe). Regarding the specific purpose of this study of comparing rapeseed oil with palm oil, these characteristics of existing LCIA methods pose a substantial limitation in the comparison exercise of the impacts on biodiversity. Thus, the aim of the development of a new method is to have a fine-grained model with global coverage.

6.2 Research question 4: Comparative LCA of rapeseed oil and palm oil

The fourth research question relates to the environmental assessment of 'global' versus 'local' product alternatives:

Research question 4
What characterises the environmental impact from the supply of rapeseed oil from Denmark and palm oil from Malaysia/Indonesia to the European market and what are the most essential options for improving the environmental performance of these two oils?

Box 6.4: Research question 4.

In order to answer research question four, life cycle assessment (LCA) is used as a method for environmental assessment of the two vegetable oils. The LCA is based on the developed LCA methods (research questions 1, 2 and 3).

The purpose of the LCA is to assess and compare the environmental impacts from a local and a global alternative for supplying the EU with vegetable oil for food purposes, and to identify improvement options along the two product chains.

The LCA uses the consequential approach for modelling and various scenarios are taken into account reflecting the complexity of the affected product system identified through the methods developed in relation to research question 1 and 2.

6.3 Research question 5: Capacity for environmental governance in the product chains of rapeseed oil and palm oil

Whereas the fourth research question is related to the assessment of environmental impacts and the identification of improvement options, the fifth research question concerns the capacity for reducing the environmental impact, i.e. taking actions in order to implement the improvement options. The research question is formulated as:

RESEARCH QUESTION 5
What characterises the capacity for environmental governance for implementing identified options for improving the environmental performance of the product chains of rapeseed oil and palm oil?

Box 6.5: Research question 5.

The approach for answering research question five is a capacity analysis using the theoretical framework for capacity analysis presented in Jänicke (1997). A typical capacity analysis would be focussed upon a comparative study of two or several countries capacity for solving/managing environmental problems aiming at identifying potentials for capacity building. Thus, the typical capacity analysis' scope is defined by country borders and the associated governance regimes. However, in this study the improvement options are identified anywhere in the product chains of rapeseed oil and palm oil, and consequently the scope of the capacity analysis in this study is determined by the boundaries of the two product systems defined in the LCA.

The primary data sources for the capacity analysis are international and national environmental conventions, protocols, action plans and legislation as well as key documents from other important actors (non governmental organisations). In addition general knowledge on the environmental regulation system in Malaysia has been achieved through interviews with officers related to command and control regulation and EIA regulation in the Malaysian Department of Environment. Due to limited access to data, the capacity analysis regarding palm oil is limited to Malaysia while the LCA covers production in Malaysia as well as in Indonesia.

6.4 Overview of research outputs

This section provides an overview of the research outputs in terms of scientific articles or reports. Each research output is linked to its corresponding research question.

Research question	Title of research output	Purpose	Format
Development of LCA methodology			
1	Article 1: Shift in the marginal supply of vegetable oil	Methodology article: System delimitation in the oil mill stage	Article
2	Article 2: Methodology for system delimitation in agricultural life cycle assessment	Methodology article: System delimitation in the agricultural stage	Article
3	Article 3: Development of applicable characterisation factors for land use in LCA	Methodology article: LCIA method for biodiversity from land occupation and transformation	Article
Comparative LCA of rapeseed oil and palm oil			
4	Article 4: LCA of soybean meal	Empirical LCA study: Data input to LCI-report	Article
4	Life cycle inventory of rapeseed oil and palm oil	Empirical LCA study: LCI-report. Includes the modelling and data collection for the comparative LCA of rapeseed oil and palm oil	Report
4	Article 5: Comparative life cycle assessment of rapeseed oil and palm oil	Empirical LCA study: Presents the main results of the comparative LCA	Article
Capacity for environmental governance in the product chains of rapeseed oil and palm oil			
5	Article 6: Capacity for environmental governance in the product chains of rapeseed oil and palm oil	Empirical capacity study: Analyses the capacity for environmental governance for implementing improvement options	Article

Table 6.1: Overview of research outputs

The linkages between the individual research outputs are illustrated in **Figure 6.1**. The relations between the individual research outputs are further described in section 7.2, 8.2 and 9.2.

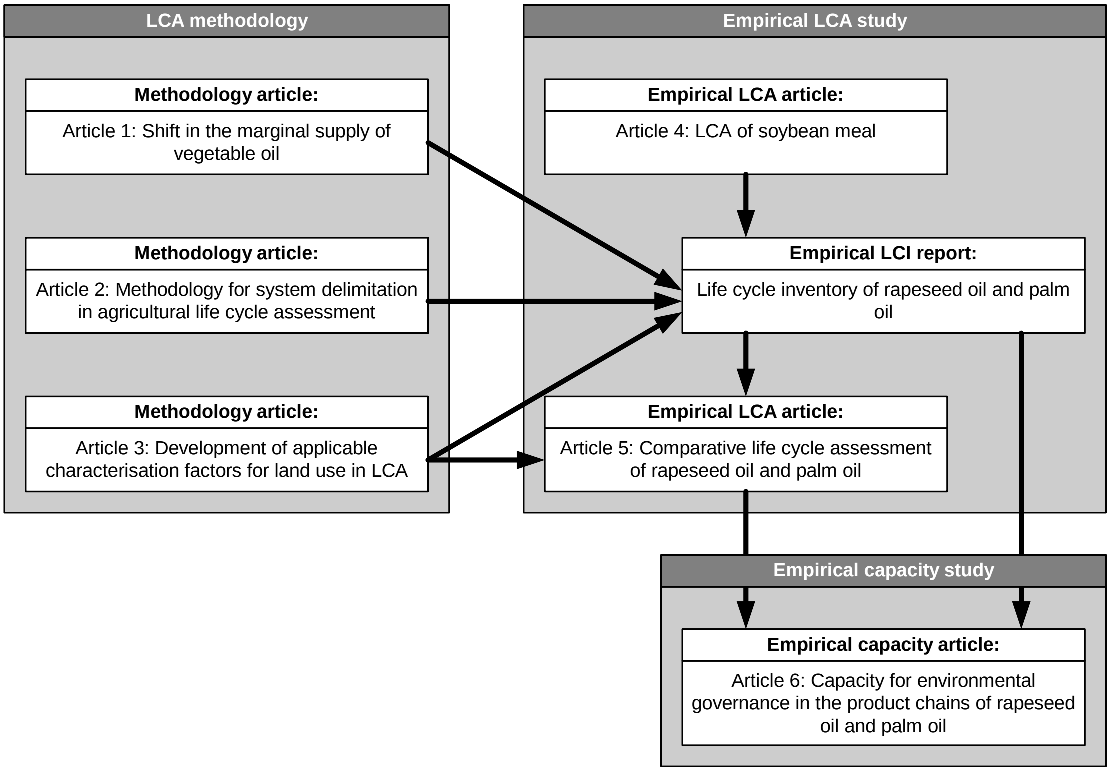


Figure 6.1: Overview of the linkages between the single research outputs.

