IDA´s klimaplan 2050

Tekniske energisystemanalyser og samfundsøkonomisk konsekvensvurdering - Baggrundsrapport

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Publication date:
2009

Document Version
Også kaldet Forlagets PDF

Future Climate
Engineering Solutions

The IDA Climate Plan 2050

Technical energy system analysis, effects on fuel consumption and emissions of greenhouse gases, socio-economic consequences, commercial potentials, employment effects and health costs

BACKGROUND REPORT

IDA
STRENGTH THROUGH KNOWLEDGE

IDA’s Climate Plan 2050
Background Report

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Cover: Rune.Anders.Lars
Printer: IDA's Print Centre

Published by The Danish Society of Engineers, IDA, August 2009
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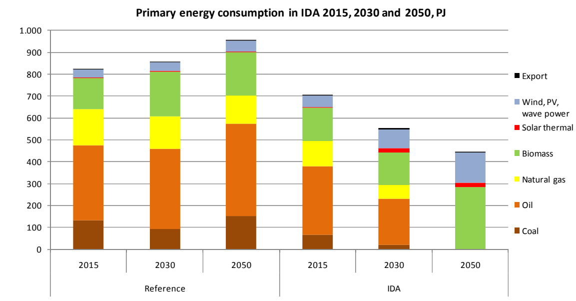
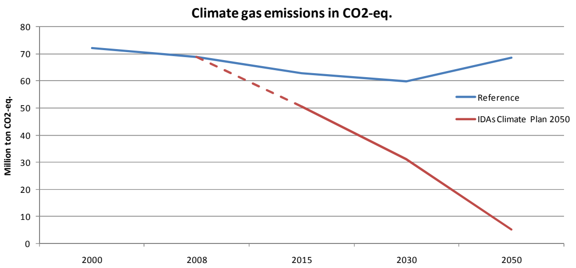
The technical energy system analyses and estimations of economic consequences for IDA's Climate Plan 2050 are presented in the Background Report. This Plan is the Danish contribution to the international project Future Climate. The Report has been completed during the period December 2008 to July 2009. IDA's Climate Plan 2050 was released on 11 May 2009 as a public consultation draft. Adjustments have been done after the public consultation period. The final results of the analyses in IDA's Climate Plan 2050 are presented in this Report, and along with a description of both the assumptions and the analyses in the Climate Plan.

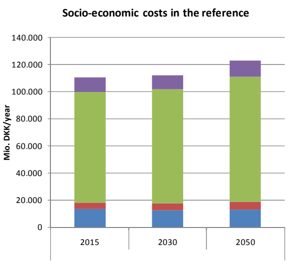
Background Report to

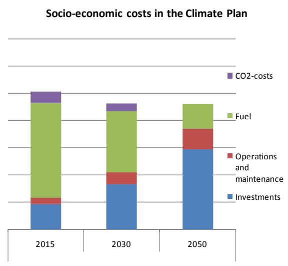
IDA's Climate Plan 2050

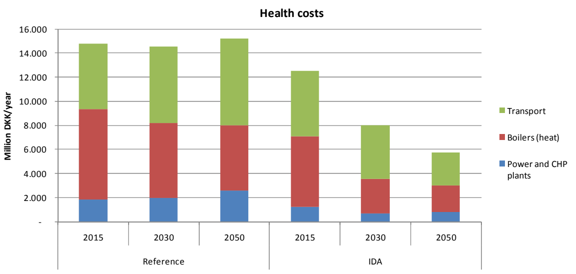
Technical energy system analysis, effects on fuel consumption and emissions of greenhouse gases, socio-economic consequences, commercial potentials, employment effects, and health costs

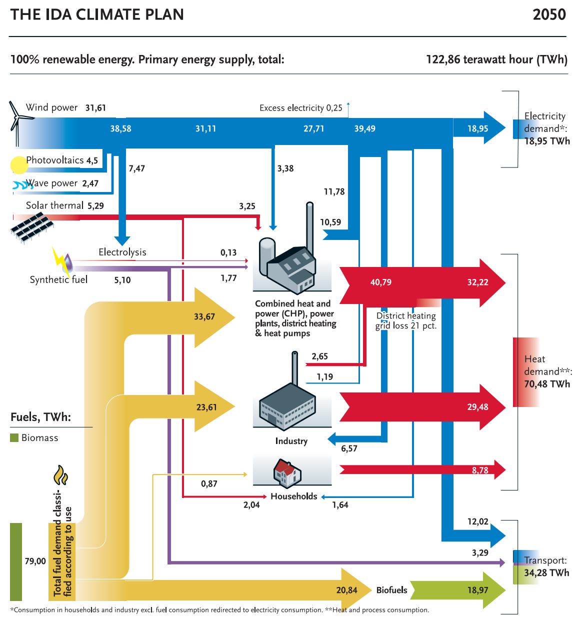


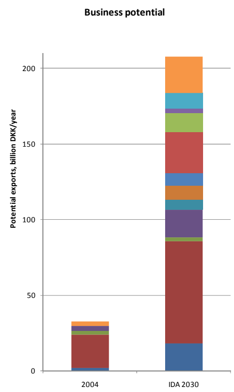


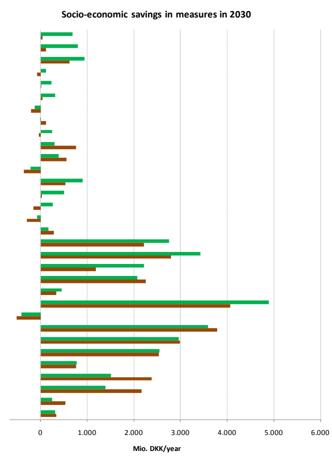












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August 2009

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1 Preface

It has been a great challenge to assemble the threads in this climate plan and to perform the collected analyses of the energy systems on behalf of The Danish Society of Engineers, IDA. Not least because it looks at the energy system in the short term in 2015, in the medium term in 2030, and in the long term in 2050. The vision in this plan is a 100 per cent renewable energy system. It was not possible to assemble an integrated plan without those active in IDA's technical specialist societies and groups, the IDA employees, and the project coordinators for the themes into which the project has been divided. There has also been invaluable support for the work from large parts of the Danish energy sector. Therefore, all of these deserve a personal thank you. During the development of the Background Report we have drawn especially upon a range of specialists from universities and firms. They have contributed directly with various inputs and we owe them a special thank you. Together with these people it has been possible to procure the large amount of data necessary for the analyses:

Niclas Scott Bentsen, PhD Student	Forest and Landscape, Copenhagen University
Helge Bach Christiansen, Engineer	IDA Energi
Anders Dyrelund, Director Marketing	Rambøll A/S
Claus Felby, Professor	Forest and Landscape, Copenhagen University
Peter Frigaard, Head of Department	Aalborg University, Department of Civil Engineering
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Mogens Weel Hansen, Engineer	Weel & Sandvig A/S
Helge Holm-Larsen, Director Business Development	Topsoe Fuel Cell A/S
Jacob Ilsøe, Energy Consultant	Birch & Krogboe A/S
John Tang Jensen, Technical Consultant	Dansk Fjernvarme (Danish District Heating Association)
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Per Alex Sørensen, Engineer	PlanEnergi s/i
Göran Wilke, Managing Director	The Danish Electricity Saving Trust
Kim Winther, Environmental Economist	DONG Energy

Finally we owe a thank you to our closest colleagues, who have helped with specialist inputs and corrections: Frede Hvelplund, Poul A. Østergaard, Marie Münster, Morten Boje Blarke and Mette Reiche Sørensen, all from Aalborg University, Denmark and David Connolly, University of Limerick, Ireland.

Brian Vad Mathiesen, Henrik Lund and Kenneth Karlsson
August 24, 2009

2 Summary

The central technical and economic results of the Background Report are described in this chapter. Please note that the results are based on assumptions, subjective analyses, etc., which are described in the following chapters.

2.1 100% Renewable Energy and Large Reductions in fuel consumption

The current primary energy supply in Denmark, i.e. fuel consumption and renewable energy for production of electricity and heat for households, transport and industry, is approx. 800 PJ. If new initiatives are not taken, it is expected that energy consumption will decrease marginally until 2015, but then increase gradually until 2050 to about 950 PJ. Initiatives are proposed in IDA's Climate Plan 2050 which can reduce primary energy supply to 707 PJ in 2015, 556 PJ in 2030, and 442 PJ in 2050. At the same time, the share of renewable energy from wind turbines, photovoltaic, solar thermal, wave energy, and biomass will be increased. The share of renewable energy in the reference energy systems increases from about 16 per cent in 2008 to 22 per cent in 2015 and to about 25-29 per cent in 2030 and 2050. The share of renewable energy in the Climate Plan increases to 30 per cent in 2015 and 47 per cent in 2030. ***In 2050 the entire Danish energy system, incl. transport, is based on 100 per cent renewable energy.*** The primary energy supply is illustrated in Fig. 1. The energy flows for the reference energy system in 2030, IDA 2030 and IDA 2050, are illustrated in **Fig. 2** to Fig. 4.

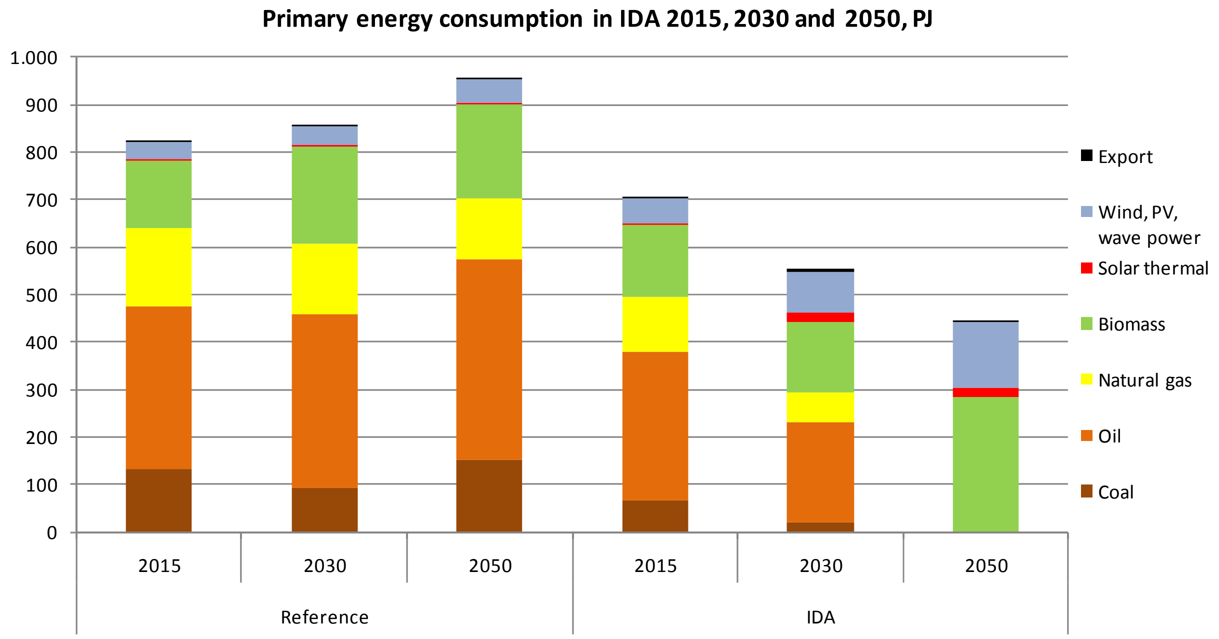

Fig. 1, Primary Energy Supply in IDA's Climate Plan 2050.

The energy system in IDA 2015 is based on measures which can be realised with current technology. Although some of the measures in IDA 2015 plan must be implemented over a period from 2010 to 2020, they are considered as fully implemented by 2015 for the analyses. In IDA 2030 large parts of the transport system are changed, district heating systems are heavily expanded, there are more efficient power plants, more mature and new renewable energy technologies are introduced, and further energy savings implemented. In general large parts of the fossil fuel consumption are replaced by electricity demands, especially within transport, with battery electric vehicles and electrically powered trains.

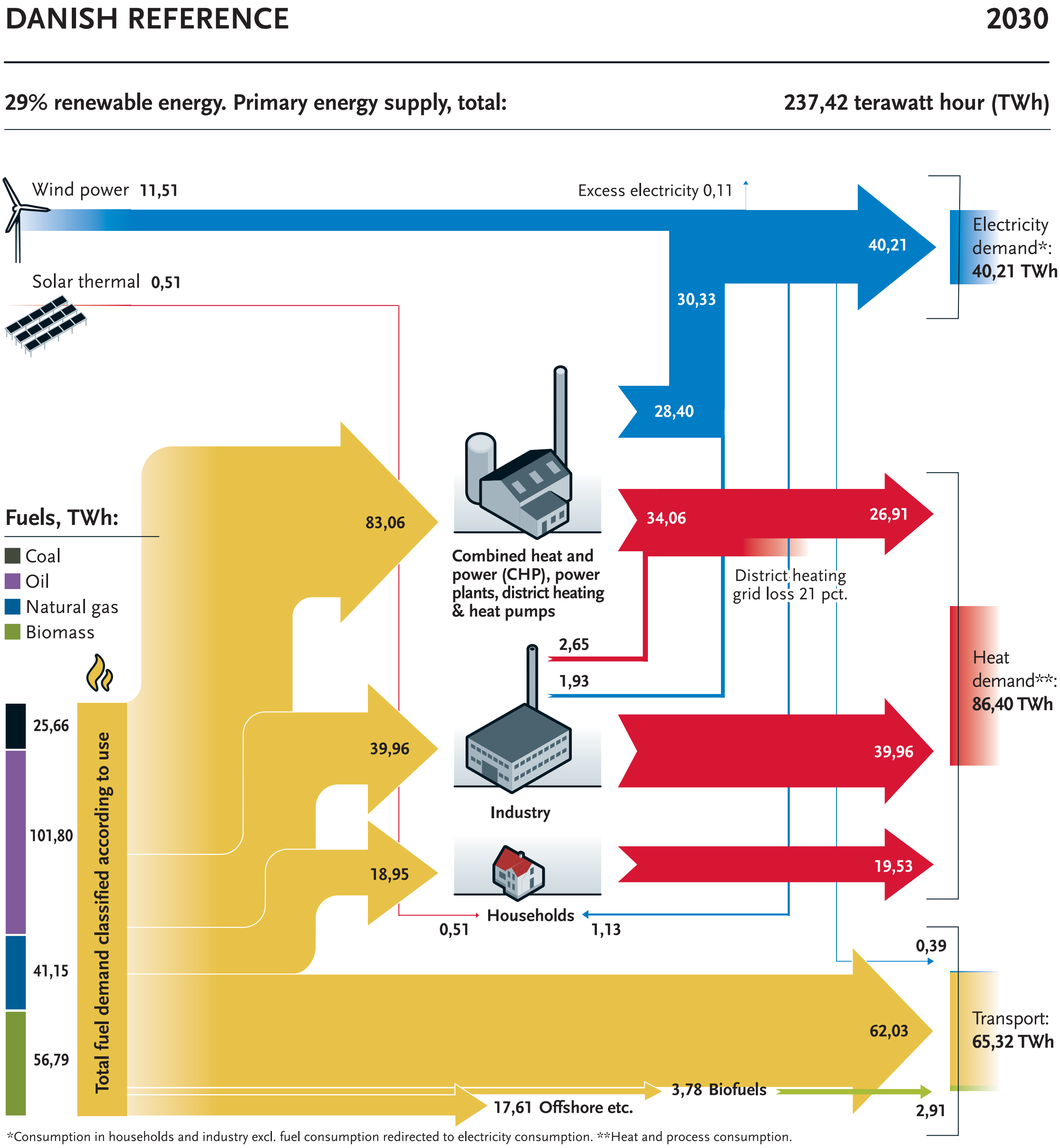

Fig. 2, Sankey diagram of the reference energy system for 2030.

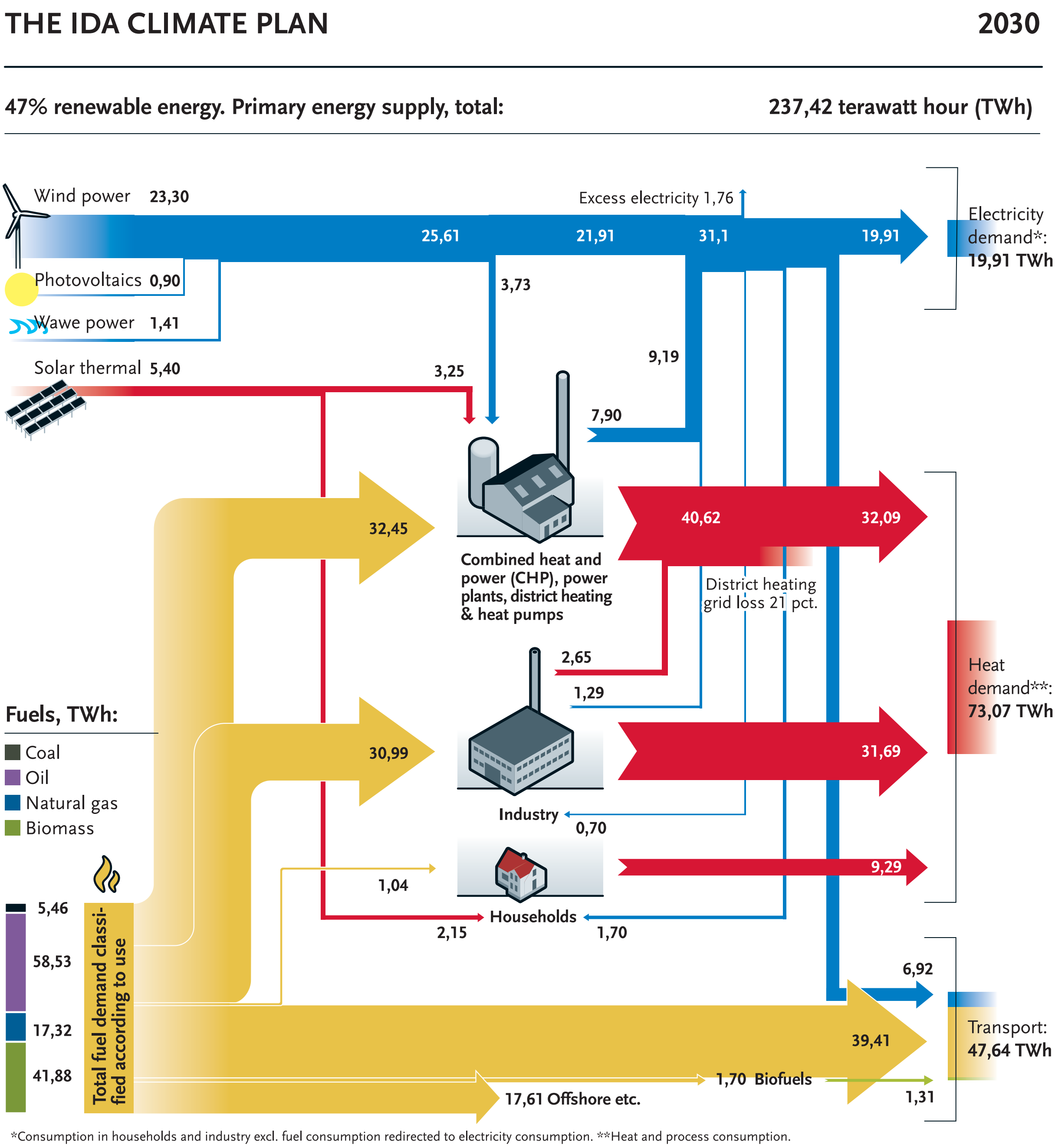

Fig. 3, Sankey diagram of IDA 2030 in IDA's Climate Plan 2050.

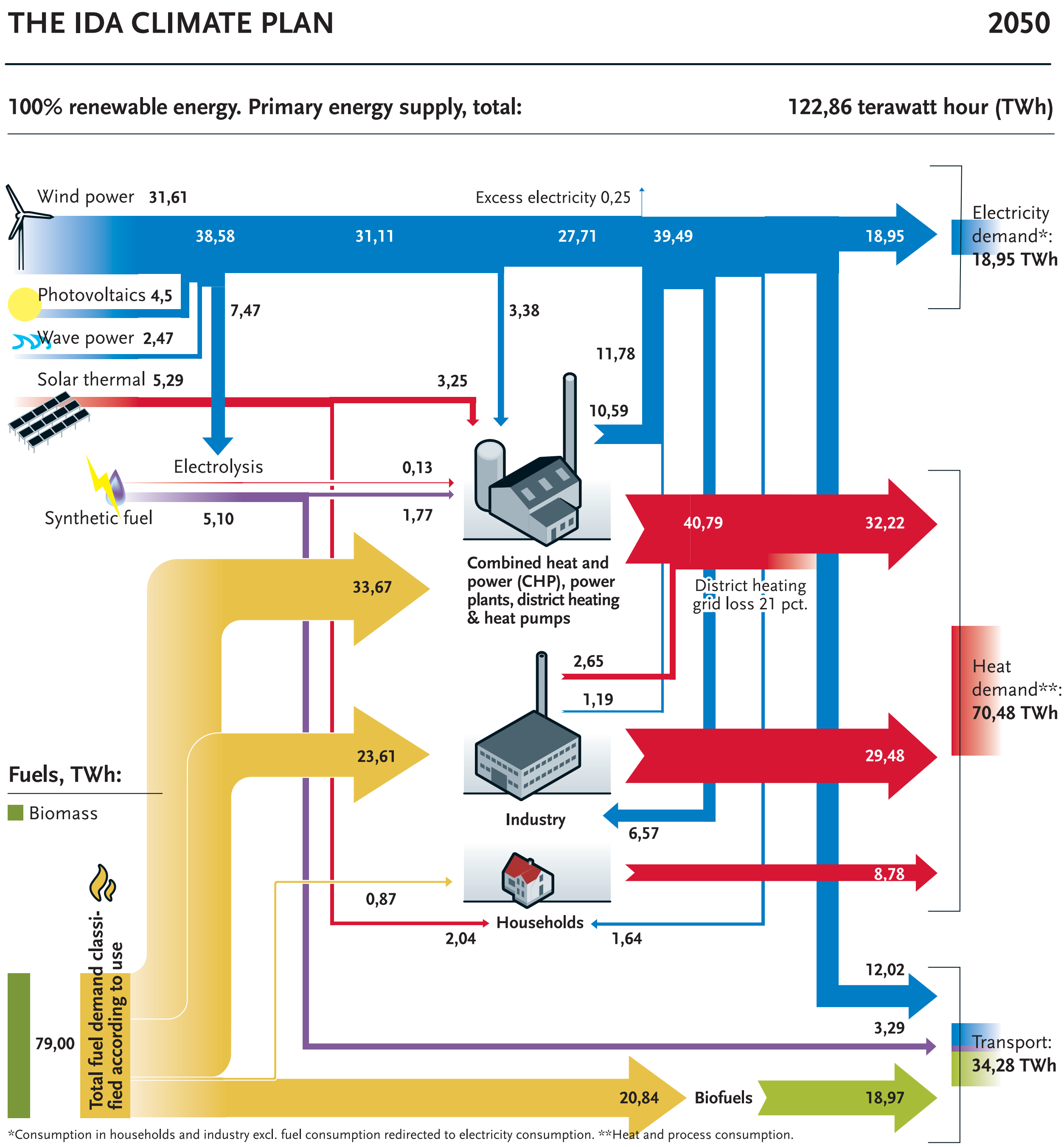

Fig. 4, Sankey diagram of IDA 2050 in IDA's Climate Plan 2050.

In IDA's Climate Plan 2050, an energy system is designed which is based on 100 per cent renewable energy, starting from the initiatives proposed in IDA 2015 and IDA 2030. This is partly to ensure that these energy systems do not stand in the way of this objective and partly because of the Danish Government's objective that Denmark shall be 100 per cent independent of fossil fuels and nuclear power, when the oil and natural gas resources stop. The result is that this is possible, but there is a key issue surrounding the consumption of biomass: should biomass be used to generate electricity for direct use or should it be used for the production of synthetic fuels. A balance must be met between these two requirements to utilise the biomass resource effectively and therefore, an estimate is presented in this report for this balance.

Further savings are presented and more renewable energy is introduced in IDA 2030 toward a 100 per cent renewable energy system. There are sufficient domestic biomass resources to meet demand for both the IDA 2015 and IDA 2030 scenarios. However, there are additional challenges in the 2050 energy system when 284 PJ of biomass is used in the Climate Plan. This can potentially be supplied with domestic resources, but conversely it will not leave many resources for producing other material goods, if this is to be based on biomass as well. Therefore, due to these limitations on domestic biomass, there is a further challenge in the future regarding the fuel consumption in industry and aviation. It is uncertain if these demands can be met using direct or indirect electricity production (i.e. electrolysis), or whether further savings must be introduced.

A 100 per cent renewable energy system has been designed which potentially can be maintained by domestic biomass resources. It must however be emphasised that there is no objective in the Climate Plan not to do international trade with biomass. However the Climate Plan ensures that Denmark does not merely become dependent on imports of biomass, instead of being dependent on imports of oil, natural gas and coal which is the case in the reference scenario, once Denmark does not have any resources left in the North Sea.

2.2 *Large reductions in greenhouse gas emissions*

The initiatives in the Climate Plan reduce the emission of greenhouse gases by about 90 per cent in 2050 in comparison to 2000. The energy system constitutes only a part of the greenhouse gases emissions. For the Climate Plan this part will be reduced to 34 million tonnes CO_2 in 2015, 19 million tonnes CO_2 in 2030, and is completely removed in 2050. Beyond this, reductions in greenhouse gas emissions from industrial processes and from agriculture are proposed. Considering these, the emissions of green house gasses in 2050 can be reduced to 7.2 per cent of the emissions in 2000. However, if an extra contribution from aircraft due to discharges at high altitudes is also included, the reduction in 2050 is 10.2 per cent of the emission in 2000.

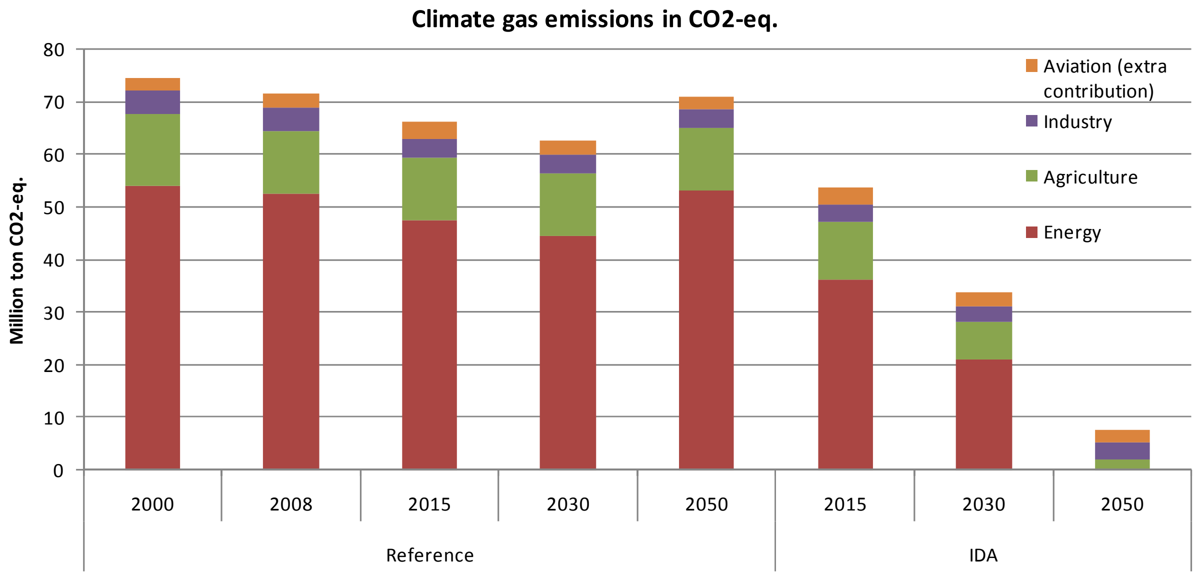

Fig. 5, Emissions of greenhouse gases in IDA's Climate Plan 2050.

2.3 Better socio-economic solutions with more renewable energy

The Climate Plan will be implemented over a period from now until 2050 by continuously replacing worn-out facilities when their lifetime expires, meaning they need to be replaced regardless of implementing the Climate Plan. Therefore, as a point of departure for this study, the expenses are calculated as extra expenses through investing in better facilities in comparison to the reference energy system. There are however exceptions to this.

The socio-economic costs are calculated as annual expenses in each of the years 2015, 2030, and 2050. The annual costs in the Climate Plan's energy systems are compared with the payments in the reference in each of the applicable years. The costs are categorised under fuel costs, operations and maintenance costs, and investment costs. A real interest rate of 3 per cent is used in depreciation investments. The economic analyses are based on the latest assumptions regarding fuel prices and CO_2 quota costs, which were defined by The Danish Energy Authority in May 2009 [1].

Three fuel price levels are used. The middle price level is based on current fuel prices which corresponds to an oil price of $122/barrel according to the Danish Energy Authority. The high fuel price is based on those that occurred in the spring/summer of 2008 and correspond to an oil price of $132/barrel [2]. The low price level is based on assumptions which The Danish Energy Authority used in its forecast in July 2008 and corresponds to an oil price of $60/barrel [3]. Calculations are also done with long-term CO_2 quota costs of 229 DKK/tonne and 458 DKK/tonne for 2030 and 2050 respectively. The CO_2 quota costs do not include all costs to the economy, such as flooding for example, but are only anticipated quota costs. If these types of effects are included in the calculation, there will be an economic advantage for the energy systems in the Climate Plan.

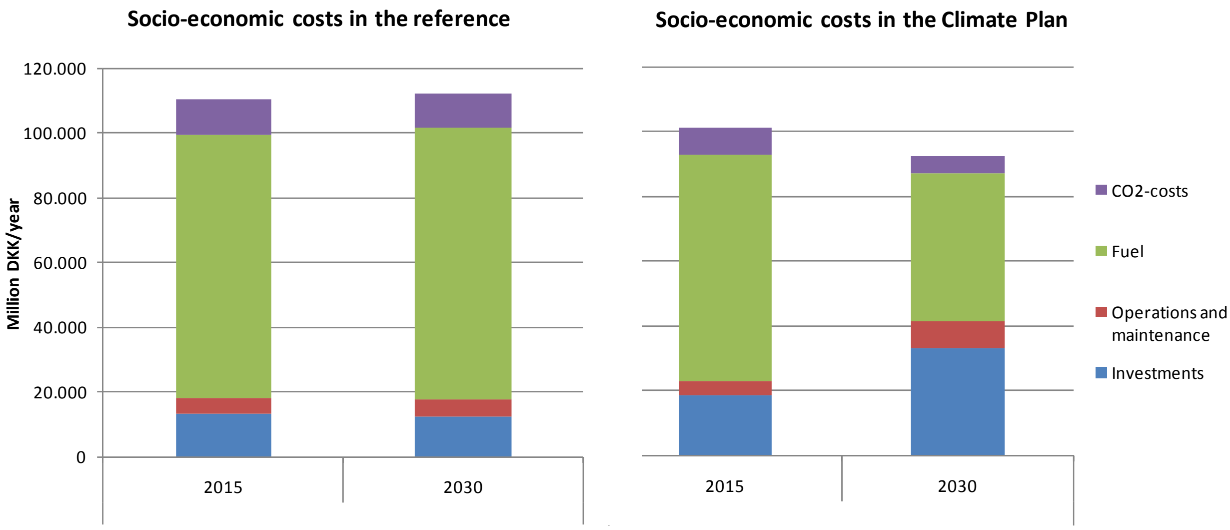

Fig. 6, Socio-economic costs in 2015 and 2030.

After analysing the implications of these various fuel and CO_2 costs, the general picture is that Denmark will achieve a significantly better economy with both IDA 2015 and IDA 2030, than with the reference scenarios. ***In 2015 and 2030 the difference with the middle fuel and CO_2 price assumptions is 9 and 20***

billion DKK/year respectively, as displayed in Fig. 6. In IDA 2015 it is important however to note that a part of the measures are undertaken in the period 2010 to 2020. On top of this there are advantages regarding saved health costs, commercial potentials, and employment effects.

In addition a more robust situation is reached with the IDA Climate Plan as the combined costs for energy are less sensitive to fluctuations in oil prices and CO_2 costs. There will be a gain even with fuel prices half as high as The Danish Energy Authority recommends at the moment. It is worth noting that between 50 and 95 billion DKK/year will be used for fuels from now until 2030, depending on the fuel prices. It is proposed in the Climate Plan that these expenditures be reduced to between 29 and 51 billion DKK/year, again depending on the fuel prices.

Two advantages can be obtained from the IDA 2015 and 2030 proposals. Firstly, they are less expensive than the reference energy systems, and secondly, these systems are significantly less sensitive to fluctuations in the fuel prices. In the future one must however expect that the world will continue to experience fluctuating fuel prices and neither constantly high nor constantly low oil prices.

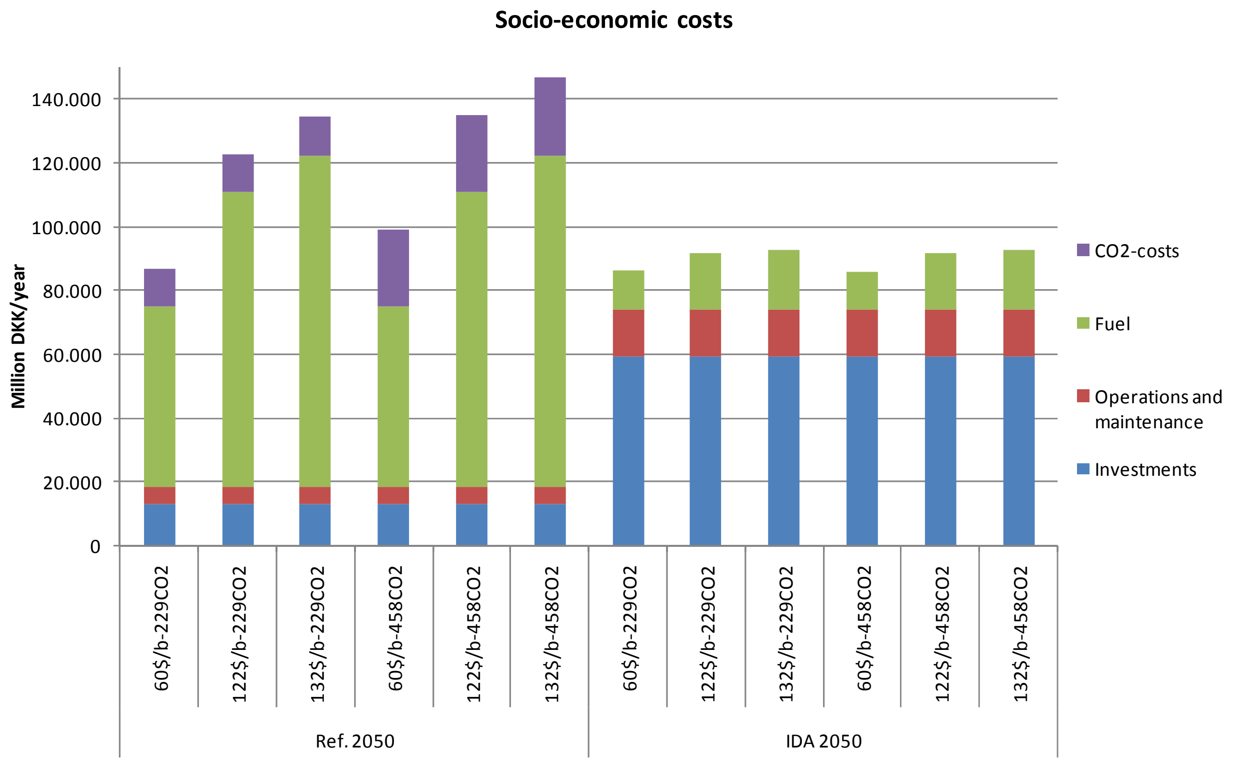

Fig. 7, Socio-economy costs in 2050 at different fuel and CO_2 prices.

IDA 2050 is based on 100 per cent renewable energy. The costs in this study should be seen as a first attempt to estimate the costs of the economy in such a system. Such estimates are however associated with significant uncertainties. In 2050 there is a wide range of measures, such as the electricity and heat savings, which are altered only marginally in relation to the measures in IDA 2030. The most important changes are that the share of renewable energy is raised significantly in the electrical system, the power plants are more efficient, synthetic fuels from electrolysis have replaced some of the biomass demand,

and the transport sector utilises more rail transportation and includes more battery electrical vehicles. It must be emphasised that the results are dependent on the fuel price assumptions, as well as the significant structural societal changes that are proposed in IDA 2050. IDA 2050 is robust even with larger changes in the biomass prices than analysed here. The results indicate that there are potential savings of over 25 billion DKK/year in the middle fuel price scenario for IDA 2050 compared to the reference, as illustrated in Fig. 7.

The above-mentioned estimation of costs to the economy is in a closed system without international electricity market exchange. Analyses of the consequences of international electricity exchange on the Nord Pool have also been conducted (The North European Power Exchange). The analyses are started using electricity prices from a normal year in the Nord Pool area and with fluctuating fuel and CO_2 quota costs. The net income is a combined calculation of import/export incomes including bottleneck incomes, as well as various CO_2 quota and fuel costs when there is electricity market exchange with the surrounding countries. The results indicate that in situations with low fuel prices and low CO_2 quota prices, income is primarily through electricity exports, while in the case of high fuel prices income is primarily through imports (i.e. money can be earnt by export or it is less costly to import than to produce electricity domestically). Therefore, there is also a difference in the earnings from electricity market exchange in the reference and IDA scenarios. The IDA energy systems provide higher incomes, primarily because of more efficient power plants combined with available capacity when the consumption is covered by wind turbines, etc. This will however result in larger CO_2 emissions in Denmark and increased coal or biomass consumption.

All in all, the economic benefits of the IDA Climate Plan due to the international exchange of electricity is insignificant compared to the economic benefits due to the annual costs of the system itself, which amounts to several billion DKK/year to the advantage of IDA 2015 and IDA 2030 as presented previously. In the references for both 2015 and 2030, as well as in IDA 2015 and IDA 2030, an increase in the transmission capacity to other countries from 2,500 MW to 5,000 MW only provides an opportunity for marginal extra incomes which are insignificant in comparison to the costs associated with this extra capacity. The conclusions of the electricity exchange analyses of the 2050 energy systems are estimated to be in keeping with the above results. It must be emphasised that the results for the electricity market exchange analyses for 2050 are simply an estimate and are based on The Danish Energy Authority's expected electricity price in 2030 and not 2050. It must also be emphasised that the analyses of a closed energy system without electricity market exchange are not an expression that international trade of electricity should not be the case in the future. This is only done in order to ensure that the energy systems in the Climate Plan are not dependent on this, or dependent on curtailing fluctuating renewable energy in certain situations as the energy systems in the Climate Plan can avoid this.

Even large changes in assumptions regarding international electricity trade in the means for electricity market exchange are not critical for the comparison. The large difference in costs between the various systems can be summed up by stating that the Climate Plan has large investments, while the reference has large fuel costs. Hence the cost comparison completed here is especially sensitive to both changes in the fuel prices and changes in the interest rate and investment requirements. Therefore, analyses have been done at three fuel levels and two CO_2 offset price levels. However, none of results change the general picture that the Climate Plan has lower costs than the reference. Nor are the results changed when the investment levels are increased by 50 per cent, although the earnings do become lower. The same is the case if the real interest rate is at 6 per cent instead of 3 per cent. It must be pointed out however that this applies to the combined package. With an altered interest rate or scope of investment, several of the individual measures will then have a negative economic result.

2.4 Health costs

The health costs have been estimated on the basis of six different emissions to the air: SO_2, NO_x, CO, particulates (PM2.5), mercury, and lead. In IDA's Climate Plan 2050 the highest reductions are in the emissions of NO_x, CO, and small particulates, while there are smaller reductions in the other emissions. The reduced emissions are primarily caused by lower coal demands for the power plants, less diesel and petrol in the transport sector, reduced demand for oil in industry, and a reduced demand for wood in individual household heating-systems. On the other hand, the emissions increase marginally because of more straw, wood, biogas, etc.

The health costs calculated here are based on the latest published data for costs connected to different technologies in different point sources. The costs are based on enumerated lost work days, hospital admissions, health damage, deaths, etc. The combined health costs estimated for the reference energy systems for 2015, 2030, and 2050 are approximately 14 to 15 billion DKK/year, which fit well with other studies. In Fig. 8 the health costs have been estimated by sector. It is important to emphasise that the total health costs presented here only give an indication of the total costs because of health effects. For a more precise measure of the health costs, the energy system scenarios would need to be analysed with the new preconditions in air-pollution analyses modelling tools.

In IDA 2015 and IDA 2030 these costs have been reduced to approximately 13 and 8 billion DKK respectively. ***Thus there are savings in the health costs of approx. 2 billion DKK in 2015 and approximately 7 billion DKK in 2030***, if the measures in the climate plan are implemented. Approx. 0.9 billion DKK of the saved costs in 2015 are located in Denmark and about 2.3 billion DKK in 2030. The rest of the savings in health costs are placed in the neighbouring countries. The health costs included are based exclusively on the six emissions and do not include environmental costs due to damage to nature and animal life, nor costs from extraction of fuels and materials abroad, e.g., from a coal mine in South Africa. Thus it is a conservative evaluation of externality costs. If the socioeconomic environmental and health costs due to the CO_2 emissions on top of the six emissions analysed here are included, a conservative estimate shows that the above-mentioned savings are approximately twice as large. The health costs have also been analysed for 2050. Here the potential savings in health costs are 9.5 billion DKK, out of which 2.4 billion DKK is saved in Denmark.

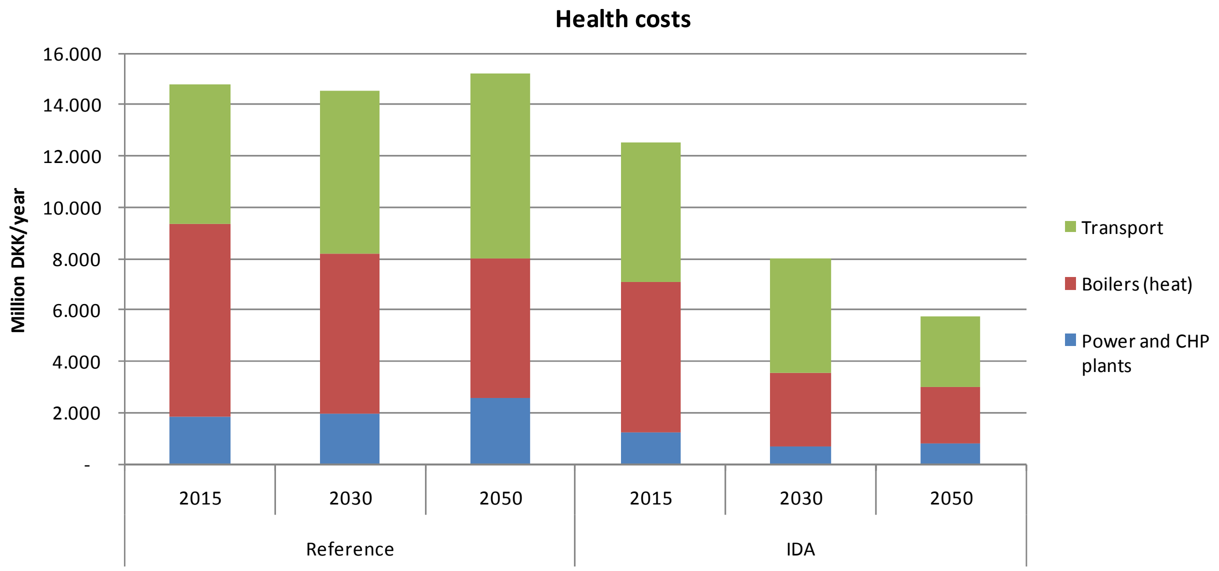

Fig. 8, Combined health costs from the energy systems divided by sector.

2.5 Commercial potentials

A systematic implementation of the technologies that are included in IDA's Climate Plan 2050 will include significant opportunities to increase exports. These commercial potentials are evaluated for the Climate Plan with a starting point in the current and historic export of energy technologies in Denmark. It is estimated that IDA's Climate Plan 2050 can create a potential export of energy technology that climbs from the present approx. 64 billion Danish crowns in 2008 to ***approx. 200 billion DKK/year*** going forward to 2030.

It must be emphasised that this type of quantification is associated with significant uncertainties and must be considered an estimate. However the rough estimate provides a good overview of the technologies which can be exploited if the Climate Plan is implemented. It must also be emphasised that these potential earnings come on top of the earnings that are shown through the changed operation and structure in the energy system itself. The results are illustrated in Fig. 9.

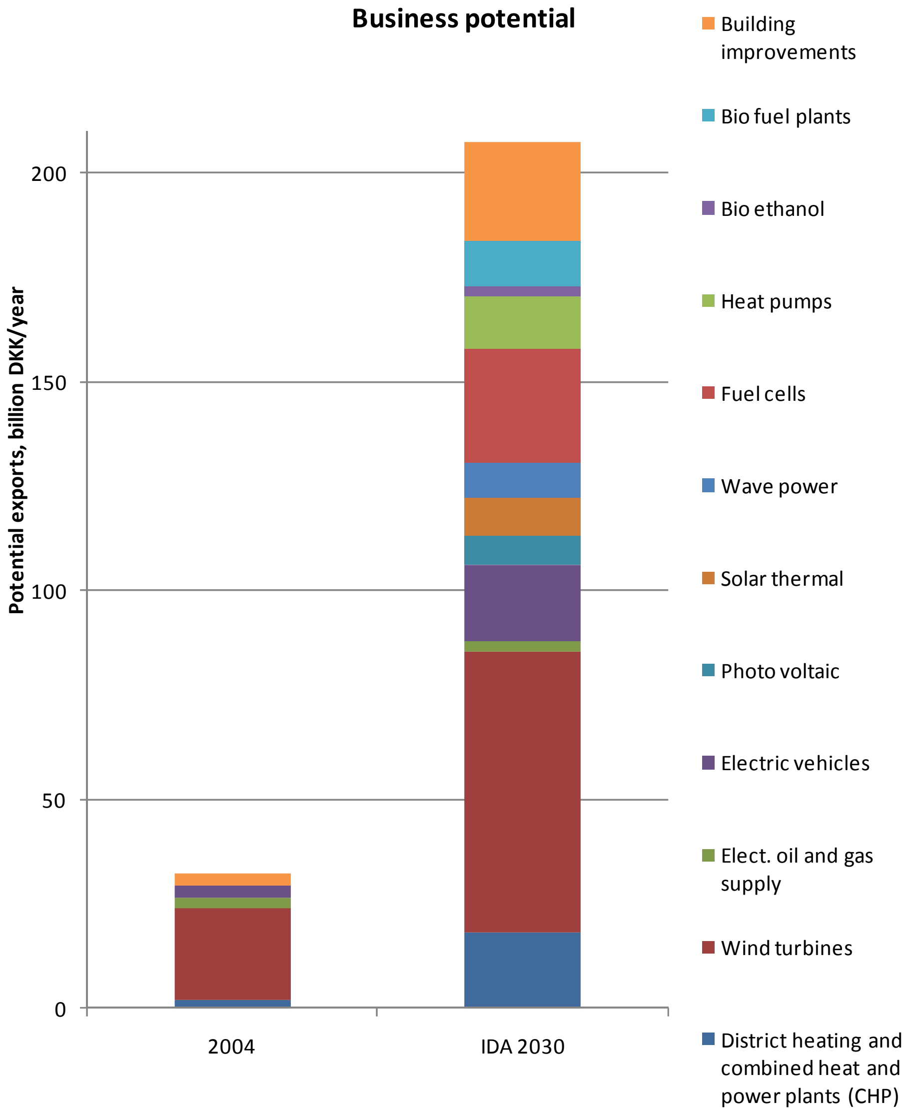

Fig. 9, Commercial potentials per year through implementation of IDA's Climate Plan 2050

2.6 Employment effects

The starting point for the estimation of the employment effect is the division in annual costs for the Climate Plan compared with that in the reference. To begin estimating the employment effects, the annual costs for both the Climate Plan and the reference were broken down into investments and operations. An implementation of the Climate Plan 2050 includes a change in the costs for fuel to expenditures for investments and hence, the Danish society will not be burdened with extra costs for energy. Such changes will include higher Danish employment while also improving the balance of payments. This effect is increased further if the above-mentioned commercial potentials in the form of increased exports are also realised.

In the Climate Plan, expenditures for fuels are reduced while expenditures for operations and maintenance are increased. In addition, an extra investment of just below 1 trillion DKK is made in the Climate Plan compared to the reference, which is spread out over the period going forward to 2050. For each cost type, an import share has been estimated based on experiences from previous collections of foreign exchange and employment data for investment in energy facilities. In relation to the previous data, a general upward adjustment of the import share has been done, as from experience these are increasing.

For the share that is left after removing the import share, two jobs are created for each million DKK. This includes derived jobs in the finance and service sector. It should be emphasised that these estimates are subject to uncertainties and again it is emphasised that they are based on adjusted numbers from previously collected data. The extra employment created in Denmark by the Climate Plan compared with the reference has been estimated with these methods and assumptions to be ***approximately 30-40,000 jobs***. Jobs will be lost in the handling of fossil fuels, but jobs will be created through investments in energy technology. In the long term, the employment will settle down as investments reduce and the transition to a 100 per cent renewable energy system is complete, so that there are about 15,000 extra jobs in the IDA Climate Plan compared to the reference for 2050. In practice this reduction will probably spread over a period of years.

It is important for a number of reasons to place the large employment effort as early as possible in the period. The first reason is that the labour force as a share of the total population is falling in the entire period going forward to about 2040 and therefore, the largest labour capacity to undertake a change of the energy system is in the beginning of the period. The second reason is that the Danish North Sea resources will run out during the next 20 years. Hence it is important to develop such energy systems and changes as early as possible in the period. Finally, the potential increase in the export of energy technologies which can replace the oil and natural gas exports will be reduced and could disappear entirely in the course of 10-20 years.

The above-mentioned effects on the employment do not include the job creation as a result of increased export of energy technology, i.e. the commercial potentials described above. These advantages will be an additional benefit of the Climate Plan. With an assumption of a 50 per cent import share, an annual export of 200 billion DKK will generate in the order of up to 200,000 jobs, depending on where the exports would have been without the Climate Plan, the extent of unemployment, and the potential for these people to be employed in other export trades. In relation to this, it should be noted that everything else being the same, a share of Danish labour will be made available as the oil and gas extraction in the North Sea comes to an end.

3 Introduction

The objective with this climate plan is to document that technically and economically feasible solutions to climate change exist which at the same time will ensure a continued positive economic development and an increased supply security. This background report constitutes, together with the main report, the Danish contribution to the international project "Future Climate – Engineering solutions". Climate plans from various countries are collected in one combined plan which has the above-mentioned objective. The combined plan is presented at the "Future Climate – Engineering Solutions" conference on 3 and 4 September 2009 in Copenhagen. Future Climate constitutes these organisations' contribution to the United Nations Climate Summit in Copenhagen in December 2009, COP15.

Thirteen engineering organisations are participating in the international project:

- The Danish Society of Engineers, IDA
- The Swedish Association of Graduate Engineers
- The Norwegian Society of Engineers and Technologists
- The Association of German Engineers, VDI
- The Institution of Engineers (India)
- Institution of Mechanical Engineers (UK)
- The Finnish Association of Graduate Engineers, TEK (Finland)
- Union of Professional Engineers, UIL (Finland)
- The American Society of Mechanical Engineers, ASME (USA)
- The Japan Society of Mechanical Engineers, JSME
- APESMA (Australia)
- Engineers Ireland
- Federation of Scientific Engineering Unions in Bulgaria

The Future Climate project was initiated by The Danish Society of Engineers in the spring of 2008, from a background of the good experiences with the development of a Danish energy plan in 2006, "The Danish Society of Engineers' Energy Plan 2030" (IDA's Energy Plan 2030) [4], and the development of an environmental plan in 2007, "Green Future – Pieces in a Sustainable Development" [5].

The Danish Society of Engineers' Climate Plan 2050 (IDA's Climate Plan 2050) constitutes the Danish contribution to Future Climate – Engineering Solutions. The input in the Climate Plan has been developed with a starting point in IDA's Energy plan 2030. Through workshops, seminars, conferences, and sub analyses the need for updates and adjustments has been identified. In 2006 the process was organised in approx. 40 seminars and meetings with over 1,600 participants. The starting point in this background report to IDA's Climate Plan 2050 is taken from the comprehensive piece of work to which the participants contributed in 2006. This shall therefore be seen as an update with regard to the knowledge about the technological and economic consequences a change to a 100 per cent renewable energy system has.

The Danish contribution to Future Climate has been developed during the period December 2008 to June 2009. A public consultation draft of IDA's Climate Plan 2050 was presented on 11 May 2009. Adjustments have been made after the consultation period. The final results and a combined description of the assumptions and analyses in IDA's Climate Plan 2050 are presented in this background report, including elements that are unchanged with regard to IDA's Energy plan 2030.

The process of developing the climate plan has been organised in the following six thematic groups: Energy Systems and Energy Production, Agriculture, Industry and Service, Construction, Transport, and Climate Adaptation. The work has been coordinated by an expert and project coordinator group for the climate plan under The Danish Society of Engineers' Steering Group for Environment, Energy and Climate.

The following objectives constitute the overall framework for the development of the climate plan:

- To reduce the emission of greenhouse gases by 90 per cent in 2050.
- To maintain Denmark's self-sufficiency with energy.
- To enlarge Denmark's commercial position within the climate and energy technology area.
- To expand the economy and prosperity of Denmark.

The background report contains a unified description of the technical energy system analyses and the economic consequence estimations of the thematic groups' input to IDA's Climate Plan 2050. The technical energy system analyses include an examination of how the plans for the years 2015 and 2030 (IDA 2015 and IDA 2030) can be a step on the road to an energy system for 2050 (IDA 2050) that is based on 100 per cent renewable energy. The objective is that IDA 2050 be able to reduce the emission of greenhouse gases by 90 per cent in 2050 in relation to 2000, including the emissions from agriculture and industry, and with regard for the security of supply and economic consequences.

The calculations in the climate plan's background report have been made by comparing the IDA scenarios with the reference energy systems for the years analysed. The Danish Energy Authority's latest basic forecast from 30 April 2009 [6] has been chosen as the reference energy system. The Danish Energy Authority's basic forecast contains a new forecast of the Danish energy consumption and production which takes into account the latest energy policy agreements in the form of the Danish Energy Conservation Agreement and the Danish Energy Agreement from February 2008, as well as the latest tax-related changes in the energy area in the spring of 2009. The International Energy Agency's (IEA) latest expectations for the trend in fuel prices from November 2008 have also been taken into account. The IEA adjusted upward the expectations for the price of oil in 2030 to $122/barrel. This is just under double the price as of this writing, but less than the price recorded in the summer of 2008, which was just under $150/barrel.

Technical energy system analyses and estimates of socio-economic consequences of a 2030 energy system and a 2015 energy system have been done, in which the necessary changes have been initiated. IDA 2015 takes its starting point in technical changes that are technologically possible today. On the other hand, an IDA 2050 energy system draws upon technologies which are expected to be developed in the future. The IDA 2030 energy system represents a step in the direction of the IDA 2050 energy system. IDA 2030 and IDA 2050 will be carried out by technological measures which are estimated to be developed from the year 2020. Technical energy system analyses of the IDA 2050 energy system are also performed, just as an estimate is made of the socio-economic consequences.

In this Climate Plan, for the first time in Denmark, ***a forecast has been done of the Danish energy consumption including transport up to 2050***. This forecast takes into account the same elements as the assumptions identified in the Danish Energy Authority's forecast from 30 April 2009 which runs to 2030. The forecast has also been done according to the same method as used by the Danish Energy Authority. A continued optimisation is assumed after 2030 going forward to 2050, at a level equal to the period 2010 to 2030. That is to say that a continued active policy to reduce the consumption of energy is included in the reference scenario. The forecast of energy consumption creates the basis for constructing a reference energy system for 2050.

In the IDA 2050 energy system, significant structural and infrastructure changes are proposed in relation to the present. One objective is to carry out a technical analysis of such energy systems. Another is to evaluate the socio-economic consequences of such energy systems. In this study a draft is completed outlining the costs of an energy system that is based 100 per cent on renewable energy, which is the first time this has been attempted in a Danish energy plan. The results of the technical and economic analyses are, just as for IDA 2015 and IDA 2030, calculated by comparing IDA 2050 with the reference for 2050.

In all the energy systems, the analyses have been done by analysing the system hour by hour in the energy system analysis model EnergyPLAN, which has been used for technical system analyses as well as estimates of socio-economic consequences. [7]

The ***technical energy system analyses*** have been done to ensure flexibility and balance between electricity production and consumption with regard for the system's fuel efficiency and ability to ensure stability of the electricity supply. A balance is identified between the fluctuating sustainable energy production, combined heat and power production, and electricity consumption, including flexible electricity consumption in heat pumps, electric vehicles, etc. In addition, a corresponding balance is ensured between district heating consumption and heat production from solar thermal, industrial surplus heat, waste incineration, centralised and decentralised combined heat and power, geothermic energy, boilers, heat pumps and electrical cartridges. The results from the analysis include among other things, the annual fuel consumption and CO_2-emissions which can be compared with a corresponding analysis of the reference.

The balance between consumption and production is ensured in a closed energy system in which electricity is not traded in the international electricity markets. This partially ensures that an energy system is established where the domestic security of supply is intact and also, that Danish energy producers are not forced to export or import at times when the market price is not favourable. Apart from these considerations, it is ensured that electricity and biomass for the energy system can be supplied with domestic resources. This ensures a more favourable position while trading in electricity and biomass with foreign countries than if Denmark was dependent on imports or exports at certain times.

The ***evaluation of socio-economic consequences*** has been done for two primary reasons: firstly, to estimate the combined energy system's costs under various assumptions for fuel prices and CO_2 quota costs and secondly, to evaluate the system's ability to earn money through electricity exchange on the

Nord Pool market under various market assumptions. Also the marginal value of each of the sub-components is calculated for 2030.

Beyond this, quantification has been done of the Climate Plan's ***effects on employment***, ***commercial potentials***, and ***health costs*** associated with various emissions, etc. The socio-economic costs through externalities as a result of various emissions have been quantified separately from the fuel consumption in the energy systems. It must be emphasised that these estimates are subject to significant uncertainties and must be considered as an indication of the level of these costs.

In the most recent report from the United Nations Intergovernmental Panel on Climate Change from 2007, IPCC Fourth Assessment Report: Climate Change 2007 (AR4), it appears that if the temperature increase is to be maintained in the level of 2-2.4ºC, the concentration of CO_2 equivalents is to be maintained between 445 and 490 ppm [8].

As the concentration of greenhouse gases already reached 445 ppm (CO_2 equivalents) in 2005, the IPCC has estimated that the emissions of greenhouse gases must peak as soon as possible and no later than the year 2015 and also, that the emissions of greenhouse gases must be reduced by 50-85 per cent by 2050 compared with the year 2000. However, if the temperature is to rise only 2 degrees, then the reduction in the emissions of greenhouse gases must lie closer to 85 per cent than 50 per cent. The United Nations estimates that the emissions per person therefore must be reduced to between 0.8 and 2.5 tonnes of CO_2 equivalents per person per year.

Even with a 2ºC increase, significant changes in the climates of Denmark and the world will occur. But it can nevertheless be possible to ensure that climate changes do not accelerate beyond the point where the effect will become self-reinforcing. A 2ºC increase through a reduction of 50-85 per cent was based on a reduction to 350-400 ppm CO_2 in the atmosphere. At the moment, the concentration of CO_2 in the atmosphere is about 385 ppm.

The most recent IPCC report from 2007 is however based on data from 2005, and the latest results from James Hansen from NASA, among others, indicate that this is not sufficient. The most recent observations and model analyses show that a reduction to 350 ppm CO_2 in the atmosphere may be necessary or that anthropogenic greenhouse gases must be avoided entirely to avoid irreparable damage to the climate's balance [9-11]. Hence the total reduction ought to settle at the high reduction level of 85 per cent. The target here in the Climate Plan is 90 per cent reduction of greenhouse gas for the following reasons:

- The 2ºC increase mentioned above is dependent on the emissions peaking in 2015
- Even an 85 per cent reduction in the CO_2 emissions may result in large climate changes
- Setting a target to implement further reductions up to 90 per cent or more provides the possibility that some measures will succeed while others will fail.
- Setting a target to implement further reductions up to 90 per cent or more provides the possibility of reaching the combined target, even if some countries do not reach the objective.

IDA's Climate Plan 2050 has the purpose of showing which technical solutions can contribute to a radical reduction in the Danish CO_2 emissions and greenhouse gases in general, as well as the socio-economic consequences of this. The agricultural sector contributes about 17 per cent of the combined Danish emission of greenhouse gases. The target is a combined reduction of 90 per cent in relation to the emission of about 72 million tonnes of CO_2 equivalents in the year 2000. Greenhouse gases from the agricultural sector, from industrial processes, and from emissions from aviation in high altitudes are included in the Climate Plan in addition to the emissions from the energy conversion as such.

4 Background

In this chapter information about similar previous work is presented as well as information about additional analyses in IDA's Climate Plan 2050.

4.1 IDA's Climate Plan 2050 starting point

IDA's Energy Plan 2030 [4] was based on inputs from seven thematic groups to the energy systems analysed and to the socio-economic analyses. The inputs where based on about 40 seminars with a combined total of more than 1,600 participants. The technical energy system analyses included an examination of how the Energy Plan for the year 2030 can be a step on the road to a 100 per cent renewable energy system, for example in the year 2050. Furthermore, a quantification of the commercial potentials connected to the Energy Plan was completed.

In this background report to IDA's Climate Plan 2050, a starting point is taken from the comprehensive piece of work the participants contributed with in 2006. Hence this report should be regarded as an update with regard to the knowledge about the technological and socio-economic consequences a change to a 100 per cent renewable energy system has. In IDA's Climate Plan 2050 under the Future Climate project, a starting point is taken from IDA's Energy Plan 2030 from December 2006 and the updated socioeconomic calculations that were done in May 2008 as a result of the changed prices for fuel, photovoltaic, and wind turbines [4;12].

4.2 IDA's Climate Plan 2050 reference energy system

The reference system in IDA's Climate Plan 2050 is the basic forecast to 2030 from 30 April 2009 from the Danish Energy Authority [6]. This reference system is significantly different from the reference energy system used in IDA's Energy Plan 2030 from 2006. Among other things, the fuel prices are now twice as high, more energy savings are included, and the Energy Agreement from February 2008 between most of the parties in the Danish Parliament is taken into account. The forecast of the energy consumption takes its starting point from the latest forecast of the Danish economy by the Danish Ministry of Finance in December 2008, where the latest period's economic trend is taken into account, as well as the tax-related changes in the energy area from the tax policy agreement in the spring of 2009. The reference system for 2050 has been designed on the basis of forecasts of the energy consumption until 2050, which was done in preparation for the analyses in this report.

4.3 Additional elements in IDA's Climate Plan 2050

Compared to IDA's Energy Plan 2030 from 2006, the Climate Plan here also analyses an energy system which is in a significantly shorter term, i.e. 2015. In addition, the technical analyses of a 100 per cent renewable energy system are supplemented by an estimate of the socio-economic costs in such a system, which was not the case in the Energy Plan.

In addition to updates of the assumptions for technologies with respect to efficiencies, lifetimes, etc., which is included in the plan, an update is done for fuel price assumptions, costs for handling and transport of fuels, electricity price assumptions for the external market electricity exchange, CO_2 quota cost, etc. These price assumptions take into account, among other things, the International Energy Agency's (IEA) latest recommendations concerning fuel prices, which are equivalent to an oil price of $122/barrel, and which are in agreement with the fuel costs used in the reference from the Danish Energy Authority [1].

Furthermore, the commercial potentials are updated, as well as marginal costs and marginal CO2 reductions for each measure in 2030. As a new part, a quantification of the Climate Plan's effect on employment has been done, as well as an estimation of the health costs.

The analyses in the background report include all of the Danish primary energy supply as well as fuel for international aviation and the energy consumption in the North Sea, which is one of the differences between the scenarios in the Climate Plan and the scenarios for 2030 in The Danish Board of Technology's report "Det Fremtidige Danske Energisystem – Teknologiscenarier" (English version: "The Future Danish Energy System") from 2006 [13]. The Danish Board of Technology's scenarios were done in co-operation with Danish members of parliament in 2006.

IDA's Climate Plan 2050 contains a calculation of the total Danish climate gas emissions, including agriculture, process emissions from industry and from high altitude emissions in aviation. In IDA's Energy Plan 2030, only the energy sector including transport was included.

5 Methods and Assumptions

In this chapter we present the assumptions for the technical and socio-economic analyses that have been done of the energy system in IDA 2015, IDA 2030, and IDA 2050 respectively and of a reference energy system for each of these years. The simulation tool employed is presented along with the method by which the socio-economic impact analysis is undertaken, including fuel price assumptions, etc.

5.1 Energy System Analyses model and simulation tool EnergyPLAN

The technical analyses and the socio-economic impact analysis have been done with the energy system analysis model EnergyPLAN, which has been developed by Aalborg University [7]. The latest version of the model can be downloaded from the website: www.energyplan.eu. On the same website, there are links to descriptions and documentation of the model's calculation methods and a list of scientific articles that use or describe various aspects of the model. In Fig. 10 an overview of the individual technologies and component in the model is shown. EnergyPLAN is a simulation tool. As input for the model, an energy system is described with regard to its plant capacities, efficiencies, distributions, and regulation strategy etc. From such inputs the model can carry out a range of technical analyses of how the energy system acts hour by hour through a year. The model calculates the balance between consumption and production over the year in the analysed energy system, as well as the resulting annual primary fuel consumption and CO_2 emissions.

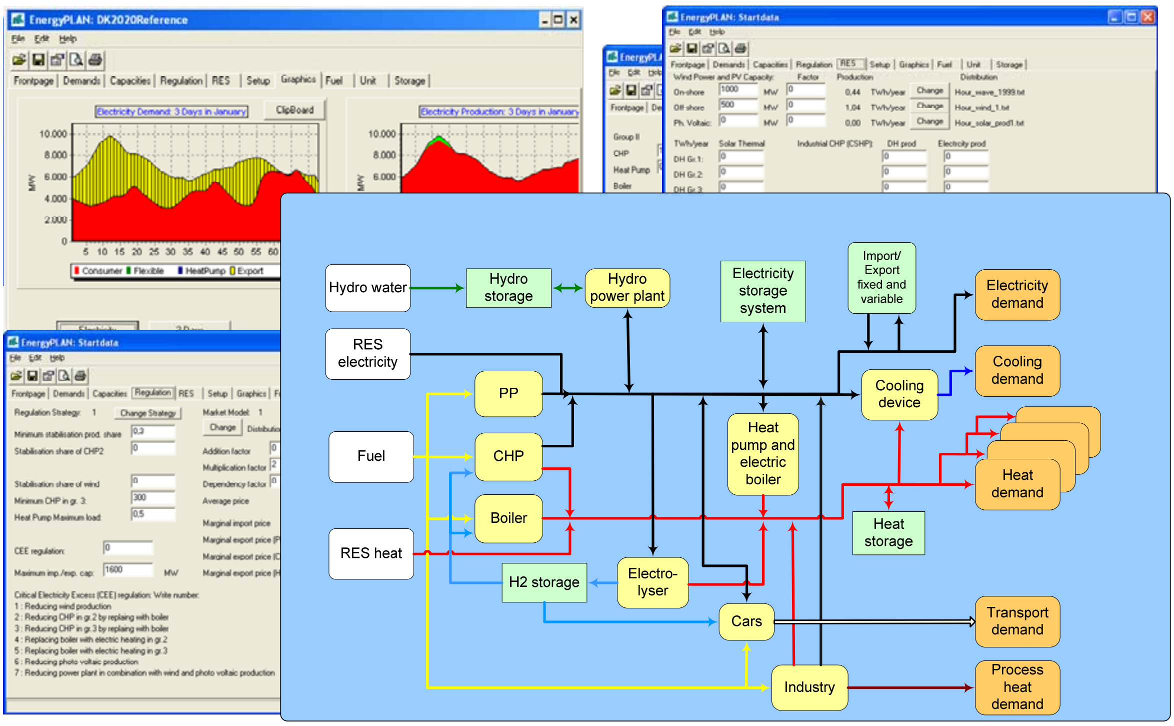

Fig. 10, Illustrations from the EnergyPLAN model's user interface and a flow diagram of the connections between the technologies and components in the model.

The model can also carry out analyses of energy system's abilities to earn a profit on electricity exchange on an external electricity market through a given transmission capacity. This requires further inputs in the form of a description of the market and a range of economic parameters, such as the price elasticity, i.e. how the market price changes through increased production or increased consumption. Such inputs enables analyses of how various groups of plants can benefit from the electricity exchange market and optimise their income based on variable production costs, fuel costs, CO_2 quota costs, and linkages in the form of heat supplies and fluctuations in electricity demands, heat demands as well as production from intermittent renewable energy sources.

Finally the model can calculate the system's combined costs, which again require inputs in the form of specific plant costs, lifetimes, fixed and variable operation, and maintenance costs for the various plants, and costs for any energy conservation measures or other alterations of the system.

5.2 Assumptions concerning methodology for energy systems analyses

The Danish Energy Authority's reference energy systems for 2015 and 2030 have been modelled in the EnergyPLAN model to ensure agreement regarding the starting point. As appears in section 6.2, the EnergyPLAN model comes to the same annual energy turnover, fuel consumption, and CO_2 emission as The Danish Energy Authority when a calculation is made on the same technical assumptions.

The reference energy systems for 2015 and 2030 can be taken directly from data from The Danish Energy Authority's basic forecast. This is not the case for the year 2050, as The Danish Energy Authority's forecast stops in the year 2030. For this report, a forecast has been done of energy consumption including transport for the period 2030 to 2050. This forecast creates a foundation for being able to create a reference energy system for 2050. The consumption side of this reference system takes its starting point from the forecast described in Appendix III. The production side takes its starting point from an expected trend if the Danish Energy Authority's forecast were continued to 2050. The results of the construction of this reference for 2050 are found in section 6.3.

After this, the individual measures have been implemented as described in chapters 7 to 12. All measures have been defined in relation to the reference for each year; 2015, 2030, and 2050 technically as well as economically.

The starting point in IDA 2015 is taken from measures technically and commercially ready now in the short term. The IDA 2030 system represents the possible measures in the middle term with technologies that are expected to be developed in 2020. In IDA 2050, an analysis has been done of whether Denmark with IDA's Climate Plan 2050 can proceed appropriately towards an energy system with 100 per cent self-sufficiency without nuclear power, after the oil and natural gas run out in the North Sea. IDA 2050 represents a vision of what a system based on a 100 per cent renewable energy could look like in 2050. The principle in the calculations is to continue in the way that has been set down in IDA 2015 and IDA 2030 and to improve on those areas in which it is expected to be technologically possible.

The measures in the energy systems: IDA 2015, IDA 2030, and IDA 2050 have been analysed in "raw versions" first in which all sub-objectives have been implemented. This first version shows energy systems with large imbalances between consumption and production, which is expressed partly in the form of excess electricity which the energy system is forced to export, and partly in the form of the system's decreased ability to earn money through exchange of electricity on the international electricity market. Hence a range of technical improvements of the "raw versions" of the energy system have been done for the purpose of creating greater flexibility, however this also results in improvements in fuel efficiency in the energy system. These changes have been incorporated accordingly into IDA 2015, IDA 2030, and IDA 2050. The result of these analyses appears in chapter 13.

After this, an overall socio-economic impact analysis of IDA 2015 and IDA 2030 has been done to estimate the combined annual costs and to compare with a corresponding estimation for the reference. Likewise, an estimation has been made to calculate the socio-economic costs associated with a 100 per cent renewable energy system in IDA 2050 using the same methodology. To a large extent the technology costs have been estimated using 2006 prices, however there are individual deviations from this. The results of the socio-economic impact analysis are described in chapter 15.

5.3 Assumptions for technical facilities and new technologies

The Climate Plan is to be carried out over a period from now to 2050 by continuously replacing worn-out structures when their lifetime runs out. The measures taken in the Climate Plan going forward to 2015 take their starting point from the technological possibilities in the short term and from a vision of the long term goal for the energy system in 2050. As a starting point, the costs that are connected with the implementation of the Climate Plan have been calculated as extra expenses for plant investments as well as operations and maintenance. Better and more efficient technologies are established in the Climate Plan than those in the reference, replacing old facilities that have to be replaced under all circumstances.

Generally, costs for production facilities, including investments, fixed and variable costs, and lifetimes have been calculated with a starting point in "Technology Data for Electricity and Heat Generating Plants" [14]. This catalogue is also used by the Danish Energy Authority for the basic forecasts of the Danish energy system. IDA's Climate Plan 2050 however includes a range of conservation measures, conversions, etc., whose costs have not been calculated in "Technology Data for Electricity and Heat Generating Plants." Likewise there are renewable energy technologies where the costs have changed. These data appear in each individual section in chapters 8 to 12. An overview of the costs can be seen in Appendix II and Appendix VII.

The calculation of costs has not included facility and operational costs for those parts of the combined energy system that are considered to be identical in the reference and in the Climate Plan. This involves, among other things, the electricity and natural gas network, large parts of the district heating network, and the transport infrastructure.

The socioeconomic impact analysis has been done by calculating the annual costs in the Climate Plan compared with the reference. The cost calculation has been divided among the costs for fuel, operations and maintenance expenditures, and depreciation of technologies. Depreciation of technologies has been calculated with the individual investment's lifetime. In addition, any possible profits or losses in international electricity market exchange with surrounding countries have been included in the comparison.

5.4 Assumptions concerning forecast of consumption from 2030 to 2050

The forecast from 2030 to 2050 is an extension of The Danish Energy Authority's basic forecast of April 2009. That is to say that the trend in energy efficiency continues at the same pace to 2050 as up to 2030, but because of a continued economic growth of about 2 per cent a year, the energy demand increases towards 2050. The average annual improvement of the energy efficiency of industry and service is 1.1 per cent, which is why the final energy demand increases by up to 0.9 per cent a year. The forecast is based on a run from the Annual Danish Aggregate Model ("ADAM") from the Ministry of Finance in "Denmark's Convergence Programme 2008" from December 2008. This forecast was used as input to the Energy and eMission Model for ADAM ("EMMA"), which then "translates" the economic activity in ADAM to an energy demand for the various industries and households. The assumptions concerning the forecast of the final energy consumption in 2050 are accounted for in Appendix III. The result of the forecast appears in Fig. 11, where the trend from 1975 is also given.

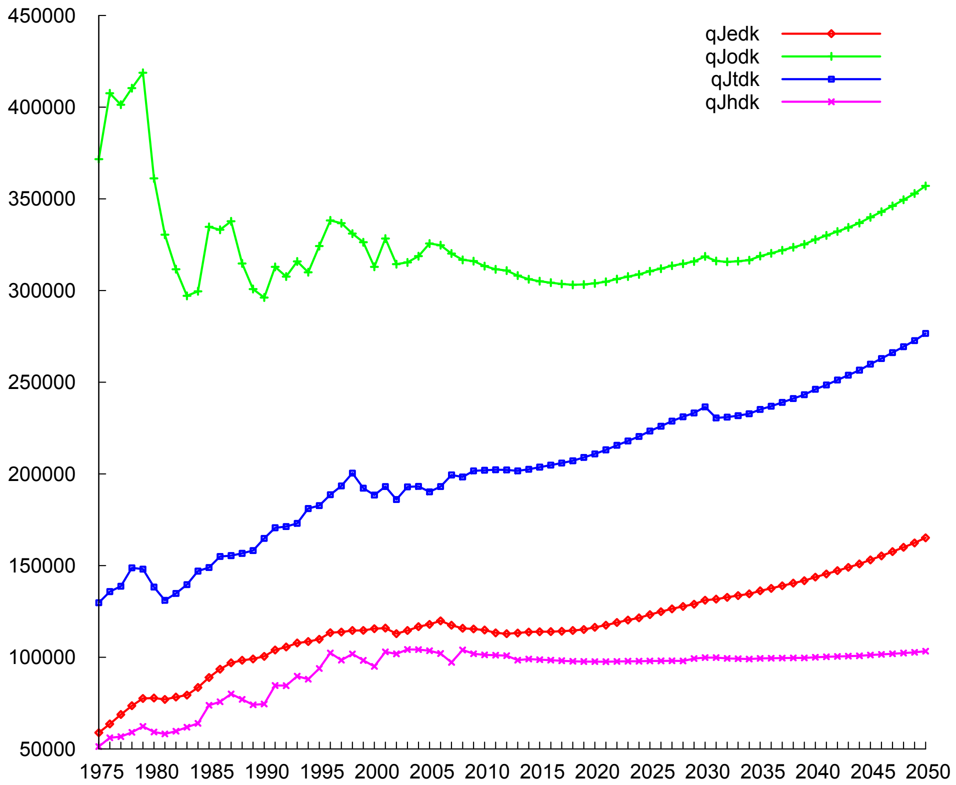

Fig. 11, Result of forecast of the Danish final energy consumption (TJ/year). [qjedk=electricity, qjodk=other energy, qjtdk=transport, qjhdk=district heating].

5.5 Assumptions for fuel prices, electricity prices, and CO_2 quota prices

The Danish Energy Authority last updated its fuel price assumptions in May 2009. The update is connected primarily with the fact that the IEA in World Energy Outlook from November 2008 re-evaluated its expectations for the fuel price trend. In The Danish Energy Authority's update, the expected oil price in 2030 increased to $122/barrel [1]. When IDA's Energy Plan 2030 [4] was completed in 2006, the Danish Energy Authority's corresponding expectations were at $40/barrel [15].

The fuel prices in IDA's Climate Plan 2050 which are anticipated in the long term use the new fuel prices from The Danish Energy Authority as a starting point, and once again three fuel prices levels are used. The Danish Energy Authority's latest assumptions represent a middle level. The high prices from the spring/summer of 2008 are used for a high price level [2]. For the low price level, the low price assumptions which The Danish Energy Authority used in its basic forecast from July 2008 are used [3]. The prices are shown in Table 1.

Table 1, Fuel price assumptions

(DKK/GJ) [1]	Crude oil	Coal	Natural gas	Fuel oil	Diesel fuel Diesel	Petrol JP	Straw[2]	Wood pellets[2]
$60/barrel	67.3	14.8	41.7	47.2	84.1	89.6	27.3	66.3
$122/barrel	126.5	25.3	77.8	88.5	158.1	168.2	44.7	80.9
$132/barrel	134.8	51.3	105.3	94.1	168.3	179.1	47.6	86.2

Transport, transmission, distribution, and handling costs have been based on the latest fuel price assumptions from the Danish Energy Authority [1] and are listed in Table 2.

Table 2, Transport and distribution costs

Additional costs (DKK/GJ)	Coal	Natural gas	Fuel oil	Diesel fuel Diesel	Petrol JP	Biomasse[2]
For power plants (including IBUS)	0.5	3.2	1.7			12.4
For decentralised CHP, district heating & industry		8.7	14.3			8.3
For individual households		22		21.7		45.7
For road transport				23.6	31.8	
For aviation					5.2	

The latest assumptions for electricity prices have been used in the electricity market exchange analyses in IDA's Climate Plan 2050. The long term electricity price from Nord Pool is expected to be 497 DKK/MWh in combination with a CO_2 quota price of 229 DKK/tonne in 2030 for IDA 2030 and IDA 2050 [1]. However, a price of 447 DKK/MWh was used in the electricity market exchange analyses in 2015, as that is the Danish Energy Authority's expectation for this year. A CO_2 quota price of 458 DKK/tonne has also been calculated in the sensitivity analyses for all target years.

In the reconstruction of the Danish Energy Authority's reference energy systems for 2015 and 2030, a starting point is also taken from the assumptions described above. For the constructed reference energy system for 2050, a starting point is taken in the assumptions for 2030 described above.

In IDA's Energy Plan 2030 from 2006, a starting point was taken in The Danish Energy Authority's expectation from 2006 of an electricity price in the year 2030 of 349 DKK/MWh on Nord Pool in combination with 150 DKK/tonne of CO_2 [15]. This was adjusted upward in May 2008 to an electricity price of 367 DKK/MWh in combination with 175 DKK/tonne of CO_2 [3]. In February 2009, it was changed again to 337 DKK/MWh and 225 DKK/tonne of CO_2 [16] and has accordingly now changed again according to the Danish Energy Authority.

[1] The low price level has been estimated with a forign exchange rate of 5.42 DKK/$. For the middle level and the high price level, the dollar rate of excange is 5.81 and 5.9 DKK/$ respectively. This has been adjusted here to a dollar exchange rate of 6.00 DKK/$.

[2] Straw at plants and wood pellets in individual households.

The Danish Energy Authority's expectation of an average price of 497 DKK/MWh is for a CO_2 cost of 229 DKK/tonne. The CO_2 cost is assumed to affect the electricity price by 90 DKK/MWh. This part is held constant, while the other part is assumed to have the same time distribution as the Nord Pool price in 2008. In analysis with a CO_2 quota price of 458 DKK/tonne, the constant part has been fixed at 180 DKK/MWh, and hence the average price over a year is 587 DKK/MWh. A price elasticity has been calculated for such electricity exchange, cf. the descriptions in "Local Energy Markets" [17].

Analyses of international electricity market exchange with consequences of changes in precipitation for the Norwegian and Swedish hydroelectric power systems have not been done in IDA's Climate Plan 2050. Such analyses were conducted in the IDA Energy Plan 2030 from 2006 [4].

It must be emphasised that the CO_2 quota costs employed here is used primarily to be able to evaluate incomes and costs from electricity market exchange. The use of respectively 229 DKK/tonne and 458 DKK/tonne of CO_2 reflects the costs of CO_2 reductions and is not an analysis of the socioeconomic impacts from the CO_2 emission. Externalities, environment, and health costs are discussed further in Appendix V.

5.6 Taxes and levies on fuels for production of electricity and heat

In the EnergyPLAN calculation, the individual groups of plants optimise their income from their marginal production costs including taxes. The expected future tax rates that are stated in "Forslag til lov om ændring af lov om afgift af elektricitet og forskellige andre love" (Proposal for Act on Amendment of Danish Act on Taxation of Electricity and Various Other Acts) have been used for the market optimisation here (not in the technical analyses). This legislation is now approved and it follows the tax agreement between the Danish government and The Danish People's Party from March 2009. The parts of the agreement that concern production of electricity and heat contain an increase of the energy taxes for fuels and electricity by 15 percent and 5 percent respectively, as well as the introduction of identical taxation of centralised and decentralised combined heat and power plants.

In Table 3 the expected tax rates used for optimisation of the operation of the individual facilities are listed. The tax rates have been developed by Technical Consultant John Tang from the Danish District Heating Association on the basis of the public consultation material distributed by The Danish Ministry of Taxation on 20 April 2009. The waste charges have been excluded here, as they have no significance for the calculations in EnergyPLAN. The V-formula[3] applies for all fossil fuel installations including waste installations. Tax reductions can be given for flue gas condensation. The NO_x tax is 0.8 DKK/Nm^3 (normal cubic metre) for boilers and 2.8 DKK/Nm^3 for motors. The NO_x tax concerns fuel and is not reduced with regard to the V-formula.

[3] The taxable gas consumption in the production of heat and power production can be calculated in one of these two methods: Either from heat production divided by 1.25. That is to say that fuel (heat) = heat production /1.25. Or from the combined gas consumption excluding gas consumption for production of electricity. The electricity efficiency is hence 65%, and hence the taxable gas consumption is calculated to be fuel (heat)= fuel (total) – (electricity production/ 0.65).

Table 3, Expected future tax and levy rates used for optimisation of the operation of the individual facilities.

Fuel	Unit	Energy tax	CO2 tax	NOx tax	Taxes in total	Calorific value	Taxes in total Total excl. NOx	Heat produced Tax per V-formula
		DKK/unit	DKK/unit	DKK/unit	DKK/unit	GJ/unit	DKK/GJ	DKK/GJ
Fuel oil	tons	2,330	493.0	28.0	2,823.0	40.4	69.9	56.6
Natural gas	Nm^3	2.3	0.35	0.028	2.6	0.0396	66.2	53.7
Coal	GJ	57.3	14.8	0.5	72.1	1	72.1	58.2
Straw	tons	15.9		6.8	15.9	14.5	1.1	1.6
Wood pellets	tons	33.8		6.8	33.8	17.5	1.9	2.3

In EnergyPLAN the taxes have been included by using the tax rate including NO_x for boilers and by using the V-formula, as well as an average heat efficiency value of 50 per cent. This corresponds to taxing half of the fuel in combined heat and power production. For natural gas the increased tax on boilers has been used, and for biomass an average of the taxes on straw and wood pellets has been used. It should be noted that the CO_2 tax is contained both in current legislation and in the above-mentioned expected future legislation, in tandem with the quota market also having an influence on the operation. The energy taxes have been reduced correspondingly. This does not mean that the CO_2 tax is used twice, but that it reflects here that the legislation is introduced before the quota market. The above-mentioned taxes and quota price are used in this report, while it is expected that if the CO_2 tax is done away with, the energy tax will be raised accordingly.

For electric boilers and heat pumps in decentralised combined heat and power plants, a tax of 208 DKK/MWh for the electricity cartridge and 675 DKK/MWh of electricity in the heat pump is used in the calculation, including a CO_2 tax of 62 DKK/MWh. The taxes are used only when it is decided what the individual player is offering in the market. The taxes are not included in the socio-economic analysis.

It must be noted that the taxes used only change the operations-related conditions very slightly in the EnergyPLAN calculations compared to the taxes that were used in IDA's Energy Plan 2030 from 2006 [4].

5.7 Assumptions concerning analysis of the socio-economic impacts for the energy system

The socio-economic comparison does not include externalities such as environmental and health costs from emission of environmentally harmful substances in its starting point, but only the costs of implementation of other technologies and operation and maintenance costs. However a CO_2 quota price is used as stated above. This quota price is used at the same time to calculate the CO_2 costs that are estimated for the energy systems' total emissions. In practice the quota system is arranged so that combined heat and power plants and power plants are allocated a free quantity of quotas. According to the latest agreements in the EU, this quantity of free quotas will be gradually reduced and a larger portion of the CO_2 quotas shall be auctioned off from 2012. The quantity of these quotas is meanwhile identical in both the reference and the Climate Plan.