The three clusters of research represented by the grey shaded boxes in Figure 6.1 are not weighted equally in the study. The weighting between the clusters are approximately 40% (LCA methodology), 50% (Empirical LCA study) and 10% (Empirical capacity study). The reason for allocating the relative large weight to the LCA (methodology and empirical study) is that there is lack of environmental assessments of the environmental effects of globalisation as well as crucial methodologies for the assessment. As soon as the environmental assessment is there, it is desirable analysing the capacity for implementing the results. Based on section 2.3 and section 4, I argue that a significant effort is needed in order to have a desirable environmental assessment of the environmental effect of globalisation. In addition a very detailed and comprehensive environmental assessment also makes it possible to identify improvement options that are not included in other existing studies.

7 LCA methodology

The development of LCA methodology consists of three research outputs which are described in this section. Each article is independently described in section 7.1 without references to the other articles/reports in the project. This description includes an abstract and an assessment of the impact of the research, i.e. further use of the contribution beyond this project. The linkages between the single articles/reports are described in section 7.2.

7.1 Findings of articles

This section presents an abstract in a text box for each of the research articles. After each text box an assessment of the impact of the research is presented, i.e. further use of the contribution beyond this project.

SUMMARY OF ARTICLE 1: SHIFT IN THE MARGINAL SUPPLY OF VEGETABLE OIL

Background, aims and scope. The consequential approach to system delimitation in LCA requires that the technologies and suppliers included are “marginal”, i.e. that they are actually affected by a change in demand. Furthermore, co-product allocation must be avoided by system expansion. Vegetable oils constitute a significant product group included in many LCAs intended for use in decision support. This article argues that the vegetable oil market has faced major changes around the turn of the century, which have resulted in a shift in the marginal vegetable oil source from rapeseed oil to palm oil.

Methods. The methods for identification of marginal technologies and suppliers and for avoiding co-product allocation are based on the work of Weidema (2003). The marginal vegetable oil is identified on the basis of agricultural statistics on production volumes and prices. A co-product from palm oil production is palm kernel meal, which is used for fodder purposes where it has two main properties: protein and energy. When carrying out system expansion, these properties are taken into account.

Results. The major vegetable oils are soybean oil, palm oil, rapeseed oil and sunflower oil. These oils are substitutable within the most common applications. Based on market trends, a shift from rapeseed oil to palm oil as the marginal vegetable oil is identified around year 2000, when palm oil turns out to be the most competitive oil. It is recommended to regard palm oil and its dependent co-product palm kernel oil as the marginal vegetable oil. The analysis of the product system shows that the demand for 1 kg palm oil requires 4.49 kg FFB (oil palm fruit) and the displacement of 0.035 kg soybeans (marginal source of fodder protein) and 0.066 kg barley (marginal source of fodder energy).

Discussion. The identification of the marginal vegetable oil and the avoidance of co-product allocation by system expansion showed that several commodities may be affected when using the consequential approach. Hence, the product system for vegetable oils is relatively complex compared to traditional LCAs in which average technologies and suppliers are applied and in which co-product allocation is carried out by applying an allocation factor.

Conclusions. This article presents how the marginal vegetable oil can be identified and that co-product allocation between oils and meal can be avoided by system expansion, by considering the energy and protein content in the meal, which displaces a mix of the marginal sources of energy and protein for animal fodder (barley and soybean meal, respectively).

Recommendations and Perspectives. The implication of a shift in the marginal vegetable oil is significant. Many LCAs on rapeseed oil have been conducted and are being used as decision support in the bio energy field. Thus, based on consequential LCA methodology, it is argued that these LCAs need to be revised, since they no longer focus on the oil actually affected.

Box 7.1: Summary of article: Shift in the marginal supply of vegetable oil.

The article is submitted to the International Journal of LCA in August 2006 and is currently under review.

So far the results of the article have affected the modelling in an LCA of Danish pig production carried out by Randi Dalgaard (Dalgaard 2007). An important input to pig production is fodder protein. The marginal source of fodder protein is soybean meal which is co-produced with soybean oil. Co-product allocation between the oil and the meal is avoided by system expansion where the marginal oil is displaced. Here, the LCA of Danish pig production takes into account that the marginal source of vegetable oil is now palm oil, where it was formerly rapeseed oil.

I expect that the results will affect the focus of environmental assessments, decision making, and the debate on especially biodiesel. In the EU, there is currently much attention to biodiesel based on rapeseed oil. EU has put forward ambitious goals for the use of renewable fuels in the Biofuel directive (Directive 2003/30/EC), Commission's Biofuel Strategy (The European Commission 2006) as well as the Commissions Renewable Energy Road Map (The European Commission 2007b). Not much attention have been given to the fact that there is currently no regulation that ensures that the increased demand for vegetable oil in the EU is based on locally cultivated rapeseed oil. Section 3.4 shows that the import share of vegetable oils has increased significantly in the last years. In addition, Thoenes (2007) emphasises that the EU has a growing gap in food oil supply because of the use of rapeseed oil for biodiesel and that this gap has primarily been filled by increased import of palm oil. Hence, even though rapeseed oil is used for biodiesel in the EU, palm oil is actually to a large extent the affected source of vegetable oil. It clearly appears from the European Commission (2007c), that the Commission is not addressing this problem since they state that only 1% of the biodiesel in the EU in 2005 is based on imported palm oil. Many LCAs of rape-based biodiesel, food products, and other technical applications have been conducted and are currently used as decision support (Mehlin et al. 2003, De Nocker et al. 1998, SenterNovem 2005, Wightman et al. 1999, McManus et al. 2004, Nielsen et al. 2005 and Beer et al. 2002). Thus, I argue that the existing environmental assessments as well as the decision makers are not focussing on the actual affected vegetable oil.

SUMMARY OF ARTICLE 2: METHODOLOGY FOR SYSTEM DELIMITATION IN AGRICULTURAL LIFE CYCLE ASSESSMENT
Background, aims and scope. When dealing with system delimitation in environmental life cycle assessment (LCA), two methodologies are typically referred to; consequential LCA and attributional LCA. The consequential approach uses marginal data and avoids co-product allocation by system expansion. The attributional approach uses average or supplier-specific data and treats co-product allocation by applying allocation factors. Agricultural LCAs typically regard local production as affected and they only include the interventions related to the harvested area. However, since changes in demand may affect foreign production, yields and the displacement of other crops in regions where the agricultural area is con-strained, there is a need for incorporating the actual affected processes in agricultural consequential LCA. This paper presents a framework for defining system boundaries in consequential agricultural LCA. The framework is applied to an illustrative case study; LCA of increased demand for wheat in Denmark. The aim of the LCA screening is to assess the environmental impact from different ways of meeting increased demand for wheat in Denmark. **Methods.** The proposed framework mainly builds on the work of Ekvall and Weidema (2004), agricultural statistics (FAOSTAT, 2006), and agricultural outlook (FAPRI 2006a). The framework and accompanying guidelines concern the suppliers affected, the achievement of increased production (area or yield), and the substitutions between crops. The framework, which is presented as a decision tree, proposes four possible systems that may be affected as a result of the increased demand of a certain crop in a certain area. **Results.** The sensitivity of the results of system delimitation and the implementation of the framework are tested through an empirical study on how to meet increased demand for wheat in Denmark. Different scenarios of how increased demand can be met show significant differences in emission levels as well as land use. **Discussion.** The great differences in potential environmental impacts of the analysed results underpin the importance of system delimitation. The consequential approach is appointed as providing a more complete and accurate but also less precise result, while the attributional approach provides a more precise result but with inherent blind spots, i.e. a less accurate result. **Conclusions.** The main features of the proposed framework and case study are 1) an identification of significant sensitivity on results of system delimitation and 2) a formalised way of identifying blind spots in attributional agricultural LCAs. **Recommendations and Perspectives.** It is recommended to include considerations on the basis of the framework presented in agricultural LCAs if relevant. This may be done either by full quantification or as qualitative identification of the most likely ways the agricultural product system will respond on changed demand. Hereby, it will be possible to make reservations to the conclusions drawn on the basis of an attributional LCA.