This means that the portion of the costs that concerns free quotas in the Danish quota system is identical in both the reference and the Climate Plan energy systems. In the event that the combined system falls under the allocated free quotas, an analysis of the costs of the total emissions reflects that these can be sold at the CO_2 quota cost. In addition no distinction is made between technologies under the quota arrangement and outside the same, while it is assumed that all sectors over time will make agreements for a CO_2 quota price on the quota market. This is in line with the recommendations from The Danish Energy Authority's "Vejledning i samfundsøkonomiske analyser på energiområdet" (Guidelines on Socio-economic Analyses in the Energy Area) [18].

In comparison with The Danish Energy Authority's "Vejledning i samfundsøkonomiske analyser på energiområdet" [18] the assumptions described herein differentiate themselves in the choice of a lower interest rate and in the exclusion of losses and gains from so called tax distortions.

The Danish Energy Authority's guidelines recommend a real interest rate (interest rate minus inflation) of 6 per cent per year. With such an interest rate, all investments that are 15-20 years in the future will go into the calculation with a value close to nil. Seen in relation to investments in changed infrastructure with a lifetime of up to 50 and 100 years, it will be very problematic to use such a high interest rate. The use of such a high interest rate will also result in wide-ranging socio-economic losses, as the market's real interest rate at present lies at about 2 per cent per anno. All investments which provide a real interest rate of return of more than approx. 2 per cent per anno can therefore pay for themselves from a socio-economic perspective. If the real interest rate requirement is at 6 per cent per anno, socio-economic investments which have a return between 2 per cent per anno and 6 per cent per anno will be excluded from the investment portfolio with wide-ranging socio-economic losses as a consequence. To avoid this 3 per cent interest rate is chosen with a sensitivity analysis at 6 per cent. After the economic crisis has struck with the current very low interest rates, there could be arguments for also doing sensitivity analyses with a real interest rate at 1 per cent per anno.

With the average inflation of the last 10 years at about 2 per cent per anno, The Danish Energy Authority's real interest rate corresponds to a market interest rate of 8 per cent, and the 3 per cent in real interest rate that is used here corresponds to a market interest rate of 5 per cent per anno for fixed-rate loans. The Danish Energy Authority justifies the recommendation of the real interest rate of 6 per cent as reflecting the lost alternative return which the invested resources are assumed to be able to bring in by investing in other projects. When a real interest rate of 3 per cent per anno is used here and not a real interest rate of 6 per cent, as The Danish Energy Authority recommends, it is for the following reasons:

- In the long term investments cannot be charged a higher interest rate than the added-value in society. With an economic real growth of 2 per cent a year, the domestic alternative investments will provide a higher return only in the short term.
- There is no documentation illustrating that the discussed alternative projects can provide an annual real interest return rate of 6 per cent or any description of which types of projects are involved.

- Even in those cases where alternatives in the form of ordinary business investments should provide a real interest rate return of 6 per cent per year, the return from these will be a function of an existing infrastructure with long lifetimes, including the energy infrastructure. That means that one cannot create independence between the "alternative" projects and investments in energy infrastructure with long lifetimes. The error that is committed in demanding a return from the energy-related infrastructure just as high as from ordinary business investments corresponds to wanting to invest in trains instead of rails, even if the return from investment in trains depends on a well-functioning rail system. Therefore, the interest rate reflecting a socio-economic perspective should be used.

- It is possible for private persons to obtain 30-year loans with a fixed interest rate after taxes of about 4 per cent per year. With an inflation of 2 per cent per year, that corresponds to a real interest rate of 2 per cent per year. Private consumption in the form of kitchens, bathrooms, and four-wheel drive vehicles can thus be financed with a real interest rate of 2 per cent per year. Therefore it is argued here that it will also be reasonable in the energy planning to use a real interest rate which is not much higher.

- Loans with a municipal guaranty and a loan period of 25 years can be obtained through KommuneKredit (The Credit Institution for Local and Regional Authorities in Denmark) at a fixed interest rate of about 4 per cent per year before inflation and therefore a real interest rate of 2 per cent per year with average inflation of 2 per cent per year. Municipalities will therefore be able to borrow money from KommuneKredit at a real interest rate of 1-2 per cent per year for improving the insulation standard in municipal buildings, for installation of renewable energy facilities, etc.

- The use of a real interest rate of 6 per cent in a socio-economic analysis of energy conservation investments and so forth can impede the identification of rational investments for the society. All of the profitable investments for the society which lie between the market's real interest rate of 2 per cent per year and the real interest demand of 6 per cent per year will thus not be carried out.

- If the profitable investments for the society which lie between the market's real interest rate of 2 per cent per year and the demand for a real interest rate of 6 per cent per year are not discovered, this demand will therefore in practice result in wide-ranging socio-economic losses. It will result in erroneous dispositions in which investments are recommended or rejected as a consequence of the high real interest rate.

- Estimates of environmental and health costs, as an example for CO_2 emissions, commonly use a real interest rate of between 1 per cent and 3 per cent per year. That applies for example for the calculations in the ExternE project [19]. As the estimation of the socio-economic costs for various emissions have been calculated with a real interest rate of 1 – 3 per cent, these cost estimates cannot be used for an interest rate of 6 per cent. This creates a methodological problem in relation to the use of a 6 per cent real interest rate. Therefore a real interest rate of at most 3 per cent will be in accordance with the interest rate that is used when the socio-economic cost of CO_2 emissions is calculated in the IPCC and ExternE context.

- The interest rate of 6 per cent in The Danish Energy Authority's guideline follows the recommendations of the Danish Ministry of Finance [18]. In other countries such as Norway, Sweden, Holland, Great Britain, and France an interest rate of 3-4 per cent is used for such analyses [20]. In the Stern report an interest rate of 1.4 per cent was used for analyses of consequences of CO_2 emissions [21]. The Danish Environmental Protection Agency recommends an interest rate of 3 per cent [22], and the economic advisers (to the Danish Government) recommend using an interest rate lower than 6 per cent .

In The Danish Energy Authority's guidelines, it is also recommended that the value of a so-called tax distortion loss is included in the calculation, in that changes in the system will change or disrupt the perfect market. This relationship has not been included here, as the Climate Plan generally does not include an increased taxation, but rather a tax reorganisation. Nor for that reason will there be any talk of tax distortion losses in connection with any possible tax reforms, as a consequence of the implementation of IDA's Climate Plan 2050. On the contrary, in several instances it could be argued that the taxation is improved in the direction of a more ideal market condition, in that, for example, external environmental costs which firms and private individuals have not paid for until now are included in the market prices. As an example through CO_2 taxation of the fuel consumption and the CO_2 emissions by aviation or through taxation of the CO_2 emissions in the North Sea and in ship traffic. The error that occurs is excluding these actual costs from the market price today and this is removed by making the polluter pay for the costs of pollution.

One could also say that a change of the vehicle excise duty and vehicle insurance over to kilometre charges will represent a taxation and an insurance premium that are more in agreement with the costs that the vehicles impose on society. As things are today, the same vehicle excise duty is paid for a vehicle which for most of the time sits in the garage, and for example only drives 5,000 km/year, as for a vehicle that drives 40,000 km/year. A tax reorganisation in which vehicle taxes are tied to the total kilometres driven on the roads, instead of a standard vehicle excise duty, will regulate behaviour and simultaneously improve the economic allocation mechanisms. This improvement of the economic allocation mechanisms is an advantage for the Climate Plan, but including this in the economic analyses has not been attempted, even though it might involve what one could call "tax distortion gains."

5.8 Assumptions for estimation of health costs from emissions from energy systems

In addition to the socio-economic costs for the "establishment and operation" itself of the energy system, a separate estimate has been done of the health costs for the analysed energy systems. These assumptions are described below. Additional information about the assumptions concerned with these calculations is described in Appendix V.

The concept of external costs covers in principle the socio-economic costs that are not included in the market price, for example for a fuel such as coal. If the energy sector (including of course the power plant owners) operates in a liberalised market, then all external costs ought to be internalised to ensure the optimal development for society. The existence of externalities can be viewed as an error which therefore ought to be corrected. The problem is just that it can be very difficult to determine the size of the external cots. Environmental taxes can be seen as an attempt to internalise the external costs, but the level of environmental taxes does not necessarily fit with the actual external costs.

External costs can be many things - it can involve including costs from environmental effects where the fuel has been extracted (e.g., a coal mine in South Africa) or it can be health and environmental effects where the fuel is used. The costs that have been used here in IDA's Climate Plan 2050 have been based on effects from the fuel conversion in Denmark, i.e., emissions from the energy system, and therefore do not include environmental and health costs from extraction and transport of the fuels to this Denmark. The effects of Danish fuel conversion on other countries are included.

A range of studies exist concerning pricing of health effects as a consequence of discharging various contaminants [23;24]. The best known is ExternE (www.externe.info), an EU project started in 1996 which is constantly updated [19]. The National Environmental Research Institute, Denmark (NERI)) has also updated these numbers several times according to Danish conditions and with a more advanced air pollution model than was originally used in ExternE. The official NERI numbers for health costs from emissions of various types are used by, among others, The Danish Energy Authority in evaluating the socio-economic value of projects [1]. NERI has recently completed a range of updates for the health costs of to the numbers recommended by The Danish Energy Authority - they can be found on NERI's website (www.dmu.dk) [25]. Centre for Energy, Environment and Health (CEEH) (www.ceeh.dk) is a cross-disciplinary centre where the Danish expertise in air pollution models has been collected. The models have been improved at the Centre, among other things with a smaller geographic resolution [26]. This means that the average concentration of air pollution contaminants to which the population is exposed can be calculated more precisely and in that way a better estimate can be given for the costs.

The costs of emissions for different types of emissions from different sectors in Appendix V, Table 42 are based on emissions from 2000. Hence they are based on the mix of emissions in this year and the specific location of different sources and population. In future energy systems the pattern of emissions, i.e. the size of the emissions, location of sources can change as can the population density. In the future the changes in the climate can change the meteorology and thus the way in which different pollutants move within the atmosphere. Also the chemical reactions are not linier and hence the costs identified cannot be said to be valid under all circumstances. The costs are valid for the specific sources in the given year that the calculations have been done and therefore, should be used with caution in other scenarios.

It must be emphasised that values used are the best possible at the current time. More precise values can be calculated by running the air pollution models again with the starting point at the emissions for the IDA energy scenarios. The ability to do calculations of the different scenarios influence one the total health costs and for the specific costs for each type of emission is the main idea for the new Centre for Energy, Environment and Health (CEEH) (www.ceeh.dk) and the Centre will most likely develop the tools to do such more precise calculations.

Due to this the following preconditions should be made about the calculations of the health costs in IDA's Climate Plan 2050:

If the assumption is that one can use the same costs per kilo of emission for the health effects for different polluting components in different future scenarios (such as those in Appendix V, Table 42) – then the calculations gives an indication of the energy systems' related health costs.

It is important to note, that the health costs include all areas affected, and hence also costs outside of Denmark affected by emissions. Therefore, only a part of the cost has a direct effect on the Danish costs. The rest of the effects will among other things be part of the international negotiations for reduction commitments for different types of emissions. As these type of emission models are used in the International negotiations and in the EU negotiations and demands for reductions, Denmark will be held responsible for the entire emissions of pollutants.

To include health costs in other countries caused by the Danish emissions is similar to the payment for CO_2 emissions, which do not cover direct costs in Denmark, but in the entire world. In Appendix V, Table 43 the part of the costs related to Denmark is listed. The greenhouse gases are very difficult to assess when it comes to estimating what the costs are in the long term from the emission of these gases. Up to a certain level, they do not necessarily have any costs, as the natural carbon cycle has a certain buffer. But if this buffer is used up (which much information indicates is close to occurring), it can result in wide-ranging consequences in the form of climate changes that affect water supply, available arable land, and shifting of climate zones, so that certain types of vegetation no longer can be cultivated where they usually are. These effects have very different time horizons and therefore their externality costs depend heavily on how much one weighs events in the future - i.e., which the real interest rate is used for calculating the costs.

The cost of emitting greenhouse gases can be dealt with from two sides: 1) It can be estimated as damage costs - i.e., the socio-economic loss occurring from the climate changes that will occur if we do not do anything, or 2) Marginal reduction costs - i.e., the price of the marginal technology or effort that is necessary to keep the level of greenhouse gases at an acceptable level. Theoretically, 2) will be the cost that a well-functioning CO_2-market will bring about, while 1) will be significantly higher, as it illustrates the effects of the worst conceivable situation, namely that we continue increasing the concentration of greenhouse gases in the atmosphere.

Beyond health effects and climate changes, there will also be damage to nature and buildings as a result of emissions from converting energy. Costs for these effects have not been found for this project although the costs can be significant. And within this area there are large uncertainties - what does it cost for example that an historic building is damaged on its facade and what is the value of the life in a Swedish forest lake?

On the basis of studies reviewed in Appendix V the assumptions regarding costs have been estimated in Table 4. These data are used in the calculations of external costs from the energy system. Most values have been chosen from CEEH (www.ceeh.dk) which originate from the most advanced calculations, and then these have been combined with NERI's latest official numbers where the CEEH numbers do not apply.

Table 4, Socio-economic costs per kg of material emitted.

DKK/kg	Power plants	Road traffic	Industry[4]	Households/ Trade & services[5]	Ship traffic
PM 2.5	81	159	120	159	81[6]
NO_x and nitrate	43	69	56	69	80
SO_2 and sulphate	68	243	155	243	146
CO	0.00596	0.1639	0.0849	0.1639	0.0067
Lead	10,016	10,406	10,211	10,406	10,016[6]
Mercury	1,658	1,906	1,782	1,906	1,658[6]

Emission of greenhouse gasses is a global problem and it makes no sense to allocate the cost by sector or by urban and rural emissions. On the other hand, the cost can vary over time, as an increased reduction of green house gasses must happen over time to ensure a stabilisation, i.e. the part about green houses gasses in Appendix V. According to the IPCC's scenarios, a stabilisation of the atmosphere's content of green house gases (measured in CO_2 equivalents) at 500 ppm will give a central estimate of a CO_2 price in the year 2030 of 300-530 DKK/tonne of CO_2, and in 2050 of 500-800 DKK/tonne of CO_2 [27]. The Stern report arrives at even higher CO_2 prices, when global damage costs are calculated [21]. Trading costs are used exclusively in the climate plan. IPCC recommendations are above the level that has been used here. The level used here is on the basis of The Danish Energy Authority's long term expectation of 229 DKK/tonne of CO_2 [1]. Thus calculations have also been done with twice that level, i.e. 458 DKK/tonne of CO_2. This does not reflect therefore the health and environmental costs that are connected with these emissions. In the ExternE report, in which the European Commission estimates among other things costs from global warming, CO_2's environmental and health costs are estimated at between approx. 40 DKK/tonne and 1300 DKK/tonne of CO_2 in 2005 prices, in which 1995 prices are adjusted upwards to 2005 by 25 per cent, corresponding to the average inflation in the European Union in the period [19]. This interval shows that it is not possible to determine an individual price, but that we are dealing with a matter involving risk and hence an insurance problem. A part of the variation is due to the fact that various interest rates have been used in the ExternE report. The market price of CO_2 quotas can thus hardly cover the full socioeconomic cost.

The socioeconomic costs as a result of various emissions have been quantified separately on the basis of fuel consumption and technologies in the energy systems. Then these costs for IDA 2015, IDA 2030, and IDA 2050 have been compared with the reference. The estimation of emissions takes a starting point in NERI's latest estimate of emissions allocated by fuels and technologies. The emission coefficients are listed in Table 5.

[4] Industry is placed both in urban areas and in the country side, hence it is assumed that the costs of emissions from industry are an average of power plants and road traffic.
[5] Household, trade and services are found mainly in urban areas, hence the cost of emissions are assumed similar to those of road transport.
[6] For ship traffic some values are missing, hence the values from power plants have been used.

Table 5, Estimation of emission coefficients used in the analysis of health costs on the basis of data from NERI's website in July 2009.

Fuel	Facility type	Plant type	SO_2 g/GJ	NO_x g/GJ	CO g/GJ	PM2.5 g/GJ	Mercury mg/GJ	Lead mg/GJ
Power and CHP facilities								
Coal	Steam turbine	Central plant	40	98	10	2.1	1.7	6
Natural gas	Steam turbine	Central plant	0.3	97	15	0.1	-	-
Natural gas	Gas turbine	Decentralised plant	0.3	124	6.2	0.051	-	-
Biogas	Gas turbine	Central/Decentralised plant	19	124	6.2	0.051	-	-
Waste	Steam turbine	Decentralised plant	23.9	124	7.4	1.084	7.39	123
Biogas	Motor	Decentralised plant	19	540	273	0.206	-	-
Straw	Steam turbine	Decentralised plant	47.1	131	63	0.102	0.53	6.12
Wood chips, wood waste	Steam turbine	Decentralised plant	1.7	69	79	1.23	0.72	3.62
Heat-producing boilers								
Fuel oil, waste oil	Boiler	District heating plant & similar	206	98	15	2.5	4.3	23.46
Diesel fuel	Boiler	District heating plant & similar	23	65	30	5	1.17	2.34
Straw	Boiler	District heating plant & similar	130	90	325	12	6.8	3.22
Natural gas	Boiler	District heating plant & similar	0.3	42	28	0.1	-	-
Wood	Boiler	District heating plant & similar	25	90	240	10	6.8	3.4
Natural gas	Boiler	Detached house equipment	0.3	30	20	0.1	-	-
Wood pellets/fire wood etc.	Boiler	Detached house equipment	25	120	3,441	615	6.8	3.4
Diesel fuel	Boiler	Detached house equipment	23	52	43	5	1.17	2.34
Transport								
Diesel	Passenger cars	Average	0.47	298	78	29.28	-	-
Petrol w. catalytic conv.	Passenger cars	Average	0.46	110	1.160	0.65	-	-
Bioethanol	Passenger cars	Average	0.46	110	1.160	0.65	-	-
Diesel	Lorries	Average	0.47	734	153	19.09	-	-
Biodiesel	Lorries	Average	0.47	734	153	19.09	-	-
Diesel	Ships	Average	93.68	1.532	184	22.87	-	-
Biodiesel	Ships	Average	93.68	1532	184	22.87		
Aviation fuel	Aviation	Average	22.99	297	135	1.16	-	-

It has to be emphasised that the emissions coefficients used here represent emissions from current technologies. Hence no adjustments have been made due to gradual improvements and higher product standards e.g., for biofuels in transport the emission coefficients from petrol and diesel were used. All emissions from waste incineration and biogas are assumed to be from combined heat and power plants. For biogas in gas turbines the emissions from natural gas in gas turbines are used, except for the SO_2-coefficient which is based on the content in biogas from a biogas engine. It is assumed that no fuel oil is used in ships. It is assumed that the power and combined heat and power plants are placed in large central plant locations and typically have a capacity above 100 MW. The decentralised plants are placed in connection with other district heating areas. The emissions coefficients for boilers in district heating production are used for emissions from industry as it is assumed that these are a good approximation of these. For individual heating in detached houses the emission confficent used is NERI's emission coefficients for wood/wood pellets/fire wood etc. based on a mixture of technologies. Wood pellet boilers count for approx. 25 per cent. The rest consist of wood boilers, fire stoves, open fireplaces etc. In the energy system analyses these technologies are represented by biomass boilers.

The health costs are presented in chapter 17.

5.9 Assumptions concerning commercial potentials and employment effects

For the analysis of commercial potentials, a starting point is taken in previous experiences with building up capacity within the energy and construction area. This is compared with the investments in renewable energy and the investments in energy conservation measures in the IDA Climate Plan 2050 compared with the reference. The commercial potential has been estimated in chapter 18.

The employment effect likewise takes a starting point in the above-mentioned differences in the Climate Plan and the reference. Previous estimates of import share with various cost types are used here, as well as an effect on employment by the domestic investments. The employment effect has been estimated in chapter 19.

6 The reference energy system

In this chapter, the references for 2015, 2030, and 2050 are defined, and the technical and economic assumptions are described. The reference is calculated in the energy systems analyses tool used, EnergyPLAN, and reflects The Danish Energy Authority's analyses.

6.1 Assumptions regarding the consumption and production

The reference energy system in IDA's Climate Plan 2050 is The Danish Energy Authority's basic forecast to 2030 from 30 April 2009 [6]. This forecast takes into account the latest policy agreements in the energy area. The reference system for 2050 has been designed on the basis of forecasts of the energy consumption until 2050, following the Danish Energy Authority's method for this purpose and done especially for the analyses in this report.

This reference system is significantly different from the reference energy system used in IDA's Energy Plan 2030, as fuel prices are twice as high now and more energy savings are included, etc. Fuel prices equivalent to $122/barrel of oil have been used, and among other things the broad energy agreement between the vast majority of the parties in Danish Parliament from February 2008 has been taken into account. The forecast of the energy consumption takes its starting point in the latest forecast of the Danish economy from the Danish Ministry of Finance from December 2008, in which the latest period's economic trend is found, as well as the tax-related changes in the energy area in the tax agreement in the spring of 2009. This forecast also includes the Danish Energy Conservation Plan, which was approved by a broad parliamentary majority in June 2005.

The Danish Energy Conservation Plan has the goal of bringing down energy consumption excluding transport by about 1.7 per cent per year between 2006 and 2013. The Danish Energy Agreement from February 2008 is trying to ensure that 20 per cent of energy consumption will be covered by renewable energy in 2011, including more biomass and more wind turbines on land. Additionally 400 MW of offshore wind turbines shall be established in 2012. An objective is also included in the agreement that the net energy consumption shall decrease by 2 per cent in 2011 and 4 per cent in 2020. The energy taxes were increased in the last tax agreement from March 2009, which has been included in the consumption forecast which is used here, just as the latest transport agreement has been included. [6]

In Fig. 12 the final energy consumption in the reference energy system from The Danish Energy Authority has been illustrated going forward to 2030. This energy consumption results in a primary energy supply of about 890 PJ in 2030, which is illustrated Fig. 13. In the reference completed by The Danish Energy Authority in 2005, the primary energy supply for 2030 was just below 1,000 PJ , which was used in IDA's Energy Plan 2030. Hence the Danish Energy Authority no longer expects that the fuel consumption will increase.

In Fig. 14 the CO_2 emissions in the reference energy system is illustrated. In 2008 the emissions were approx. 52 million ton. In 2030 the expected CO_2 emissions in the reference is approx. 45 million ton.

The latest forecasted energy system from the Danish Energy Authority is used in the Climate Plan, which is based on the assumption that these targets will be implemented with current or future means agreed upon. The energy agreements ensure that the trend shall be monitored and perhaps even matched. Hence it is a "business-as-usual" forecast for Denmark according to the "bird in the hand" principle, with regard to existing means. The measures in IDA's Climate Plan 2050 are tied to the measures and the trend in the reference energy system. This is however connected with various uncertainties, as there is a risk for certain measures that the savings will be included twice during the analyses. Hence this is carefully accounted for measure by measure in the following chapters. Many of the Climate Plan's sub-objectives are thus expressed in per cent of production or consumption in relation to the reference for 2015, 2030, and 2050.

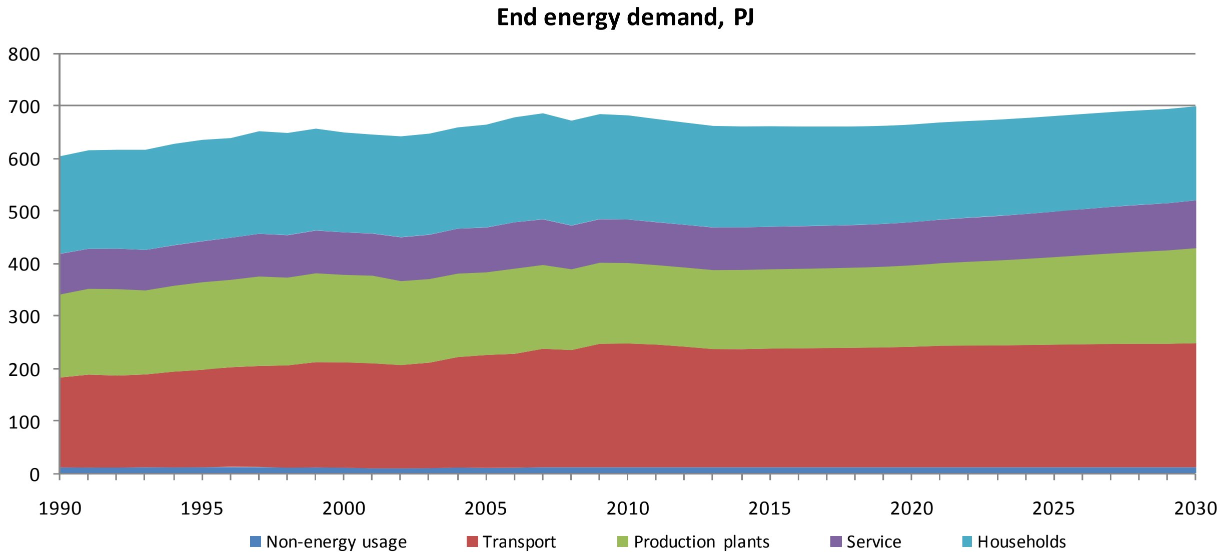

Fig. 12, The final energy demand in the reference energy systems.

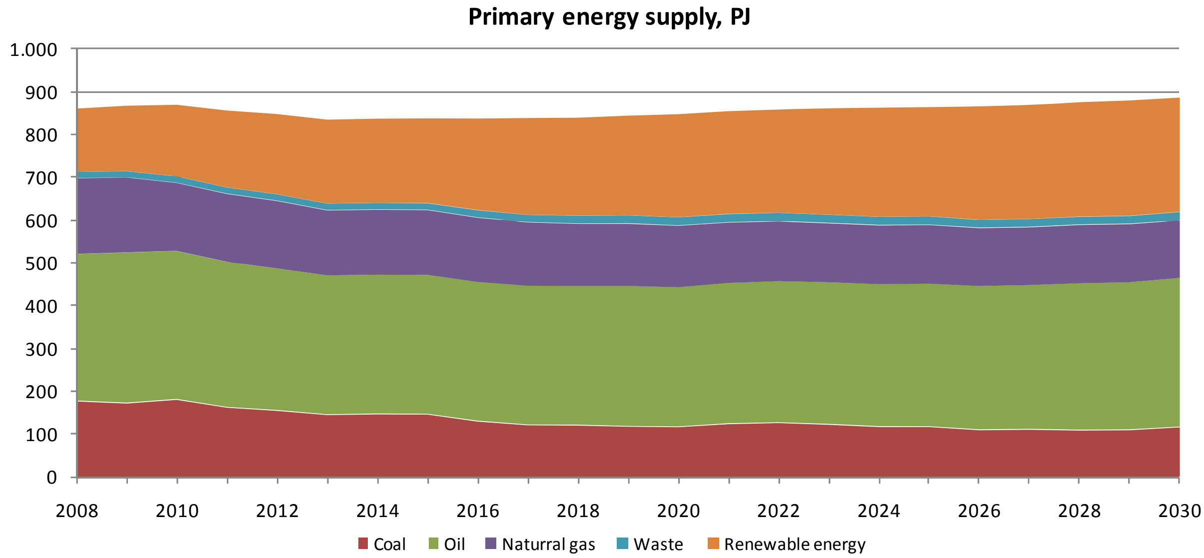

Fig. 13, The primary energy supply in the reference energy systems.

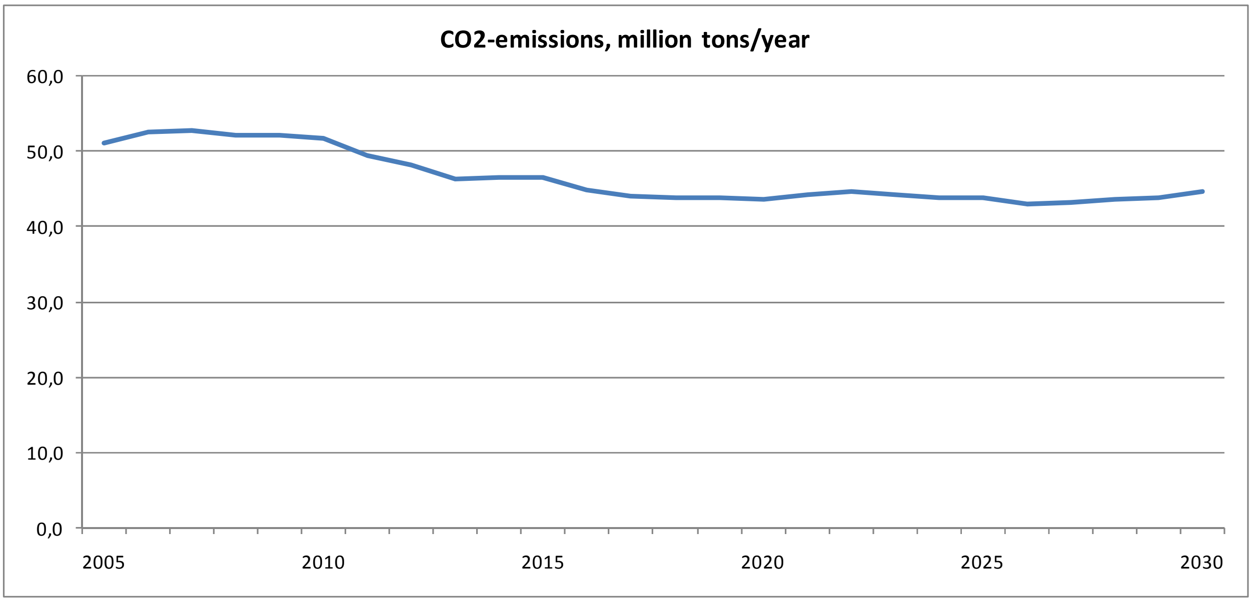

Fig. 14, CO_2-emissions in the reference energy system.

In relation to the reference energy system for 2030 used in IDA's Energy Plan 2030 from 2006, a smaller consumption of electricity and heat is used in the reference energy system for 2030 here. The heat consumption is expected to decrease now in the reference energy system, whereas the increase in the electricity consumption continues when seen as a whole. In the households however, a decreasing consumption of electricity is expected. For the transport forecast, a more moderate trend applies than expected earlier.

6.2 The reference energy system for 2015 and 2030

In order to conduct comparable calculations the reference energy systems were analysed on the EnergyPLAN model, where it has been possible to reconstruct The Danish Energy Authority's calculations, under the assumptions described below. The conversion of data from The Danish Energy Authority has been described in Appendix I.

Generally there is good agreement between The Danish Energy Authority's analyses and the analyses by the EnergyPLAN model. For the same net export of electricity, the two models arrive at the same fuel consumption and energy turnover.

In the analyses using EnergyPLAN, the active power and CHP plant capacity has been set at 20% over the maximum electricity consumption that occurred on a given hour during the year for both reference energy systems. In the reference system for 2015, this means that 7,450 MW of central combined heat and power plants has been installed. In 2030 and 2050 this is 8,552 MW and 10,608 MW respectively. It is assumed that the electricity capacity in the decentralised combined heat and power plants is 1,945 MW during the entire period, as the demand for district heating is at the same level during the entire period towards 2030 although heat savings are made. The district heating consumption decreases marginally during the period in the forecast, but simultaneously there is a conversion to district heat which leads to it being by and large at the same level during the period. The boiler capacity has been calculated by the peak demand for district heating in the individual areas plus ten percent extra capacity. The district heating demand has been divided among three areas. These are areas where district heating is delivered from boilers alone, decentralised CHP plants, and finally central CHP plant district heating areas. For security of supply, there are boilers added to generate heat in case the CHP plants cannot deliver the required heat or there is no demand for the electricity generated by CHP. Also, heat storages have been added to enable a larger CHP share in the district heating production.

In 2008 the wind turbine capacity in Denmark is about 3,150 MW. Of this, 423 MW is in offshore wind turbines. The total production is about 7 TWh. The total electricity production from wind turbines is 10.4 TWh in 2015 and 11.5 TWh in 2030 in The Danish Energy Authority's basic forecast.

In the reference for 2015, the number of full load hours is 25 per cent for onshore wind turbines and 35 per cent for offshore wind turbines. The installed capacity is about 3,080 MW and about 1,240 MW respectively according to the basic forecast. The installed capacity in 2030 is not stated in the basic forecast. It is assumed here that the number of full load hours increases going forward towards 2030. The installed wind turbine capacity onshore and offshore that is in the basic forecast reference energy system has been founded on this assumption, and it makes the installed capacity in the reference energy system comparable with what is installed in the Climate Plan with regard to full load hours. Here there is a gradual improvement in the number of full load hours based on better locations combined with the right wind turbine for the actual location. Thus the number of full load hours in 2030 is 32 per cent and 45 per cent for onshore and offshore wind turbines respectively. Going forward to 2030, the above-mentioned assumptions about full load hours mean that the installed effect for land wind turbines in the basic forecast decreases to about 2,350 MW with the same production as in 2015. The offshore wind turbine capacity is still about 1,240 MW in 2015 and 2030, but the production in MW increases because of above-mentioned improvements in the number of full load hours.

Under the above-mentioned assumptions, the reference years in the form of The Danish Energy Authority's base forecast for 2015 and 2030 have been reconstructed. The results are listed in Table 6 for 2030 and for 2015 in Appendix I.

The reference energy system has been analysed in a version with electricity market exchange as well as in a version without electricity market exchange. The first version has been used in the economic feasibility analyses and in the evaluation of the value of trading on Nord Pool. The second version has been used as the starting point for the technical analyses. This partly ensures that an energy system is established where the security of domestic supply is intact, and partly it ensures that Danish energy producers and consumers are not forced to export or to import at times when the market price is not favourable.

The first column in Table 6 shows The Danish Energy Authority's own data for the base scenario. The next column shows the EnergyPLAN calculation, which has been calculated with the same net trading on the electricity market as with The Danish Energy Authority. As displayed in Table 6, it is possible to reconstruct The Danish Energy Authority's calculation of electricity market exchange under the assumption that the net electricity export is the same. However, this reconstruction assumes different fuel prices to those stated by The Danish Energy Authority. Under identical economic assumptions there is a difference in the net export of electricity between the two models. In The Danish Energy Authority's basic forecast it is stated that there "... is great uncertainty in the calculation of the electricity exchange, as even quite small changes in relative prices, etc., can result in changes in the electricity trend of several TWh" [1]. Therefore, the difference is not conclusive and considered insignificant for the following analyses, where the reference years and the IDA scenario years are evaluated on the same basis and with the same model and method.

The last two columns show EnergyPLAN calculations where it is calculated without trading on the electricity market, other than when forced trading occurs because of excess electricity. In the first version in column three, the combined heat and power plants prioritise their production exclusively according to the heat demand, while in the second version in column four they regulate according to the electricity demand as well as the heat demand (corresponding to the decentralised CHP plants being in the electricity market and using the heat storages and boilers). Both versions are included here to illustrate that one may well bring down the excess electricity by replacing combined heat and power production with boiler production and storage, but the fuel efficiency suffers in the combined system. One must therefore choose between either an inferior use of the heat and power or a higher excess electricity.

Table 6, Reconstruction of the reference in the EnergyPLAN model for 2030.

2030		The reference	EnergyPLAN calculations		
			Identical electricity market exchange	Technical analysis version 1	Technical analysis version 2
Input:					
Electricity demand	TWh/year	41.7	41.7	41.7	41.7
District heating demand	TWh/year	34.1	34.1	34.1	34.1
Individual heating boilers	TWh/year	19.4	19.5	19.5	19.5
Industry incl. service & refineries	TWh/year	40.0	40.0	40.0	40.0
Transport (incl. aircraft and ships)	TWh/year	66.0	66.0	66.0	66.0
North Sea, losses, etc.	TWh/year	17.6	17.6	17.6	17.6
Avg. efficiency decentralised -CHP (elec./heat)	Per cent	37 / 48	37 / 48	37 / 48	37 / 48
Avg. efficiency central CHP (elec./heat)	Per cent	35 / 55	35 / 55	35 / 55	35 / 55
Avg. efficiency condensation power plants	Per cent	42	42	42	42
Primary energy supply					
Wind, waves, solar, hydropower	TWh/year	11.5	11.5	11.5	11.5
Solar thermal	TWh/year	0.5	0.5	0.5	0.5
Coal	TWh/year	22.9	21.6	26.7	25.7
Oil	TWh/year	101.8	101.7	101.8	101.8
Natural gas	TWh/year	36.5	35.4	40.7	41.2
Biomass	TWh/year	52.6	53.7	56.8	56.8
Total, incl. electricity export	TWh/year	225.8	224.4	238.0	237.4
Key figures					
Net export (excess electricity)	TWh/year	-7.5	-7.5	0.6	0.1
Total adjusted for electricity export	TWh/year	246	242	237	237
Condensing PP electricity in per cent of electricity demand	Per cent	40	38	26	27
Boilers in per cent of district heating demand	Per cent	31	29	9	12
CO_2 emission	Ton/year	40.3	41.9	44.7	44.4
Adjusted CO_2 emission	Ton/year	43.8	43.6	43.0	42.9

6.3 The reference for 2050

The reference for 2050 takes a starting point from the production trend from 2020 to 2030 in The Danish Energy Authority's reference. Here renewable energy is fairly constant in the last part of the sequence, apart from wind power. An increase of 1 per cent a year is used here going forward to 2050, which as a whole provides 14 TWh wind power instead of 11.5 TWh in 2030. This is implemented with offshore wind mills, which in total come to a capacity of about 2,460 MW.

In the reference energy system for 2050, the consumption has been forecast according to the same method as The Danish Energy Authority uses. The electricity consumption increases in the period from 36.4 TWh to 46.3 TWh or 27 per cent. The increase has been evenly distributed by sector. For households, the electricity consumption increases by 20 per cent. Principally it provides an increased peak load, which can lead to more condensing power plants. However, here the condensing power plant level from 2030 has been retained, which makes the reference energy system for 2050 relatively cheaper.

The consumption increases overall by about 32 per cent within industry and services, with respect to fuel consumption and district heating. For households, the consumption of other fuels for heat and district heating increases by about another 20 per cent going forward to 2050.

The transport sector's energy consumption increases in the period by about 46 PJ (20 per cent) to a total of about 280 PJ. Also, a starting point for the growth rate in road transport between 2030 and 2050 has been taken from The Danish Energy Authority's forecast in the period 2020 to 2030, which has led to an increase in road transport. For international aviation, a starting point has been taken from the EU's national forecasts. These forcasts indicate that energy consumption in aviation decreases by about 2.4 per cent annually from 2020 to 2030, but the usage increases by 1.2 per cent annually in person kilometres. The energy reduction occurs as fleet is gradually replaced with aircraft that are more efficient. Hence the fuel consumption in aviation decreases from 37.8 PJ in 2030 to 33.4 PJ in 2050. This has been calculated by assuming that the entire fleet has been replaced with more efficient aircraft by approx. 2040, after which the growth of 1.2 per cent annually becomes visible.

The total primary energy supply in 2050 has increased from about 240 TWh in 2030 to about 275 TWh. It is assumed in the reference energy system for 2050 that the energy consumption of about 33 PJ for extraction of oil and gas in the North Sea has been eliminated, but that the use in oil refineries continues in 2050. This reduces the primary energy supply in 2050 in the reference to about 265 TWh. The result of the construction of the 2050 reference energy system has been provided in Appendix I.

6.4 Technical assumptions

The focus in the analyses is on imbalances in the electricity supply i.e. excess electricity. By excess electricity an imbalance between consumption and production is represented, where Denmark has been forced to export, there is sufficient capacity in the transmission network, and the neighbouring countries are able to consume this electricity. Critical excess electricity is a part of the electrical surplus that exceeds the transmission capacity. Critical excess electricity is removed in the energy system analyses here by decreasing the combined heat and power production and replacing it with boiler production, and, as a last resort, stopping a part of the wind power production.

In these calculations, a technical limitation of 2,500 MW for export/importis used in both the reference and Climate Plan energy systems. The transfer capacity is actually higher, but there are limitations in the surrounding network. In the calculations here, a starting point is taken in the existing capacity from Jutland to Norway of about 1,000 MW, and 700 MW in the exchange capacity from Norway to Jutland. From Zealand to Sweden, the capacity is 1,300 MW in exports and 1,700 MW in imports [28]. In the analyses it is assumed that Denmark has a continuous electricity transmission network, i.e., that there are no local bottlenecks and that the Great Belt Power Link has been established. In The Danish Energy Authority's calculations, the link to Germany is not included in the export capacity in the calculations, as there is no functioning market. The same assumptions about connections with neighbouring countries have been used in the calculations here. Finally, a sensitivity analysis has been done with a transmission capacity of 5,000 MW, which only has marginal significance for the results.

In connection with the decision to put new transmission lines underground and to replace old transmission lines with underground ones continuously, the regional transmission companies and Energinet.dk (the Danish TSO) have developed a cable action plan. In this action plan the focus is on the 132 - 150 kV transmission network. The plan shows that by completing this conversion over a 30 year period, these networks can be redesigned so that they support much more renewable energy. The current electricity transmission network has originally been based on the location of the central power plants in relation to the consumers in urban and industrial areas. In this conversion, the plan focuses on the opportunities to redesign the combined transmission network and to optimise it in relation to, among other things, the massive expansion of renewable energy, the location of future offshore wind turbine parks, and forecasts of the electricity consumption, including an expected increased use of electricity in heat pumps and electric vehicles for the integration of wind. This conversion also considers the potential for underground cables and assess the life expectancy for the existing transmission and distribution networks, so they can be converted as replacements are required [29]. Such plans by Energinet.dk support the conversions that are done in IDA's Climate Plan 2050.

6.5 The primary energy supply in the reference energy systems

In Fig. 15 the energy consumption in 2015, 2030, and 2050 are illustrated and compared with the situation in 2008. The fossil fuel part of the waste resource is a part of oil and the biogenic part is a part of biomass.

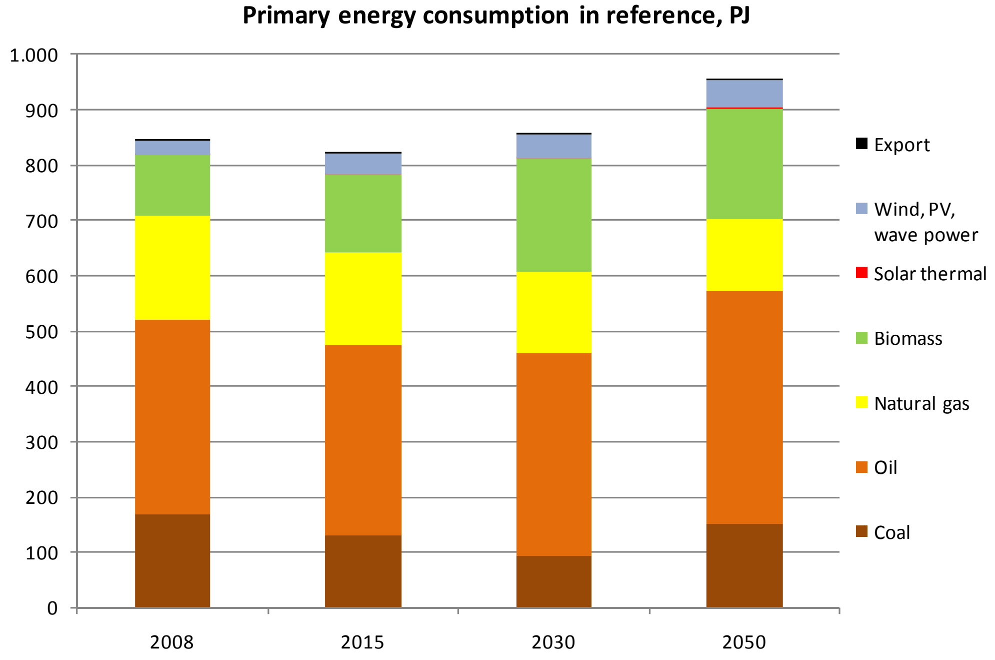

Fig. 15, Primary energy supply in the reference energy systems.

7 Sub-objectives in IDA's Climate Plan 2050

The overall objectives in IDA's Climate Plan 2050 that constitute the framework for the work are:

- To reduce the emission of greenhouse gases by 90 per cent in 2050.
- To maintain Denmark's self-sufficiency with energy.
- To enlarge Denmark's commercial position within the climate and energy technology area.
- To expand the economy and prosperity of Denmark.

Under these overall objectives, a range of sub-objectives have been developed within six thematic groups: Energy Systems and Energy Production, Agriculture, Industry and Service, Construction, Transport, and Climate Adaptation. In the following chapters the sub-objected are accounted for with regard to how these are implemented with the help of individual measures in the energy system analyses. The individual measures can be characterised as sub-elements which each contribute individually to the fulfilment of the overall objectives in the combined Climate Plan for the target years. The following chapters use these thematic groups as a starting point for discussing the Climate Plan. There are however exceptions to this, which is why under some sub-paragraphs we have dealt with individual measures for sub-objectives from several of the thematic groups. There are no sub-objectives within the theme Climate Adaptation which have influence on the analyses here.

Many of the sub-objectives have appeared and have been determined after an iterative process, out of regard for the integration in the energy system as a whole, the technological possibilities, socioeconomic analyses, etc.

Generally costs for production facilities have been estimated with a starting point in costs in the years 2020 - 2030 from "Technology Data for Electricity and Heat Generating Plants" [14], which also has been used in The Danish Energy Authority's calculations. There is however exceptions in the IDA 2015 energy system, as the technologies that are available from 2010 are implemented in this system. The measures that are implemented in the Climate Plan encompass a range of measures, such as conservation measures, which are not described in "Technology Data for Electricity and Heat Generating Plants". Hence these have been specially estimated, as discussed in the individual sub-paragraphs. The costs have also been estimated specially in the paragraphs, if the costs from the above-mentioned technology catalogue have since been updated. The costs that are not listed in "Technology Data for Electricity and Heat Generating Plants" have been listed in Appendix II. Additionally an overview of all costs is supplied in Appendix VII for 2015, 2030 and 2050, as well as an overview of individual measures in 2030 in Appendix VIII.

The general principle is that the energy system in the Climate Plan is thought to be completed over a period up to the applicable years: 2015, 2030, or 2050. Worn-out facilities are replaced continuously at the expiration of their lifetime. As a starting point, the costs of completion of the Climate Plan have thus been estimated as the extra expenses in establishing better facilities than those of the reference, in step with replacing old facilities under all circumstances.

It is noted that large-scale demonstration, pilot schemes or subsidies can be established in order to implement and develop technologies, but these measures are not considered here. The measures that are considered in the 2015 energy system are measures which are changes in relation to the reference system. In addition, there are energy conservation measures within construction that have been considered in IDA 2015, but that are thought to be implemented over a range of years between 2010 and 2020.

The sub-objectives for IDA 2015 represent measures that are considered to be technologically developed and can be implemented in the short term. IDA 2030 and IDA 2050 will be carried out by technological measures which are estimated to be developed from the year 2020 as well as with known technologies.

Each theme is introduced with a list of sub-objectives within the theme, after which the implementation of each sub-objective in the EnergyPLAN model is described systematically. The individual measures in IDA's Climate Plan 2050 that are described here create the basis for the total energy system in the energy system described in chapter 13. The share of renewable energy, fuel consumption, and so on in various sectors appears here also.

8 Energy systems and energy production

In this chapter the measures in electricity production from renewable energy sources, including onshore and offshore wind turbines, photovoltaic, and wave energy is described. In addition, an account is given of the measures for waste incineration CHP, geothermal facilities, fuel cells, and oil and gas technology. Building integrated photovoltaic is a part of the photovoltaic that are described here.

There is a range of measures in energy systems and energy production which are more appropriate to describe in other chapters. These are measures concerning expansion of district heating areas, solar thermal, and small household heat pumps, as these measures are connected with energy conservation in construction and buildings. These measures appear in chapter 9. Large heat pumps in district heating areas, flexible electricity consumption, flexible charging of battery electric vehicles, and use of fast and flexibly regulating fuel cells for network-stabilising purposes appear in chapter 13, as these measures are connected with the final adjustment of the energy systems.

The starting point in IDA 2015 is taken from technologies that are developed and can be implemented in the short term, and the IDA 2030 system represents the possible measures in the middle term. In IDA 2050 the objective is to go even further, so that the energy system is totally self-suffice and free of fossil fuels and without nuclear power, after the Danish oil and natural gas reserves run out in the North Sea. IDA 2050 represents a vision of what a system with a 100 per cent renewable energy supply could look like in 2050. The principle in the analyses is to continue in the way that has been set down in IDA 2015 and IDA 2030 and to improve on those areas in which it is expected to be technologically possible.

8.1 Onshore and offshore wind turbines

In IDA's Climate Plan 2050, wind power takes a central role in supplying renewable energy. The objective is approx. 60-70% wind power by 2030. In IDA 2030 the objective is 67 per cent. Going forward towards 2050, the power consumption increases from approx. 33 TWh to approx. 50 TWh, even though significant savings are accomplished. In 2050 the share is hence approx. 63 per cent, which is proposed to be implemented by increasing the expansion from the current level on land from approx. 3,000 MW by 50 per cent to approx. 4,500 MW, corresponding to a production of an expected 12.6 TWh/year, and on the ocean to expand to approx. 4600 MW, corresponding to an expected production of 18.9 TWh/year. The expansion is proposed to be done as shown in Table 7.

Table 7, Wind turbine expansion and production from wind turbines.

MW / TWh	*2015*	*2030*	*2050*
Onshore wind turbines	*3,914 / 9.1*	*4,454 / 12.6*	*4,454 / 12.6*
Offshore wind turbines	*1,619 / 6.3*	*2,600 / 1.,7*	*4,625 / 18.9*

Since the completion of "Technology Data for Electricity and Heat Generating Plants" in 2005, the expected long term prices for wind turbines has increased and hence The Danish Energy Authority's expectations for the price of wind turbines has increased in January 2008 [30]. Here we use The Danish Energy Authority's new expectations for the costs of onshore wind turbines built from the year 2020 in

IDA 2030 and IDA 2050. In IDA 2015 a starting point is taken in The Danish Energy Authority's expectations for onshore wind turbines in 2015.

In 2020 The Danish Energy Authority states the costs for operations and maintenance (O & M) at 90 DKK/MWh for onshore wind turbines [30]. These costs include balancing and trading costs however. As these costs have been included in other places during the calculation of IDA's Climate Plan 2050, they are deducted here. For these costs a starting point is taken in the Danish Energy Agreement from February 2008, where the contribution due to balancing was 2.3 Danish øre/kWh. Hence 23 DKK/MWh is subtracted from the above-mentioned O & M costs. The costs have been recalculated to per cent of the facility investment per year. For onshore wind turbines in IDA 2030 and 2050, the costs are 8 million DKK/MW, and for IDA 2015 the costs are 8.5 million DKK/MW. We calculated the O & M costs for IDA 2030 at IDA 2050 using 2.4% per year, whereas for IDA 2015 1.8% is used, as there are a lower total of full-load hours here. The lifetime of the onshore wind turbines is 20 years.

For offshore wind turbines we have used numbers from the Risø report "Offshore Wind Power Experiences, Potential and Key Issues for Deployment" [31], from January 2009, after consultation with Per Nielsen from EMD International A/S. This report states an expected construction cost of 1.81 MEUR/MW corresponding to 13.5 MDKK/MW in the year 2015 decreasing to 10.4 and 10.1 MDKK/MW respectively in the years 2030 and 2050. The operational cost is expected to be 97 DKK/MWh in 2015 decreasing to 89 DKK/MWh in the year 2030 and forward.

On this basis the costs used are 13.5 million DKK/MW in IDA 2015 and 12 million DKK/MW in IDA 2030 and IDA 2050. In both the target years we used 3 per cent in O & M costs.

8.2 Photovoltaic

It is expected that approx. 10 per cent of the electricity consumption can be covered by photovoltaic in 2050. This corresponds to approx. 3,400 MW installed capacity and a production of 4.5 TWh, with 15 per cent full-load hours. An insignificant expansion of photovoltaic is expected in the reference. In the Climate Plan it is proposed that the expansion starts now, so that building integrated photovoltaic can gradually be installed, eventually as ordinary replacement and maintenance occur. Already in 2030 it is planned for approx. 680 MW photovoltaic to have been installed, which can cover approx. 2 per cent of the electricity consumption with a production of approx. 0.9 TWh per year and with 15 per cent full-load hours.

The expected expansion with regard to photovoltaic has been faster than expected since 2006. Where the number of full-load hours was expected until now to be 10 %, it can now be expected that the photovoltaic of the future will have 15% full-load hours. According to Peter Ahm from PA energi A/S, photovoltaic installed in Denmark can be expected to have a construction cost in 2016 of 15,000 DKK/kW installed and to have a construction cost of 7,500 DKK/KW from 2030 going forward. The cost trend must however be taken with some precautions.

In IDA 2030 and IDA 2050, a cost corresponding to 7,500 DKK/kW with a lifetime of 25 years and O & M at 0.25 per cent of the investment per year is used.

8.3 Wave power

For wave energy the objective is that approx. 5 per cent of the electricity consumption is covered with the installed capacity in 2050. According to Peter B. Frigaard from Aalborg University, the number of full-load hours for wave power will amount to 40-45 per cent, depending on which wave power technologies obtain the best results. In order for 5 per cent to be covered with wave energy, 700 MW will need to be installed by 2050. The objective for 2030 is to install 400 MW, which corresponds to approx. 3 per cent of the consumption. With a starting point in "Technology Data for Electricity and Heat Generating Plants," a calculation has been done with a cost of 14 million DKK/MW with a lifetime of 30 years and O & M of 1.13 per cent [14]. It must be emphasised that the costs of wave power is connected to great uncertainty. Should the prices be completely different than assumed here, IDA 2030 will however be able to be completed by merely compensating with a little more wind power. Wave power has not been included in the 2015 energy system.

8.4 Waste incineration CHP

In the reference energy system, the amount of waste increases from 9.2 TWh in 2008 to a total of 12.33 TWh in 2030 in The Danish Energy Authority's base scenario. It is assumed in the reference here for 2050 that the amount of waste quantity remains at that level from 2030. In IDA 2030 and IDA 2050 plant improvements increase the electricity efficiency of waste CHP from 22.5 per cent in the reference to 27 per cent, which corresponds to RENO-Nord's efficiency, a waste CHP facility already operating in Aalborg [14]. The total efficiency is increased from 85 per cent in the reference to 104 per cent in the Climate Plan with the help of flue gas condensation, in keeping with the recommendations from Heat Plan Denmark (Varmeplan Danmark) [32]. In addition, 0.7 TWh is transferred from pure heat production in waste incineration boilers to waste incineration CHP in central CHP district heating areas. The result is that the electricity production from waste incineration in CHP increases to 3.3 TWh and the heat production increases to 9.5 TWh.

In order to increase the flexibility in the energy system, a part of the waste is sorted out. According to the report "Vurdering af mængden af forbrændingsegnet affald i Danmark" (Evaluation of the quantity of combustible waste in Denmark) from 2008 which Rambøll has completed for Affald Danmark (Waste Denmark), 19 per cent can be sorted out for co-incineration and storage [33]. A solution has been chosen here in which 10 per cent is sorted out or seasonally stored, as it is assumed here that the entire potential will not be used because of economic or technical reasons.

In principle, waste incineration CHP plants can be constructed to enable switching from pure heat production on short notice. Therefore,these plants can earn money by firstly acting as a demand side management unit and secondly, simultaneously avoiding electricity production which is worth less than heat in a period with low electricity prices. This also creates flexibility, but means that the energy value of waste incineration becomes lower. These solutions have therefore been rejected here. Another possibility is to operate a heat pump with low pressure steam in periods of low electricity prices in connection with using geothermal energy. This can also increase the flexibility, but has not been included here.

The results for waste incineration in 2030 and 2050 are listed in Table 8. Improvements in the IDA 2015 energy system for waste incineration have not been implemented.

Table 8, Improvements of waste incineration CHP plants. 10 per cent of this has been assumed to be stored seasonally or co-incinerated.

	Reference for 2030 and 2050				
TWh/year	Waste	Heat efficiency (%)	Heat production	Electricity efficiency (%)	Electricity production
District heating area	0.07	80	0.06	00	0.00
Decentralised CHP area	4.31	62	2.69	23	0.97
Central CHP area	7.95	62	4.96	23	1.79
Sum	12.33	-	7.71	-	2.76

	IDA 2030 and IDA 2050				
TWh/year	Waste	Heat efficiency (%)	Heat production	Electricity efficiency (%)	Electricity production
District heating area	0.00	-	0.00	-	0.00
Decentralised CHP area	4.31	77	3.33	27	1.15
Central CHP area	8.02	77	6.20	27	2.14
Sum	12.33	-	9.53	-	3.29

In consultation with Bettina Kamuk from Rambøll, the following extra expenses have been determined for establishing better facilities than in the reference energy system. It is assumed that:

- All plants have new boiler/turbine equipment by 2030, even if this is not actually the case, as a part of the maintenance simply will happen through replacement of certain parts any way.
- Only marginal costs from "normal" boilers to "high efficiency" boilers will be included.
- The flue gas cleaning equipment is replaced and only extra expenses for condensing scrubbers, related equipment, and fibreglass-laminated flue ducts are included.
- The facilities will be built on plants with 10 t/h - 30 t/h. We have calculated using an average facility of approx. 15 t/h and apportioned the whole quantity of waste.
- The 12.33 TWh of waste or approx. 3.7 million tonnes, corresponds to approx. 30 new facilities of 15 t/h each.

With the above-mentioned considerations and assumptions, the extra expenses for the boiler and turbine are approx. 20-22 million DKK/facility, i.e., 30 times 20-22 million DKK/facility, in all is 600-660 million DKK. Additionally the flue gas part of 30 times 25 million DKK, in all is 600-660 million DKK, which has to be added. This is implemented in IDA 2030 and IDA 2050 with total extra expenses of 1.4 billion DKK with a lifetime of 25 years and 2 per cent in O & M costs.

The use of seasonal storage principally means that the operating time at the waste fuel facilities becomes lower, whereby the costs increase. On the other hand, there is a better possibility for higher income because of higher electricity prices with this operation in IDA's energy systems, as here there is significantly more fluctuating renewable energy in the system. Seasonal storage also provides increased costs for handling and for storage. However this can be minimised by planning the sorting and the use of the waste at the plant. It has not been possible to determine these costs in this report. Hence these costs are identical with the handling cost of biomass described in chapter 5.

8.5 Geothermal energy

Today geothermal energy is used in two locations in Denmark, in Thisted since 1984 and in Copenhagen, Amager since 2005, and produces a total of approx. 0.33 PJ/year. The potential to use geothermal energy in Denmark is however far greater. An investigation of the potential in Copenhagen showed that the reserves amounted to 60,000 PJ. That can be compared with an annual heat demand of 30-40 PJ in Copenhagen. Theoretically, all of the Danish district heating demand of approx. 120 PJ can be covered. However, it is not profitable or physically possible at all places to establish a geothermal energy facility, and geothermal energy is not suited for producing peak loads. It has been estimated that between 25 and 40 PJ can be covered by geothermal energy. A facility can typically supply around 5,000 households. Normally a hole is bored down 1-3 km in depth where the water is typically between 35°C and 80°C. Heat pumps for geothermal energy can be absorption heat pumps driven by 160°C heat from a CHP plant, or from other district heating suppliers such as straw boilers. They can also be electrical heat pumps.

According to Jesper Magtengaard from DONG Energy, it is estimated that cities such as Aalborg, Brønderslev, Frederikshavn, Helsingør, Hillerød, Hjørring, and the Copenhagen metropolitan area, Næstved, Randers, Ringsted, Slagelse, Sønderborg, Thisted and Århus can be supplied with heat from geothermal energy. Geothermal energy has the advantage that it can also be used together with storage well for surplus heat from waste incineration CHP for example or from heat pumps. Approx. 90 per cent can be reversed and used again in seasonal storage. However, seasonal storage must be tried out in practiceand it is not a part of this measure here.

It is assumed in IDA 2030 and IDA 2050 that approx. 15 per cent of the district heating demand in larger cities is covered by geothermal energy facilities. This corresponds to approx. 10 per cent of the total district heating demand in IDA 2030 and IDA 2050 covered with geothermal energy.

This has been implemented in the EnergyPLAN model according to input from Poul Østergaard, Aalborg University, in the following way.

In the Climate Plan it is assumed that geothermal energy plants are located in connection with waste incineration CHP plants, where there is an opportunity for steam extraction to drive an absorption heat pump which uses geothermal heat as a low temperature source. A variable steam extractor is used to ensure the largest flexibility concerning the production of electricity and heat, to accomodate the time-varying demands for these. As mentioned, there can be heat sources other than waste incineration plants.

The calculations have been based on analyses done by Rambøll in connection with the Energy City Frederikshavn project. The boiler in a waste incineration CHP plant can burn the waste in a constant consumption, and the steam produced can then be used either for CHP or for CHP in combination with geothermal energy.

Similar to the Frederikshavn project, flue gas condensation is assumed to be installed at the waste-incineration CHP plants in the IDA's Climate Plan 2050. The condensated heat from the flue gas is used for the production of district heating. The condensation temperature is considered too low to affect the steam production for the geothermal energy facility, so the district heating efficiency value both with and without geothermal energy are higher in the IDA Climate Plan than in Frederikshavn. With full steam extraction for geothermal energy, the district heating efficiency value is determined to be 20 per cent, corresponding to the modelled 7.5 per cent for Frederikshavn's plus the difference between the two facilities' heat efficiencies without steam extraction for geothermal energy.

Between the two extremes defined as no steam extraction and full steam extraction, the efficiency values vary linearly in order to simulate aggregated populations of waste incineration CHP plants in EnergyPLAN where there are varying shares of plants with geothermal energy.

The Coefficient of Performance (COP) value for Frederikshavn is retained. Hence here this does not vary for different inputs of geothermal energy. The steam quantity sets the limit for heat production with geothermal energy: the COP value does not change with various values of geothermal energy input. The COP has been calculated on the basis of low temperature sources at 32°C-40°C. It is thus assumed that corresponding temperature levels are found at the other places where geothermal energy is included.

Upon a modelling with 50 per cent input of geothermal energy relative to the modelled system for Frederikshavn, there is a combined production at geothermal energy facilities of 4.1 TWh out of a combined district heating consumption of 26 TWh in the larger cities, corresponding to a combined coverage of approx. 16 per cent of the district heating consumption in these cities. That corresponds to an installed capacity of 478 MWth.

This coverage is reached with average efficiency values for all the plants, including plants both with and without geothermal energy, at $\eta_{electricity}$: 21.8 per cent, η_{th}: 48.7 and η_{steam}: 31.7 per cent.

The costs have been estimated in "Technology Data for Electricity and Heat Generating Plants" at approx. 150-300 DKK/MWh production [14]. According to "Technology Data for Electricity and Heat Generating Plants," the investment costs are 6 million DKK/MWth in 2015. Here 8.25 million DKK/MWth is used. With an installed capacity of 478 MWth, the investment cost is thus 3.9 billion DKK, assuming the investment includes the operating heat. The lifetime for the absorption heat pump is estimated to be 15 years, while the lifetime of the well is significantly longer. Here an average lifetime for the whole investment of 30 years is used.

O & M costs for geothermal energy can be divided up into indirect and direct costs. The indirect costs include energy costs for steam extraction or electricity consumption in connection with the district heat production. This part has been included in the modelling of the energy systems here. The other part is connected with general maintenance and replacement of pumps. For larger facilities, Allan Mahler from DONG Energy estimates that operations and maintenance excluding the purchase of energy typically is at 2.5 per cent of the combined facility investment, with local variations. In particular, costs for the injection boring can vary.

8.6 Fuel cells

Fuel cell plants are introduced in IDA's Climate Plan 2050 gradually in decentralised CHP plants, in central CHP facilities, and in power plants. There are no fuel cell plants installed in IDA 2015. In IDA 2030, half of the decentralised CHP plants are fuel cells. In IDA 2030, a third of the central power and CHP plant population is based on fuel cells while in IDA 2050 all the power plants are based on fuel cell technology. In IDA 2050 however, some of the facilities could be combined cycle gas turbines in the larger power plants, without it changing the final system significantly [34]. However, in this proposal for IDA 2050 only fuel cells are implemented.

At the same time as these fuel cells are installed, the power plant population is reduced because of the reduced electricity demand. In the reference energy system for 2030, the hourly peak load for electricity is approx. 7,130 MW and thusthe installed power plant capacity is 8,550 MW, i.e., 20% over the peak load. Electricity savings are accomplished in IDA 2030 in households, industry, and as a result of the installation of district cooling. At the same time however, the electricity consumption has been increased because of, among other things, more rail transport, more industrial heat pumps, biogas facilities, IBUS facilities, etc. This has on a net basis reduced the hourly peak load for electricity to just below 4,100 MW. Electrical vehicles must also be added, which are assumed to be recharged over six hours aquivalent to 2,100 MW peak. Heat pumps in households, which have electrical boilers installed for peak load situations, are also installed. The peak load for these has been set at 600 MW. Consequently, the combined power plant capacity required can be estimated at 8,100 MW with 20% capacity over the peak load.

Table 9, The electricity consumption in the reference and in the Climate Plan.

TWh electricity consumption	2008	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Households	10.2	9.5	9.4	11.3	7.6	5.1	5.1
Individual heat pumps	0.5	0.8	1.1	1.1	2.0	1.7	1.6
Large heat pumps	-	-	-	-	1.2	2.9	2.9
Electrical cartridges	-	-	-	-	1.0	0.6	0.2
BOLIG+	-	-	-	-	-	-0.5	-1.0
Industry incl. refineries	23.0	23.6	28.7	36.5	15.8	13.2	12.8
Industrial heat pumps	-	-	-	-	0.7	0.7	6.6
Transport - roads	-	-	-	-	-	4.6	6.8
Transport - buses	-	-	-	-	-	0.2	0.3
Transport - rail	0.4	0.4	0.4	0.4	0.4	2.1	5.0
IBUS	0.0	0.2	0.2	0.2	0.2	0.1	-
Biogas	-	-	-	-	-	0.2	0.3
District cooling	-	-	-	-	-	-0.4	-0.4
Electrolysis	-	-	-	-	-	-	7.5
Other and net losses	2.3	1.9	1.9	1.9	1.9	2.5	2.5
Sum	36.3	36.4	41.7	51.5	30.7	33.0	50.0

Subsequently, flexible electricity demand was established which reduced the necessary power plant capacity to approx. 7,600 MW. In addition there are approx. 1,950 MW of decentralised CHP plants in IDA 2030. Therefore, approx. 3,500 MW of fuel cells is installed in power and CHP plants in IDA 2030. The electricity consumptions in the reference and in the Climate Plan are listed in Table 9. The explanation of the individual sub-elements is in the respective paragraphs that deal with the topic.

The average efficiencies at the plants thus become:

- Power plants: 50.2 per cent
- Central CHP plants: 45.6 per cent electricity and 44.5 per cent heat,
- Decentralised CHP plants: 46.6 per cent electricity and 41.0 per cent heat.

From 2015 onwards, new fuel cell plants are installed, including power plants with an efficiency of 66 per cent, central CHP plants with efficiencies of 66 per cent electricity and 24 per cent heat, and decentralised plants with efficiencies of 56 per cent for electricity and 34 per cent for heat. It is assumed that the large central CHP plants are combined with gas turbines to achieve the higher efficiency value.

In IDA 2050 it has been assumed that the entire power plant capacity of approx. 10,300 MW in central CHP plants and approx. 1,950 MW in decentralised CHP plants is made up by fuel cells. In this report the efficiency value of fuel cell power plants and fuel cell CHP plants has been reduced however by 2 per cent in power efficiency value, as these have been assumed to use fuels based on biomass. All of the above-mentioned efficiency values have been determined in consultation with Topsoe Fuel Cells in connection with the completion of IDA's Energy Plan 2030 from 2006 [4], while the fuel cell technology is solid oxide fuel cells.

It has been assumed in IDA 2015 that the power plant capacity is identical with that in the reference for 2015, i.e., approx. 7,450 MW in central plants and approx. 1,950 MW in decentralised ones.

To begin estimating the costs of fuel cells, expected prices reported by Topsoe Fuel Cells A/S were used. For decentralised CHP plants with the above-mentioned efficiency values, the facility price is 800 €/kWe along with the same lifetime as other CHP plants. Annual costs including the replacement of the stack and catalytic converter are 100 €/kWe. In connection with IDA's Climate Plan 2050, a conference has been held regarding fuel cells and electrolysis facilities, in which Topsoe Fuel Cells also participated, but there was no reason identified to adjust the above-mentioned evaluation with regard to prices and efficiency values. On the basis of this information, the following costs have been used:

- For decentralised CHP plants, the investment costs are 6 million DKK/MW, the lifetime is 20 years, and O & M costs of approx. 750,000 DKK/MW have been divided into a fixed cost of 10 per cent of the plant investment costs and a variable cost of 20 DKK/MWh.

- For central power plants and CHP plants, a combination of gas turbine and fuel cell costs have been used, i.e. 6 million DKK/MW and O & M costs of approx. 450,000 DKK/MW, which are divided into a fixed cost of 6 per cent of the plant investment costs and variable costs of respectively 20 DKK/MWh for CHP and 15 DKK/MWh for the power plant. The lifetimes are assumed to be 30 years.

8.7 Oil and gas

In the reference for IDA's Climate Plan 2050, the energy consumption for the production of oil and gas in the North Sea is practically constant from 2008 to 2030. According to the reference that was used in the completion of IDA Energy Plan 2030, the energy consumption in the North Sea of approx. 30 PJ/year in 2008 was expected to increase to approx. 70 PJ/year by the year 2030. The objective in this plan was to reduce the 70 PJ of fuel consumption in 2030 by approx. 45 per cent, corresponding to increase of 30 per cent instead of 130 per cent in relation to 2004, and that the CO_2 emissions also were reduced by 45 per cent.

In the meantime, a political initiative has been taken to implement this objective, which is accounted for in the new reference, i.e., the North Sea energy consumption increases moderately from approx. 28 PJ at present to 33 PJ in the year 2030. The identified expectations for the fuel consumption are based on three contributions.

- Fuel consumption for production from known deposits with known technology.
- Fuel consumption for production from new finds.
- Fuel consumption for production by use of new technology.

Against that background, further measures have not been proposed in this area within the time horizon going forward to the year 2030. After the year 2030, the energy consumption in the North Sea is expected to be eliminated in step with the cessation of oil and gas production. For the year 2050 we have calculated with an energy consumption of 0 as is done in the reference. In the reference oil refinancing using 30 PJ is present in the reference also in 2050, as well as in IDA 2015 and IDA 2030. In IDA 2050 however the transport sector has changed to other fuels and the refinery has been left out.

9 Energy consumption in buildings

In this part the initiatives in building construction are presented. The electricity savings and heat savings in households, new construction according to the BOLIG+ standard, conversion to ground source heat pumps, water-to-water heat pumps combined with solar thermal, and biomass boilers are all discussed. Building integrated fuel cells have been introduced in chapter 1.

As the heat savings are connected with the district heating system, we have chosen to describe expansion of district heating areas here, including solar thermal in district heating areas. For industry and service, electricity savings and heat savings are described in chapter 1, but as a portion of the heat consumption in industry and service is converted to district heating, it is included in this chapter.

9.1 Reduction of electricity consumption in households

The reference energy system from The Danish Energy Authority accounts for the Danish Energy Agreement, the consumption effects corresponding to a fuel price $122/barrel of oil, and the tax changes from March 2009. As an result of these assumptions alone, the electricity consumption decreases by approx. 1 per cent annually going forward to about 2015. Afterwards, the electricity consumption is constant for the most part.

In IDA's Climate Plan 2050, the electricity consumption in households is reduced by 50 per cent in relation to the 2008 level. The 50 per cent electricity savings is achieved by the year 2030. The objective in IDA's Climate Plan 2050 is to achieve 25 per cent savings in the period from 2010 to 2020. In practice all of the 25 per cent savings have been included in IDA 2015.

In 2015, household electricity consumption is reduced by 6 per cent compared to 2008 in the reference. In this report, the 25 per cent in household electricity savings correspond to another approx. 19 per cent, in other words the consumption decreases from 9.4 TWh in the reference for 2015 to 7.7 TWh in IDA 2015. In IDA 2030, a further 25 per cent of electricity savings in relation to 2008 are carried out, corresponding to a reduction from 9.5 TWh in the reference for 2030 to 5.1 TWh. In 2050, the electricity consumption has been increased to 11.2 TWh in the reference, but in this study savings are implemented so that a constant consumption of 5.1 TWh is achieved from IDA 2030.

Electricity savings for industrial buildings, including service activities and offices, etc., have been estimated in section 10.1. The final total electricity consumption has been estimated in Table 9.

The objective of a 50 per cent reduction in the electricity consumption in households is implemented through information campaigns and replacement of appliances. A range of estimates for the technical electricity savings feasible indicates that the consumption can be reduced by 50 per cent via relatively simple improvements in the households' electric appliances, along with a socioeconomic gain as a result. According to The Danish Electricity Saving Trust (Elsparefonden), investment in the current situation will typically have a socioeconomic payback period of up to 4 years at an electricity price of 2 DKK/kWh. The payback period of 4 years has been worked out as the payback period for the additional investment required for an electricity-saving appliance. The investment costs thus become approx. 8 billion DKK to reduce the electricity consumption by 1 TWh/year. The average technical lifetime of the investment has been set at 10 years in consultation with The Danish Electricity Saving Trust and the marginal extra operational cost at nil DKK. If the investment is divided over the lifetime, then there must be 0.9 billion DKK/TWh invested each year for a reduction of the electricity consumption by 1 TWh/year.

If the energy efficient technologies become market dominant, the extra investment will result in a change from niche production, with a limited market, to market dominance among these products. A report from OECD from 2006 points out that when electricity-saving appliances first become market dominating, the extra cost will be reduced significantly because of advantages of scale, and there is a tendency for it to touch nil DKK [35]. This means that the calculated extra expense is reduced as a result of large production and that market and competition conditions in some cases will eliminate the expected extra expense in the setting of the products' prices on the market. On this basis the socioeconomic extra investment cost in the scenario in which the energy efficient technology dominates the market has been estimated to be 4.0 billion DKK or 0.47 billion DKK per year for each saved TWh per year. This has occurred in consultation with The Danish Electricity Saving Trust.

In the socioeconomic analysis, the value of saved power plant capacity at condensation power plants is included, which has been estimated at approx. 450 MW in 2015 and approx. 780 MW in 2030. In the scenario for the year 2050, this has been estimated at approx. 1,100 MW saved capacity in relation to the reference.

9.2 BOLIG+ standard in new building construction from 2020

In the latest energy agreement, an agreement was included that the energy consumption in newly-constructed houses shall be reduced by 25 per cent in 2010 (low energy class 2), by 50 per cent in 2015 (low energy class 1), and by 75 percent in 2020 (low energy class 0). In the reference energy system a reduction of 75 per cent of today's energy consumption in new building from 2020 and going forward is assumed in the case of new building construction. In IDA's Climate Plan 2050, it is proposed to make BOLIG+ as the standard from 2020 onward, and to approve this concept now already. In practice, the consequence has been calculated here for residences, but the standard also ought to apply to offices, etc.

For the BOLIG+ concept, the energy production shall be neutral when seen across the year with respect to both electricity and heat. It means therefore that these residences are entirely dependent on flexibility in the rest of the system. However, solutions ought to be thought about that include connection to solar thermal, photovoltaic, and low temperature district heating. It also requires that the building at a minimum shall be insulated to the Danish energy class 1, and that the electricity consumption per residence shall be at a maximum 2,000 kWh.

For newly-constructed residences the costs are approx. 10,000 DKK/m^2 today. These residences must have an energy consumption of approx. 85 kWh/m^2, including electricity and heat, according to the current standard. With the measures that have been implemented in the Danish Energy Agreement, this energy consumption shall thus be decreased to approx. 21 kWh/m^2. This requires thoroughly considered solutions and just as in the low energy classes, in BOLIG+ renewable energy must be also play a part.

The Danish Building Research Institute (SBI - Statens Byggeforskningsinstitut, Aalborg University) has estimated that the extra expenses connected with low energy class 1 are approx. 6 per cent in relation to today's residence, if energy efficient solutions have become standard [36].

Today the quantity of new construction is approx. 2.5 million m^2 per year for residences. From 2020 to 2030, it is assumed that there will be 2.5 million m^2 of new construction annually, so in IDA 2030 there are 25 million m^2 according to this standard. This results in a combined building stock of approx. 370 million m^2 living area by 2030 for the reference. From 2030 to 2050, the living area built according to this standard is expected to double, i.e., 50 million m^2. The extra costs to build energy-neutral residences are estimated to be 5 per cent from 2020 and forward. Therefore, in 2030 the extra costs are approx. 12.5 billion DKK, although it is assumed that this investment has been completed gradually from 2020 to 2030. If the lifetime of the investment is assumed to be 30 years, then the annual costs of the investment will be approx. 640 million DKK/year for the IDA 2030 scenario. As it is assumed that approx. twice as many new residences have been built in 2050, the costs are doubled in 2050, i.e., 25 billion DKK with a lifetime of 30 years. Also, approx. 1.1 TWh of electricity and heat must be produced in IDA 2030 and 2.1 TWh in 2050 by these households to be energy neutral.

In practice, BOLIG+ in IDA's Climate Plan 2050 is implemented by subtracting 0.5 TWh of electricity consumption in 2030 and 1 TWh in 2050. The remaining part is calculated as saved heat consumption in relation to the reference. Half of the savings occurs in central district heating areas and the other half in the houses which have biomass boilers in the reference, as it is assumed that biomass boilers would be the alternative. The results were calculated in this manner because building-integrated photovoltaic as well as solar thermal have been separately implemented in other parts of the report. In practice these households will however have other effects on the energy system in addition to the savings calculated here.

9.3 Heating of existing buildings

The district heating areas are expanded gradually going forward towards 2030 so that district heating covers 63-70 percent of the Danish net heat demand. Here it is assumed that the district heating is expanded so that individual boilers up to one kilometre from existing district heating areas are supplied with district heating. As a sub-objective in 2015, the district heating areas have been expanded to neighbouring areas with heating boilers, i.e., areas that adjoin the existing district heating areas. Further expansions have not been assumed from 2030 going forward to 2050. The expansions that are carried out use the synergistic effect: they combine savings in space heating consumption and reduction of the return temperature with expansions of the district heating at the margins and adaptations of pipe dimensions and peak load boilers. In practice it is done here in two steps, to clarify the costs in this report. In IDA's Climate Plan 2050, a starting point is taken in the report Heat Plan Denmark, where fuel consumption, CO_2 emissions, and the socioeconomic impacts for the supplying of heat in Denmark were analysed [32].

In the period from 2010 to 2020, heat savings corresponding to a 25 per cent in demand are implemented. In practice it is assumed that these savings have been fully implemented in IDA 2015. In IDA's Climate Plan 2050, further heat savings are achieved in the heat consumption for buildings, reflecting the fact that the energy consumption is approx. 50 per cent lower in IDA 2030 and IDA 2050 in relation to the reference energy systems. These savings are undertaken both within and outside of district heating areas.

In the reference, savings in the heat consumption have been realised in 2015 corresponding to approx. 5 per cent in relation to 2008, primarily in residences. In 2030, the energy consumption for residential heating in the reference decreases by approx. another 20 per cent. Going forward to 2050, the residential energy consumption in the reference decreases by a total of approx. 35 per cent in relation to 2008. This is however more than offset by strong increases in consumption by the industry and service sectors. A connection between economic growth and heat consumption is the method used by the Danish Energy Authority, hence the heat savings in the reference are offset by the economic growth in the period 2030 to 2050, as strong increases in the consumption in industry and service sectors occur. The savings in IDA's Climate Plan 2050 and the savings contained in the reference have been compared to each other below.

When heat savings are implemented both inside and outside of district heating areas, the share of the heat consumed for space heating, losses, and hot water is changed. As heat savings are introduced space heating demand becomes less for each hour, but the net losses and the demand for domestic hot water are held at a more constant level. This is taken into account in the calculations. Electric heating has not been included, as it is assumed that electric heating has been removed in the reference energy system. In addition the minimal consumption of coal and coke has been omitted.

9.4 Costs of heat savings

According to a new report from SBI, "Sharpened requirements for new construction in 2010 and forward - Economic Analysis" (Skærpede krav til nybyggeriet 2010 og fremover - Økonomisk analyse), it is economically feasible for individuals' to reduce the heat consumption in buildings by 23 per cent or 37 PJ [37].]. The investment costs for these savings have been estimated at a total of approx. 38 billion DKK, as the savings are implemented together with planned renovations, etc. This corresponds to approx. 1,000 DKK/GJ in investments per reduced GJ/year. It is proposed that these savings be implemented going forward towards 2020. These savings mean that 75 per cent of the most poorly insulated residences have been renovated in 2020. Further savings in installations can be found totalling approx. 20 PJ going forward to 2020, which will have costs of approx. 34 billion DKK. Half of these costs, or about 17 billion DKK, are estimated to be energy related. This corresponds to between 500-1,000 DKK/GJ. The energy consumption in buildings can be reduced by a further 21 PJ, corresponding to 37 per cent compared to today, with marginal extra costs of 62 billion DKK, or approx. 3,000 DKK/GJ. These savings are realised in the period 2020 - 2030. In this report the rest of the most poorly insulated residences are renovated, along with some of the residences which have insulation of medium quality.

All the above-mentioned initiatives correspond to an energy consumption reduction of approx. 50 per cent in comparison to today. On average, it means that the costs of reducing the energy consumption are approx. 1,500 DKK/GJ.

In IDA's Energy Plan 2030, the costs of reducing the domestic space heating demand by 50 per cent were determined to be 3,000 DKK/GJ in consultation with Henrik Tommerup and Svend Svendsen. The lifetime was estimated to be 50 years on average. Investigations show that it will cost 155 billion DKK in extra investments in residences to achieve a 42 per cent savings in the energy demand, including extra investments during new construction. This corresponds to the existing residences achieving the same energy consumption as new residences in accordance with the Danish General Building Regulation 1995 - BR95 [38]. The energy demand in residences was reduced in that way in corresponding to 51 PJ/year, or approx. 42 per cent of 122 PJ/year. This corresponds to approx. 3,000 DKK/GJ in energy savings. In IDA's Energy Plan 2030, these costs were divided with approx. 2,000 DKK/GJ for the first 25 per cent of reductions and approx. 4,000 DKK/GJ on the remaining 75 per cent, while a lifetime of 50 years was also used. For the energy savings in the Climate Plan this figures have been updated so that the latest data was used, as described below.

On this basis, 1,000 DKK/GJ is used in IDA's Climate Plan 2050 for the savings in IDA 2015, while it is assumed that the least expensive savings are implemented first. In IDA 2030 and IDA 2050, marginal extra costs of 2,000 DKK/GJ are used, while it is assumed that approx. half of the energy savings with the best economy have been carried out in the reference. The lifetime is estimated again to be on average 50 years.

9.5 Heat savings in district heating areas

In the Climate Plan, energy savings are carried out first followed by conversions to district heating. In IDA 2015, further energy savings are implemented in district heating areas, corresponding to 20 per cent of the heating demand, so that the combined energy conservation measures reach a total savings of 25 per cent compared to a situation where no savings are carried out. Achieving savings of 25 per cent is recommended to be implemented in the period 2010 - 2020, but in this report the measure has been calculated as implemented in IDA 2015.

According to the same principle, heat savings have been implemented in IDA 2030 and IDA 2050 corresponding to approx. another 30 per cent in relation to the reference for these years. In this way, the combined savings in the heat consumption of 50 per cent are achieved. In the reference for 2050, the district heating consumption is at the same level as in 2030, while 20 per cent less heat is used in residences and correspondingly more in industry and service. In IDA's alternative for 2050, the trend in the reference means that the savings in practice must be carried out more in industries and services than in residences.

The combined savings in district heating areas is approx. 4.8 TWh in IDA 2015, 6.8 TWh in IDA 2030, and 6.7 TWh in IDA 2050. The costs for this are 17.1 billion DKK, 49.0 billion DKK, and 48.5 billion DKK in IDA 2015, 2030, and 2050 respectively. Primarily these savings provide an opportunity for changes in the supply system, e.g., in CHP plants and boilers. However these changes have not been included here, as the Climate Plan already includes expansions of district heating and other changes in the power plants.

The heat savings have been allocated among the three district heating areas - areas with district heating produced by boilers, decentralised CHP areas, and central CHP areas. A net loss was calculated, including domestic hot water consumption, corresponding to 32.6 per cent, cf. table 13.16 in the report Heat Plan Denmark [32]. In Table 10 the allocation to the various areas can be seen, as well as the changes that have happened as a result of the energy savings.

Table 10, Heat savings in district heating areas

2015	Reference		+ heat savings	
TWh	District heating total production	Heat consumption	Heat consumption	District heating ex plants
District heating area	2,73	1,84	1,47	2,36
Decentralised CHP area	10,25	6,91	5,53	8,87
Central CHP area	22,30	15,03	12,02	19,29
Sum	35,28	23,78	19,02	30,52

2030	Reference		+ heat savings	
TWh	District heating total production	Heat consumption	Heat consumption	District heating ex plants
District heating area	2,64	1,78	1,25	2,11
Decentralised CHP area	9,90	6,67	4,67	7,90
Central CHP area	21,52	14,50	9,97	16,86
Sum	34,06	22,96	15,89	26,86

2050	Reference		+ heat savings	
TWh	District heating total production	Heat consumption	Heat consumption	District heating ex plants
District heating area	2,64	1,78	1,25	2,11
Decentralised CHP area	9,90	6,67	4,67	7,90
Central CHP area	21,52	14,50	9,79	16,55
Sum	34,06	22,96	15,70	26,55

9.6 Heat savings outside district heating areas

Heat savings outside district heating areas are implemented with the same starting point as above, but with an adjustment in 2050. In 2015, 25 per cent of the heat consumption is assumed to be for domestic hot water in individual dwellings, while the corresponding share is 30 per cent in 2030 and 2050. In the reference, an average efficiency value for natural gas boilers of 90 per cent is assumed, for oil boilers 85 per cent, and for biomass boilers 80 per cent. In IDA 2015 and IDA 2030, the savings have been achieved in the space heating demand in parallel with the savings implemented in district heating areas, i.e., another 20 per cent in 2015 and another 30 per cent in 2030.