Box 7.2: Summary of article: Methodology for system delimitation in agricultural life cycle assessment.

The article is submitted to the International Journal of LCA in November 2006 and is currently under review.

Currently, the consequential approach to LCI modelling has been applied to most industrial processes, e.g. electricity, district heating, steel production, aluminium production, the plastics industry, the dairy industry, the pulp and paper industry, forestry, production of building materials and food processing. However, the consequential approach has currently not fully been applied to the production of agricultural crops. Weidema (2003) and Nielsen et al. (2005) identify the marginal crop in Denmark as spring barley, but they do not model the effects of that, i.e. if rapeseed cultivation in Denmark is increased it displaces a corresponding area cultivated with spring barley. This ‘missing’ barley may then be compensated for by increased yields in Denmark and by increased production of barley in other countries (both increased area and increased yield). Kløverpris (2007) is currently working on related issues by carrying out detailed economic modelling but he has not published his results yet. I expect that the article presented in **Box 7.2** will contribute to the work of Kløverpris as well as the general development of methods for system delimitation in agricultural and land use related LCAs. In addition the article serves as a conceptual eye-opener for how local actions (changes in local cultivation) may have global effects.

SUMMARY OF ARTICLE 3: DEVELOPMENT OF APPLICABLE CHARACTERISATION FACTORS FOR LAND USE IN LCA
Background, aims and scope. The UNEP/SETAC life cycle initiative has recently proposed a framework for life cycle impact assessment (LCIA) of land use (Milá i Canals et al. 2006). Still, a lack of appropriate LCIA-methods for assessing land use impacts exist in Life cycle assessment (LCA). Most existing methods are either too coarse-grained regarding the differentiation between different land use types (e.g. conventional farming versus organic farming), or they are too narrow regarding spatial coverage (e.g. only part of Europe). This article proposes a method for land use impact assessment on biodiversity at the midpoint level. **Methods.** The framework for the method developed is coherent with the UNEP/SETAC life cycle initiative (Milá i Canals et al. 2006). The method is based on Köllner (2000) and Weidema and Lindeijer (2001). The proposed LCIA-method assumes that characterisation factors are possible to determine for any land use type in any region without the need for overwhelming data and data manipulation requirements. **Results.** The developed method for LCIA of biodiversity focuses on species richness of vascular plants which can be determined from species-area curves. Data accessibility of species surveys is quite good for most regions and land use types. The category indicator is calculated as the multiplication of occupied and transformed area, the number of species affected per standard area (100 m^2), the duration of occupation and renaturalisation from transformation, and a factor for ecosystem vulnerability. **Discussion.** The main uncertainties of the method are related to the absence of weighting between species and the determination of renaturalisation times. Also uncertainties in establishing species-area curves have proven to be significant. **Conclusions.** This article proposes a midpoint level method for LCIA of land use on biodiversity. The intention, i.e. to develop an applicable model with global coverage and no constraints on resolution regarding spatial and land use type differentiation, has widely been met. The limiting factor for applicability is the access to species richness surveys for the relevant regions and land use types. But still, the method shows that, with limited efforts, it is possible to calculate characterisation factors for a large range of land use types in different parts of the world. **Recommendations and Perspectives**. In order to facilitate future data collection, a common accessible databank is suggested. Another important effort in the future is better determination of renaturalisation times.

Box 7.3: Development of applicable characterisation factors for land use in LCA.

The article is submitted to Journal of Cleaner Production in February 2007 and is currently under review.

The article provides an LCIA method for impacts on biodiversity from land use activities. The method is based on the most prominent existing methods, but differs in the way that it is applicable in any region in the world and that it is capable of capturing any differences in the impact on biodiversity from any land use activity. However, only a limited number of characterisation factors for different land use types in different regions in the world are provided in the article. However, by the use of species diversity surveys of vascular plants establishing species area relationships, it is relatively simple to calculate characterisation factors for other land use types in other regions.

7.2 Linkages between findings

The three articles that deal with development of LCA methodology all represent independent methodological contributions. The articles presented in **Box 7.1** and **Box 7.2** concern system delimitation and relate to the first and second phase of an LCA while the article presented in **Box 7.3** concern method for LCIA and relates to the third phase of an LCA.

The two articles on system delimitation deal with two different stages of the life cycle of vegetable oils, i.e. the agricultural stage and the oil mill stage. The methodological findings of the articles are used in the empirical LCA study presented in section 8.1 where the main input is to the report presented in **Box 8.1**. Applying the proposed methodology from each of the two articles is relatively straight forward. However, when applying the methodology from both articles the life cycle inventory is becoming more complex. The article on system delimitation in the oil mill stage (**Box 7.1**) prescribes that the affected crops related to increased demand and production of palm oil are; oil palm (from Malaysia and Indonesia), soybean (from Brazil) and barley (from

Canada). Since the types of outputs from rapeseed oil milling (oil, fodder protein and fodder energy) are similar to the outputs of the palm oil milling, rapeseed oil affects the same crops. The article on system delimitation in the agricultural stage (**Box 7.2**) prescribes that cultivation in Denmark does not lead to increased land occupation in Denmark. Instead the marginal crop (barley) is displaced and consequently produced somewhere else, i.e. in Canada which is identified as the marginal supplier of barley. Hence, it appears that barley in Canada is affected by the agricultural stage of rapeseed oil as well as by the oil mill stage of rapeseed oil. Since increased production of agricultural products can be achieved by increased cultivated area as well as increased yield, the determination of the magnitude of the affected area is becoming even more complex. It appears that system expansion in the agricultural stage may affect the same crops as system expansion in the oil mill stage and that the affected area is depended on how increased agricultural production is achieved (area/yield). Thus, determining the land use in terms of occupation (ha y) and transformation (ha) related to increased demand for rapeseed oil and palm oil is relatively complex, and the calculated land use may differ significantly from what is perceived by intuition and from the land use specified in other LCA studies.

The article on the LCIA method for the impacts on biodiversity from land use is used as an input to the empirical LCA study. The LCIA method is used in the LCI report (**Box 8.1**) for carrying out sensitivity analyses regarding biodiversity and in the comparative LCA of rapeseed oil and palm oil (**Box 8.3**) as the LCIA method for biodiversity.

8 Empirical LCA study: Rapeseed oil and palm oil

The empirical LCA study on rapeseed oil and palm oil consists of three research outputs which are described in this section. Each article/report is independently described in section 8.1 without references to the other articles/reports in the project. This description includes an abstract and an assessment of the impact of the research, i.e. further use of the contribution beyond this project. The linkages between the single articles/reports are described in section 8.2.

8.1 Findings of articles and report

This section present an abstract in a text box for each of the research articles. After each text box an assessment of the impact of the research is presented, i.e. further use of the contribution beyond this project.

SUMMARY OF REPORT: LIFE CYCLE INVENTORY OF RAPESEED OIL AND PALM OIL
Background, aims and scope. In order to provide the needed data for a detailed comparative life cycle assessment of rapeseed oil and palm oil, this report documents the most work intensive part of the LCA, namely the second phase of an LCA; the life cycle inventory (LCI). In addition various sensitivity analyses are carried out and the data are evaluated in order to ensure confidence in LCA results. Existing LCAs on rapeseed oil and palm oil do not represent the level of detail intended for this study and they do not incorporate the state of the art regarding modelling in LCI in particular in the agricultural stage, the oil mill stage and refinery stage. The aim of this report is therefore to carry out the LCI modelling and the detailed data collection for all relevant processes in the product systems of rapeseed oil and palm oil. As a part of the data collection, improvement options for improving the environmental performance of the products are identified. The identified improvement options are evaluated in sensitivity analyses. **Methods.** The consequential approach for modelling in LCI is applied. The consequential approach requires that the actual affected processes are included and that co-product allocation is avoided by system expansion. Therefore an important part of the LCI modelling is to identify marginal suppliers of the affected agricultural crops and carry out system expansion in order to avoid co-product allocation. Another aspect of the modelling is the system delimitation in the agricultural stage. Here the first problem is to determine how increased agricultural production is achieved, i.e. by increased area and by increased yield. Secondly, the affected land is to be identified when cultivating in regions with land constraints. In Denmark the agricultural land has been slightly decreasing the last several decades. Thus, when increasing rapeseed cultivation, other crops are displaced, and consequentially these crops have to be cultivated somewhere else. The data collection for the agricultural stage includes collection of primary as well as secondary data and modelling of nutrient balances. The data collection for the oil mill stage and refinery is mainly based on collection of primary data. **Results.** The LCI modelling shows that the crops; rapeseed, oil palm, soybean and barley are inter-linked by the co-products of the oil mill and refinery. In addition the following oil mills are affected; rapeseed oil mill, palm oil mill, palm kernel oil mill and soybean oil mill. For each of the vegetables oils, rapeseed oil, palm oil, palm kernel oil and soybean oil there is an oil refinery process as well. The LCI results are presented as detailed data sheets for each of the affected crops, oil mills and refineries. In total 21 sensitivity analyses are carried out. These sensitivity analyses have identified the most significant uncertainties in system delimitation, data and LCIA-methods as well as the most significant improvement options. **Discussion.** The collected data regarding land use and emissions related to energy use and the nitrogen cycle are regarded as very robust. The data collected for pesticides and heavy metals are more uncertain. In the LCIA results these characteristics will be further intensified because the LCIA methods are in general relatively certain regarding the emissions relating to energy and nitrogen cycle while toxicities caused by pesticides and heavy metals are less certain. **Conclusions.** This report presents detailed LCI results for the product systems of rapeseed oil and palm oil. The LCI results are presented at a disaggregated level per main stage which facilitates large flexibility in the further use of the collected data. **Recommendations and perspectives.** The data collected and presented in this report mainly serves as an input to a comparative LCA of rapeseed oil and palm oil. However, the collected process specific data for the agricultural stage and oil mill stage represent some of the most detailed data available. Therefore, the data may serve as an important data input for other LCAs in the area of rapeseed, oil palm, soybean and barley cultivation as well as rapeseed oil, palm oil, palm kernel oil and soybean oil milling.

Box 8.1: Summary of report: Life cycle inventory of rapeseed oil and palm oil.

The report was published by Department of Development and Planning, Aalborg University in June 2007. The report is available at www.vbn.dk.

Currently, the existing life cycle inventory data available in literature relating to the product systems of rapeseed oil and palm oil are inappropriate meeting the needs prescribed by the purposes of this study. Firstly, most existing studies are based on the attributional approach for modelling in LCI, secondly existing data are not detailed enough, thirdly existing data do include identification of improvement options along the product chains, and fourthly, the existing data do not consistently include data for all affected processes (cultivation of the relevant crops, and data for oil milling and oil refining of the relevant vegetable oils). Based on the methods developed in relation to research question 1 and 2, the following processes have been identified as affected as a result of increasing the demand for rapeseed oil and palm oil in the EU:

- Cultivation of rapeseed in Denmark
- Cultivation of oil palm in Malaysia/Indonesia
- Cultivation of soybean in Brazil
- Cultivation of barley in Denmark and Canada
- Rapeseed oil mill
- Palm oil mill
- Palm kernel oil mill
- Soybean oil mill
- Rapeseed oil refining
- Palm oil refining
- Palm kernel oil refining
- Soybean oil refining

Hence this, report include detailed state-of-the-art life cycle inventories of the above given processes. In addition a number of improvement options in the product chains of rapeseed oil and palm oil are evaluated.

Vegetable oils, soybean meal (marginal source of fodder protein) and barley (marginal source of fodder energy) are used in many products and for many purposes:

- Food oils
- Vegetable oils are used for non-food purposes in many products of the oleochemical industry
- Biodiesel
- Animal fodder (protein as well as energy)

The data presented in this report are created with the purpose of carrying out a comparative LCA of rapeseed oil and palm oil. However, do to the disaggregate level of the LCI, the data are relevant for other LCA practitioners within these areas as well.