Table 11, Heat savings outside district heating areas

2015	Reference		+ heat savings	
TWh	Fuel	Heat consumption	Heat consumption	Fuel
Natural gas	6.55	4.42	3.54	5.57
Oil	4.15	2.65	2.12	3.53
Biomass	12.42	7.45	5.96	10.56
Solar thermal*	0.21	0.21	0.21	0.21
Heat pumps **	2.43	1.82	1.46	2.07
Sum	25.76	16.55	13.28	21.93

2030	Reference		+ heat savings	
TWh	Fuel	Heat consumption	Heat consumption	Fuel
Natural gas	4.79	3.02	2.11	3.78
Oil	2.62	1.56	1.09	2.07
Biomass	11.21	6.20	4.34	8.89
Solar thermal*	0.50	0.50	0.50	0.50
Heat pumps **	3.26	2.28	1.60	2.58
Sum	22.38	13.56	9.64	17.82

2050	Reference		+ heat savings	
TWh	Fuel	Heat consumption	Heat consumption	Fuel
Natural gas	3.83	2.41	2.17	3.56
Oil	2.09	1.24	1.12	1.94
Biomass	8.57	4.64	4.18	7.99
Solar thermal*	0.50	0.50	0.50	0.50
Heat pumps **	3.26	2.28	2.05	3.03
Sum	18.25	11.08	10.02	17.03

* The solar thermal installed in the reference energy systems is used continuously in areas with biomass boilers after the savings.

**Heat pumps ex facilities.

The heat savings outside district heating areas are listed in Table 11. In the reference for 2050, savings in households which are outside of the district heating areas corresponding to approx. 20 per cent have already been implemented from 2030 to 2050. Hence further savings are carried outside district heating areas, corresponding to only 10 per cent, so that in all savings are achieved of approx. 50% in relation to today. The costs for these space heating savings are 11.8 billion DKK in IDA 2015, 28.2 billion DKK in IDA 2030, and 7.6 billion DKK in IDA 2050.

9.7 Conversions to district heating

In order to implement the expansion of district heating gradually towards 2030, so that a district heating coverage of 63-70 percent of the Danish net heat demand is achieved, a starting point is taken from the report Heat Plan Denmark [32]. Currently approx. 46 per cent of the net heating demand is supplied by district heating in Denmark, to approx. 60 per cent of all households.

The scenario used for expansion of district heating in IDA 2015 is a mix between Scenarios 1 and 2 in Heat Plan Denmark, so that it supplies between 53 and 63 per cent of the heating demand. In Scenario 1 the existing areas which are planned for expansion are converted, while in Scenario 2 areas adjoining the district heating areas and today typically supplied with natural gas are connected.

In IDA 2030 and 2050, a mix is used between Scenarios 2 and 3. In Scenario 3, areas are converted up to a distance of one kilometre from existing district heating areas. Further expansions have not been assumed from 2030 going forward to 2050.

Thus a solution is chosen between the scenarios for 2015, 2030, and 2050, while the profitability and the technical possibilities depend on the actual project. Conversely, it is ambitious to reduce the natural gas consumption for heating to the greatest extent possible.

The implementation of these scenarios in the Climate Plan has occurred with a starting point in Appendix 13.4, page 125, in the Appendix Report to Heat Plan Denmark [32]. In that connection, the numbers here have been adjusted, because Heat Plan Denmark relates itself to a different reference.

In IDA 2015, the district heating demand is 30.5 TWh after implementing savings which correspond to a 25 per cent reduction of the residential space heating demand. In Heat Plan Denmark this number is 27.53 TWh (Table 13.4), which (through an expansion of the district heating areas corresponding to Scenarios 1 and 2 and 25 per cent space heat savings) increases to between 30.94 TWh and 36.68 TWh. This is an increase of 6.28 TWh to 33.81 TWh, corresponding to 23 per cent. With a corresponding increase, the district heating demand is increased in year 2015 to 37.49 TWh, an increase of 6.97 TWh.

The 1.11 relationship between the increase in Heat Plan Denmark and the Climate Plan respectively has been used to adjust the other changes. It means that the combined fuel consumption in households decreases from a total of 19.7 TWh to 15.1 TWh in the Climate Plan, compared with a decrease from a total of 18.3 TWh to 14.4 TWh in Heat Plan Denmark (mix between Scenario 1 and Scenario 2). The conversion in IDA's Climate Plan 2050 is done in areas with natural gas, oil, and biomass boilers, so that heat pumps and solar thermal are installed as outlined in the reference.

In the reference for the Climate Plan, a larger share of biomass boilers has been used than in the reference used in Heat Plan Denmark, cf. the assumed conversion in The Danish Energy Authority's basic forecast [6]. This is why the conversion has been adjusted here in proportion to the relationship between natural gas, oil, and biomass boilers in the Climate Plan's reference. In all, the fuel consumption of the households in IDA 2015 is changed in the Climate Plan from 5.57 TWh to 4.34 TWh for natural gas boilers, from 3.53 TWh to 2.75 TWh for oil boilers, and from 10.56 TWh to 7.97 TWh for biomass boilers.

In Heat Plan Denmark district heating is expanded not only in residential areas, but also in industrial and service areas. According to a corresponding process as described above, with a starting point in Appendix 13.4 from Heat Plan Denmark and by using the 1.11 factor, total fuel savings of 3.6 TWh have been identified for industry. Half to savings have been acheived in buildings with natural gas boilers and half with oil boilers.

In IDA 2030 and IDA 2050, the combined district heating demand after the implementation of 50 per cent heat savings (but before the conversions) is 26.9 TWh and 26.6 TWh respectively. In Heat Plan Denmark these consumptions correspond to 21.12 TWh (refer to its Appendix 13.4). This increases when the district heating coverage is increased to 63-70 per cent. We implement this here as a mix between Scenarios 2 and 3. In Scenario 3, Heat Plan Denmark is expaned further than in Scenario 2, as the expansion goes up to 1 kilometre from the current district heating areas. The consumption increases in Heat Plan Denmark in Scenario 3 to 31.46 TWh, which is an increase of 10.34 TWh corresponding to 49 per cent. According to a corresponding process as described above, the resulting demand has been identified in IDA 2030 and IDA 2050. In this process the district heating demand is written up, the fuel demand in individual houses is adjusted, savings in industry and services are carried out, and the result are adjusted to fit the reference in IDA's Climate Plan 2050.

In Table 12 the total production (including network losses) from district heating plants is shown, allocated to the three groups and fuel consumption for heating of house outside district heating areas. The way in which these change as a result of heat savings and conversions to district heating appears in this table. The table also indicates the savings feasible within the industry and service sectors as a result of the expansion of district heating areas.

The costs for changing and expanding the district heating network, which can use lower supply temperatures as a result of lower final demand and a larger distribution network, etc., appear in the Appendix Report in Heat Plan Denmark on page 107. In Scenario 1, the investment costs are 8 billion DKK, in Scenario 2, 33 billion DKK, and in Scenario 3, 78 billion DKK. The lifetime is 40 years and O & M costs are 1 per cent. In IDA 2015, a compromise between Scenarios 1 and 2 is used, and the costs become 20.5 billion DKK. In IDA 2030 and 2050 a compromise is used between Scenarios 2 and 3, or 55.5 billion DKK. This averaged estimation reflects that socioeconomically inexpensive and expensive conversions will both be undertaken, in equal measure. In addition, savings are included to reflect district heating replacing boilers.

Table 12, District heating total production (including network losses), fuel consumption for heating in individual households, and fuel savings concerning space heating converted to district heating in industry and services.

Reference without savings, incl. BOLIG+						
TWh	District heating areas	Decentralised CHP	Central CHP	Sum	Fuel consumption in households	-
2008	2.78	10.42	22.67	35.87	25.51	-
2015	2.73	10.25	22.30	35.28	25.76	-
2030	2.64	9.90	21.13	33.67	22.38	-
2050	2.64	9.90	20.74	33.28	18.25	-

+ savings						
TWh	District heating areas	Decentralised CHP	Central CHP	Sum	Fuel consumption in households	-
2015	2.36	8.87	19.29	30.52	21.93	-
2030	2.11	7.90	16.86	26.86	17.82	-
2050	2.11	7.90	16.55	26.55	17.03	-

+ conversions						
TWh	District heating areas	Decentralised CHP	Central CHP	Sum	Fuel consumption in households	Savings in industry
2015	2.90	10.89	23.70	37.49	17.60	-3.60
2030	2.96	11.09	23.67	37.72	11.13	-4.95
2050	2.96	11.09	23.23	37.28	10.42	-4.89

9.8 Heat pumps, solar thermal, and biomass boilers outside district heating areas

The share of heat pumps, solar thermal, and biomass boilers in individual households shows that a conversion to district heating has already occurred, as outlined in the above-mention measures. The Climate Plan's initiatives must therefore be seen in the light, when for example the solar thermal share is determined. If a solution for the future is chosen in which less heating demand is converted to district heating, then more heat pumps and more solar thermal, etc., can be installed than outlined here. In the references for 2030 and 2050, approx. 0.5 TWh of solar thermal has been installed and approx. 3.26 TWh of the heat demand has been covered by heat pumps. In the reference for 2015, 0.2 TWh of solar thermal has been installed and 2.4 TWh of the heat demand is covered by heat pumps.

Here heat pumps must gradually replace heating by boilers going forward to 2050, so that the heat pumps cover 90 per cent of the heat demand outside district heating areas. The remaining 10 per cent is covered by biomass boilers.

In IDA 2015, heat pumps replace 90 per cent of all oil boilers, corresponding to a decrease in the oil consumption from 2.75 TWh to 0.28 TWh. It is assumed also that 50 per cent of all natural gas boilers are converted to heat pumps, corresponding to a decrease in the fuel consumption from 4.34 TWh to 2.17 TWh. This means however that the heat demand for heat pumps increases from 2.07 TWh to 6.12

TWh. An annual COP of 2.9 is used for heat pumps in IDA 2015, which corresponds to the average of the COP between two types of heat pumps. It is assumed in IDA 2015 that 50 per cent of the heat pumps is ground source heat pumps and 50 per cent is air-to-water heat pumps. Ground source heat pumps have a COP of 3.2, whereas air-to-water have a COP of 2.6. The costs have been estimated in Appendix II. In the reference the heat pumps are also presumed to have an annual COP of 2.9, corresponding to this average.

Also in 2015, biomass boilers cover approx. 40 per cent of the hot water and space heating demand in the reference energy system which is 13.6 TWh in total, after the implementation of savings and conversions. This is retained for IDA 2015.

In IDA 2015, a total of approx. 0.6 TWh of the heat demand is covered by solar thermal, which is approx. five times as much as today. Twenty percent of the demand is covered by solar thermal in 20 per cent of the households, corresponding to a total of approx. 0.1 TWh in areas with oil and natural gas boilers. In areas with biomass boilers, 20 per cent of the demand is covered by solar thermal in 20 per cent of the households, or approx. 0.26 TWh. Solar thermal is also installed in combination with heat pumps, corresponding to 20 per cent of the demand in 20 per cent of the households, which is approx. 0.25 TWh. In areas where 20 per cent of the heat demand is covered by solar thermal, a typical domestic water installation is installed. In areas with greater solar thermal coverage, a standard combined domestic water and space heating installation is used.

In the future additional combinations must also be considered. For example solar thermal can be combined with water-to-water heat pumps, so that the solar thermal preheats the water and consequently, according to Danfoss and Sonnenkraft increases the COP to between 4 and 5 for these installations. Here an intermediate solution is chosen of 4.5 in annual COP. A solution is chosen where half of all heat pumps in 2030 and in 2050 have been combined with solar thermal, and half with ground source installations which have an annual COP of 3.2. For the combined installations, a solution is chosen in the Climate Plan where it is assumed that 25 per cent solar thermal coverage of the annual demand can raise COP to 4.5. In the remaining half of the households which have heat pumps, a solution is chosen where ground source heat pumps are combined with 25 per cent solar thermal, hence they have an annual COP of 3.2. In EnergyPLAN, these have been considered as an average, while the combined solar thermal coverage in households with heat pumps is 25 per cent, and the heat pumps have an average annual COP of 3.85, cf. above-mentioned combination of 50/50.

In IDA 2030, heat pumps are installed as replacements for 95 per cent of all natural gas and oil boilers. Ten percent of the combined heat demand is covered by biomass boilers and the remaining approx. 90 per cent by heat pumps. In IDA 2030, the share of solar thermal is expanded to a total of approx. 2.15 TWh. In IDA 2030, 95 per cent of all households have solar thermal outside district heating areas, which covers 20 per cent of the demand in areas with boilers and 25 per cent in areas with heat pumps.

In IDA 2050, a corresponding solution is chosen, while natural gas and oil boilers are however entirely phased out. In all, in IDA 2050 there is a solar thermal coverage of approx. 2.04 TWh or 23 per cent outside district heating areas. In Table 13 the result of the conversions is listed.

Table 13, Conversions in the heat supply in individual households.

	2015	IDA 2015	2030	IDA 2030	2050	IDA 2050
TWh	Not converted to district heating	+ solar and heat pumps.	Not converted to district heating	+ solar and heat pumps.	Not converted to district heating	+ solar and heat pumps.
Natural gas	4.34	1.95	2.07	0.08	1.82	0.00
Oil	2.75	0.24	1.13	0.04	0.99	0.00
Biomass	8.23	6.38	4.86	0.92	4.08	0.87
Solar thermal*	0.21	0.54	0.50	2.15	0.50	2.04
Heat pumps **	0.71	2.04	0.89	1.62	1.05	1.56
Sum	16.25	11.15	9.44	4.81	8.44	4.47

* Solar thermal ex facilities
** Electricity consumption in heat pumps

Solar thermal installations will reduce the idle time loss for boilers in the summer. We have calculated a loss of 300 kWh/year per boiler corresponds to 2-3 per cent of the net heat demand for a residence with a heat demand of 10-15,000 kWh/year. This has been included in the EnergyPLAN model calculations by increasing the efficiencies for boilers by 2 percentage points to 82, 87, and 92 per cent for biomass, oil, and natural gas respectively. In this way the resulting fuel consumption is reduced further. However, this has not been included in IDA 2015.

According to the EnergyPLAN model calculations, the thermal storage capacity which can be used for domenstic solar thermal installations is equivalent to the average heat demand over one day. For a house with a heat demand of 10,000 kWh, it thus corresponds to a storage facility of approx. 27 kWh or 4-500 litres and for a house with a heat demand of 7,500 kWh to approx. 20 kWh or more or less 300 litres.

The costs for individual solar thermal installations are from IDA's Energy Plan 2030. The costs for installing and mounting an integrated individual solar thermal facility with a 10 m^2 area and a 500 litre storage tank were used as a starting point. Mounted on an existing house in the year 2006, such an installation would have been able to produce 5 MWh/year and will cost (according to the solar thermal manufacturer Arcon) a total of 45,000 DKK, allocating 30,000 for solar collectors including mounting and 15,000 DKK for the tank including the heat exchanger and connections. If the boiler is replaced as well (as a result of the assumption of continuous replacement), the current price is reduced to 35,000 DKK. With the inclusion of an economy of scale advantage in the outlined market, the price according to Arcon could be expected to be 25,000 DKK in the period 2015-2030. Operations and maintenance costs have been set at 1 per cent, corresponding to an extra cost of 250 DKK /year for the solar thermal installation. The lifetime for an installation has been calculated at 20 years. All prices exclude the Danish value-added tax (VAT).

Danish Solar Thermal Association (Dansk Solvarmeforening) has evaluated this expected price in relation to the price reductions that have been achieved in the period 1986 to 2006. The comparison indicates that Arcon's expectations are realistic.

Solar thermal installations on house roofs can also be combined with district heating. At the moment, district heating areas are being established with decentralised production from solar thermal for example. These concepts provide the opportunity to reduce the pipe dimensions, as well as build larger solar thermal installations, for example, which have lower costs. We have not calculated here for solar thermal installations sized in the range between individual installations and solar thermal installations in district heating areas.

The installation costs for heat pumps combined with solar thermal are assumed to be the same as for solar thermal and for installation of air-to-water heat pumps individually, which is possibly on the high side. The costs for the boilers that are replaced have been estimated in Appendix II.

9.9 Establishment of solar heating in district heating areas

The building of large solar thermal installations for the district heating network is done gradually going forward to 2030, after which the district heating expansion has not been continued. A starting point is taken in the calculations that as much fuel as possible must be saved without involving loss of the solar thermal that is produced. This has been implemented with the following assumptions for IDA 2050:

- 5 per cent solar thermal in 50 per cent of the central CHP areas. This corresponds to 2.5 per cent of 24.34 TWh or 0.61 TWh, which according to the model calculations can be integrated in the CHP system without extra heat storage facilities.

- 25 per cent solar thermal coverage in 50 per cent of the decentralised CHP areas. This corresponds to 1.39 TWh, which according to the model calculations can be integrated in the systems with a heat storage facility of approx. 8 GWh. This is less than the current storage facilities, which typically have are around one day's average district heating demand in 2008, corresponding to approx. 1.5 days in 2030 after savings. In the 50 per cent of decentralised CHP areas where it is planned to add solar thermal, the reference has 20 GWh of heat storage facilities.

- 50 per cent of the district heating demand is covered in 90 per cent of the district heating areas without CHP. This corresponds to 1.33 TWh. For this a storage facility corresponding to just less than 10 days of average district heating production is required, which is equal to 80 GWh. This storage facility capacity is thought to be implemented as dam storage facilities, where a storage loss of 0.01% an hour has been included. In this way 1.25 TWh corresponding to 94 per cent of the production can be utilised.

Solar thermal is established in areas with district heating corresponding to a total of 3.25 TWh in IDA 2050. This corresponds to more or less 8 per cent of the combined demand, including network losses and after the implementation of heat savings, conversions to district heating and BOLIG+, more biogas facilities, and district cooling. In IDA 2030 the solar thermal production and its share are at the same level.

In IDA 2015, a total of 1 per cent of the district heating demand is covered by solar thermal. This is divided into 20 per cent solar thermal coverage in 25 per cent of the district heating areas without CHP, 10 per cent coverage in 10 per cent of the decentralised CHP areas, and 5 per cent coverage in 10 per cent of the central CHP areas. In all, 0.4 TWh is from large solar thermal facilities in IDA 2015.

The costs for solar thermal in district heating areas take a starting point in the information in IDA's Energy Plan 2030, while a simple upward adjustment of the price level has been done in consultation with Per Alex Sørensen, PlanEnergi s/i. The price for solar thermal in district heating areas, which produce 500 KWh/m², has been set at a facility cost of 1,600 DKK/m² and operating costs of 2 DKK/MWh. For heat storage facilities in district heating areas, the costs are 18 million DKK for 30,000 m^3, corresponding to 1.6 GWh. For a dam heat storage facility, the cost is 250 DKK/m^3 for facilities over 100,000 m².

Solar thermal and seasonal storage facilities can be combined with heat pumps and can cover up to 80 per cent of the heat demand in decentralised CHP plants. In IDA's Climate Plan 2050, we have calculated separately for large-scale solar thermal and large heat pumps, so this is a possibility that can raise the share of solar thermal beyond what has been implemented here.

In all, solar thermal thus covers (in areas both inside and outside the district heating areas) 0.91 TWh in IDA 2015, 5.4 TWh in IDA 2030, and 5.29 TWh in IDA 2050. This corresponds to approx. 2 per cent of the combined net heat demand in IDA 2015 and approx. 11 per cent in IDA 2030 and IDA 2050.

10 Industry and service

The initiatives in industry and service build on the report "Energy savings in Industry and services" (Energibesparelser i erhvervslivet), which has been completed in connection with IDA's Climate Plan 2050 in March 2009 [39]. In the report the energy consumption in industry and services is analysed, combined with experiences on what can actually be accomplished in real life. The report evaluates manufacturing activities, private services, building and installation activity, retail trade, wholesale trade, refineries, agriculture, market gardens, and fishing. In addition, district cooling is implemented in this chapter, although it has not been included in the above-mentioned report. The district cooling implemented here builds on the experiences with this in Denmark so far. The portion of industry and services which deals in space heating has not been included here, as this has been included in the potential for conversion to district heating in industry and services found in section 9.7.

10.1 Reduction of the electricity consumption in industry and services

A starting point is taken in the calculations from the fact that the feasible electricity savings have a payback period of between 5 and 10 years, cf. Table 14. With this starting point, electricity savings are implemented corresponding to 32 per cent of the 2008 consumption in IDA 2015 and 43 per cent in IDA 2030. In 2050, it is assumed that a further 2 per cent can be achieved corresponding to a reduction of 45 per cent of the consumption in 2008. The electricity consumption in industry and services is decreased in IDA 2015 from 23.6 TWh to 15.8 TWh. In IDA 2030, the electricity consumption is decreased from 28.7 TWh to 13.2 TWh and in IDA 2050 from 36.5 TWh to 12.8 TWh. In the reference energy system, public services are a part of industry and services, and it has been assumed here that within this sector savings just as large can be achieved.

Table 14, Percentage potential for electricity savings in 2007 [39].

Ultimate use	Payback period 2015			Payback period 2030		
	2 years	5 years	2 years	5 years	2 years	5 years
Lighting	15	20	60	25	35	70
Pumping	20	35	45	35	45	60
Cooling/freezing	15	35	50	30	40	55
Ventilation	20	30	35	30	40	50
Compressed air	25	35	60	40	60	75
Other electric motors	10	15	25	20	25	30
Data and computer processing	10	15	25	20	25	30
Melting and so forth	5	10	15	15	20	30
Space heating	5	10	15	15	20	30
Total	15	23	40	26	35	50

The electricity savings can be carried out with a socioeconomic payback period of an average of 7.5 years. The facility costs have been set at 2.4 billion DKK/TWh on the assumption that the electricity price in 2008 is approx. 60 Danish øre/kWh and that the interest rate is 10 per cent. This results in total costs of 18.9, 37.1, and 57.1 billion DKK respectively in IDA 2015, IDA 2030, and IDA 2050. There are no extra O & M costs, and the calculation has been done with a lifetime of 15 years. Some investments will have a shorter lifetime than the 15 years because of, for example, adjusting production to new products. There will however also be other investments which are more structural in nature and therefore have a longer lifetime. As with electricity savings in the households, the power plant capacity at condensing power plants is reduced in relation to the peak consumption in an hour.

10.2 District cooling

A total of 1.65 TWh district cooling is implemented in IDA 2030 and IDA 2050, corresponding to half of the potential that Euroheat & Power has estimated for Denmark. According to an example calculation from The Danish Energy Authority, which is presented in a report regarding district cooling in Denmark [40], compression cooling facilities that have been installed today can be assumed to have an average COP of 2.5. New facilities have a significantly higher COP at an average of 4, hence it must be assumed in the evaluation of long term potentials that the alternative to district cooling is compression cooling with an average COP of 4. The annual electricity consumption for production of 1.65 TWh of cooling can thus be calculated at 0.41 TWh.

For the absorption heat pump used in the district cooling system, a COP of 1.5 units of heat is assumed for 1 unit of district cooling [40]. Hence the total heat demand for cooling is 0.91 TWh. The net loss in the district heating systems is 21.4 per cent in the scenario used from Heat Plan Denmark (Varmeplan Danmark) [32] . The resulting district heating demand excluding plants is 1.10 TWh. It is assumed that all of this potential is to be found in areas with district heating from central CHP plants. The saved electricity consumption is 0.41 TWh.

Table 15, Percentage potential for heat savings in 2007 [39].

End use	Payback period 2015			Payback period 2030		
	2 years	5 years	2 years	5 years	2 years	5 years
Boiler losses and net losses	5	20	40	7	25	50
Heating/Cooking	5	15	35	10	25	55
Drying	10	20	30	15	25	35
Steaming	10	23	57	15	30	65
Distillation	5	15	35	10	20	40
Burning/Sintering	5	10	25	10	15	30
Melting/Casting	5	15	35	10	20	40
Space heating	5	20	30	20	45	75
Sum of heat consumption						
Further by process integration	10	20	30	10	25	45
Further by enzymes	10	20	30	10	25	40
Total	8	21	38	15	34	62

According to Helge Bach Christensen, IDA Energy, the investment costs for this conversion are 10 billion DKK, if one takes a starting point in budget numbers from a known large facility in the Copenhagen metropolitan area. Here a lifetime for this investment of 40 years is assumed for 80 per cent of the investment, and 20 years for 20 per cent, as some of the investment concerns piping while the rest relates to the cooling facility. This corresponds to an investment of 9.44 billion DKK with a lifetime of 30 years. For O & M 0.5 per cent annually of the entire investment is used.

10.3 Fuel savings

The heat consumption in industry and services has been allocated among a range of uses. The potential in various areas appears in Table 15 based on the above-mentioned report [39]. Again it is estimated that the heat savings can be carried out with a payback period of 7.5 years, which is between the 5 and 10 years in Table 15. The heat savings are implemented solely in the fuel consumption for industry and services. The part of the space heating that is supplied with district heating has not been dealt with here, but in section 9.5 and 9.7, where heat savings have been made in district heating areas as well as conversions to district heating. The remaining part of the space heating, which is supplied from boilers, etc., is a part of the fuel consumption that is reduced here.

Table 16, Conversions in industry and services

Reference				
TWh	2008	2015	2030	2050
Coal	2.9	2.7	3.0	4.0
Oil	24.4	22.7	26.4	32.7
Natural gas	14.0	11.0	10.5	14.0
Biomass	3.1	3.2	3.5	4.3
Sum for fuels	44.4	39.6	43.4	55.0
Electricity consumption	23.0	23.6	28.7	36.5
Electricity production	1.0	1.1	1.9	1.9
Heat production	1.0	1.4	2.7	2.7

Step 1, + electricity and fuel savings and heat pumps			
TWh	2015	2030	2050
Coal	2.1	2.0	1.9
Oil	18.0	16.9	16.4
Natural gas	10.3	9.7	9.4
Biomass	2.3	2.1	2.1
Sum for fuels	32.6	30.6	29.8
Electricity consumption	16.5	13.9	13.5
Electricity production	0.8	1.3	1.3
Heat production	1.4	2.7	2.7

Step 2, + increased CHP production			
TWh	2015	2030	2050
Coal	2.1	2.0	1.9
Oil	18.0	16.9	16.4
Natural gas	10.4	10.0	9.8
Biomass	2.3	2.1	2.1
Sum for fuels	32.8	31.0	30.1
Electricity consumption	16.5	13.9	13.5
Electricity production	0.9	1.6	1.6
Heat production	1.4	2.7	2.7

Step 3, + conversion to biomass			
TWh	2015	2030	2050
Coal	1.5	0.5	0.0
Oil	12.5	4.3	0.0
Natural gas	7.3	2.5	0.0
Biomass	11.5	23.6	30.1
Sum for fuels	32.8	31.0	30.1
Electricity consumption	16.5	13.9	13.5
Electricity production	0.8	1.3	1.2
Heat production	1.4	2.7	2.7

Step 4, + conversion to electricity consumption			
TWh	2015	2030	2050
Coal	1.5	0.5	0.0
Oil	12.5	4.3	0.0
Natural gas	7.3	2.5	0.0
Biomass	11.5	23.6	23.6
Sum for fuels	32.8	31.0	23.6
Electricity consumption	16.5	13.9	19.3
Electricity production	0.8	1.3	1.2
Heat production	1.4	2.7	2.7

In IDA 2015, the above-mentioned fuel savings of 27 per cent of the consumption in relation to 2008 and 31 per cent in IDA 2030 are carried out. In 2050, it is assumed that a further 2 per cent of savings can be achieved, corresponding to 33 per cent of the consumption. According to the report “Energy savings in Industry and services” (Energibesparelser i erhvervslivet) [39] , some of the savings are achieved using heat pumps. In the report it is stated that this will result in an extra electricity consumption of up to 2.3 PJ in 2015 and up to 3.4 PJ in 2030, assuming a COP of 5. In this analysis, this has been implemented by increasing the electricity consumption by 2.5 PJ or 0.7 TWh in 2015, 2030, and 2050, which increases the peak demand for condensing power plant capacity by approx. 120 MW. The resulting fuel consumption and the reduced electricity consumption after implementation of heat pumps are listed in Step 1 in Table 16.

The costs for fuel savings have been evaluated on the basis that they can be carried out with a socioeconomic payback period of 6 years. In IDA's Energy Plan 2030 from 2006 [4], the costs were estimated using the allocation of fuel types in the reference and 2006 fuel prices, including energy taxes and levies for industry. Using a similar methodology here, the fuel costs saved annually can be estimated at 4.8 billion DKK, with a payback period of 6 years and a real interest rate of 5-10 per cent. This corresponds to an investment of approx. 20 billion DKK for savings of 21.5 TWh/year. As in IDA's Energy Plan 2030, a lifetime of 30 years for the savings and an extra O & M cost of nil DKK are used. Hence the costs become 6.4 billion DKK in IDA 2015, 11.9 billion DKK in IDA 2030, and 23.6 billion DKK in IDA 2050.

10.4 Expansion of CHP production in industry

With the reduction of the fuel consumption at the above-mentioned levels, the electricity production from industrial CHP in the reference is reduced by corresponding levels. However, as a result of measures IDA’s Climate Plan the electricity production is raised by 11 per cent in 2015, 20 per cent in 2030, and 23 per cent in 2050. The increased electricity production occurs by raising the efficiency value at existing facilities. The fuel consumption is worked out marginally at process heating facilities and is set to be equal to the facilities' total efficiency, which is assumed here to be 80 per cent. The natural gas consumption is thereby assumed to increase by 0.11 TWh in 2015, 0.33 TWh in 2030, and 0.37 TWh in 2050. The result appears in Step 2 of Table 16.

Note that the electricity production decreases again as a result of converting to biomass and electricity in Step 3, which has been described below. The combined change in production after all measures in industry and services is 10 per cent in IDA 2015, 17 per cent in IDA 2030, and 18 per cent in IDA 2050, in relation to a situation where the above-mentioned measures concerning co-generation with process heating facilities, etc., were not carried out. It is assumed that there will still be surplus heat for district heating from industry in the future to the same extent as today.

10.5 Conversion to biomass and electricity consumption in industry

A conversion to biomass is done as the next step. In 2015, 35 per cent of the fuel consumption is biomass. In 2030, this share has increased to approx. 75 per cent and in 2050 to 100 per cent. In IDA 2050, the biomass quantity used in IDA 2030 is maintained, however the other fuel consumptions are converted to electricity consumption. It has been assumed that this can save approx. 10 per cent, as the use of electricity is more efficient. Therefore, the electricity consumption increases by 5.9 TWh in total.

It must be emphasised that there are technical challenges connected with converting all the industrial demand to biomass.

This conversion is significant for the electricity production from industry. According to Mogens Weel Hansen from Weel & Sandvig, the electricity production is reduced by 40-50 per cent, if the current industrial CHP producers convert to biomass. This implies a decrease in the electricity production of 18 per cent in IDA 2015, of 38 per cent in IDA 2030, and of 50 per cent in IDA 2050 with the current technology. In consultation with Mogens Weel Hansen, it is estimated however that the actual decrease in the electricity production from industrial CHP is only half of these values, as new technology such as the gasification of wood chips, etc., can improve the electricity efficiency value. A starting point is taken in the same heat production as in the reference. Therefore the decrease in the electricity production as a result of the conversion has been set at 9 per cent, 18 per cent, and 25 per cent in IDA 2015, IDA 2030, and IDA 2050 respectively.

Overall, the electricity production in relation to the reference is still reduced, which principally provides savings in the investment costs. This has not been included here, but it would provide lower costs in IDA's Climate Plan 2050. The result of the conversion and the reduced CHP share appear in Step 3 in Table 16.

The district heating production remains unchanged in relation to the reference, among other reasons because of the reduced fuel consumption through efficiency improvements which reduce the quantity of available surplus heat from industry.

Costs for conversion from coal, oil, and natural gas to biomass have been estimated at 15 DKK/GJ in the extra costs for biomass boilers in relation to oil boilers, in accordance with the report "Technology Data for Electricity and Heat Generating Plants" [14]. In this report, biomass boilers cost between 0.25-0.6 million €/MW against 0.05-0.1 million €/MW for a gas boiler. The price of oil boilers has not been provided in the report. In the calculations here, oil boilers have been represented by choosing the high price for the gas boiler. The annual operating costs for both gas and oil boilers have been set at approx. 3 per cent of the investment costs. A combined operation of 5,000 hours, a lifetime of 20 years, and an interest rate of 5 per cent have also been included in the calculation. From these assumptions, the price difference between facilities becomes 2.4 million DKK/MW, corresponding to 190,000 DKK/year. In this way, the operating costs amount to 70,000 DKK/year. With an operating period of 4,500 hours and an efficiency of 90 per cent, the fuel conversion becomes 18,000 GJ per year, corresponding to costs in the order of 15 DKK/GJ per year converted. The costs of converting from coal are less; although a certain part of the conversion will be CHP, which has been connected with higher costs.

In IDA 2015, 9.2 TWh are converted, which is associated with marginal extra costs of approx. 500 million DKK/year. In IDA 2030 and IDA 2050 the conversion is to 21.2 TWh and the costs are approx. 1,150 million DKK/year. In IDA 2050, other fuels are converted as mentioned to electricity consumption. Extra costs as a result of the plants installed have not been included, but the increased peak load capacity of approx. 900 MW at condensing power plants has been included. The result of the conversion appears in Step 4 in Table 16.

11 Transport and mobility

It is a great challenge to deal with the energy consumption of the transport sector, not least because the the demand is expected to grow in the coming years, but also because the fuels used for transport must be safe while simultaneously being energy-rich. One simple solution does not exist and hence many alternatives must be employed to decrease the total transport demand while also replacing the fossil fuel consumption: some in the short term and the remainder in the long term. Some of the initiatives which can be implemented in the short term include road pricing, conversion of garage taxes, energy taxes, and insurance to kilometre charges, while other initiatives will require a long term strategy such as, how will market share of rail transport be increased.

11.1 Handling of the transport demand for passenger cars and vans

In the transport area, a wide range of different initiatives must be implemented for the various types of transport technologies and demands. First and foremost it is necessary to do something about the conditions that create a larger demand for transport, i.e. the way we live and the way the taxes, fees, and levies system have been organised. [41] If the transport sector's CO_{2}-emisions are to be reduced dramatically, it is necessary to carry out the following:

- Road pricing with a strong incentive for environmentally-friendly vehicles
- Introduction of environmental zones in large cities which allow access only to vehicles which meet continuously sharpened emission requirements
- Differentiated property taxes and abolition/reduction/changes for the mileage deduction so that garage taxes are replaced by kilometre charges
- Physical planning that ensures the location of new industrial activities is near commuter rail stations
- An objective-oriented concentration on railways, buses, and bicycles as the main elements in the future traffic system

In IDA 2015, the above-mentioned changes are not implemented, as it has already been assumed that road transport will become approx. 0.4 per cent more energy efficient each year [6] in the reference energy system. However it is still important that the transport measures have been set in motion to be able to reach the objectives for IDA 2030 and IDA 2050. The result of the transformations in the transport sector appears in Table 19.

In order to reduce the growth in the transport demand going forward to IDA 2030, a range of measures are to be carried out. In consultation with Per Homann Jespersen from RUC, it was estimated in IDA's Energy Plan 2030 [4] that, with a revenue-neutral conversion of all vehicle taxes to a kilometre charge, the passenger transportation demand can be reduced by up to 15 per cent. Going forward to 2030, better physical planning should be done, as well as making cities denser, so that these three measures can work together to reduce the growth in passenger and van transport. Additional means are differentiated property taxes and abolition/reduction of the work-home tax mileage deduction.

In IDA 2030, half of the growth of 18 percent for passenger cars and vans, etc., in the period has been reduced with the help of the measures mentioned, and half has been transferred to the railway system. The 15 per cent that is possible in principle has thus been implemented in the form of a 9 per cent reduction. With that the passenger road traffic is 18 per cent less in IDA 2030 than in the reference for 2030, but there is still a growth of 9 per cent which has been transferred to the railway system. The objective in IDA 2050 from 2030 to 2050 is that the mentioned measures concerning road pricing, physical planning, etc., can keep the transport activity at a constant level in relation to IDA 2030 by using the above-mentioned 15 per cent potential for reduction of the growth in the transport activity as a target.

The socioeconomic costs associated with these measures are neutral. However, this assumes that a conversion of taxes and fees occurs in line with these objectives, a combined plan is made where the physical planning is prioritised, and investments are made in public transport instead of more roads.

11.2 More efficient road transport with electric vehicles, etc.

In IDA 2030, half of the car fleet for passenger cars and vans are electric vehicles or plug-in hybrid vehicles. Such vehicles are expected to be able to cover 90 per cent of the transport demand, cf. Table 17. From the transportation habits in Denmark in 2006, it appears that over 95 per cent of the transport demand occurs on trips bellow 150 kilometres and that 80 per cent of the trips are bellow 100 kilometres.

Table 17, Trip lengths and forms of transport in Denmark in 2006, based on numbers from the Transport Survey. "Other" is ferries, aircraft, etc [42].

Trip length (mill, km)	Other	Walk	Bi-cycle	EU moped/ motorcycle	Driver in vehicle	Van/ Lorry	Passenger in vehicle	Bus	Commuter train, undergrd,	Train	Sum
1-2 km	4	612	528	18	618	18	93	34	4		1,929
3-4 km	7	233	519	33	1,466	78	288	87	17		2,728
5-6 km	20	110	404	39	1,250	73	340	145	32	5	2,418
7-10 km	38	32	378	91	3,076	170	780	295	71	14	4,945
11-15 km	59	12	210	87	3,472	166	969	303	151	47	5,476
16-20 km	60	3	82	66	2,981	272	891	178	177	131	4,841
21-30 km	50	5	68	69	4,767	367	1,304	208	380	170	7,388
31-40 km	47	6	31	35	3,479	252	802	147	309	305	5,413
41-50 km	18		64	20	2,652	332	839	16	84	291	4,316
51-100 km	193		42	33	6,838	968	2,138	100	63	1,040	11,415
101-200 km	293				6,099	740	2,105	119		1,423	10,779
201-300 km	649			49	1,072	416	556	102		883	3,727
301 km -	503				991	775	288	210		906	3,673
Sum	1,941	1,013	2,326	540	38,761	4,627	11,393	1,944	1,288	5,215	69,048
% under 50 km	16	92	98	85	61	37	55	73	74	20	57

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In the calculations here, 45 per cent of the passenger and van transport in IDA 2030 is based on electricity. In The Danish Energy Authority's report "Alternative propellants in the transport sector" (Alternative drivmidler i transportsektoren) from 2007, it was calculated that electric vehicles will have an efficiency of approx. 90 per cent after 2020, whereas standard vehicles have an efficiency of approx. 25 per cent, measured by propulsion in relation to fuel input [43]. Therefore, for the part that is replaced by electricity use, a factor three improvement can be used compared to conventional vehicles. Even though the calculation is done here with a transfer from standard vehicles on petrol, diesel, or bioethanol to electric vehicles, it can in practice be the case that a portion of these are plug-in hybrid vehicles (based on, for example, combustion engines combined with batteries). Therefore, this corresponds to 50 per cent of the combined vehicle fleet being electric vehicles or hybrid vehicles.

The costs of this transfer are calculated here as the marginal extra costs for introducing electric vehicles as replacements for 45 per cent of the combined vehicle fleet in 2030. The combined vehicle fleet with regard to passenger cars and commercial freight vehicles has been assumed to be 2.5 million units, which is the same as today. The socioeconomic costs in 2020 and going forward are 98,000 DKK/unit for ordinary diesel vehicles and 77,000 DKK/unit for petrol vehicles [43]. The corresponding O & M costs can be calculated at 7.7 per cent per year, excluding fuel costs. In IDA 2030, approx. 40 per cent of petrol vehicles and 60 per cent of diesel vehicles are replaced. The costs for electric vehicles take a starting point in the same report and are 87,000 DKK/unit. In addition to this are the O & M costs, which have been adjusted here to a battery price of approx. $250/KWh. Using the report "Alternative propellants in the transport sector" [43] in combination with adjustments undertaken as a result of the battery price in the report "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark" [44], the O & M costs including battery replacement can be calculated as 11.2 per cent for an electric vehicle with a range of 150-200 kilometres. The lifetime for the above-mentioned electric vehicles and standard vehicles has been set at 13 years [44].

In IDA 2030, 45 per cent of the vehicle fleet (1.13 million units) is replaced, which corresponds to an investment of approx. 4.2 billion DKK/year, when using the above-mentioned marginal costs. With a lifetime of 13 years and O & M costs of 11.2 per cent, this has been implemented in IDA 2030 with an extra investment of approx. 20.5 billion DKK. The electricity consumption for charging the electric vehicles is assumed in IDA 2030 to be flexible when they are not in use. In IDA 2030, petrol, diesel, and bioethanol are reduced as a result of this from 135 PJ to 61 PJ. The electricity consumption for electric vehicles becomes 16.6 PJ. In practice a portion of these vehicles can be hybrid vehicles, and therefore, it is assumed that the marginal costs for 45 per cent of electric vehicles can also represent that a scenario where 50 per cent of the vehicle fleet is hybrid vehicles.

In IDA 2030, electric and hybrid buses have been implemented so that a total of 20 per cent of the fuel consumption is being covered by electricity. Extra costs as a result of this have not been included. With a starting point in the marginal extra costs for electric cars, it has been assumed that the extra costs will be half as large for electric buses as for electric cars. Therefore, the marginal extra costs become 468 million DKK. Totally 20.9 billion DKK shall be used for electric cars and electric buses in IDA 2030. It is important to have a well-developed bus network that can support the expansion of the railway system outlined below.

Costs for charging stations for electric vehicles have been included corresponding to two charging stations per vehicle. The costs are calculated with a starting point in the report "Alternative propellants in the transport sector" [43] at 5,000 DKK/charging station, with a lifetime of ten years. In IDA 2030, it means that a total of 11.3 billion DKK must be invested, or annually approx. 1.3 billion DKK.

Even though a portion of the passenger transport has been transferred to the railway system in 2050, the same number of vehicles as today will be present. Seen as a whole, 100 per cent is covered by electric and plug-in hybrids vehicles in 2050. In the calculations it is assumed that the hybrid vehicles have been supplied with hydrogen, but hydrogen could in principle also be replaced by other fuels such as dimethyl ether (DME), methanol, etc. The hydrogen vehicles are 2.5 times more efficient in the calculations than conventional vehicles [45].

From the total transport demand for passenger vehicles in IDA 2050, 80 per cent is covered by electricity vehicles and 20 per cent by hydrogen hybrids in the calculations here. With the above-mentioned starting point for electric vehicles, the marginal extra costs for electric vehicles are approx. 36.5 billion DKK compared to conventional vehicles with the same lifetime and O & M as above (2 million vehicles). The extra costs for hydrogen vehicles and electric vehicles take a starting point in the report "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark" [44] , where the price of a hydrogen vehicle with 6 KWh hybridisation has been estimated at 126,000 DKK/unit, O & M at 6 per cent, and a lifetime of 13 years. With the same process as above, the combined extra investments in 0.5 million hydrogen vehicles have been calculated at 17 billion DKK, with O & M at 6 per cent and a lifetime of 13 years. Hydrogen vehicles are expected to be 2.5 times as efficient as conventional vehicles. In total the electricity consumption for electric vehicles increases to 24 PJ and the hydrogen demand for vehicles is 7 PJ. The costs in IDA 2050 for charging stations are 20 billion DKK or 2.3 billion DKK/year.