SUMMARY OF ARTICLE 4: LCA OF SOYBEAN MEAL
Background, Aim and Scope. Soybean meal is an important protein input to the European livestock production, with Argentina being an important supplier. The area cultivated with soybeans is still increasing globally, and so is the number of LCAs where the production of soybean meal forms are part of the product chain. In recent years there has been increasing focus on how soybean production affects the environment. The purpose of the article is to estimate the environmental consequences of soybean meal consumption using a consequential LCA approach. The functional unit is 'one kg of soybean meal produced in Argentina and delivered to Rotterdam Harbor'. **Materials and Methods.** Soybean meal has the co-product soybean oil. In this study, the consequential LCA method is applied, and co-product allocation is thereby avoided through system expansion. In this context, system expansion implies that the inputs and outputs are entirely ascribed to soybean meal, and the product system is subsequently expanded to include the avoided production of palm oil. Presently, the marginal vegetable oil on the world market is palm oil but, to be prepared for fluctuations in market demands, an alternative product system with rapeseed oil as the marginal vegetable oil has been established. EDIP97 (updated version 2.3) is used for LCIA and the following impact categories are included: Global warming, eutrophication, acidification, ozone depletion and photochemical smog. **Results.** Two soybean loops are established to demonstrate how an increased demand for soybean meal affects the palm oil and rapeseed oil production, respectively. The characterised results from LCA on soybean meal (with palm oil as marginal oil) were 721 g CO_2 eq. for global warming potential, 0.3 mg CFC11 eq. for ozone depletion potential, 3.1 g SO_2 eq. for acidification potential, -2 g NO_3 eq. for eutrophication potential and 0.4 g ethene eq. for photochemical smog potential per kg soybean meal. The average area per kg soybean meal consumed is 3.6 m^2year. Attributional results, calculated by economic and mass allocation, are also presented. Normalised results show that the most dominating impact categories are: global warming, eutrophication and acidification. The 'hot spot' in relation to global warming, is 'soybean cultivation', dominated by N_2O emissions from degradation of crop residues (e.g., straw) and during biological nitrogen fixation. In relation to eutrophication and acidification, the transport of soybeans by truck is important, and sensitivity analyses show that the acidification potential is very sensitive to the increased transport distance by truck. **Discussion.** The potential environmental impacts (except photochemical smog) are lower when using rapeseed oil as the marginal vegetable oil, because the avoided production of rapeseed contributes more negatively compared with the avoided production of palm oil. Identification of the marginal vegetable oil (palm oil or rapeseed oil) turns out to be important for the result, and this shows how crucial it is in consequential LCA to identify the right marginal product system (e.g. marginal vegetable oil). **Conclusions.** Consequential LCAs are successfully performed on soybean meal and LCA data on soybean meal are now available for consequential (or attributional) LCAs on livestock products. The study clearly shows that consequential LCAs are quite easy to handle, even though it has been necessary to include production of palm oil, rapeseed and spring barley, as these production systems are affected by the soybean oil co-product. **Recommendations and Perspectives.** It would be desirable if the International Journal of Life Cycle Assessment had articles on the developments on, for example, marginal protein, marginal vegetable oil, marginal electricity (related to relevant markets), marginal heat, marginal cereals and, likewise, on metals and other basic commodities. This would not only facilitate the work with consequential LCAs, but would also increase the quality of LCAs.

Box 8.2: Summary of article: LCA of soybean meal.

The article is submitted to the International Journal of LCA in July 2006 and the revised manuscript is accepted for publication. The article is prepared in cooperation with Randi Dalgaard and Niels Halberg (Faculty of Agricultural Sciences, Aarhus University), Per Christensen and Mikkel Thrane (Department of Development and Planning, Aalborg University) and Walter Pengue (GEPAMA, Landscape Ecology Group, University of Buenos Aires)

Currently no good quality consequential LCAs on soybean meal exist. Only two LCAs of soybean meal have been identified; Nielsen et al. (2005) and ecoinvent (2004). The LCA in Nielsen et al. (2005) is of soybean meal from South America (marginal supplier of soybean) but the level of detail is low, and the LCA in ecoinvent (2004) is more detailed but it represents soybean cultivation in Switzerland which do not represent the marginal supplier of soybean. One of the main environmental impacts from consumption originates from the use of meat and an important input in livestock production is fodder protein. Hence, the LCA of soybean meal may contribute to better LCAs of meat in the future. The data are currently used in an LCA of Danish pig production carried out by Randi Dalgaard (Dalgaard 2007). Another important function of the LCA of soybean meal is, that this commodity is affected by the co-products from the vegetable oil industry. Therefore, the LCA of soybean meal may also contribute to better LCAs of vegetable oils in the future.

Summary of article 5: Comparative life cycle assessment of rapeseed oil and palm oil
Background, aims and scope. The environmental effect of globalisation has been debated intensively over the last decades. Only few well documented analyses of global versus local product alternatives exist while recommendations on buying local are vast. At the same time the European Environmental Agency's Third Assessment concludes that the resource use within the EU is stabilising at the expense of increased resource use for import of products to the EU. Taking its point of departure in vegetable oils, this article compares rapeseed oil and palm oil as a local and a global alternative for meeting the increasing demand for these products in the EU. Little environmental information on local versus global product alternatives exists just as there is no policy or strategy on how to decrease the increasing environmental impact outside the EU associated with EUs consumption. Therefore, by using detailed life cycle assessment (LCA), this study compares the environmental impacts and identifies alternative ways of producing rapeseed oil and palm oil to the EU market in order to reduce environmental impacts. **Methods.** The consequential approach for system delimitation is applied (Ekvall and Weidema 2004; Weidema 2003; Schmidt 2007b; Schmidt and Weidema 2007). This approach differs from the attributional approach in the way that the actual affected suppliers and technologies are modelled instead of averages. In addition co-product allocation is avoided by system expansion. The method for life cycle impact assessment (LCIA) is EDIP97 updated (LCA-Center 2007). In addition land use and the associated impacts on biodiversity are assessed using the LCIA method described in Schmidt (2007c). **Results.** The characterised results of the comparative LCA show that palm oil is environmentally preferable to rapeseed oil within ozone depletion, acidification, eutrophication, photochemical smog and land use, while the difference within global warming and biodiversity is less clear. The most significant process contributing to global warming from rapeseed oil is the cultivation of rapeseed while the oil palm cultivation and the palm oil mill are equally important. Regarding land use and biodiversity for rapeseed oil, the avoided production caused by system expansion has a major role, while system expansion does not affect the results of palm oil to the same extent. **Discussion.** Alternative cultivation practises and technologies are assessed. The findings for rapeseed oil are that local expansions of the cultivated area on set-aside area is preferable to displacement of crops which are compensated for by increased agricultural production abroad, and that the full press technology in the oil mill is preferable to solvent extraction. Concerning palm oil, cultivation on peat increases the contribution to global warming significantly with a factor of 4-5 compared to cultivation on the current mix of soils types. Another hotspot related to global warming can be markedly reduced by installation of digester tanks and subsequent utilisation of biogas as treatment of palm oil mill effluent. **Conclusions.** The results of the scenarios show that the approach to system delimitation matter. When the consequential approach to system delimitation is applied in the agricultural stage uncertainties show to be significant. Overall palm oil tends to be environmentally preferable to rapeseed oil within all impact categories except global warming, biodiversity and ecotoxicity where the difference is less pronounced. However, changes in technology and cultivation practises may significantly make the one oil environmentally preferable to the other. **Recommendations and perspectives.** The supply of rapeseed oil to the EU can be environmentally improved if; i) the full press technology for oil milling is used instead of the solvent extraction technology, ii) prioritising land use transformation of agricultural land to take place on sandy soils rather than on clay soils, and iii) it is ensured that increases in production causes total net increase in the EU cultivated area rather than pushing out the marginal crop which then is compensated for somewhere else in the world. Correspondingly, demands to the supplying countries of palm oil can improve the environmental performance if biogas utilisation is required and cultivation of peat soils is avoided.

Box 8.3: Summary of article: Comparative life cycle assessment of rapeseed oil and palm oil.

The article is submitted to the International Journal of LCA in June 2007 and is currently under review.