In IDA 2050, electricity covers 25 per cent of the fuel consumption in buses. With the above-mentioned assumptions, the marginal extra costs become 585 million DKK. In total, 37 billion DKK shall be used for electric cars and electric buses in IDA 2050.

In IDA 2050, 25 per cent of the lorries and the buses have been converted to hydrogen/DME. With a starting point that these are also 2.5 times more efficient than ordinary lorries, the hydrogen/DME consumption can be calculated at 4.5 PJ in all. The costs for this have been included with a starting point in the above-mentioned costs for hydrogen cars, but with an assumption that the marginal costs are only half as large in relation to ordinary lorries. This corresponds to an extra marginal cost of 5.2 billion DKK with a lifetime of 13 years and O & M costs of 6 per cent. Seen as a whole, the extra costs are 22.2 billion DKK for hydrogen/DME vehicles in IDA 2050.

In IDA 2050 it is assumed that the hydrogen can be produced using high temperature electrolysis and then kept in large steel pressure tanks. For high temperature electrolysis, an efficiency of 73 per cent from electricity to hydrogen to transport is used. The costs after 2020 for such a facility can be estimated at 1.9 DKK/MW, a lifetime of 20 years, and O & M costs of 2 per cent, cf. Appendix IV [46].

Losses of 3 per cent have been included as a result of compression, from an output of approx. 40 bar from high temperature electrolysis to 430 bar, which is necessary if the hydrogen tank in the vehicle is kept at 350 bar. In addition, hydrogen storage facilities are assumed to be located in association with electrolysis and tank facilities. Although in practice, part can be blended into the natural gas network, for which extra costs have not been included here in relation to the reference. Therefore, a 5 per cent loss due to hydrogen storage facilities has been included,which is reflected in the calculations by decreasing the efficiency of the electrolysis facility to 67.6 per cent. In practice, the hydrogen can be kept at low pressure to keep storage losses and costs down, after which the hydrogen is compressed to the necessary level.

For the cost of hydrogen storage facilities, a starting point is taken from "Scenarios for a combined use of hydrogen as an energy carrier in Denmark's future energy system" (Scenarier for en samlet udnyttelse af brint som energibærer i Danmarks fremtidige energisystem) from 2001 [47]. In IDA 2050, costs for large steel hydrogen storage facilities are used in the calculations. These keep hydrogen at 10-15 bar, with a loss of approx. 3 per cent as a result of compression. The typical facility size is 14-28 MWh. The costs are 40 DKK/GJ or 144,000 DKK/MWh, the lifetime is 30 years, and according to the reference there are no O & M costs (other than electricity) [47]. In the calculations here, a storage loss of 5 per cent is included and not 3 per cent, which is why the costs have not been changed because of the difference in storage pressure. It is assumed in IDA 2050 that O & M costs are 0.5 per cent of the investment costs each year.

A 50 per cent operating period is assumed over a year at the electrolysis facilities, which requires a 564 MWe capacity and a 63 GWh hydrogen storage facility, which isis a week's average consumption. In all, for transport approx. 1 billion DKK is invested in electrolysis facilities. The annual investment costs can be estimated at 71 million DKK/year and the O & M costs are 21 million DKK/year. For hydrogen storage facilities for transport, the investment costs have been estimated at approx. 9 billion DKK .Therefore, the annual investment costs are approx. 463 million DKK/year and the O & M costs are approx. 45 million DKK/year.

11.3 Expansion of the railway system

In IDA 2030, half of the growth in passenger car and freight transport has been transferred to the railway system. This corresponds to about 9 per cent of the growth of 18 per cent in the reference. In IDA 2030, half of the growth in road traffic from 2008 has been moved from roads to railways and ships, and simultaneously 95 per cent of the train transport is operated with electrically-driven trains. Only on a few side-tracks will still need diesel trains as the rest will be covered by electrification or hybrid technology.

The domestic aviation is reduced to 5 per cent of today's level in the period going forward to 2030, as the trains become significantly more competitive with the improved infrastructure and higher speeds.

It is assumed that electric trains are 3 times more efficient than diesel trains, 6 times more efficient than aircraft, and 5 times more efficient than passenger cars. Goods transferred to the railway and goods transferred to ships are 10 times more efficient. In all, the electricity consumption increases from approx. 0.4 TWh in the reference for 2030 to 2.1 TWh in IDA 2030.

In IDA 2030, a portion of the passenger and goods transport on roads is converted by an investment of 200 billion DKK in total, which is used for upgrading the railway network to a higher speed, more regional railways, rapid transit, light rail, commuter rail, underground railways, including an electrification of the main railway network and bicycle infrastructure, and better goods facilities, etc. [4;48]. Additionally there is an investment of 3 billion DKK in bicycle infrastructure and park and travel facilities for both bicycles and cars. The conversion to a high speed railway network (200 km/h) requires new construction at Copenhagen-Ringsted over Køge, new construction of the high speed track over Femern, upgrading of Kastrup Station, and capacity expansion at Kastrupbanen, Køge-Femern (new track plus upgrading of existing), new fast track at Odense-Fredericia, Vejlefjordbroen (short cut, including related new construction of railways), new railway (short cut) Hatting to Skanderborg, new railway Århus-Randers, upgrading of the railway Randers-Aalborg, and new railway Vejle-Billund (Airport)-Herning. Electrification of the primary railway network includes electrification of Roskilde-Kalundborg, electrification and capacity expansions for Fredericia-Aalborg (beyond the high speed railway), and electrification and capacity expansions Kolding-Esbjerg, which needs electrification Ringsted-Næstved (regional train). In addition, among other things a new regional railway is built from Århus to Silkeborg and beyond there to Billund, and all signal facilities are upgraded. These upgrades and new construction will reduce the travel time between the parts of the country dramatically.

The lifetime for the investments in public transport is estimated to be 100 years for track construction, which makes up 50 per cent of the investment, and 30 years for the rest. With a socioeconomic real interest rate of 3 per cent, it corresponds to an annual write-down of 8.4 billion DKK. The above-mentioned investments were estimated in IDA's Energy plan 2030 by Alex Landex to be able to bring about a doubling of the public traffic's market share of goods as well as passenger transport.

The conversion has also brought additional economical improvements due to the reduction in travel time and energy savings. The value of the saved time has been estimated at 5.7 billion DKK/year as a conservative estimate for Copenhagen alone, during an investigation undertaken by COWI in 2004 [49]. The difference in the costs of infrastructure and congestion benifits is 2.7 billion DKK/year, which has been included in IDA 2030 as the cost of the conversion. This net-cost has been included as an investment of 53 billion DKK with a lifetime of 30 years.

For the new Nordhavnskvarter area in Copenhagen it is a vision in a 40 year time-horizon that physical planning can result in the passenger transport activity divided into 33 per cent vehicle traffic, 33 per cent public transport (trains), and 33 per cent walking and cycling. This is perhaps not realistic across the entire country and hence, a solution has been implemented in IDA 2050 where the share of transport covered by walking/cycling is 10 per cent of the passenger transport activity, which is double compared to today. This can happen by following the example from, among others, Odense and Copenhagen [50]. For railways, including light rail, etc., the market share increases from approx. 30 per cent to approx. 40 per cent in IDA 2050. Public transport makes up 15-20 per cent of the passenger traffic activity today.

In IDA 2050, the public transport traffic has been expanded even more than in IDA 2030. It is very difficult to estimate the costs for this. The electricity consumption for the railway system is more than doubled. Already in IDA 2030, calculations have been done with investments in large and small infrastructure facilities for 203 billion DKK. It must however be expected that a further expansion requires a similar investment at least. The following measures can be pointed to that will increase the capacity and the coverage with public transport: a focus shall be put on the urban stretch from Kolding to Århus, and beyond to Aalborg, which today is poorly served; the capacity on the main stretches shall be expanded, and further considerations are required to identify which larger measures can further decrease the travel time between the large cities, as well as how the connection with the European high speed network is improved: there must be a focus set on the transversal connections from west to east in Jutland, and development of the service on Zealand outside the Copenhagen metropolitan area.

The electricity consumption for trains has been increased by 1.7 TWh to 2.1 TWh in IDA 2030 with the investment of 203 billion DKK. In IDA 2050, the electricity consumption has increased to 4.9 TWh. With this starting point, the extra investments from 2030 to 2050 have been estimated at 340 billion DKK, as this vision for 2050 requires a massive infrastructure investment in line with the proposals mentioned for between 2030 and 2050 above. Meanwhile, costs can be saved on new construction and maintenance of roads, but these have not been included here. Costs for converting the transport to rails in IDA 2050 must be added to the costs in IDA 2030, as in the reference for 2050 this expansion has not been undertaken. Therefore, the total investments are 543 billion DKK in IDA 2050. A lifetime of 100 years has been calculated for half of the investment and 30 years for the other half.

The conservative estimate that the time lost due to road transport costs society 5.7 billion DKK/year is included in the calculations again [49]. However, the cost gain which could occur when this time is spent working while riding public transport is not included. Also, the savings obtained due to a lower investment demand for new roads is not included. In the calculations the gross investment is 543 billion DKK with the above-mentioned assumptions of 328 billion DKK. It must be noted that, whereas the investments going forward to 2030 have been based on actual projects, the additional investments have been based on assumptions that are the result of investing in public transport instead of new road facilities. It has not been possible within the framework of IDA's Climate Plan 2050 to obtain more precise information about actual projects concerning expansion of the infrastructure for public transport traffic.

The railway system in IDA 2050 is fully electrified and Denmark has been fully integrated in the European high speed networks, which will make it possible to reach Oslo, Stockholm, and a range of cities in northern Germany within 3 hours from Copenhagen. It is assumed that the air traffic to these destinations has diminished corresponding to the extent of the current domestic traffic in Denmark, but a decrease in the transport activity in international aviation has not been included as a result of this.

11.4 Efficiency improvements in aviation and shipping

International aviation is expected to follow the reference. It is increased generally by 1.2 per cent, but from 2020 to 2040 an improvement in the efficiency of new aircraft is included. The manufacturers anticipate that aircraft starting in 2020 can be up to 50 per cent more efficient than today. This has already been included in the reference, which is why changes have not been done here beyond this for fuels in 2050. Meanwhile, it is important to be aware that demands/standards must be put to the industry in order to achieve the greatest efficiency improvements.

In IDA 2030, half of the growth in road traffic from 2008 has been moved from road to railways and ships. Shipping can reduce its energy consumption by carrying out a range of energy conservation initiatives by 40 per cent going forward to 2030 and by 60 per cent going forward to 2050. Better technical design of the ships and operational measures like speed reductions will contribute to reaching this objective. Requirements should also be made for improvements within the shipping industry in order to enable that this goal is achieved. It is assumed that an objective-oriented effort will be able to make the efficiency improvement in the shipping cost neutral, as the saved fuels more than offset the costs for the development of more efficient shipping.

11.5 Biofuels in the transport sector

Even if a large proportion of the transport demand can be supplied by electricity or fossil fuels, biofuels will probably still be used in the future until it is possible to completely convert to electricity.

In the reference for 2015, 0.3 PJ is covered by biofuels. In the reference for 2030 and for 2050, biofuels cover 5.75 per cent. In the calculations here it has been assumed that this is bio-ethanol, produced at the IBUS facility described below.

In IDA 2030, a portion of the biofuels for the road sector have been converted to electric vehicles or plug-in hybrid vehicles. Therefore the quantity of biofuels decreases to 4.7 PJ in IDA 2030. In IDA 2050, the use of bio-ethanol has been phased out and replaced with electric or hybrid vehicles based on fuels from electrolysis.

With respect to the costs, a conversion of 3 per cent of the vehicle fleet to vehicles powered by at least 85 per cent bio-ethanol in IDA 2030 is included. This has been associated with an extra cost of approx. 3 per cent per vehicle, as O & M costs increase to 8.2 per cent in the above-mentioned petrol vehicle [43]. The costs for a standard petrol vehicle can be estimated at 77,000 DKK/unit and 7.7 per cent in O & M costs. In all the extra costs have been calculated for 64,000 vehicles. Therefore, the combined extra investment is 170 million DKK and 8.2 per cent O & M costs with a lifetime of 13 years. In the reference more bio-ethanol is used than in IDA 2030. Here extra costs for these vehicles are included at the amount that corresponds to 5.7 per cent of the vehicle fleet. The extra investment in the reference is 400 million DKK. In the reference for 2015 and in IDA 2015, the same quantity of bio-ethanol vehicles is assumed. Therefore these extra expenses have also been included in these energy systems.

In the reference for 2015 and in IDA 2015, 9.6 PJ of bio-ethanol is used for road transport. In the reference for 2030 and 2050, 10.5 PJ is used for road transport. In IDA 2030, 4.7 PJ of bio-ethanol is used, but in IDA 2050, bio-ethanol is not used at all for road transport. Meanwhile, the fossil fuel quantity of 37.9 PJ in aviation is replaced in IDA 2050. At the current point in time, it is not clear which alternatives are best for replacing the existing fuels in aviation. Likewise, it is not clear either how much of the aviation can be replaced by international high speed trains. In IDA 2050, bio-diesel is therefore used in aviation and therefore, extra losses of 10 per cent for converting bio-diesel to aircraft fuel are included. In all 33.4 PJ of bio-aircraft fuel is used for aviation in IDA 2050, which is primarily for international aviation.

In IDA's Energy Plan 2030 [4], estimates were made in for the resource consumption and the costs of producing bio-ethanol. Biomass consumption and costs were evaluated, by starting with information from Niclas Scott Bentsen, University of Copenhagen, Kim Winther, DONG Energy, and Lars Henrik Nielsen, Risø-DTU, about an IBUS facility in the year 2006 with the following data. The IBUS facility is better than expected in IDA's Energy plan 2030, as C5 and C6 sugars can be used. An energy input of 2,320 TJ of straw, 28 GWh of electricity, and 613 TJ steam/heat is converted to 1,078 TJ of ethanol, 1,033 TJ of biofuel, and 33,000 fodder (molasses 70 per cent dry material). The calorific value in the fodder can be estimated at 257 TJ, which is seen here in relation to the biomass quantities used.

It is assumed that the facility is located in association with an existing combined-cycle plant or an industrial process facility which uses biofuel as a supplementary fuel and which can produce the necessary steam and heat at an efficiency of 167 per cent. The biofuel is worked out as the marginal extra fuel that must be supplied to the combined facility, i.e., 2,320 TJ of straw minus 1,290 TJ of biofuel (1,033+257), equals to 961 TJ net of biomass. Next, the quantity of extra biofuel required to produce steam and heat is also subtracted: 613 TJ / 1.67 = 367 TJ. Therefore, 1,397 TJ net must be used to produce 1,078 TJ of ethanol, corresponding to a conversion factor of 1.3 units of biomass per unit of ethanol. Hence, the electricity consumption amounts to 28 GWh.

The IBUS facility has been reported to cost 590 million DKK and will have operating costs in addition to energy of approx. 30 million DKK/year. A lifetime of 20 years is used in the calculation. In addition there is the purchase of enzymes, but these costs are difficult to quantify as there is no commercial market for them. However, enzymes are understood on the basis of announcements from Novozymes to cost 0.95 DKK/litre of ethanol in the year 2006, decreasing to 0.16 DKK/litre in the year 2030. Therefore, assuming a lower calorific value of 21 MJ/litre, the costs are 43 million DKK/year in the year 2006, decreasing to approx. 7 million DKK/year in the year 2030.

It is assumed that a future facility in the years 2015-2030 will not produce more ethanol, but that it will be more efficient and have lower heat and electricity consumption. Therefore, there will be lower operating and facility costs. These assumptions have been included here by using savings of 20 per cent for heat/steam and 30 per cent for electricity consumption, as well as approx. 15 per cent reduction for facility and operation costs. However, it may not be possible to produce the steam required (in IDA 2030) at an efficiency value of 167 per cent, as there will not always be condensing power plant operations at all points in time. Therefore the efficiency value has been set here at 130 per cent, corresponding to condensing power plant operation in half of the time and boiler operations in the other half (613 TJ – 20 per cent = 490 TJ / 1.3 = 377 TJ). For production of 4.7 PJ of bio-ethanol in IDA 2030, a net 6.2 PJ of biomass must be used and a total of 0.09 TWh electricity. The combined facility price is 2.2 billion DKK, the lifetime is 20 years, while the O & M is 6.4 per cent of the investment each year. The result has been shown in Table 18 for IDA 2030.

Table 18, Estimate of data concerning IBUS facility used in IDA's Climate Plan 2050 in IDA 2030 energy system

		2006	2030	IDA 2030
Straw	TJ	2,320	2,320	10,153
Biofuel (incl. fodder)	TJ	-1,290	-1,290	-5,645
Fuel for steam/heat	TJ	367	377	1,651
Net biomass consumption	TJ	1,397	1,407	6,158
Bio-ethanol	TJ	1,078	1,078	4,717
	TWh			1.31
Factor (Biomass/Ethanol)	-	1.30	1.31	1.305
Plant cost	Million DKK	590	500	2,188
Operations and maintenance	Million DKK/year	30	25	109
Purchase of enzymes	Million DKK/year	42	7	31
Lifetime	Year		20	20
Electricity consumption	GWh	27.8	19.46	85

With the above-mentioned starting point, the costs and biomass consumption for bio-ethanol in the other energy systems can be estimated. For the reference in 2015 and IDA 2015, the biomass consumption is 12.5 PJ, the investment costs are 4.4 billion DKK, and the electricity consumption is 0.17 TWh. Correspondingly for the reference in 2030 the biomass consumption is 13.7 PJ, the investment costs are 4.9 billion DKK, and the electricity consumption is 0.19 TWh.

Beyond bio-ethanol, in IDA 2050 biodiesel is also used in some buses, heavy lorries, and in shipping. In IDA 2050, 25 per cent of the fuel consumption is expected to be covered by hydrogen/DME and the remaining 75 per cent is expected to be covered by biodiesel, which corresponds to 25.2 PJ. As a result, the consumption of biodiesel comes to 5.7 PJ for bus transport and to 34.8 PJ for aviation. It is assumed that 96 per cent of the biomass calorific value has been kept after the conversion to biodiesel, corresponding to a biomass demand of 75 PJ. Further costs have not been included, except that caused by the 4 per cent loss of biomass due to the production of bio-diesel, which also occurs in the ordinary refining of diesel. However, the same transport and handling costs have been included as The Danish Energy Authority recommends. It is assumed that the transport consumption in the military is bio-diesel.

11.6 The transport scenarios

The measures within transport can reduce the energy consumption for transport in IDA 2030 by 22 per cent in relation to 2008, and in IDA 2050 by 44 per cent. The results of these transformations in the transport sector are displayed in Table 19.

Table 19, Fuel consumption in transport in IDA's Climate Plan 2050

Transport type	(PJ)	2008	2030	2050	IDA 2030	IDA 2050
Road transport	Sum	171.2	184.3	223.4	120.9	68.1
Passenger cars	Petrol	81.4	60.9	74.6	27.5	-
	Diesel	12.0	15.5	19.0	7.0	-
	Bio-ethanol	0.3	10.5	10.5	4.7	-
	Electricity	-	-	-	10.7	17.1
	Hydrogen/DME	-	-	-	-	5.1
Delivery vans	Petrol	8.0	7.0	8.6	3.2	-
	Diesel	31.6	41.1	50.3	18.5	-
	Electricity	-	-	-	5.9	7.4
	Hydrogen/DME					2.2
Buses	Diesel	8.9	11.4	13.9	9.1	-
	Hydrogen/DME	-	-	-	0.8	1.1
	Electricity	-	-	-	-	0.9
	Biodiesel					5.7
Lorries	Diesel	29.2	38.0	46.5	33.6	-
	Hydrogen/DME	-	-	-	-	3.4
	Biodiesel	-	-	-	-	25.2
Railways		4.2	5.1	4.6	7.7	17.9
Passenger trains	Diesel	2.7	3.4	4.2	0.2	-
	Electricity	1.2	1.3	-	6.6	16.9
Freight trains	Diesel	0.2	0.3	0.4	0.0	-
	Electricity	0.1	0.1	-	0.9	1.0
Domestic aviation	JP	1.4	1.3	1.3	0.1	-
	Bio-aviation fuel	-	-	-	-	0.1
International aviation	JP	38.5	37.8	33.4	37.8	-
	Bio-aviation fuel	-	-	-	-	33.4
Ship transport	Diesel	4.5	4.5	4.5	2.8	-
	Biodiesel	-	-	-	-	1.8
Defence	Diesel	2.1	2.1	2.1	2.1	-
	Biodiesel	-	-	-	-	2.1
SUM		222.0	235.2	269.3	171.5	123.4

12 Agriculture and Biomass

In this chapter the Danish biomass potential for energy and materials purposes is estimated, by starting point from information that is contained within the main report. In addition, the costs are estimated for biogas in IDA's Climate Plan 2050, and the biomass consumption for IDA 2015, IDA 2030, and IDA 2050 are calculated. For initiatives in this theme which have no impact on the energy sector, refer to the estimate of CO_2 emissions in chapter 15 and the description of themes in the main report.

12.1 Biomass potential for energy and materials in Denmark

For most scenarios and prognoses, the use of biomass has initially been determined for energy purposes, which includes electricity, heat, and propellants for transport. However, materials must also be produced using biomass if they can no longer be produced using fossil fuels. As the IDA Climate Plan tries to substitute fossil-based raw materials altogether and not only raw materials for energy purposes, a focus on the entire use of biomass has been carried out. In Table 20 a range of estimates for the Danish biomass resources are displayed. In addition, the consumption for 2006 has been shown, as well as imports and Danish-produced biomass.

Table 20, Biomass resources for energy purposes in Denmark: Consumption 2006 and various scenarios. Numbers have been expressed as PJ, understood as the calorific value of the various forms of biomass.

PJ	Consumption of Danish resources	Imports	Danish potential* [51]	Potential in IDA Energy Plan 2030	IDA Climate Plan 2050
Straw	18	0	55	55	30
Wood	38	16.1	40	40	50
Biomass to biogas	4	0	40	40	40
Slurry fibre fraction			0	108	5
Energy crops			0	144	52
Biodegradable waste	30	0	30	30	30
Algae	-	-	-	-	100
Total	90	16.1	Ca. 165	417	307

* According to the Danish Energy Authority

The differences in the various potentials for biomass for Denmark have to do with evaluating yields, size of area, quantity of straw, crop types, etc. Algae have been brought into the scenario in the Climate Plan. As energy crops, algae are associated with significant uncertainties, as the environmental effect of this technology is uncertain as well as the potential yield.

Energy crops such as maize or beets can be cultivated without affecting agricultural production, partially because they porduce by-products such as fodder, liquid biofuels, and solid fuels, but also due to the introduction of fallow fields. Under the assumption that current agricultural production is maintained, approx. 20 per cent (500,000 hectares) of the Danish agricultural area can be converted to cultivation of energy crops such as maize. Therefore, the Danish biomass resource will be increased considerably. In connection with the completion of IDA Energy Plan 2030, Claus Felby, University of Copenhagen, estimated that if maize is used for combined production of liquid biofuels, solid fuels, and fodder, the net area demand for an energy production of 144 PJ is approx. 330,000 hectares or around 15 per cent of the agricultural area.

In IDA's Climate Plan 2050, 100 PJ from algae is displayed, cf. the main report. However, this will requie a large area, cf. the main report. Therefore, a final position has not been taken in the background report on the balance between the use of biomass from algae and that from energy crops. This illustrates why it is important to improve the overall efficiency in the energy system and to shift to electrically-driven operations.

In IDA's Climate Plan 2050, biomass is used in CHP plants, in transport in the form of IBUS facilities, in waste incineration, and in industry. It must be noted that it has not been possible within this project's framework to state precisely where biogas facilities, waste incineration facilities, IBUS facilities, etc., have been located.

With regard to use of straw, wood, waste, and energy crops, the investment costs and operating and maintenance costs have been partly estimated under the section concerning fuel price assumptions, and partly under extra costs for facilities in the respective theme descriptions. Biogas facility investment and O & M costs are described below.

12.2 Use of Biomass

The consumption of biomass in IDA's Climate Plan 2050 has been estimated by sector in Table 21. A total of approx. 284 PJ is used in IDA 2050 for energy production and transport purposes. In IDA 2015 and IDA 2030, the biomass used is 154 and 151 PJ respectively, when taking into account that approx. 59 per cent of the waste for incineration is biodegradable, cf. The Danish Energy Authority's latest basis for distribution of this [1]. For waste there are some uncertainties about the size of the bio-degradable part, hence the 30 PJ predicted potential is inconclusive. Additionally there are uncertainties regarding algae and energy crops. Hence the data in Table 21 should be used with care as the final potential may prove different. In IDA 2015 and IDA 2030 however more than enough biomass is available witin Denmark to meet the required demand.

Table 21, Use of biomass in IDA's Climate Plan 2050.

PJ	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Transport	12.5	13.6	13.6	12.5	6.1	75.0
Individual heating	44.7	41.5	32.9	27.6	3.3	3.1
Industry	11.5	12.5	15.5	41.3	85.1	85.0
District heating plants	4.0	2.7	2.7	4.0	4.3	6.5
Decentralised CHP	10.3	11.6	11.6	10.3	14.0	28.7
Central CHP	38.8	96.4	96.4	37.4	11.7	41.7
Waste incineration	21.2	26.2	26.2	21.2	26.2	44.4
Sum	143	204	199	154	151	284

In IDA 2050 it has been assumed that waste for incineration is exclusively biodegradable, as the material production has been assumed to be based on biomass. It can be noted that if that is not the case, it does not change the final conclusions concerning the 90 per cent reduction in the greenhouse gas emissions, cf. section 14.3.

In IDA 2050, the energy system, including transport, can also be supplied with biomass from Denmark, at least from a quantity point of view. However the surplus biomass resource beyond this is small and consequently, there is not much biomass left for other activities such as the production of materials. As a large portion of the biomass in IDA 2050 goes to international air aviation, industry, and waste incinerations, the distribution of it among these sectors should to be investigated in the future:

- Whether fuels for aviation other than biomass-based ones will be developed.
- Whether a portion of the international aviation can be covered by international high speed trains.
- Whether the transport activity in international air transport can be made even more efficient.
- Whether the transport activity in international aviation can be reduced.
- Whether even more than displayed here can be moved from fuel consumption for industrial processes to electricity.
- Whether more can be saved within industry.
- Whether a large quantity of waste can be recycled instead of being burned.
- Whether a portion of the waste resource can be converted to gaseous biofuels for example, where part can be stored and part can be used more efficiently than in waste incineration facilities.
- Whether waste incineration can be made more flexible in another way, without the waste simply being burned off in a boiler.
- Whether waste incineration can be done more efficiently by raising the electricity efficiency.

It has not been possible to investigate the above-mentioned technological possibilities within the framework of this report.

12.3 Biogas

By 2030 75 per cent of the biogas potential is included, corresponding to 32 PJ, as it is not realistic to use the entire biogas potential. In IDA 2050, the the entire potential of 40 PJ is used.

Extra costs for the construction of biogas facilities are included. To estimate biogas costs, a starting point has been taken from "Technology Data for Electricity and Heat Generation Plants" [14]. In "Technology Data for Electricity and Heat Generation Plants," it appears that the cost of transporting slurry from agriculture to the biogas facilities is around 16 DKK/GJ. In addition to this are operations and maintenance of the biogas facilities. In 2030, the O & M costs will be approx. 20 DKK/GJ at small facilities and approx. 15 DKK/GJ at large centralised biogas facilities. Thus there are O & M costs in total of approx. 33 DKK/ GJ. From "Technology Data for Electricity and Heat Generation Plants," it appears that the investment costs are 55 million DKK for large centralised biogas facilities with a capacity of 800 m^3 of biomass a day. The daily production is just under 500 GJ, when one considers that the number of industrial products is limited for large scale production. The combined investment in biogas facilities in IDA 2030 has been estimated at 10 billion DKK and a lifetime of 30 years is assumed.

In connection with the completion of IDA Climate Plan 2050, the above-mentioned numbers have been sent for consultation to key experts in the biogas area. The response indicates that the operating costs will probably be higher than assumed in "Technology Data for Electricity and Heat Generation Plants".

On that basis the operating costs have been adjusted upwards for transport from 16 to 20 DKK/GJ and for large centralised biogas facilities from 15 to 20 DKK/GJ, so that the combined cost becomes 40 DKK/GJ. In addition the facility costs have been adjusted upwards from 55 to 70 million DKK for a facility with a daily production of 500 GJ.

With a starting point in these assumptions, an investment has been calculated of 12 billion DKK in IDA 2030 and 15 billion in IDA 2050. The electricity consumption for this is 0.2 TWh/year in IDA 2030 and 0.27 TWh/year in IDA 2050. The extra heat consumption for this is 1.8 and 2.4 TWh/year respectively.

Note that IDA's Climate Plan 2050 assumes that the methane emission from biogas facilities has been entirely removed in IDA 2030 and IDA 2050 due to plant improvements, cf. the main report

13 The Energy Systems in IDA's Climate Plan 2050

Using the three reference energy systems as a starting point, the following chapters describe the energy system for IDA 2015, IDA 2030, and IDA 2050 after the above-mentioned initiatives are incorporated. Initially, these initiatives cause large imbalances between consumption and production on the electricity system, which are evident from the significant amounts of excess electricity which the energy system is forced to export. As a result, the energy system cannot maximise its income from trading on the international electricity market. Hence a range of technical improvements have been added to create more flexibility within the energy system, which are implemented accordingly into IDA's Climate Plan 2050.

Firstly, adjustments are made to IDA 2015, then to IDA 2030, and finally to IDA 2050. Both the reference for the individual years and the results in IDA's Climate Plan 2050 appear in the tables in the individual sections. Note that the initiatives in IDA 2015 only include technologies which are available now. IDA 2030 and IDA 2050 introduce technologies which have not been fully developed, while IDA 2050 specfically requires large structural changes and economic investments. After the adjustments have been taken into account, the combined results and the share of renewable energy in various sectors is presented.

13.1 The Energy System in IDA 2015

In Table 22 the initiatives in relation to IDA 2015 have been implemented in the reference. In ***Step 1***, the calculation assumes that the power plants are not regulated according to the heat demand. Regardless, the energy consumption has been decreased here from 228 TWh/year to 209 TWh/year, due to the savings and efficiency improvements that can be implemented in the short term with known technologies. It is clear from the results that the excess electricity has increased from 0.3 TWh to 9.2 TWh. However, it is not only the wind turbines, with a production of 15.4 TWh, that cause the excess electricity. Electricity from waste CHP plants and industrial CHP contributes a further 3.1 TWh. Therefore, the critical excess electricity production must be removed by firstly decreasing the output from CHP, then by using electric boilers, and as a last resort, by decreasing the output from the wind turbines.

Also, in Step 1 the CHP production was not regulated according to the wind power production (or the market). In ***Step 2*** the CHP plants have been instructed to regulate their production in relation to wind production and electricity production from other auto producers. With this, the excess electricity is reduced dramatically from 9.2 to 1.5 TWh/year. Consequently, by regulating the production at the CHP plants and replacing it with boilers, as well as using 1.4 TWh in electric boilers in CHP plants, 7.7 TWh of the excess electricity can now be used within the energy system. This leaves 1.5 TWh where the wind turbines must be shut down or the production must be exported. However, using boiler production instead of CHP plants reduces the fuel efficiency of the combined energy system. Hence the fuel consumption has grown from 187 to 195 TWh/year, adjusted for electricity exports, i.e. adjusting for fuel consumption for electricity export.

In ***Step 3***, 250 MWe of heat pump capacity has been added to the CHP systems. These replace the boiler production and increase the energy system's abilities to regulate and integrate wind power. After implementing the heat pumps, the excess electricity and the fuel consumption are reduced. This measure has been included in the calculations in IDA 2015 with an investment of 20 million DKK per MWe in heat pumps, a lifetime of 20 years, and an operating cost of 0.2 per cent. This cost includes the investment required for supplementary heat intake at the facilities, to accommodate some of the additional heat pump capacity. Heat pumps have already been installed in individual households, cf. section 9.8.

Table 22, Technical system analyses of IDA 2015

		The reference	Step 1	Step 2	IDA 2015
Input:			Starting point	Market regulation	Large heat pumps
Electricity consumption	TWh/year	36.4	28.5	29.9	30.7
District heating consumption	TWh/year	35.3	37.5	37.5	37.5
Individual heating	TWh/year	23.3	10.0	10.0	10.0
Industry incl. service & refineries	TWh/year	34.8	32.8	32.8	32.8
Transport (incl. aircraft and ships)	TWh/year	62.8	62.8	62.8	62.8
North Sea, losses, etc.	TWh/year	16.8	8.4	8.4	8.4
Avg. efficiency decentralised CHP (elec./heat)	%	36 / 47	36 / 47	36 / 47	36 / 47
Avg. efficiency central CHP (elec./heat)	%	32 / 52	32 / 52	32 / 52	32 / 52
Avg. efficiency condensation plants	%	41	41	41	41
Primary energy supply					
Wind power	TWh/year	10.4	15.4	15.4	15.4
Solar thermal	TWh/year	0.2	0.9	0.9	0.9
Coal	TWh/year	36.6	27.5	17.3	18.0
Oil	TWh/year	94.9	87.3	87.3	87.4
Natural gas	TWh/year	46.4	36.2	36.1	31.8
Biomass	TWh/year	39.7	41.9	41.9	42.8
Total, incl. electricity export	TWh/year	228.2	209.2	199.0	196.3
Key figures					
Net export (excess electricity)	TWh/year	0.3	9.2	1.5	1.4
Total adjusted for electricity export	TWh/year	227.5	186.9	195.4	192.9
Electricity from condensing power plants in % of electricity demand	%	22	6	6	7
Boilers in % of district heating demand	%	15	9	31	19
CO_2 emission	Million tonnes	47.4	40.2	36.7	36.0
Adjusted CO_2 emission	Million tonnes	46.0	33.1	34.6	34.0

With the above-mentioned measures and the steps by which the system has been adjusted here, the energy consumption can be brought down to 196 TWh, corresponding to 707 PJ in IDA 2015. In 2015 initiatives within the transport sector are not implemented, but the district heating network is expanded, investments are made in renewable energy, individual and large heat pumps, and energy savings. The CO_2 emissions can be brought down to approx. 36 million tonnes in IDA 2015 from 47 million tonnes in the reference for the same year (unadjusted). The results of the above-mentioned steps appear in Fig. 16 for IDA 2015.

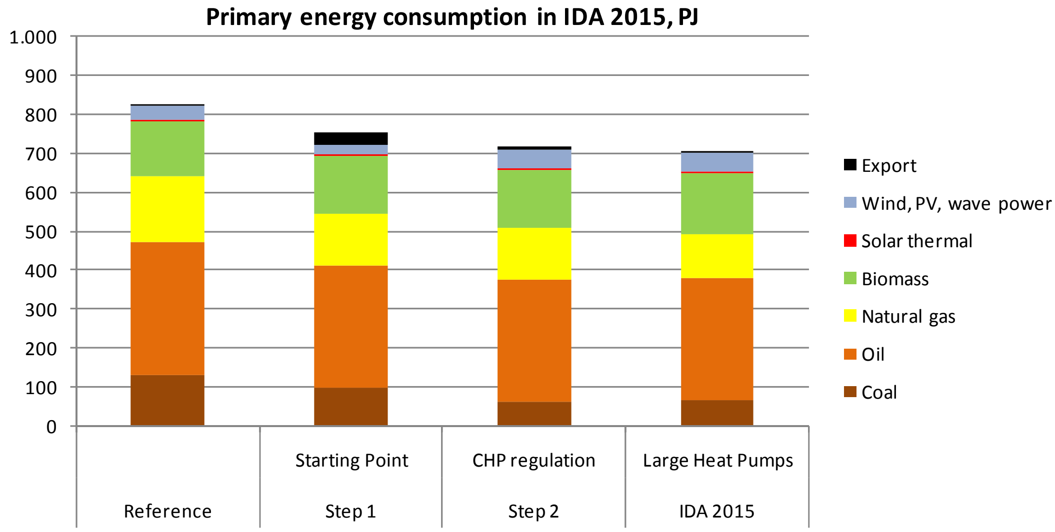


Fig. 16, The allocation of fuels in IDA 2015 and an illustration of the primary energy supply for additional technical improvements to the system.

13.2 The Energy System in IDA 2030

Just as for the year 2015, the initiatives in IDA 2030 have been introduced into The Danish Energy Authority's reference energy system. In the energy system for 2030, the same adjustments have been implemented as mentioned above. However the share of large heat pumps in district heating areas has been increased from 250 MWe in IDA 2015 to 450 MWe in IDA 2030. The first three steps in the adjustments have the same effects here as in 2015 described above.

Three additional steps have been completed in IDA 2030, partly because the imbalances are larger and partly because new technologies have been introduced in IDA 2030, which can be used to increase the flexibility within the energy system. All six steps and the data illustrating their consequences on the energy system can be found in Appendix VI. The results for each of these steps appear in Fig. 17 for IDA 2030.

In the first three steps of the conversion, the energy consumption in IDA 2030 is reduced from 187 to 162 TWh. The excess electricity however is still high at 6.3 TWh. Hence flexible electricity consumption is implemented in ***Step 4*** so that 15 per cent of the electricity consumption in households, industry, and services is flexible. 7.5 per cent is flexible during a 24-hour period and 7.5 per cent during a week. It is difficult to estimate the costs for flexible electricity consumption. Here it was assumed that the costs correspond to an investment of approximately 500 million DKK, with a lifetime of 20 years and with 1 per cent in extra operating costs. With flexible electricity, the demand for power plant capacity is reduced by 570 MW. The value of this has been included in the socioeconomic calculations. This does not have a great effect on the total primary fuel supply, but can reduce the excess electricity by 1.0 TWh.

Originally in IDA 2030, electric vehicles were charged when they were not being driven. However, when there are a large number of electric vehicles, this can have an adverse effect on the operation of the energy system i.e. it increases both the fuel consumption and the power plant capacity required. In ***Step 5*** a new charging technique has been introduced for the electric vehicles: they charge when the wind turbines are producing power (or when electricity is cheap) and where possible, avoid charging during hours of peak demand (or when electricity is expensive). Each vehicle was charged enough by the grid to cover its required transport demand. Also, to ensure that there were enough electric vehicles to cover the total transport demand in 2030, it was assumed once again that 45% of the 2.5 million vehicles were electric. Each vehicle had a power capacity of 18 kW [52], so in total, there was a combined capacity of approx. 20 GW. Like in reality, it was assumed here that these cannot be charged simultaneously. Contrary to what one would believe, experiences from the USA show that only 20 per cent of all vehicles are on the road during rush hour. Therefore, this has been used in the calculations here. Finally, it was also assumed that 70 per cent of all vehicles are connected to the network when they are parked [53]. Extra costs have not been included, as costs have already been included for two charging stations per vehicle, cf. section 11.2. By completing Step 5, it is possible to reduce the energy consumption from 160 TWh to 157 TWh, while also significantly reducing the excess electricity production from 5.3 TWh after Step 4 to 3.8 TWh now.

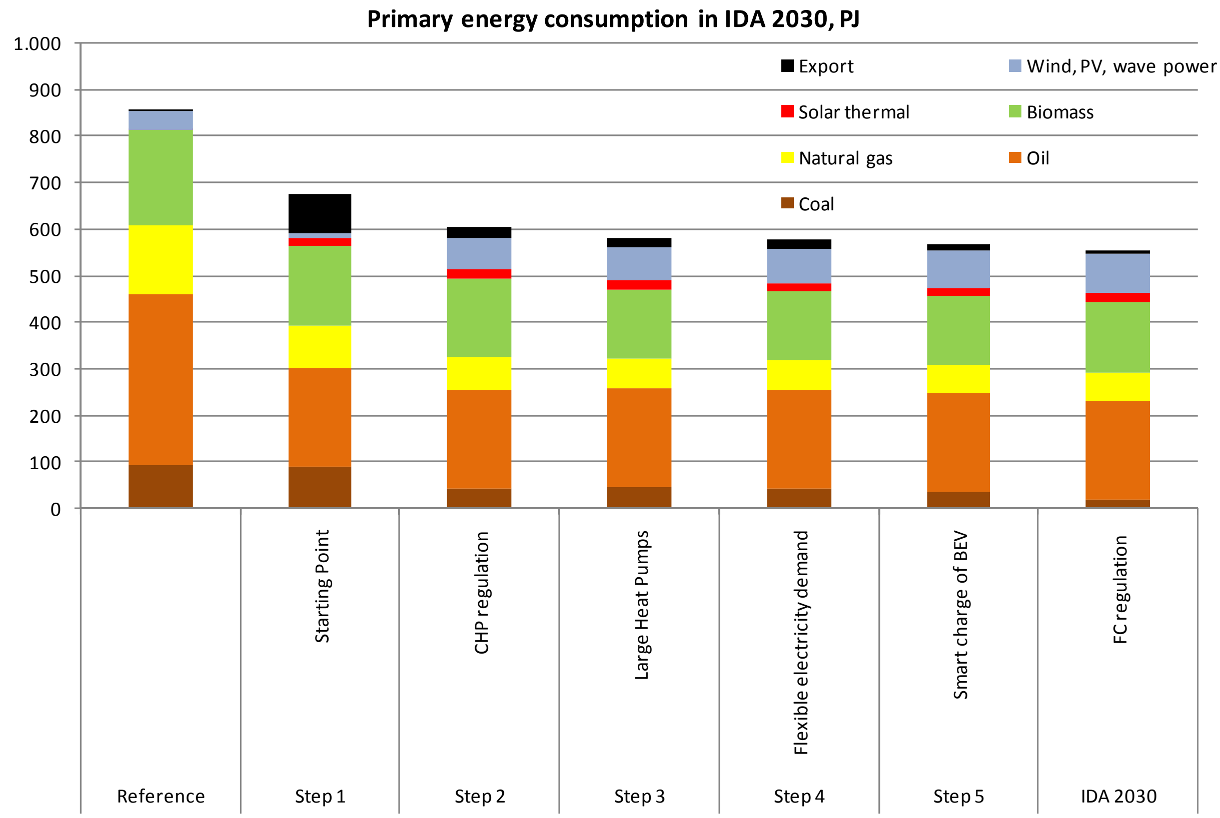


Fig. 17, The allocation of fuels in IDA 2030 and an illustration of the primary energy supply for additional technical improvements to the system.

In the reference, the calculation assumes that the large steam turbine plants must be kept at a combined minimum production of 450 MW in order to secure the regulation and stability of the electricity network. Such technical limitations do not apply however for the fuel cell CHP plants installed in IDA 2030, cf. section 8.6. Such plants can potentially be regulated very quickly from zero to full capacity, much faster than the current steam turbines. Therefore, this minimum requirement has been removed in ***Step 6***. After implementing this adjustement, the simulation was completed once again for IDA 2030 while ensuring that both the frequency and voltage on the electric grid were maintained. However, unlike in IDA 2015, electric vehicles, flexible electricity consumption, and renewable energy technologies such as wind turbines can also be a part of solving these tasks. In IDA 2030, the energy consumption was reduced to approx. 154 TWh, the excess electricity to 1.8 TWh, and the CO_2 emission to 21 million tonnes, in comparison to 44 million tonnes for the reference of the same year (unadjusted).

13.3 The Energy System in IDA 2050

In IDA 2050 all of the above-mentioned steps have also been carried out. As a result, the fuel consumption decreases from 160 at the outset to 124 TWh after Step 6. In the IDA 2050 energy system there is significantly more renewable energy from fluctuating sources than in IDA 2030. Hence there are also larger challenges when integrating this onto the system. This is evident from the 2.3 TWh of excess electricity that remains even after Step 6 has been implemented. All of the data illustrating the actual consequences of the adjustments on the IDA 2050 energy system can be found in Appendix VI, while the results are displayed in Fig. 18.

In IDA 2050, the objective is to create an energy system which is based entirely on renewable energy sources. At the same time, biomass is a limited resource which will not be able to cover the entire demand, even if massive savings are carried out. Therefore electrolysis facilities are installed in IDA 2050 to produce hydrogen for CHP facilities in ***Step 7***. 600 MW-e electrolysis facilities have been installed, allocated into 200 MW-e at decentralised CHP plants and 400 MW-e at central CHP plants. Also, a total of 101 GWh of hydrogen storage facilities are installed, corresponding to the above-mentioned electrolysis facilities being able to operate at full capacity for one week.

In IDA 2050 it is assumed that the hydrogen can be supplied with high temperature electrolysis. It is assumed that the hydrogen is kept in large steel pressure tanks. For high temperature electrolysis, an efficiency value of 73 per cent from electricity to hydrogen has been used. In addition, the heat produced from the facility is also used, so that a total of 7.5 per cent can go into the district heating networks.

To introduce hydrogen storage facilities in IDA 2050, data was taken from the report "Scenarios for a combined use of hydrogen as an energy carrier in Denmark's future energy system" (Scenarier for en samlet udnyttelse af brint som energibærer i Danmarks fremtidige energisystem), which was completed in 2001 [47]. This report stated that large steel tanks keep hydrogen at 10-15 bar, with a loss of approx. 3 per cent as a result of compression. The typical facility size is 14-28 MWh while the costs are 40 DKK/GJ or 144,000 DKK/MWh, the lifetime is 30 years, and there are no O & M costs calculated in the reference [47]. Therefore, the costs assumed after 2020 for electrolysis can be estimated at 1.9 DKK/MW with a lifetime of 20 years, cf. Appendix IV [54]. In the calculations for IDA 2050, a 5 per cent storage loss was used instead of 3 per cent, while the O & M costs were 2 per cent of the investment costs each year instead of 0. Losses in hydrogen storage facilities corresponding to 5 per cent have been included by decreasing the efficiency value of the electrolysis facility to 69 per cent. Just as for the production facilities for transport, the hydrogen storage facilities are assumed to be located in association with electrolysis and tank facilities. In practice, a certain part can be blended into the natural gas network, for which extra costs have not been included here in relation to the reference. In all, a total of 1.1 billion DKK in electrolysis facilities must be invested for Step 7 in IDA 2050. The annual investment costs can be estimated at 76 million DKK/year and the O & M costs at 22 million DKK/year. For hydrogen storage facilities, the total investment costs have been estimated at 14.5 billion DKK, the annual investment costs at 740 million DKK/year, and the O & M costs at 73 million DKK/year. These electrolysis facilities and hydrogen storage facilities are additional to the facilities that have been installed for transport, cf. section 11.2. In all a total of 2.1 billion DKK is invested in electrolysis facilities and 23.6 billion DKK in hydrogen storage facilities.

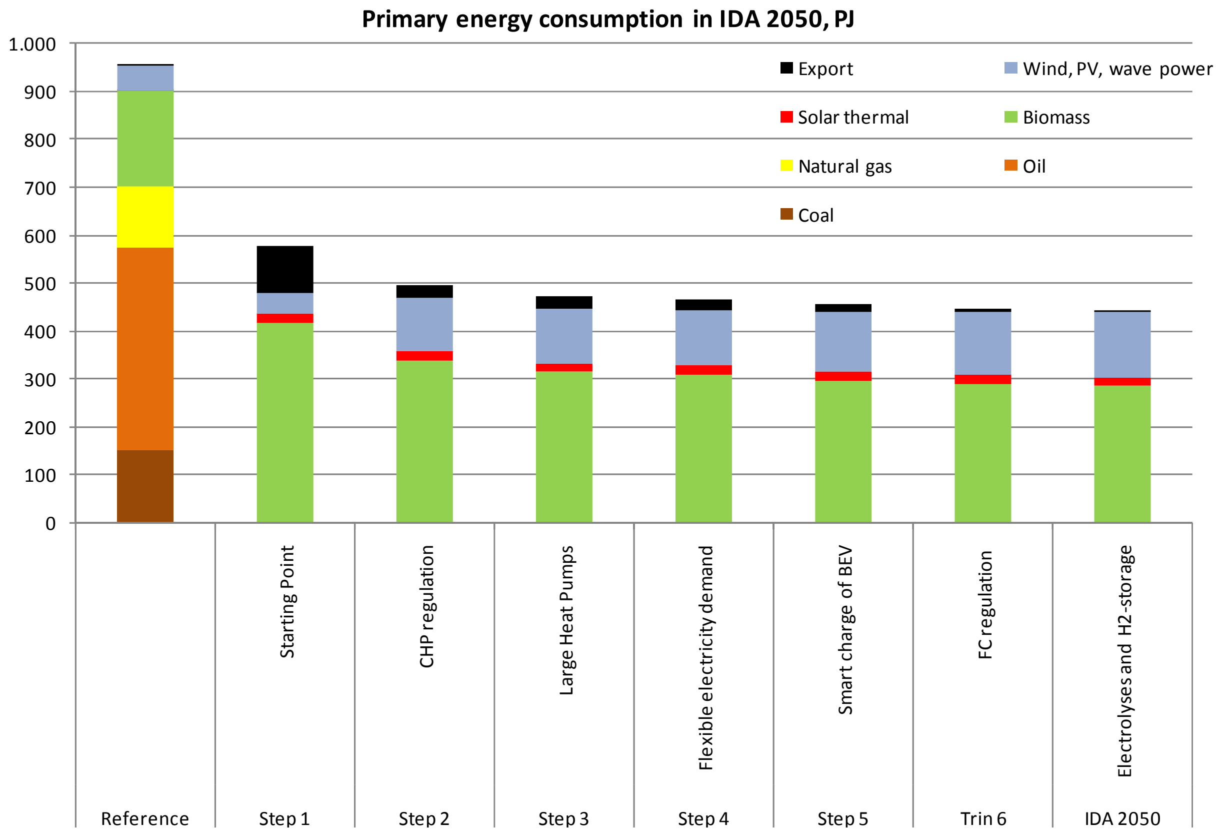


Fig. 18, The allocation of fuels in IDA 2050 and an illustration of the primary energy supply for additional technical improvements to the system.

A total of 5.1 TWh of hydrogen is produced including 3.29 TWh of hydrogen for transport. In Step 7 the demand for biomass is reduced by 1.2 TWh in IDA 2050. In all, the consumption decreases from 124 TWh to 123 TWh. On the other hand the excess electricity decreases from 2.3 TWh to 0.3 TWh. Note that this technology is relatively inefficient in relation to the other adjustments, when comparing the reductions in the excess electricity and the fuel consumption. Greenhouse gases from the energy sector have been removed in IDA 2050. However, as outlined in chapter 14, there may be emissions if the waste incineration is not CO_2-neutral. Finally, refer to chapter 12 for details on the consumption of biomass compared to the potential Danish resource.

13.4 Combined results for fuel consumption and renewable energy

The combined results of the technical analyses appear in Fig. 19. In these energy systems renewable energy has been integrated with the various supply sectors. In Table 23 to Table 25 the percentages of renewable energy have been calculated for all of the energy systems.

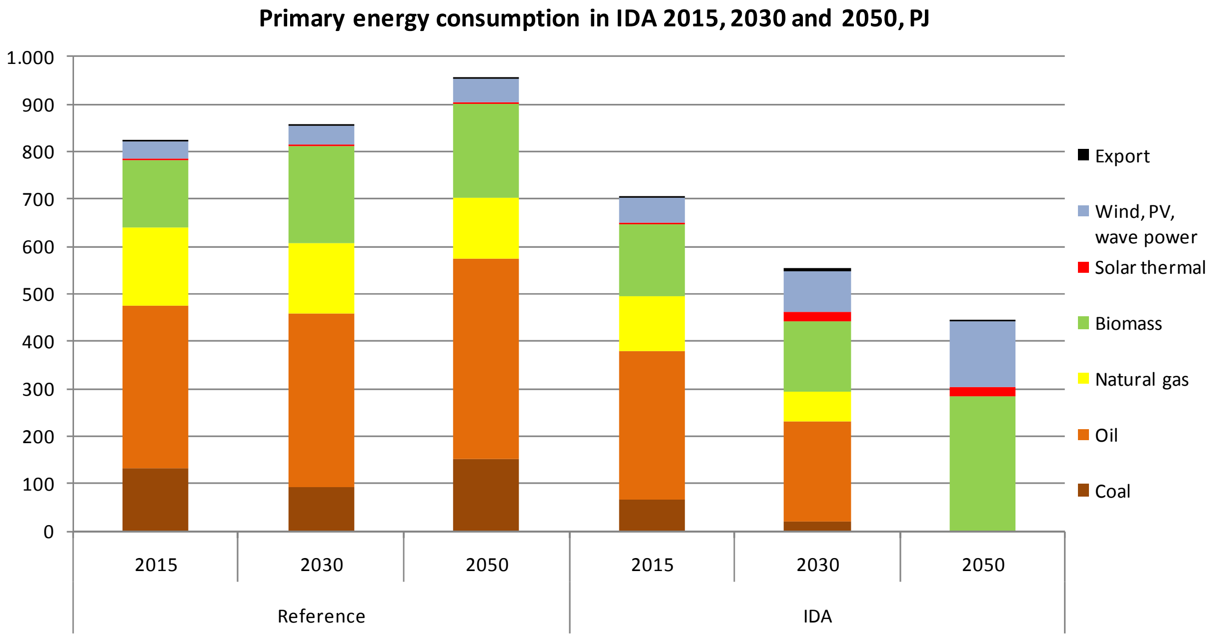


Fig. 19, The allocation of fuels in the reference energy systems and in IDA's Climate Plan 2050.

Table 23, Percentage of renewable energy (RE) sources used in the production of electricity for the reference and IDA energy systems

% of RE in electricity production	2008	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Wind turbines	19%	28%	28%	27%	48%	67%	63%
- of this land wind turbines	16%	18%	16%	13%	28%	36%	25%
- of this offshore wind turbines	3%	10%	12%	14%	20%	31%	38%
Wave power	0%	0%	0%	0%	0%	4%	5%
Photovoltaic	0%	0%	0%	0%	0%	3%	9%
Biomass	11%	17%	32%	26%	19%	11%	22%
- of this power and CHP	8%	13%	28%	23%	15%	4%	15%
- of this waste incineration	3%	4%	4%	3%	4%	4%	5%
- of this industrial CHP	0%	0%	0%	0%	0%	3%	2%
Synthetic fuel	0%	0%	0%	0%	0%	0%	1%
Total electricity production	30%	45%	60%	53%	67%	85%	100%
Total production (TWh)	36.54	36.74	41.84	51.54	32.1	34.8	50.36
Total consumption (TWh)	36.35	36.42	41.72	51.48	30.67	33.04	50.11
Total diff. (TWh)	0.19	0.32	0.12	0.06	1.43	1.76	0.25

In Table 23 the share of the electricity production from renewable energy is listed. It is worth noting that, for example, for wind turbines the production increases during the entire period, both in the reference and in the energy systems for the Climate Plan. However the electricity consumption increases as well, which reduces the percentage of the final demand. The electricity consumption appears in Table 9.

In Table 24 the share of renewable energy for the heat supply, with respect to both individual supply technologies and with respect to district heating is listed. For the technologies where electricity is consumed such as heat pumps, electric boilers, etc, the annual average penetration of renewable energy in the production of electricity has been used from above.

Table 24, Percentage of renewable energy (RE) sources used in the production of heat for the reference and IDA energy systems

Industry supplying, heat demand	2008	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Solar thermal	1%	1%	3%	3%	4%	23%	23%
Heat pumps	4%	9%	14%	17%	35%	65%	67%
Biomass	47%	46%	50%	48%	43%	10%	10%
Total of industrial demand	51%	56%	67%	68%	83%	98%	100%
Total industrial demand	22.90	22.00	19.53	16.28	14.69	9.29	8.78

District heating production	2008	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Solar thermal	0%	0%	0%	0%	1%	8%	8%
Heat pumps	1%	0%	0%	0%	10%	24%	25%
Electrical cartridges	0%	0%	0%	0%	2%	1%	1%
Biomass	25%	26%	35%	35%	24%	39%	66%
- of this CHP	6%	12%	19%	19%	11%	3%	9%
- of this boiler	7%	3%	3%	3%	3%	16%	26%
- of this waste incineration	11%	10%	13%	13%	10%	15%	25%
- of this industrial CHP	0%	0%	0%	0%	0%	5%	6%
Synthetic fuel	0%	0%	0%	0%	0%	0%	0%
Total of district heating demand	25%	26%	35%	35%	37%	71%	100%
Total production	36.70	36.10	35.52	35.53	38.04	40.63	40.79
Total production for district heating customers	35.87	35.28	34.06	34.06	37.49	37.72	37.28
Total heat demand (to consumer)	26.90	27.87	26.91	26.91	29.62	29.80	29.45
Solar thermal of total consumption	0%	0%	1%	1%	2%	11%	11%

In Table 25 the share of renewable energy used in sub-elements of the energy systems and for the total systems is listed. For the energy systems in the Climate Plan where electricity is used for supplying heat and transport, the annual average has been used to calculate the percentage share of renewable energy. For example, this applies to electric vehicles in transport.

Table 25, Percentage of renewable energy (RE) sources used in sub-elements for the reference and IDA energy systems

	2008	2015	2030	2050	IDA 2015	IDA 2030	IDA 2050
Electricity	30%	45%	60%	53%	67%	85%	100%
District heating	25%	26%	35%	35%	37%	71%	100%
Individual heating	51%	56%	67%	68%	83%	98%	100%
Transport	0%	6%	6%	5%	6%	16%	100%
District heating plants	45%	39%	27%	27%	39%	66%	100%
Decentralised CHP	10%	18%	22%	22%	25%	59%	100%
Central power and CHP	13%	21%	50%	38%	31%	33%	100%
Waste incineration	59%	59%	59%	59%	59%	59%	100%
Total of system	16%	22%	29%	25%	30%	47%	100%

In IDA's Climate Plan 2050, an energy system has been constructed that has been based on 100 per cent on renewable energy. The result is that this is possible, but that the balance between large consumption of biomass and large amounts of electricity for direct use or for production of synthetic fuels is still a challenge. One possible scenario for this balance is presented here.

In both IDA 2015 and IDA 2030 there are sufficient domestic biomass resources, but there are challenges for the 2050 energy system when 284 PJ of biomass is required to meet the demand. Although this can potentially be supplied using domestic resources, it will leave very little biomass for producing material goods. Therefore, due to these limitations on domestic biomass, there is a further challenge in the future regarding the fuel consumption in industry and aviation. It is uncertain if these demands can be met using direct or indirect electricity production (i.e. electrolysis), or whether further savings must be introduced.

It must be emphasised that there is no objective in the Climate Plan not to participate in the international biomass market. It does, however, enable Denmark to avoid a future dependence on foreign biomass as it would experience with oil, natural gas, and coal in the reference, due to the anticipated exhaustion of oil and natural gas resources in the North Sea within the next decade or so.

14 Greenhouse Gas Emissions in IDA's Climate Plan 2050

The greenhouse gas contributions from the energy systems presented in the preceding chapters only represents a part of the emissions. In this chapter, the combined reductions in the climate plan for 2015, 2030, and 2050 are calculated. The objective in IDA's Climate Plan 2050 is to reduce the emissions of greenhouse gases by 90 per cent in the year 2050 compared with the emissions in the year 2000. The greenhouse gases are converted here to CO_2 equivalents. In the year 2000 the combined emissions (adjusted) corresponded to 72 million tonnes of CO_2 equivalents, of which 54 tonnes came from energy (75%), while 18 came from agriculture and industrial processes (25%). In addition there is an extra contribution for aviation, which has not been included in these numbers.

14.1 Initiatives beyond changes in the energy system

Industry's combined greenhouse gas contribution has been estimated according to NERI at 25 million tonnes in the year 2007. Of this amount, the portion that is not already included under energy production, cf. the previous chapters, corresponds to 4.2 million tonnes of CO_2 equivalents/year including emissions from waste disposal sites.

Table 26, Emission of greenhouse gasses from industrial processes in 2007.

	Tons	Tons CO_2-ækv.
CO_2 emissions from industrial processes	2,062,000	2,062,000
CH_4 emissions from industrial processes	4,650	97,650
N_2O emissions from industrial processes	10	3,100
Fluorinated gas (F-gas) emissions from industrial processes	885,710	885,710
CH_4 emissions from waste disposal sites	54,900	1,152,900
Sum		4,201,360

According to an estimate of the Danish greenhouse gas emissions from 2005 which was completed for the United Nations (UN), the emissions of F-gases are expected to reduce by approx. 80 per cent by 2015 [55]. Hence the total emissions from industrial processes including waste disposal sites are reduced to 3.5 million tonnes of CO_2 equivalents. There are several opportunities to bring down the CO_2 emissions from cement production. Out of the 2 million tonnes from industrial processes, approx. 1.7 million tonnes of CO_2 stems from cement production. This emission can be reduced by using cement more efficiently, using alternatives, using materials other than limestone, increasing the production efficiency, etc. [56]. Savings of 20 per cent have been implemented here by mixing in finely-ground glass powder, based on research results from Aalborg University. Meanwhile other or additional initiatives could be implemented. The 20 per cent reduction in emission of greenhouse gases has been implemented from 2030 with 350,000 tonnes in annual CO_2 savings. No additional measures were taken to reduce the greenhouse gas emissions from cement production by 2050.

For agriculture, the total greenhouse gas emission corresponds to 19 million tonnes/year, including the energy related emissions which can be estimated at 7 million tonnes/year. The Climate Plan proposes that these 19 million tonnes/year are reduced by 11.7 million tonnes/year through reduced food wastage, dietary habits, improved agricultural practices, and increased organic operations. This has been implemented here by starting with data from the main report. From the 19 million tonnes of CO_2 equivalents, 7 million tonnes can been subtracted because of improved agricultural practice and conversions. In addition, the 7 million tonnes which is energy related and has been dealt with in the previous chapters of this report can also be subtracted. There are also 4.7 million tonnes that are related to less wastage (1.2 million tonnes) and altered dietary habits (3.5 million tonnes). It is assumed that this enables savings of 3 million tonnes on arable land (corresponding to a 12/19 share of the total). Seen as a whole, this provides reductions of 10 million tonnes of CO_2 equivalents from agriculture, excluding the energy related emissions. In IDA's Climate Plan 2050, 10 per cent of this has been carried out by the year 2015, 50 per cent by 2030, and all of the savings are implemented by 2050.

It has been argued that aircraft CO_2 emissions should count for more than their direct CO_2 emission because they release additional greenhouse gases also. However, there is no widespread consensus on the magnitude of this increase, with multipliation factors from 1.7 up to 5 proposed for ordinary aviation fuel. Therefore, this has been included here by multiplying the direct CO_2 emissions from aviation by a factor of 2. In the year 2000, Denmark used approx. 34.8 PJ of primarily Jet Petrol in connection with domestic and international aviation. With a CO_2 emission of 72 kg/GJ it corresponds to an emission of 2.5 million tonnes of CO_2 equivalents are obtained. Therefore, the CO_2 emissions for the year 2000 are increased from 72 to 74.5 million tonnes of CO_2 equivalents on the basis of this assumption. A corresponding adjustment has also been applied for the remaining years in the Climate Plan.

It is a huge technical challenge to develope and produce alternative fuels for aircraft. Therefore, it can be difficult to decide whether conventional aviation fuel is less environmentally friendly than an alternative. The question is whether the condensation clouds, including cirrus clouds, increase because of more particles and water vapour or not with new fuel types. For example, if aircraft were propelled by hydrogen, it would result in 2.6 times more water vapour according to the IPCC.

When forecasting towards 2050 it is reasonable to assume that alternative bio-fuels for aircraft will not be significantly different from conventional fuels, cf. the main report. Therefore, the CO_2 emissions from alternative bio-fuels for aviation should also count for more than the direct CO_2 emissions, similar to conventional aviation fuels. Consequently, if bio-fuels are used for aviation in 2050, as proposed in section 11.5, and the above-mentioned factor of 2 is assumed to account for indirect CO_2 from aviation fuel, then an additional 2.4 million tonnes of CO_2 equivalents are emitted in 2050.

14.2 Resulting emissions of greenhouse gases

The result of the above assumptions concerning emission from industrial processes, agriculture, and aircraft appears together with the result for the energy supply in IDA's Climate Plan 2050 in Table 27. In addition the emissions in 2000 and in the reference for 2008 - 2050 are displayed.

Table 27, CO_2 equivalents in 2000 and in the reference for 2008 - 2050, as well as in IDA's Climate Plan 2050.

		Reference				IDA's Climate Plan 2050		
CO_2 equiv. (million tonnes/year)	2000	2008	2015	2030	2050	2015	2030	2050
Energy	54.0	52.5	47.4	44.4	53.1	36.0	21.0	0.0
Agriculture	13.8	12.0	12.0	12.0	12.0	11.0	7.0	2.0
Industry	4.2	4.2	3.5	3.5	3.5	3.5	3.1	3.1
Sum	72.0	68.7	62.9	59.9	68.5	50.5	31.1	5.2
Aircraft (extra contribution)	2.5	2.9	3.3	2.8	2.5	3.3	2.7	2.4
Sum incl. aircraft extra contribution	74.5	71.6	66.1	62.7	71.0	53.8	33.9	7.6

With the conversions in the energy system and in agriculture proposed in IDA's Climate Plan 2050, the CO_2 emissions can be reduced to 7.2 per cent of those that occurred in the year 2000, by 2050. If the extra contribution from aircraft is included, the reduction is 10.2 per cent in 2050.

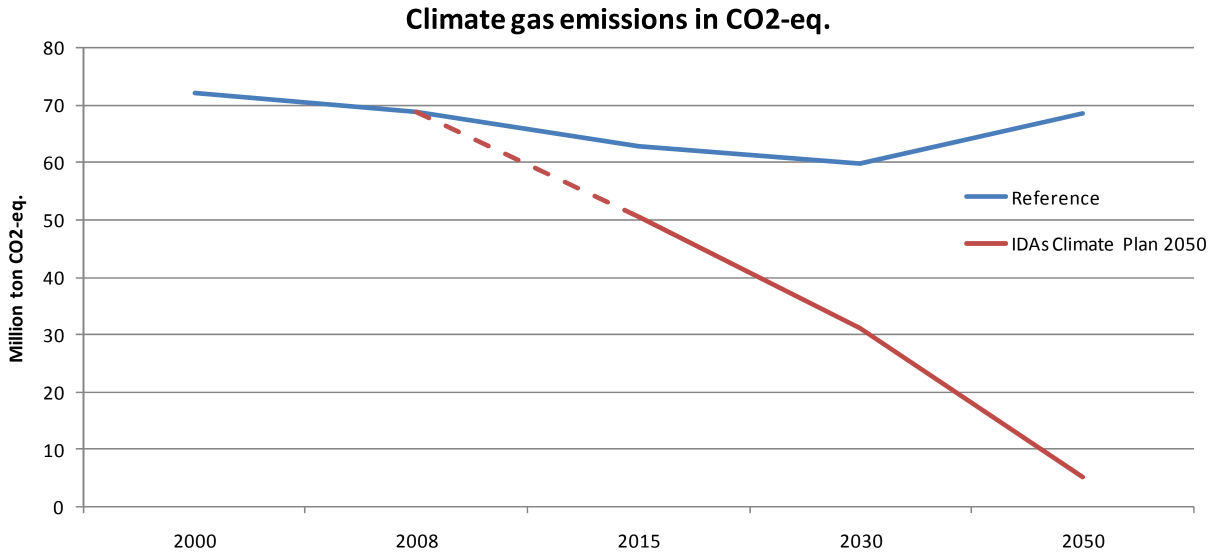


Fig. 20, The discharge of greenhouse gases in the reference years and in IDA's Climate Plan 2050.

14.3 Sensitivity analyses

In these calculations it is assumed that waste is CO_2-neutral in 2050 and not 32.5 kg/GJ as recommended by The Danish Energy Authority [1], as materials are recycled or will be based on biomass. If this is not the case, the emissions increases by approx. 1 million tonnes of CO_2 compared to 2000. With this the percentages become 9.0 per cent with and 11.9 per cent without the extra contribution for aircraft . It should be mentioned also that the emissions of methane from biogas facilities must be entirely discontinued in 2050, cf. the main report.

If the proposed dietary conversions do not succeed, the CO_2 emissions will increase by approx. 3.5 million tonnes. Hence the CO_2 emissions will be reduced to 12.0 per cent of those in the year 2000 in 2050. If the extra contribution from aircraft is included, the reduction is to 14.9 per cent of the 2000 emission in 2050.

15 Socioeconomic analysis of the energy systems

In this chapter a socioeconomic impact analysis of IDA's Climate Plan 2050 is presented. The socioeconomic impact analysis includes an evaluation of the entire energy system. In addition, an evaluation of the systems' ability to exchange electricity on Nord Pool under various assumptions has also been completed. Finally, sensitivity analyses for the socioeconomic results have been conducted. The general assumptions in the analyses here have been presented in chapter 5. Results are presented for 2015, 2030, and 2050. It must be emphasised that the estimation of the socioeconomic impacts is associated with the assumptions that have been described in the preceding sections. There are significant uncertainties associated with the estimation of the socioeconomic costs in IDA 2050, which has been based on 100% renewable energy.

15.1 Overall socioeconomic impact analysis of IDA 2015 and IDA 2030

In this section the socioeconomic costs of the reference have been estimated and compared with IDA 2015, IDA 2030, and IDA 2050 for the three fuel cost levels and for the two CO_2 quota costs levels. The results are illustrated in Fig. 21 for 2015 and 2030 for the middle fuel cost, which was recommended by The Danish Energy Authority. Fuel costs are equivalent to $122/barrel of oil and CO_2 quota prices to 229 DKK/tonnes.

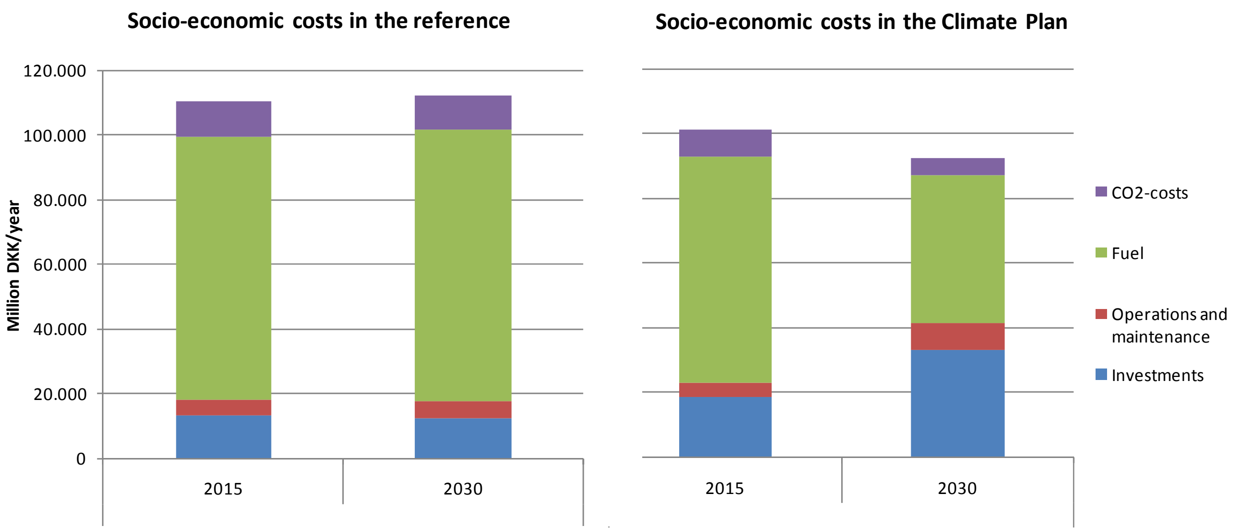
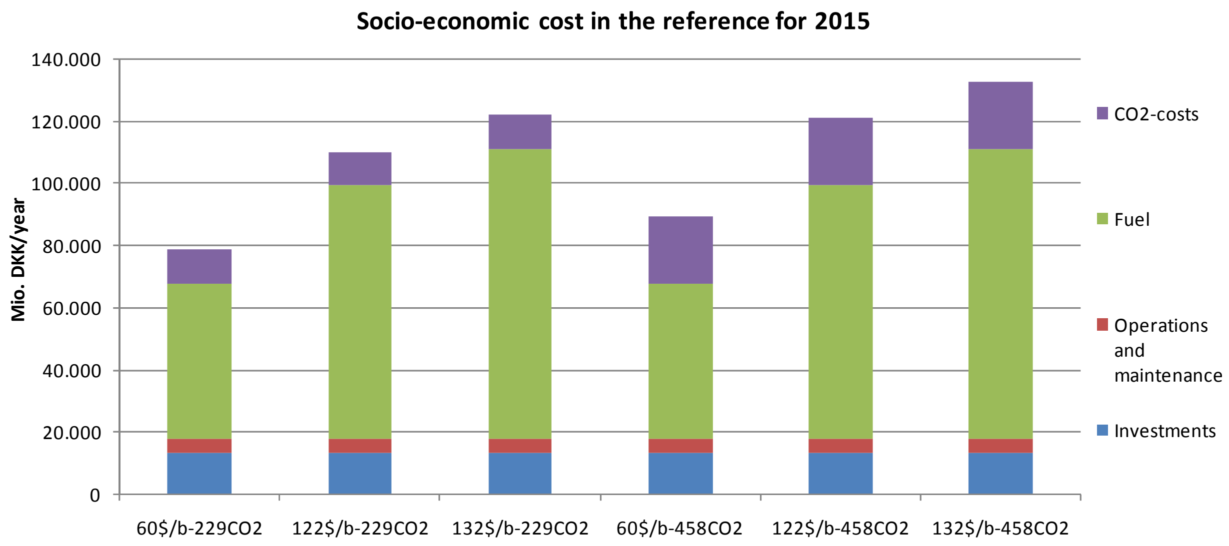


Fig. 21, Socioeconomic costs in the reference years 2015 and 2030, as well as for IDA 2015 and IDA 2030.

The first costs estimated were obtrained for a closed system without electricity market exchange at the Nord Pool market. This has been done to be able to show the net value of electricity market exchange under various relevant assumptions. The additional gains in electricity market exchange with neighbouring countries have been estimated in section 15.3.

The general picture is that Denmark will achieve a significantly better economy than in the reference with both IDA 2015 and IDA 2030. In 2015 and 2030 the difference between the reference and the IDA scenarios at the middle fuel and CO_2 cost assumptions is approx. 9 and approx. 20 billion DKK/year respectively. In IDA 2015, it is important however to note that some of the measures are undertaken in the period 2010 to 2020. This applies to electricity and heat savings in households, as well as the replacement of individual boilers with heat pumps. In addition, with the IDA scenarios one reaches a more robust situation as the combined costs for energy are less sensitive to fluctuations in oil prices and CO_2 costs, cf. Fig. 22 and Fig. 23. The results in Fig. 22 and Fig. 23 also indicate that the IDA scenarios are more economical even when the fuel prices are half those recommended by The Danish Energy Authority at the moment.

It is worth noting that depending on the fuel costs, between 50 and 95 billion Danish crowns/year are currently spent on fuels in Denmark, which will continue to be the case until 2030. It is proposed in IDA's Climate Plan that these expenditures be reduced to between 29 and 51 billion DKK/year in 2030 depending on the fuel prices.



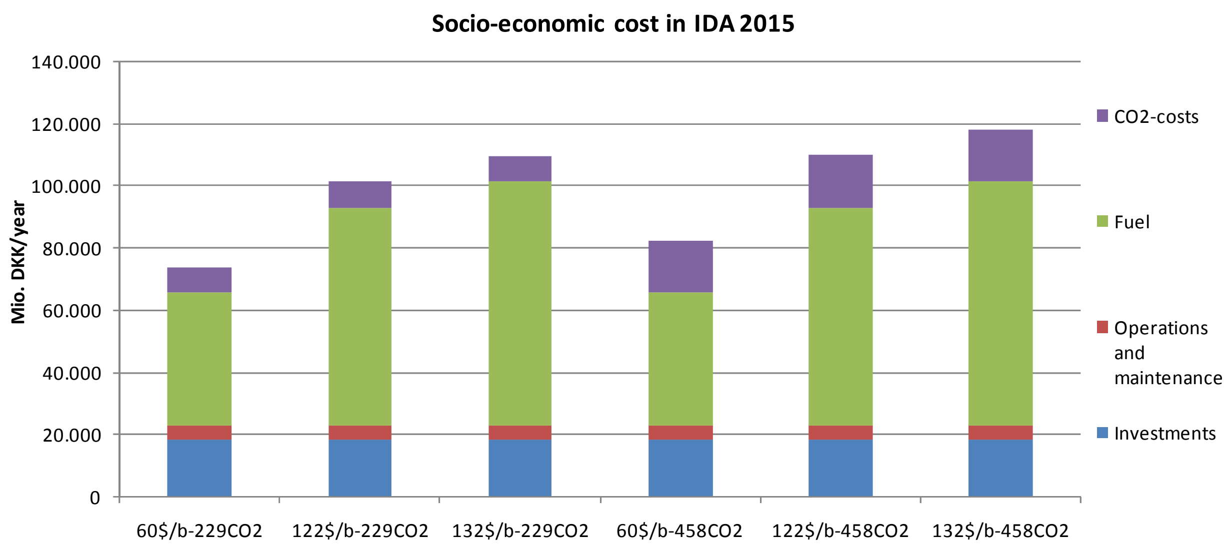
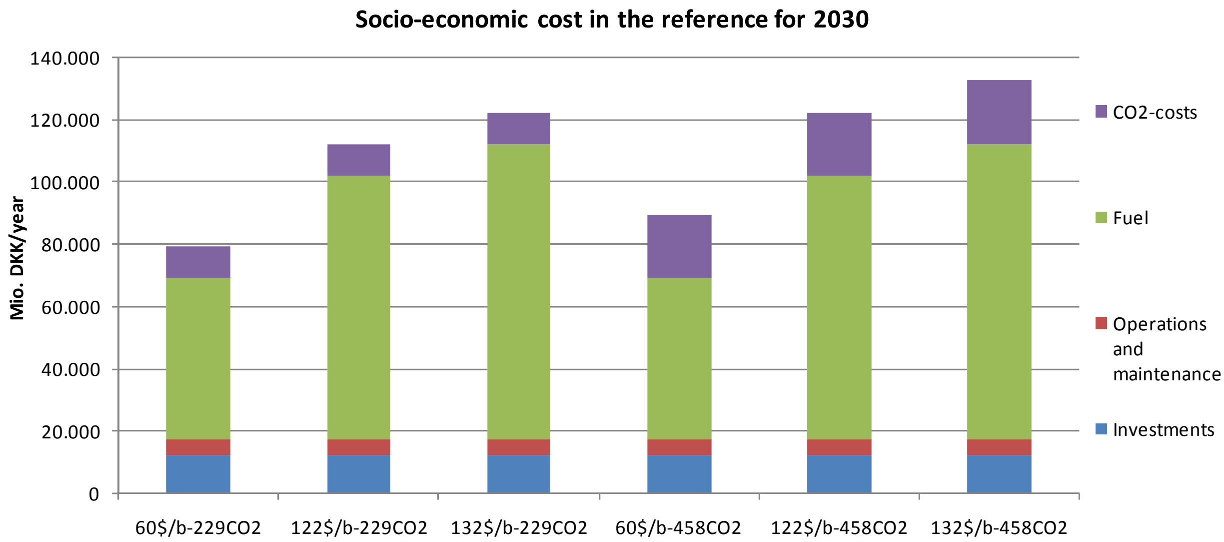


Fig. 22, Socioeconomic costs for the reference in 2015 and IDA 2015 with varying fuel and CO_2 quota prices.



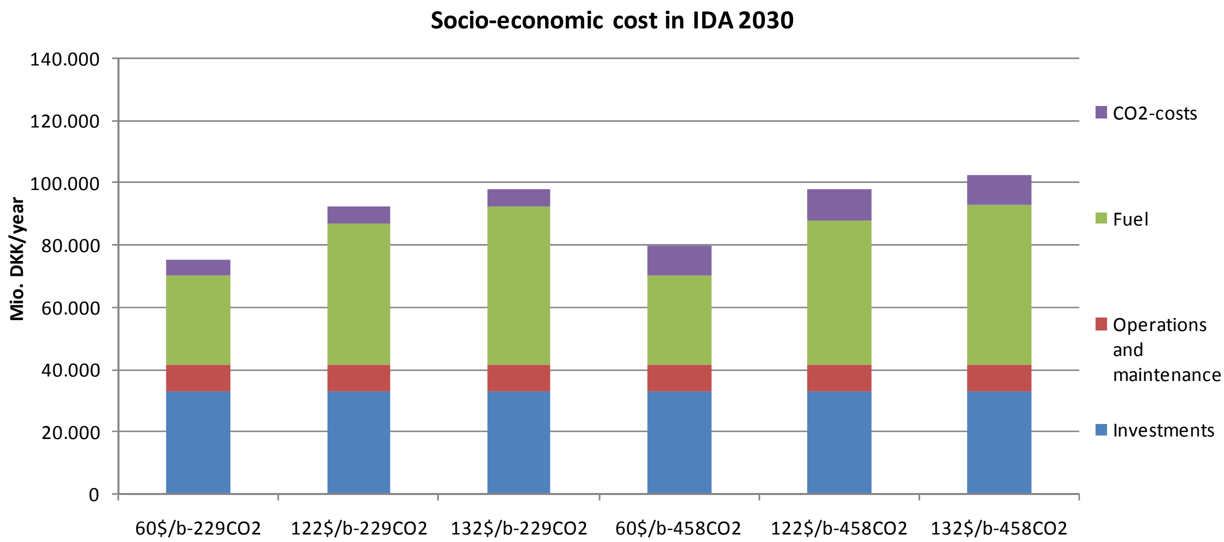


Fig. 23, Socioeconomic costs for the reference in 2030 and IDA 2030 with varying fuel and CO_2 quota prices.

As a small country, Denmark cannot influence the oil prices and the world oil market. In this frame of reference, Denmark must prepare for fluctuating oil prices and not constantly low or high prices over 20-year periods. In some years the prices will be low and in other years they will be high, meaning the prices will change faster than Denmark can change its buildings and power plants. Thus it is essential to have a flexible energy system that can deal with high as well as low oil prices. In this context, IDA 2015 and IDA 2030 are far superior to the reference as displayed in Fig. 22 and Fig. 23.

With the above-mentioned results, a comparison can be made between the reference and the IDA scenarios from a security-of-supply perspective. This can be done starting from an assumption that IDA's Climate Plan 2050 is a part of a combined effort in Europe, the US, and possibly other oil consuming parts of the world. By reducing the demand for fossil fuels, pressure can be taken off the oil market resulting in lower fuel prices. On the other hand, high oil prices must be foreseen if everyone continues to increase their demand. Seen in this context it is relevant to compare ***IDA 2015 and IDA 2030 at the low oil prices*** with ***the reference at high oil prices***.

Fig. 23 above indicates that lower costs can be achieved with IDA's Climate Plan 2050, even if Denmark is the only country to reduce its dependence on fossil fuels i.e. the IDA scenarios are more economical than the reference scenarios from the same year. However, if other countries also follow Denmark, then the gain is even more significant, cf. Fig. 24.

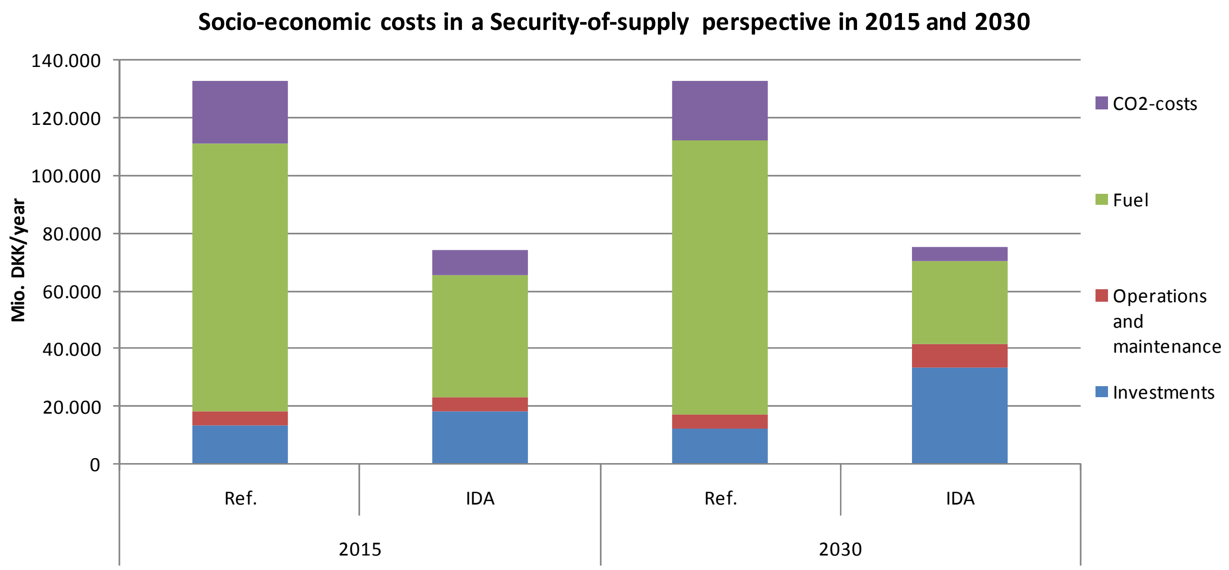


Fig. 24, Socioeconomic costs in a "security policy-oriented comparison" for 2015 and 2030.

It is important to understand that the really large gain from ***low energy costs for society*** will hardly be realised unless one ensures that ***the consumers experience high energy prices***, which to a large extent will be the foundation for carrying out many of the savings and efficiency improvements IDA's Climate Plan 2050 contains. Hence an active tax, fee, and subsidy policy must be conducted to realise the large socioeconomic gain.

Not all of the individual measures are associated with equally large socioeconomic gains, which are discussed in detail for IDA 2030 in the next chapter. However, these measures have other advantages in relation to fuel and CO_2 reductions, as well as trade potentials, and are thus important in relation to fulfilling the combined set of objectives. Moreover, these measures enable the Danish energy system to develop into a 100% renewable energy system in IDA 2050.