The article provides an example of a comparative study of a local and a global product alternative, i.e. rapeseed oil and palm oil respectively. Thus, state-of-the-art environmental information of the two oils is presented. The main messages are:

1. that it is not possible clearly to conclude which one of the two vegetable oils that is preferable from an environmental point of view
2. that local as well as global production is associated with global effects
3. that overseen circumstances, e.g. cultivation on peat soils, may cause a multiple times more significant impact on especially global warning than cultivation on mineral soils

Regarding the first point, the ranking of the two oils depends on the system delimitation, i.e.: Is the change in production achieved by yield or area? Which crops are displaced in regions with constrained land and under which circumstances are the displaced crops compensated for? Are the marginal soils peat soils or mineral soils? And what land is reclaimed for agricultural expansion; is it degraded land or is it nature? Therefore, the environmental performance of local versus global vegetable oils is determined rather by cultivation circumstances than by whether it is local or global.

Concerning the second point, increased cultivation of rapeseed in Denmark may displace other crops if not the total agricultural area is increased. Thus, the gaps from these missing crops have to be filled somehow – typically by increased import. Especially in light of the rapidly increasing rapeseed production in the EU, this aspect should be addressed.

Concerning the third point, cultivation of oil palm on peat soils may cause significant emissions of carbon dioxide emissions from the mineralisation of the organic matter in the soil. Thus, the greenhouse gas emission from 1 tonne palm oil may change from around 2.4 t CO_2-eq. to 12.9 t CO_2-eq. if the cultivated soil is peat. 12.9 t CO_2 is dramatically more than the CO_2 emission from the burning of 1 tonne fossil oil which is at around 3-4 tonne.

The findings of the article are intended for being used in future environmental governance of vegetable oils through the framework of integrated product policy. Significant improvement options in the product chain of rapeseed oil as well as palm oil have been identified. Implementation of these improvement options would be a relevant focus of future environmental governance.

8.2 Linkages between findings

The inventory report (**Box 8.1**) contains the primary documentation of data collection, modelling, uncertainty evaluation, and identification of improvement options for improving the environmental performance of the product systems of rapeseed oil and palm oil. Empirically, it draws on the article on LCA of soybean meal (**Box 8.2**) which provides inventory data on some of the interventions in the agricultural and oil mill stages of soybean meal. The LCA of soybean meal is a full LCA including all four phases of an LCA. However, only the data obtained through the inventory phase are used in the inventory report. The inventory report draws on the three articles on development of LCA methodology presented in section 0.

The inventory report has elements of all four phases of an LCA, but the main focus is on the second phase, i.e. the life cycle inventory phase. The sensitivity analyses in the inventory report are part of the third phase, i.e. the life cycle impact assessment phase, and the evaluation of sensitivity, completeness and consistency is part of the fourth phase, i.e. the life cycle interpretation phase.

The comparative LCA of rapeseed oil and palm oil (**Box 8.3**) draws almost entirely on the data and the modelling in the inventory report. Corresponding to the inventory report, the comparative LCA also has elements of all four phases of an LCA. The main focus of the comparative LCA is to present the results of the LCA, i.e. on the life cycle impact assessment phase. Together, the inventory report and the comparative LCA comprise a full LCA. In this respect the inventory report mainly documents the results while the comparative LCA presents the results.

The results of the comparative LCA and the identified improvement options in the inventory report are used in the capacity study (**Box 9.1**). The results of the comparative LCA are used in order to focus the capacity study on climate change and biodiversity and to point out hotspots in the product chains. The identified improvement options in the inventory analysis are central for the capacity study because the capacity analysis is focused on the implementation of these improvement options.

9 Empirical capacity study

The capacity analysis of rapeseed oil and palm oil consists of one article which is described in this section. The article is independently described in section 9.1 without references to the other articles/reports in the project. This description includes an abstract and an assessment of the impact of the research, i.e. further use of the contribution beyond this project. The linkages between the single articles/reports are described in section 9.2.

9.1 Findings of article

This section present an abstract in a text box for each of the research article. After the text box an assessment of the impact of the research is presented, i.e. further use of the contribution beyond this project.

SUMMARY OF ARTICLE 6: CAPACITY FOR ENVIRONMENTAL GOVERNANCE IN THE PRODUCT CHAINS OF RAPESEED OIL AND PALM OIL

Background, aims and scope. Several studies show that a considerable share of the environmental impacts related to a country's consumption is located in other countries and that there is a tendency that the share is increasing. Consequently, a significant share of the environmental impacts is becoming out of reach of the nation state's capability for environmental regulation. This article analyses the capacity for implementing six identified improvement options of the environmental performance of the product chains of rapeseed oil from Denmark and palm oil from Malaysia. These two commodities represent a local and a global alternative for supplying the EU with vegetable oils. The improvement options include technical changes as well as more management oriented changes of land use administration.

Methods. The applied analytical approach is a capacity analysis based on Jänicke (1997) but with focus on product chains instead of capacity building for national environmental protection. Thus, the included actors and institution are determined by the system boundaries of the product system instead of national borders. The six improvement options are identified through a detailed life cycle assessment of rapeseed oil and palm oil (**Box 8.1**). The data for the analysis are primarily obtained from international and national environmental conventions, protocols, action plans and legislation as well as key documents from other important actors (non governmental organisations). For each improvement option, the relevant actors, knowledge about the option/problem among relevant actors, regulation and economic-technological conditions are analysed. Together these elements constitute the existing capacity for implementing the improvement options. The utilisation of the capacity is determined by the strategy, skill and will of the proponents and of the variable conditions of action, e.g. public awareness or strong opponents.

Results. The analysed improvement options are 1) applying best available techniques in N-fertiliser production (fertiliser used in rapeseed cultivation, Denmark), 2) prioritising the most fertile soils when agricultural land is reclaimed for other purposes (rapeseed cultivation, Denmark), 3) Avoiding cultivation on peat in order to avoid significant CO_2 emissions (oil palm cultivation, Malaysia), 4) Expanding the agricultural area on grassland and avoiding transformation of forests (oil palm cultivation, Malaysia), 5) yield increases by additional fertiliser (oil palm cultivation, Malaysia) and 6) Installation of digester tank and utilisation of biogas instead of anaerobic ponds for treatment of palm oil mill effluent (palm oil production, Malaysia). All improvement options focus on reducing either the impact on climate change or biodiversity. In general governments play a larger role as proponents of implementing improvement options in Denmark than in Malaysia were NGOs and industry play a larger role. No remarkable differences in the strength of capacity in Denmark and Malaysia were identified. Normally the capacity for environmental governance in Denmark would be expected to be stronger than in Malaysia. The reason why it is not the case here is that climate change and biodiversity generally fall out of the scope of traditional environmental regulation (command and control).

Discussion and conclusion. The analysis show that legal capacity is lacking for most improvement options. Consequently, the implementation of improvement options relies on voluntary efforts mainly driven by economic incentives. The analysis also shows that the proponents of improvements in Denmark are primarily constituted by governmental and industry bodies while they are constituted by non-governmental and multi-national bodies in Malaysia where the capacity of government regulation is generally weaker than in Denmark. The strongest capacity for governing the environmental problems related to globalisation is primarily found within different non-governmental organisations driven by green market mechanisms.

Recommendations and perspectives. The analysis showed to provide a good overview of the capacity for implementing different improvement options in different contexts. The analysis is regarded as a fruitful input to the process of developing integrated product policy (IPP) for different product groups. Hence using capacity analysis as presented in this article, a formalised coordinated IPP can contribute significantly to capacity building in achieving improved collaboration between actors, strengthened framework conditions, and maximised utilisation of the capacity for implementing improvement options in product chains.

Box 9.1: Summary of article: Capacity for environmental governance in the product chains of rapeseed oil and palm oil.

The article was submitted to Journal of Industrial Ecology in June 2007 and is currently in review.

The proposed use of capacity analysis in the article as an essential input to IPP may contribute to a broadening of the scope of IPP. While the empirical LCA study shows that global product systems are affected, the capacity study shows that global governance is lacking. By incorporating the capacity analysis in the development of IPP projects, a closer link to legal regulation is established. At least weak capacity for legal regulation is identified when present. This may serve as an eye opener for new regulatory options. However, the use of capacity analysis in the development of IPP projects still needs to be tested.

9.2 Linkages between findings

The capacity article (**Box 9.1**) uses the hotspots identified in the comparative life cycle of rapeseed oil and palm oil (**Box 8.3**) for focusing the study on only climate change and biodiversity. The analysis of the capacity study focuses on the capacity for implementation of the improvement options identified in the inventory report (**Box 8.1**).

All of the analysed improvement options are related to the product chains of rapeseed oil and palm oil (including inputs of energy, materials etc.). Thus, no improvement options are located in the processes identified through the system expansion using the methodology proposed in the two articles on system delimitation (**Box 7.1** and **Box 7.2**). However, it is still important to include the induced effects on processes outside the product chains of rapeseed oil and palm oil in the LCA because this ensures that sub optimising is monitored if present in the improvement options.

10 Perspectives and recommendations

This study has taken its point of departure in the overall question: what is the environmental effect of globalisation? In this respect the main focus has been on an assessment of the environmental impacts from a local versus a global product alternative for supplying the EU with vegetable oil, i.e. rapeseed oil from Denmark and palm oil from Malaysia and Indonesia respectively. The focus has been to assess the environmental performance of the supply of vegetable oils, i.e. changes in the total supply are not considered. Due to present lack in crucial LCA methodology, a large part of the LCA work has been focussed on development of methodology. Attention has also been paid to the issue of how to manage undesirable effects of globalisation. Here the focus has been on the capacity for environmental governance regarding some identified improvement options in the product chains of rapeseed oil and palm oil.

10.1 Characteristics of the environmental impacts from local versus global agricultural products

The findings of above mentioned research issues have been presented and concluded on in the previous three sections. Here in this section, attention is paid to the general overall question referred to above without focussing on the specific case of rapeseed oil and palm oil. The research process has lead to some recognition of what is significant regarding the environmental effect of globalisation and agricultural products. The characteristics are important to be aware of in comparative studies of local versus global agricultural products:

- Increasing cultivation in the developed part of the world often lead to displacement of other crops which has to be grown in other countries. In most of the developed part of the world (e.g. Europe, USA, Canada and Japan) the area covered with annual and permanent crops has been constant or declining the last decade (FAOSTAT 2007). At the same time the global agricultural area has been increasing. Therefore, it is likely that increased demand for a crop grown in the developed part of the world will lead to an increase of the total cultivated area in the developing part of the world.
- Crop yields are typically considerably higher in developing countries (in the tropical countries) than in the developed part of the world (in the temperate countries)
- Cultivating peat soils causes significant greenhouse gas emissions. Tropical peat swamps, in especially in Indonesia, are rapidly being transformed into agricultural land.
- Treatment of the waste water from the processing of agricultural products may cause significant greenhouse gas emissions (methane) if anaerobic treatment in open ponds is used. Waste water is typically not treated in anaerobic ponds in the developed part of the world, while the technology is more widespread in developing countries.
- Transport from remote countries does not have a significant impact in a life cycle perspective. This is because local transportation with lorry in Europe is many times less efficient per tkm than long distance transport with transoceanic freight ship (up to a factor 40).
- Greenhouse gas emissions from agriculture mainly comes from dinitrogen oxide emissions from the field (denitrification of surplus nitrogen in the field) and from the production of N-fertiliser. Carbon dioxide emissions from traction are less significant. However, when cultivating on peat, the most significant greenhouse gas emissions are carbon dioxide from the mineralisation of the organic material.
- Utilisation of crop residues for energy purposes may displace alternative energy production. Examples are burning of barley straw and empty fruit bunches from palm oil mills. If large amounts of biomass are removed from the field, the effect on the carbon and nitrogen balances in the field may be significant. This may lead to carbon dioxide emissions from decreasing stock of carbon in the field and exhaustion of the soil affecting the yields, the need for additional fertiliser input and possibly erosion.

- The impacts on biodiversity in terms of species diversity from occupation and transformation of land in Europe may be as significant as from occupation and transformation of land in rainforest regions e.g. Malaysia and Indonesia. Two factors contribute to this surprising characteristic: 1) The yields in the tropics are often higher than in the temperate regions leading to a smaller affected area in the tropics, and 2) since a smaller share of the original nature in Europe is left than in Malaysia and Indonesia, the ecosystems in Europe are also more sensitive to further occupation and transformation.
- Depending on the crop and the agricultural practises and regulation in the affected region, increased production can be achieved by either increased cultivated area or by intensification, e.g. by additional fertiliser input. The environmental impact from the two different ways of increasing agricultural production may differ significantly.

Based on the empirical LCA study in this project and above characteristics, it is not possible to say whether local or global product alternatives are the best from an environmental point of view. Several factors determine the environmental performance of agricultural products. And in the case of cultivation in regions with constrained land, the actual affected crops and land may be located in another part of the world. Hence, local production may have effects on the global agricultural system.

Therefore, the issue of globalisation is not limited to a choice between local and global product alternatives. The associated product system to local products is globally inter-linked. Therefore, the environmental performance of the supply of agricultural products may be difficult to improve just by choosing one crop alternative over another. The empirical LCA study of rapeseed oil and palm oil showed that the ranking of the two oils could be changed both ways by implementing improvement options in the product chains of the two commodities. Therefore, the greening of the supply of agricultural products should be based on implementing improvement options by imposing criteria for the production processes in the product chains.

Based on the empirical LCA study, the following examples of general criteria can be defined. Such criteria could be a starting point for a development towards integrated product policy for products from the agricultural sector.

- Avoid cultivation on peat soil and restore cultivated peat to natural peat swamp
- Extensively cultivated land should be checked for environmentally sound intensification in order to minimise the environmental impact per product
- Increased utilisation of crop residues, but without sub-optimising caused by negative effects on the carbon stock and soil fertility from the removal of organic material
- Avoid anaerobic waste water treatment in open ponds. Install digester tanks for capturing biogas and utilise biogas for energy purposes
- Use N-fertiliser produced with best available techniques for minimising dinitrogen oxide emissions from the fertiliser production
- Give high priority to cultivation on the most fertile soils, i.e. expansion of the agricultural area should be on the best soils and reclaiming agricultural land for other purposes should be on the least fertile soils
- When expanding the agricultural area priority should be given to transformation of already degraded land, e.g. alang-alang grassland (mainly in SE-Asia) or set-aside/idle agricultural land
- Requirements for a minimum standard of cultivation practise and land utilisation in order to maximise yields. This is especially relevant in the case of smallholders who are often characterised by poor cultivation standards and low yields

10.2 Challenges for governing a globalised agricultural product system

It appears from the previous section, that if the supply of agricultural products to the EU is to be greened, the way to go is not to ban imports and rely on local supply. Instead criteria for the production processes and the environmental governance system in the supplying countries should be introduced. These criteria could be based on the characteristics mentioned above. The analysis of capacity for environmental governance regarding the identified improvement options showed that legal capacity were lacking in general. Thus, the traditional national environmental regulating institutions in general have a weak capacity for implementing the identified improvement options. But led by NGOs and industry and driven by voluntary efforts and economic incentives some promising initiatives have been started, e.g. the Roundtable on Sustainable Palm Oil (RSPO) and the Round Table on Responsible Soy (RTRS). These initiatives have members from most stages of the product chains and in order to be certified, the members must comply with an agreed set of criteria. However, it is noteworthy that no such incentives, that reduce the environmental impacts from the supply of agricultural products, have been initiated for agriculture in the developed part of the world.

A relevant question to be answered is then: Can we rely on voluntary efforts alone to provide a desirable management of the undesirable environmental effects of globalisation. Here the term ‘globalisation’ refers to the fact that a growing share of the environmental impacts from agricultural products takes place in other countries than in the consuming country. Hereby, the governance of the environmental impacts from a country’s supply of commodities falls out of reach of the traditional environmental regulation system (nation state based command and control and EIA). I argue that there are some important weaknesses of voluntary efforts that should be addressed; Voluntary efforts basically rely on market mechanisms since they are mainly driven by economic incentives (better image, avoiding command and control regulation, competitive advantages etc.). Firstly, the problem related to this is that the market does not ensure that overall environmental goals are defined, monitored and fulfilled. Secondly, the goals defined in voluntary efforts are agreed-upon outside the environmental policy system. Thirdly, the market reacts in accordance with an economic rationality and not an environmental rationality. This means that e.g. the round tables on sustainable palm oil and responsible soy are initiated mainly because someone (NGO’s) has raised concern of the environmental impacts from palm oil production and from soybean cultivation (WWF, Friends of the Earth). When industry reacts positively to these concerns, it is obviously because they see some potentially economic advantages. The problem here is that the NGOs that raise the concern may not have a better overview of the environmental problems than national and international scientifically based environmental bodies, e.g. national environmental protection agencies, the EU, IPCC, UNEP etc. Thus, the initiated efforts are not coordinated in order to capture the most relevant polluters. Some good examples are that only a round table on sustainable palm oil has been initiated. But in a life cycle perspective palm oil is probably in the better end compared to the competing vegetable oils. Thus, the voluntary approach does not ensure that rapeseed oil, sunflower oil, olive oil coconut oil etc. are receiving attention even though the environmental performance of these vegetable oils may be less good than of palm oil.

It is evident that some voluntary efforts are promising and that they contribute positively to the environmental performance of the supply of agricultural products. However, it is also evident that voluntary efforts alone can hardly provide a complete and environmentally rational governance system for the supply of agricultural products. Important polluters are overseen and the definition, monitoring and achievement of overall environmental goals are not ensured. However, the same weaknesses may be present if the efforts were left alone in the hand of national environmental agencies and international bodies. But the advantages of these institutions are that they normally have a broader focus than only one single product (e.g. palm oil or soybean), and they may have the power to put into force legal requirements to the production. Hereby, completeness in terms of products (e.g. all vegetables oils) and all polluters (not only the actors who have joined the voluntary initiative) could be ensured. Thus, the relevant national and international institutions should follow up on the initiated voluntary efforts as part of the development of integrated product policy and this should be supplemented with legal requirements.

The European Commission started the work on integrated product policy in 1998. In 2001, the Commission launched a green paper on integrated product policy (The European Commission 2001) and in 2003, a communication integrated product policy was adopted (The European Commission 2003a). As part of the European Commission's work with integrated product policy, two pilot projects have been carried out (The European Commission 2007a). The two projects have been carried out in five stages: (The European Commission 2007a)

1. Environmental assessment based on the life cycle approach
2. Identification of improvement options
3. Analysis of economic and social effects of the improvement options
4. Selection of improvement options, and commitments made by the different participants
5. Implementation and monitoring of the commitments

As it also appears from the five stages, the integrated product policy in the EU has only focussed on voluntary participation and industry's voluntary commitments to implementing environmental improvement options. Hence, initiatives led by the EU have not shown to be more promising than the round tables on palm oil and soybean in terms of including a broader range of products and polluters. Only two pilot products have been included so far and the inclusion of polluters relies only on the voluntary commitment of the polluter.

Hence I argue, that if integrated product policy has to have a significant impact, it should be supplemented by legal requirements. My suggestion in that respect is to add a stage in the procedure for carrying out integrated product policy projects. This stage should be placed between stage 2 and 3, and it should analyse the capacity for environmental governance regarding the identified improvement options. This would point at existing strong capacities for implementing the improvement options, and at actors and institutions that need capacity building in order to implement the improvement options. The procedure presented in the article described in **Box 9.1** could be a starting point for the capacity analysis. In addition, the life cycle assessment shows that the affected product systems are relatively complex and that simple results such as 'local is better than global' may not be obtained. Therefore, if IPP should have a significant impact, the complex product systems and their associated improvement options require that IPP should be very detailed and on the specific level.

10.3 Identified further research issues

Through the project data collection, modelling and development of LCA methodology have been focussed within the areas where this was most needed. However, still some areas need further research. These are identified as:

- Short and long term effects on the carbon cycle from different cultivation practises. Different cultivation practises (especially management of organic residues) have an effect on the carbon cycle. This may be in the short term (0 – 10 years) or in the longer term (10 – 100s of years). Considering utilisation of crop residues as biofuel, it is important also to assess the effects on the stocks of carbon in the soil, and not only the displaced alternative source of energy.
- More precise predictions of responses to changes in demand for agricultural products, i.e: How is the change in demand met (by area or by yield changes)? Which regions will respond to changes in demand? Which other crops are affected if the change in demand for a certain crop is met by increased

cultivation in a region with land constraints? Will the displaced crops be compensated for? Where will the compensation take place?

- What are the causes of degradation of nature, e.g. transformation of primary forests? Nature is transformed into other land use types in steps which gradually changes the biodiversity and life support functions. In this respect, it is important to address the actual role of expanding agricultural land. In most tropical rainforest nations the rate of deforestation of primary forest is larger than the rate of expansion of agricultural land. Thus, there are indications that agriculture is not affecting primary forests since logging is responsible for the degradation step from primary to secondary forest. But reality may be more complex. E.g. what are the roles of migration programs, building of roads, expansion of the urban area and other activities? Maybe some of these activities determine some of the expansion of the agricultural land, i.e. agricultural expansion may not be only driven be changes in demand?

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