There are also large socioeconomic savings in the IDA Climate Plan because of lower health costs, which have been estimated in chapter 17. Further gains can also be realised by implementing IDA's Climate Plan, as the measures will provide a significant commercial potential for Denmark, which includes a large export potential of approx. 200 billion DKK/year. This has been estimated in chapter 18. Meanwhile the above-mentioned socioeconomic gains from the "establishment and operation" of the energy system itself can be harvested, regardless of export potential and whether it is the Danish workforce or foreign labour. This means that approx. 30-40,000 jobs can be created between now and

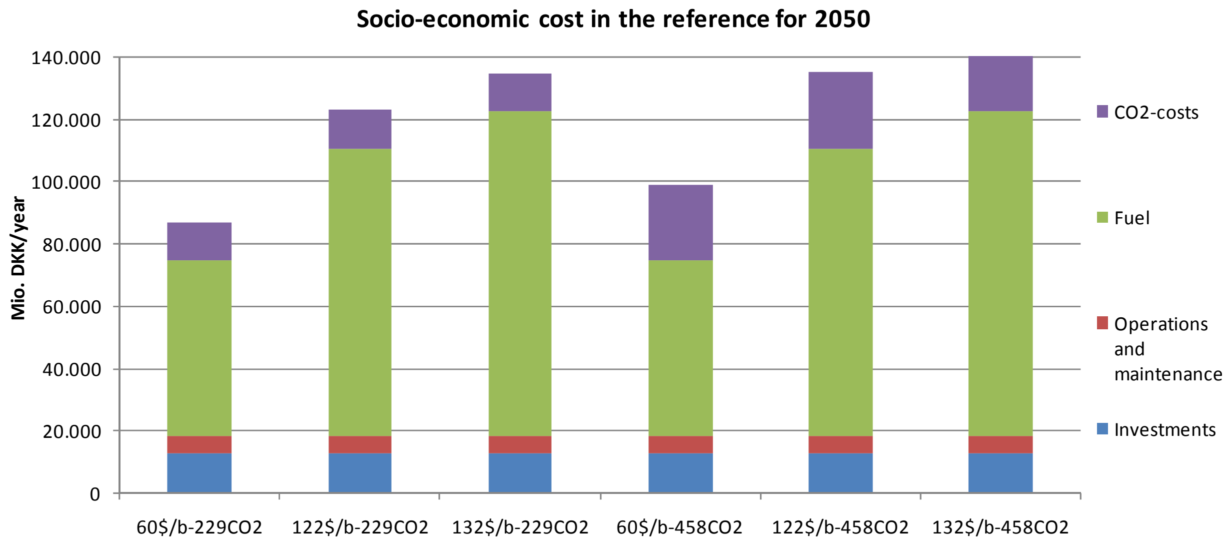
2050, when the 100 per cent energy system has been established. If the export potential is realised, there could be three times as many jobs created, which is discussed in chapter 19. Finally, the positive effects on the balance of payments have not been estimated.

15.2 Overall socioeconomic impact analysis of a 100% renewable energy system

IDA 2050 has been based on 100 per cent renewable energy. Therefore, the calculations below must be seen as a first attempt to estimate the socioeconomic costs for such a system. Such estimates are associated however with significant uncertainties. There is a large range of measures in the IDA 2050 energy system such as the electricity and heat savings, which are only altered marginally compared to IDA 2030. In five areas however, there are significant changes:

- The share of renewable energy has been increased significantly in the electricity system.
- Even more of the fuel consumption in industry and transport has been replaced with electricity consumption.
- Most of the power plants are based on fuel cell technology and use gaseous fuels based on biomass. The larger ones of these can however be replaced by combined cycle gas turbines.
- Electrolysis facilities and hydrogen storage technologies have replaced some of the biomass consumption.
- The transport sector has more track-borne forms of transport and electrical motor vehicles than in IDA 2030.

The largest changes in the system with respect to costs are the significant investments in electrolysis and hydrogen technologies, as well as the expansion of public transport, cf. chapters 11 and 13. The costs in the reference energy system for 2050 and an estimate of the costs for IDA 2050 appear in Fig. 25. It must be emphasised that the results are dependent on the fuel price assumptions, as well as the significant structural and societal changes that are proposed in IDA 2050. However, the costs associated with IDA 2050 do not change dramatically even for biomass prices above and below those analysed here, cf. the assumptions for fuel prices in section 5.5. In the middle fuel price scenario, there are potential savings of over 25 billion DKK/year.



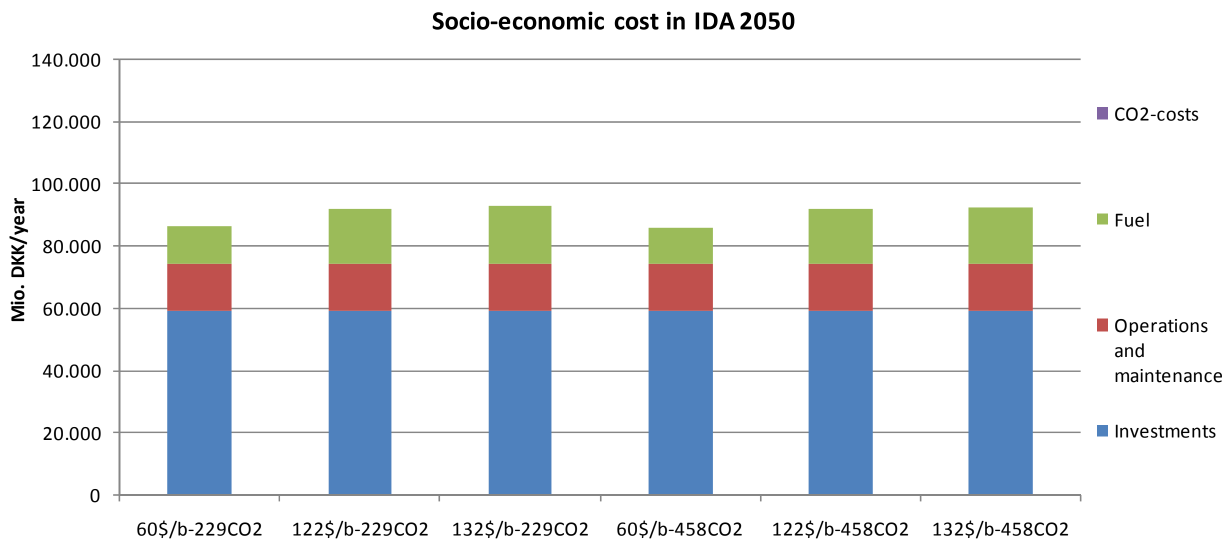


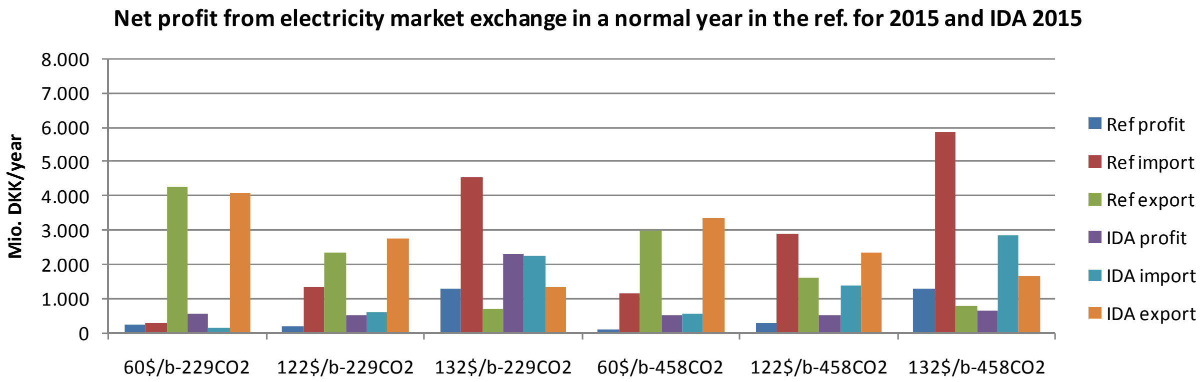
Fig. 25, Socioeconomic costs for the reference in 2050 and an estimate of the socioeconomic costs for IDA 2050, with varying fuel and CO_2 quota prices.

15.3 Electricity market exchange analyses

As mentioned the socioeconomic costs above represent a closed system without electricity market exchange with other countries. In this section, the various systems' abilities to trade on the Nord Pool market with the surrounding countries are evaluated. For assumptions concerning the electricity market exchange analyses, refer to section 5.5.

The analyses began by using the electricity prices in a so called normal year. The result of the analyses appears in Fig. 26. The net income is a combined calculation of import/export incomes, including bottleneck incomes and various CO_2 and fuel costs, which is compared to a scenario where there is no electricity trading with the surrounding countries. In addition, electricity export incomes and electricity import costs are also displayed.

The reference energy systems as well as IDA 2015 and IDA 2030 are able to earn money by trading electricity in all of scenarios analysed, apart from the reference for 2030 in a situation with high fuel prices and high CO_2 quota prices. This occurs becouse the electricity prices produced at the coal-powered plants becomes more expensive than importing at the high fuel and CO_2 quota prices. This causes a high import along with only very few opportunities for export.



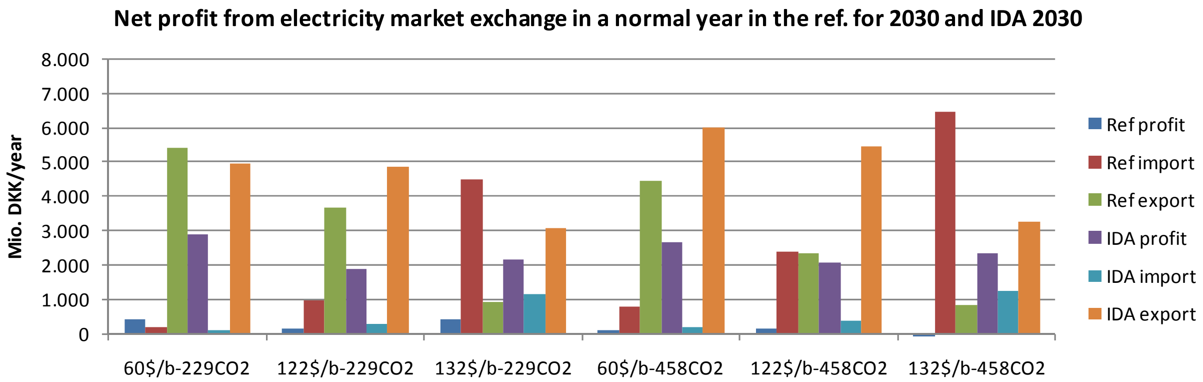


Fig. 26, Incomes and expenditures when trading electricity under various fuel and CO_2 quota prices in the reference for 2015 and 2030 as well as in IDA 2015 and IDA 2030.

If one takes an average of the net income in the analyses from the fuel and CO_2 quota prices used, the incomes in the reference for 2015 become approx. 570 million DKK/year. For IDA 2015, the corresponding average is approx. 845 million DKK/year. In the reference for 2030, approx. 175 million DKK/year can be earned on average from electricity trading, and for IDA 2030 the corresponding number is approx. more than 2 billion DKK/year. If one takes the low CO_2 quota prices for IDA 2030, the income is halved. Thus there is a significant gain if the CO_2 quota prices are high for the IDA energy systems.

In situations with low fuel prices and low CO_2 quota prices, money is earned primarily through exports, while in the case of high fuel prices money is earned primarily through imports.

Hence there are differences in the way money is earned from electricity trading in the two systems. The reference has a large consumption of electricity and heat in Denmark, which demands a large capacity from the power plants and increases their number of operating hours. In the IDA systems, energy savings have been made and more renewable energy has been introduced. Even if the power plant capacity has been adjusted to match the electricity peak load in the new systems, the number of operating hours for supplying electricity is still low, while the power plant population is significantly more efficient. At the same time, there are relatively low fuel prices and relatively high electricity prices in the adjoinging countries. Hence it will pay to use the available operating hours for export. This will increase CO_2 emissions in Denmark however and increase fuel consumption in the form of coal or biomass.

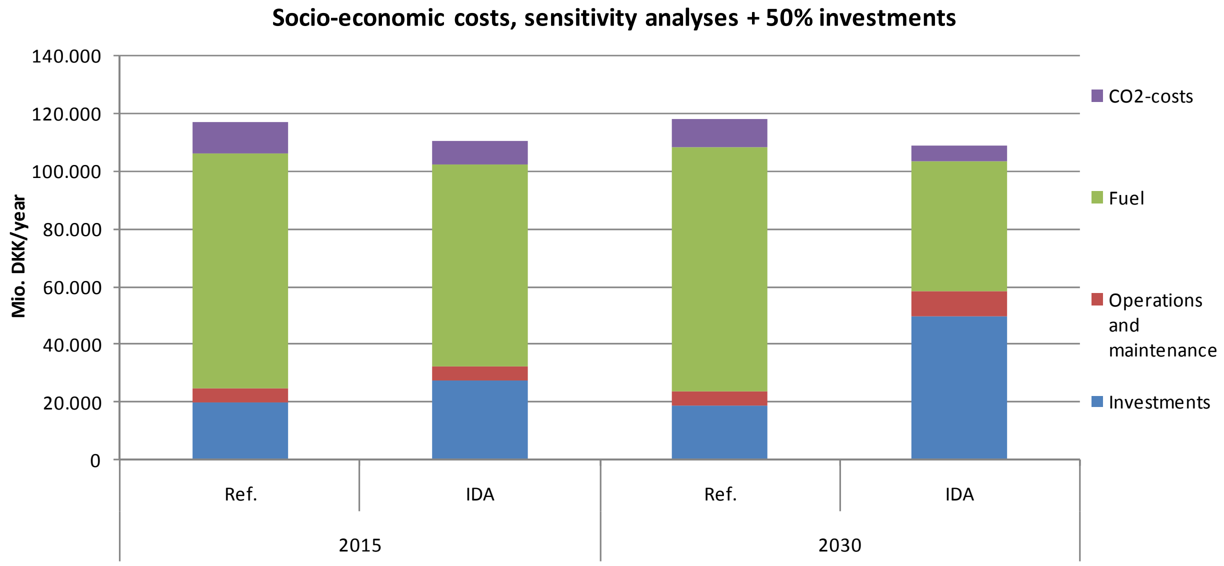
All in all, this difference is much less significant to the difference in the total system costs, which amounts to several billion DKK/year to the advantage of IDA 2015 and IDA 2030. In the references for both 2015 and 2030, as well as in IDA 2015 and IDA 2030, an increase in the transmission capacity to other countries from 2,500 MW to 5,000 MW only increases the net income marginally, which does not justify the costs associated with the development of this capacity. Equally, comprehensive electricity trading analyses have not been undertaken in IDA's Climate Plan 2050 as were conducted in IDA's Energy Plan 2030. No analyses have been completed with regards to wet and dry years etc. which have large influences on the Nordic electricity prices at Nord Pool. Such analyses however, will hardly change the above-mentioned conclusions significantly and more importantly, it will not change the fact that the most significant economic savings are associated with the changes in the total energy system.

Starting from the same assumptions concerning electricity trading prices, fuel prices, and CO_2 quota prices, a similar analysis was carried out to estimate the net incomes for the reference in 2050 and IDA 2050. The conclusions from this are similar to IDA 2030: although the net incomes have been increased to an average of approx. 500 million DKK/year for the reference energy system, they are still approx. 2 billion DKK/year for IDA 2050. This is due to the fact that for the reference, electricity consumption is significantly higher in 2050 and therefore it can be covered profitably by imports in certain situations. For IDA 2050, the flexible technologies that have been implemented can exploit the fluctuating prices profitably, by placing consumption when the price is low. It must be emphasised that the results for the electricity trading analyses for IDA 2050 are only estimates and are based on The Danish Energy Authority's expected electricity price in 2030 and not 2050.

15.4 Sensitivity analyses

As discussed in the preceding sections, the electricity market exchange is not a critical issue when comparing the reference and the IDA Climate Plan. The primary difference between the reference years and IDA's Climate Plan 2050 is the way that money is spent: the Climate Plan requires large construction costs, while the reference has large fuel costs. As a result, the comparison is particularly sensitive to changes in the fuel prices, as shown in the preceding sections, and also to changes in the interest rate and investment requirements. Therefore, a sensitivity analysis has been completed where the construction costs have been raised by 50 per cent and the real interest rate has been doubled to 6 per cent.

The results of the sensitivity analysis appear in Fig. 27, which were calculated using the middle fuel price recommendations, cf. section 15.1. The results indicate that IDA 2015 and IDA 2030 have the lowest socioeconomic costs even under these conditions. It must be pointed out however that this applies to the combined package. With an altered interest rate or scope of investment, several of the individual measures will have a negative socioeconomic result.



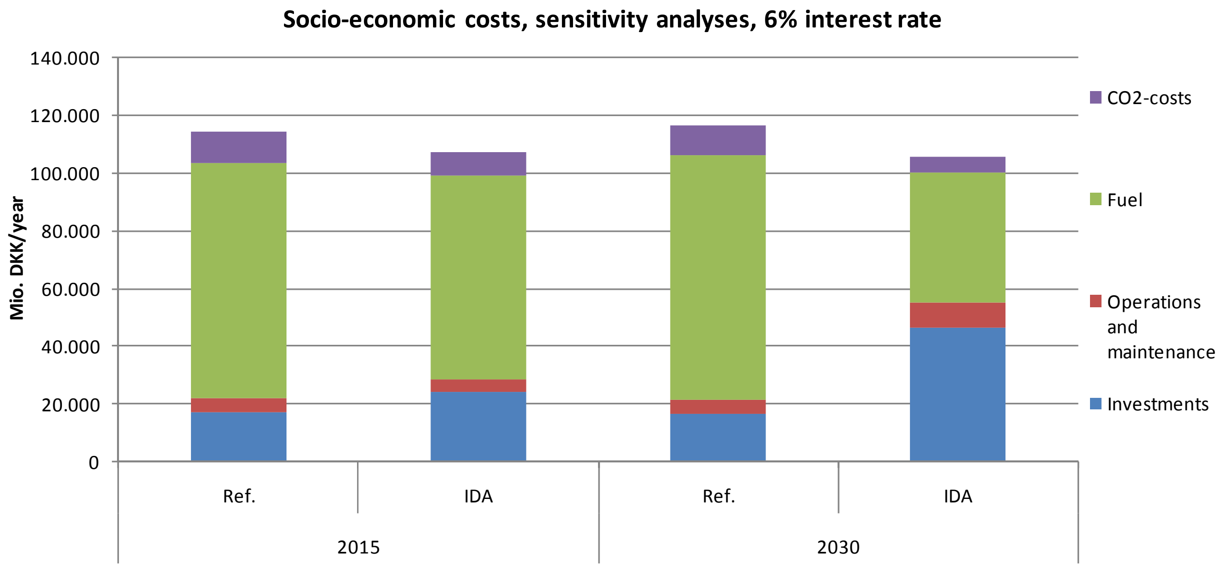


Fig. 27, Socioeconomic costs from sensitivity analysis concerning investment demand and changed real interest rate for 2015 and 2030.

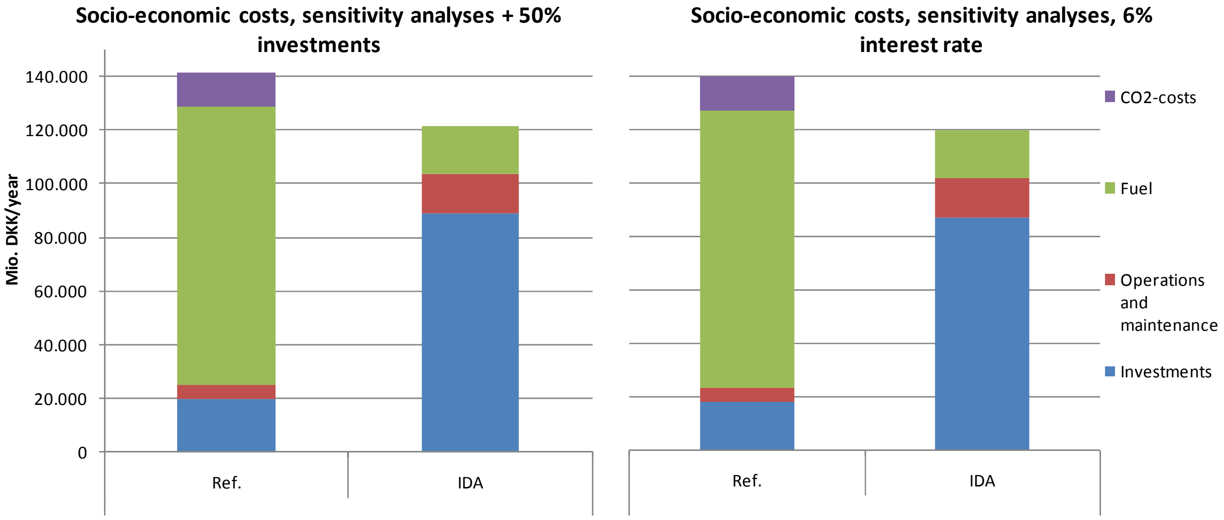


Fig. 28, Socioeconomic costs from sensitivity analysis concerning investment demand and changed real interest rate for 2050.

Similar sensitivity analyses for the reference in 2050 and for IDA 2050 appear in Fig. 28. This system is also robust to these changes, although it must be noted that there are large uncertainties associated with the estimation of the socioeconomic costs for IDA 2050 when taken as a whole. Again individual measures will result in shortfalls in certain instances, whereas others will be robust regarding investment costs and/or a higher real interest rate.

16 Socio-economic costs and CO_2 emissions for individual measures

The socio-economic cost of each individual initiative is calculated for 2030. These estimates are based on the reference energy system for 2030 and IDA 2030.

16.1 Analyses of individual initiatives

The individual initiatives are assessed in relation to the 2030 energy systems as if they were implemented separately. The size of the profit or loss most often depends on the system in which the initiative is implemented. Therefore, socio-economic costs and CO_2 emissions for each of the initiatives are estimated for both the IDA 2030 energy system and the reference energy system for this year. In both cases, the individual initiatives are assessed using an open system model, incorporating electricity market exchange and fuel price recommendations by the Danish Energy Authority with prices equivalent to 122$/barrel of oil, a CO_2 quota price of DKK 229/ton and an electricity price of DKK 497/MWh in 2030 [1]. There is a complete overview of the inputs for the individual initiatives provided in Appendix VIII. The results of the analyses are shown in Fig. 29 and Fig. 30.

The savings and extra costs described below enable the transition to a 100% renewable energy system, reduce CO_2 emissions, may reduce costs on health, provide employment and create a significant commercial potential. Therefore, they should be seen from this perspective. Thus, the costs identified in this analyses are purely based on the actual "establishment and operation" of the energy systems with the individual technologies. Health costs, commercial potential, and the impact on employment for all of the energy systems are not assessed here, but in chapters 17 to 19. It must be emphasised that the results of the analyses are based on the assumptions described for the individual technologies in the previous chapters.

16.2 Wind turbines, wave power, and photovoltaic

There is a socio-economic profit to be gained from both onshore and offshore wind turbines. Their value in the reference energy system is greater than in IDA 2030. This is due to the fact that electricity consumption is greater in the reference system, which means they can replace more power plant production. In addition, the production of electricity from other renewable energy sources is smaller, which results in more opportunities in electricity market exchange. Furthermore, power plants are more efficient in IDA 2030, which reduces the benefits of wind turbines. An analysis of the marginal value of all wind turbines indicates that the first wind turbines are of the greatest value in the energy systems. 67 per cent of electricity consumption is covered by wind power in IDA 2030 and the total marginal profit amounts to approx. DKK 600 million per year. In the reference system, wind turbines generate approx. 63 per cent of electricity consumption. This amounts to almost DKK 1 billion per year. It should be noted that enough wind turbines are already installed on the reference system to cover approx. 30 per cent of the electricity. Therefore, the profits mentioned here are additional to any profit that is obtained due to a 30 per cent wind power penetration.

The same mechanisms that are described for wind turbines apply to both wave power and photovoltaic. Wave power covers approx. 4 per cent of electricity consumption in 2030, which gives around 230 DKK million per year in profit to the reference and a small profit of approx. DKK 20 million per year according to IDA 2030. In the case of photovoltaic, approx. 2.5 per cent of electricity consumption is covered in 2030, which provides a profit of DKK 120 million per year to the reference energy system and a loss of around DKK 70 million per year to IDA 2030. Hence, investments in wave power and photovoltaic balance out as savings in fuel and CO_2 costs compensate for the total investment over the lifetime of the facilities. Thus, the total investment in wave power amounts to about DKK 5.6 billion while the investment in photovoltaic amounts to around DKK 5.1 billion.

Wind turbines, wave power, and photovoltaic reduce CO_2 emissions in all of the analyses. The CO_2 reduction is largest in the reference energy system as this system provides the greatest potential for replacing coal and natural gas at the power plants. By increasing the wind power penetration from approx. 30 per cent to approx. 65 per cent on both the reference for 2030 and IDA 2030, wind turbines will provide a total reduction in CO_2 emissions of around 4 to 5 million tons of CO_2 per year. In the case of wave power and photovoltaic, CO_2 reductions amount to between 0.3 and 0.7 million tons of CO_2 per year and again, the largest reductions can be identified in the reference energy system.

16.3 Improved waste incineration CHP, geothermal energy, and large solar thermal systems

Improvements in waste incineration CHP provide a small profit of approx. DKK 310 million per year in the reference energy system. Solar thermal and geothermal heating are already in the district heating systems in IDA 2030. As a result, the profit associated with waste incineration CHP in IDA 2030 is only approx. DKK 50 million per year. If geothermal energy is added to the calculations, the resulting socio-economic loss will amount to DKK 130 million per year in the reference energy system and approx. 200 million DKK per year in IDA 2030. Once again, the losses are larger in IDA 2030 because it already contains a range of other heat sources and also, because it has a higher constant production of electricity from the incineration of waste. This reduces the potential profit from the exchange of electricity in the IDA energy system, as there is more renewable energy and a greater need for flexibility than in the reference energy system. These analyses are based on the fact that geothermal energy is linked to waste incineration CHP. On the whole, these investments balance out in the reference energy system and provide a small profit of DKK 115 million per year in IDA 2030, cf. Fig. 29. Again, investments of DKK 1.4 billion for improving waste incineration CHP and DKK 3.9 billion in geothermal energy should be kept in mind when reviewing these results. It may be possible to reduce the investments in geothermal energy in the future with better technology and with the possibility of seasonal storage.

Solar thermal in district heating areas creates a socio-economic profit of DKK 250 million per year in the reference energy system, but the investment costs in storage and solar thermal systems offset the fuel savings in IDA 2030. Again, the difference is due to the technologies already used to supply the heat demand in the two energy systems.

Improvements in waste incineration CHP and investments in geothermal energy reduce the CO_2 emissions by approx. 0.5 million tons of CO_2 per year. However, waste incineration CHP and geothermal energy both provide smaller reductions in IDA 2030, as they compete both with each other and with solar thermal. Again, in the case of solar thermal alone, the greatest reductions are seen in the reference.

16.4 Large heat pumps in district heat production

The socio-economic profit from large-scale heat pumps in district heating areas is larger in the IDA 2030 energy system, as this system enables the heat pumps to operate more frequently due to the large amounts of renewable energy. However, there are also profits in the reference energy system. Socio-economic profits amount to DKK 0.3 billion per year in the reference energy system and approx. DKK 0.8 billion per year in IDA 2030.

These heat pumps increase the CO_2 emissions marginally by 0.1 million tons of CO_2 per year in the reference energy system. In IDA 2030, the emissions are reduced by 0.2 million tons of CO_2 per year. The emissions did not reduce in the reference energy system because the installed heat pump capacity is too large compared to the consumption and the proportion of renewable energy in this energy system.

16.5 Flexible electricity consumption

Flexible electricity consumption amounts to 15 per cent of consumption in households, industry, and service. When introduced it produces socio-economic savings of DKK 340 million per year according to the reference energy system and DKK 550 million per year in IDA 2030. There are higher savings in IDA 2030 because there is a greater need for flexibility in this energy system.

Although the emissions reduce by 0.5 million tons of CO_2 per year in the reference, there are no large reductions of CO_2 emissions in IDA 2030. This occurs because the IDA 2030 energy system is very efficient and the proportion of renewable energy is larger than in the reference.

16.6 Fuel cells in CHP plants

Fuel cells can increase the efficiency of the entire system and hence form an important element in the reduction of CO_2 emissions and in the use of limited resources. These fuel cells are high temperature solid oxide fuel cells. It is important that they are versatile, flexible, and can be regulated quickly according to changes in wind power production etc. From a socio-economic point of view, fuel cells result in a small loss in decentralised CHP areas and a small profit in centralised areas. For all fuel cells, the reference energy system gives a profit of DKK 0.5 million per year and IDA 2030 a profit of approx. DKK 40 million per year. For the most part, profits originate from the increased energy system efficiency, which reduces the fuel consumption, and from a better potential to trade on the electricity market exchange. However, expenses include large operating costs linked to the replacement of fuel cell stacks. The overall reductions in CO_2 emissions are small due to the improved potential for electricity export.

16.7 Electricity savings in households and new houses built in BOLIG+ standards

Electricity savings are crucial when reducing fuel consumption and CO_2 emissions, while ensuring a socio-economic balance. In the reference energy system the savings give a socio-economic profits of approx. DKK 270 million per year and in IDA 2030 a small loss of approx. DKK 140 million per year. This shall be viewed in the light of a total investment of around DKK 17 billion. The difference is, in particular, due to the fact that electricity production is significantly more efficient in IDA 2030 than in the reference energy system. This is also reflected in the reductions of CO_2 emissions. In the reference, the emissions are reduced by 2.4 million tons of CO_2 per year whereas in IDA 2030 they are reduced by 1.5 million tons of CO_2 per year.

The calculations here indicate that new houses according to BOLIG+ (a zero emission building concept) standards will result in a socio-economic loss of up to DKK 300 million per year. The analyses presuppose a concept whereby energy production in the dwelling depends on the rest of the system. It may be possible to achieve savings by designing the standard such that two or more dwellings collaborate on common solutions, as this may reduce the investment and the cost of construction. Finally, the solution here results in CO_2 reductions of between 0.3 and 0.4 tons of CO_2/year. These concepts are significant during the transition to a lower consumption of fuel and fewer CO_2 emissions.

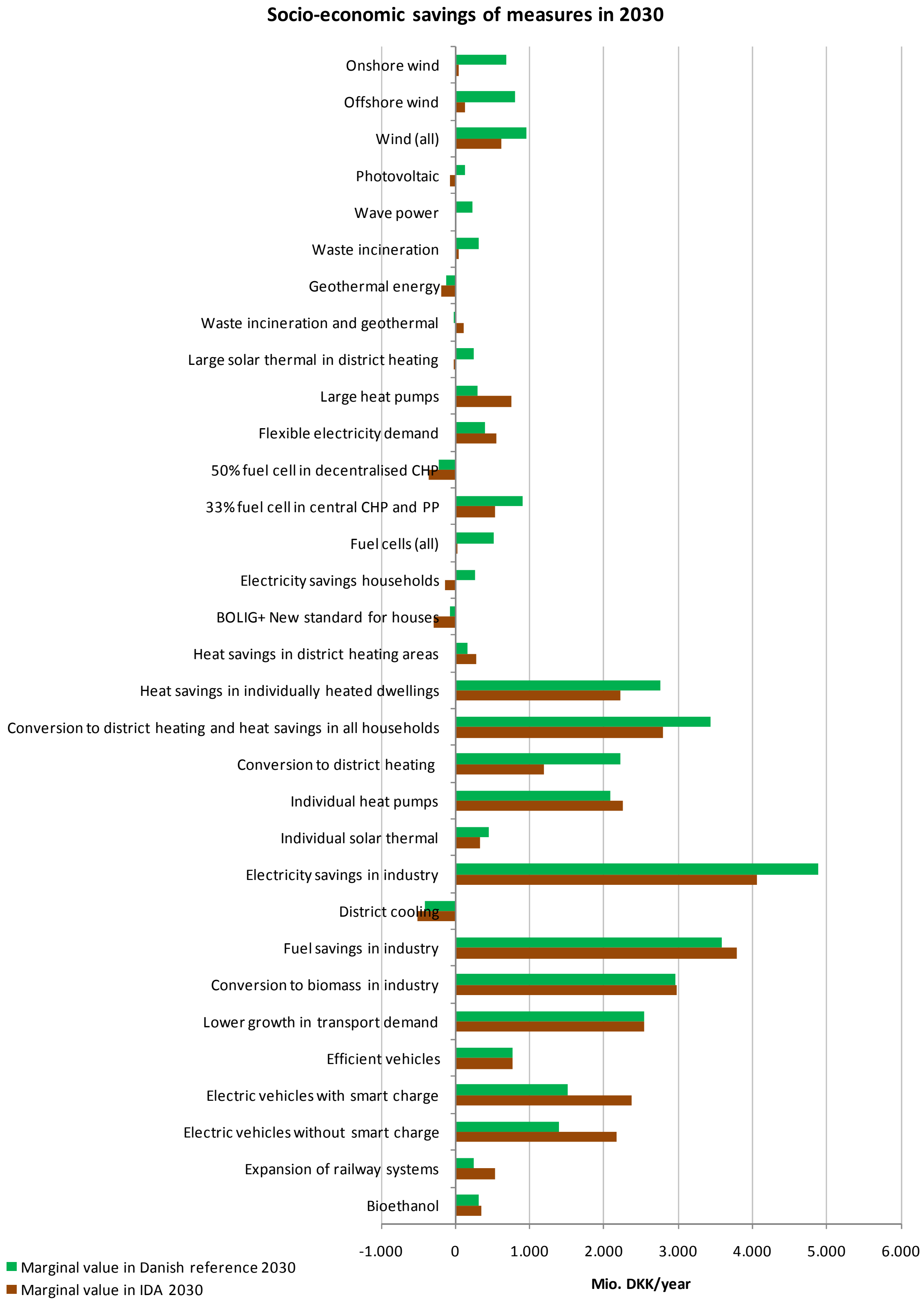


Fig. 29, Socio-economic savings for individual initiatives, estimated using the reference energy system for 2030 and IDA 2030.

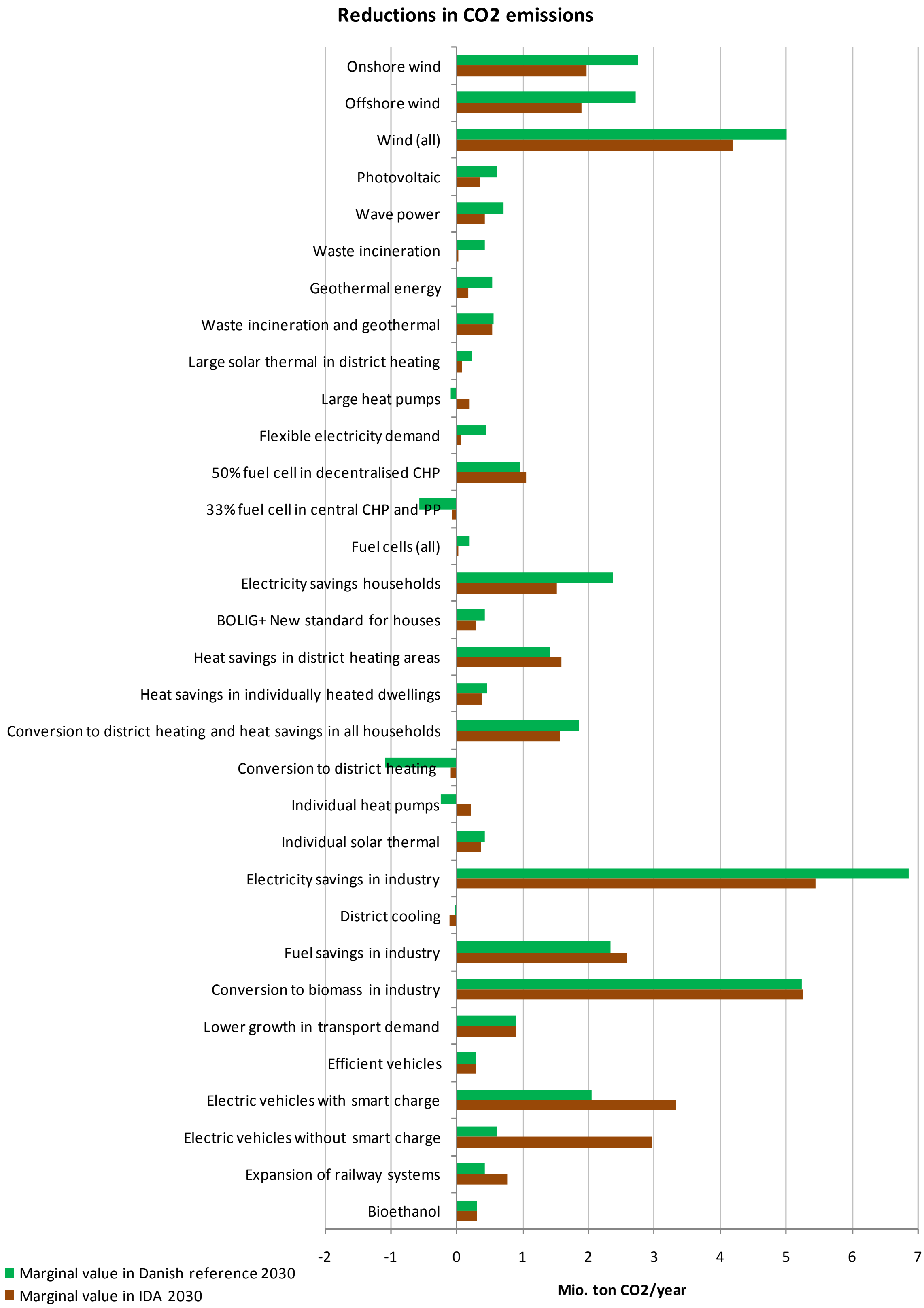


Fig. 30, Reductions in CO_2 emissions for individual initiatives, estimated using the reference energy system for 2030 and IDA 2030.

16.8 District heating and heat savings

Three versions of heat savings are analysed: in district heating areas alone, in areas where households are heated individually, and in all areas combined with an expansion of the district heating area. These analyses indicate that there is significant synergy in combining marginal expansions in district heating with heat savings.

If heat savings are made in existing district heating areas, the cost of insulation in these areas, which is DKK 49 billion, will be offset if the savings in fuel are combined with a gradual decline in the capacity of boilers and CHP plants. Heat savings in individually heated households will yield significantly greater gains of over DKK 2 billion per year, with a total investment of DKK 28 billion in these areas. The difference here originates from the fact that heat production in district heating areas is more efficient. In district heating areas, a large proportion of the heat comes from CHP production whereas in individually heated households, boilers are the primary source of heat. This means that fuels savings are much larger in areas with individual heating systems.

District heating is expanded to cover approx. half of the areas that lie up to a kilometre from existing district heating areas. An expansion of district heating systems will result in a profit of DKK 2.2 billion per year in the reference energy system. It is a good idea to expand district heating areas even if this is not combined with heat savings and as a result, heat consumption remains essentially the same as it is today. In IDA 2030, the expansion of district heating alone will create a profit of DKK 1.2 billion per year as this system uses 50 per cent less heating compared to today.

However, there is synergy between expansions in district heating and heat savings. If all analyses are considered together, the profit from marginal expansions to district heating areas, combined with heat savings and gradual adjustments of boilers and CHP plants, amounts to around DKK 3 billion per year.

The same synergies are evident for CO_2 reductions. In the reference energy system, an expansion of the district heating network increases the CO_2 emissions by 1 additional ton per year if no savings are made. However, if this is combined with heat savings, reductions amount to approx. 1.5 million tons of CO_2 per year. Heat savings alone in district heating areas result in the greatest CO_2 reductions. This is primarily due to the reduction in operation of peak load boilers, which typically use oil.

16.9 Heat pumps and solar thermal in individually heated households

In areas outside the district heating network, a large proportion of heat consumption is reverted to heat pumps and solar thermal. Heat pumps yield a socio-economic gain of over DKK 2 billion per year as they are more cost-efficient than boilers. The installed heat pumps are a mix of geothermal heat pumps and water-to-water heat pumps, while both are combined with solar thermal. The installed solar thermal system alone provides a socio-economic gain of approx. DKK 450 million per year in the reference and approx. DKK 340 million per year in IDA 2030.

CO_2 emissions increase by approx. 0.2 million tons of CO_2 per year in the reference energy system if heat pumps are used, due to the fact that no energy savings are made in this case and the proportion of coal and natural gas in electricity production is greater. In IDA 2030, heat pumps result in reductions of approx. 0.2 million tons of CO_2 per year. In both systems, the solar thermal installations create reductions of approx. 0.4 million tons of CO_2 per year.

16.10 Savings, biomass, and district cooling in industry

Both electricity and fuel savings provide a very large gain for industry and service, as compared to households very few savings have been made here in the past. Hence, the profit to be made from the implementation of savings is larger in industry and service than in households. In addition, conversion to biomass also yields profits as the fuels are cheaper and the cost of conversion is limited. Conversion to district cooling results in a socio-economic loss of DKK 0.4 to 0.5 million per year. However, it must be kept in mind that the total investment is approx. DKK 10 billion and also, this investment is subject to uncertainties as it was estimated using the first data available on the cost of these systems. Reductions in CO_2 emissions are significant for the savings in industry and service. In the case of district cooling, the implemented solution does not result in any significant change, with only a slight increase in CO_2 emissions for both energy systems.

16.11 A smaller growth in the transport demand and an increased efficiency of ships

It was proposed in IDA 2030 that the growth of private vehicles should be reduced from 18 per cent to 9 per cent by 2030. If implemented, this initiatvie results in a profit of up to DKK 2.5 billion per year and a reduction in CO_2 emissions of 1 ton of CO_2 per year. Therefore, the measure is cost neutral. Although the transport sector will continue to grow, the growth will be reduced by introducing incentives such as road pricing etc. This initiative is important as management of the growth in transport activities is the only way to ensure that there are sufficient resources to cover the transport requirements of the future. It should be noted that reduced growth in goods transport, air traffic, and shipping has not been proposed.

The efficiency of ships is improved by imposing greater demands on manufacturers and reducing their speeds etc. This results in a socio-economic profit of approx. DKK 0.8 billion per year and reductions in CO_2 emissions of approx. 0.3 million tons of CO_2 per year.

16.12 Conversion to electric vehicles

Approx. 50 per cent of all private cars are electric vehicles by 2030. A small proportion of these are hybrid electric vehicles. Two versions of this initiative are analysed: one which incorporates intelligent charging, i.e. charging at times when the wind is blowing (and the electricity price is low), and one which involves the charging of electric vehicles when they are not on the road. Overall, electric vehicles create a socio-economic profit of approx. DKK 1.5 billion per year in the reference energy system and DKK 2.4 billion per year in IDA 2030. Although there is a great deal of additional costs linked to electric vehicles, fuel savings more than compensate for these costs, even though electricity consumption increases. Approximately DKK 100 - 200 million per year extra of socio-economic savings are created if the electric cars are charged at the right times.

A conversion to electric vehicles reduces the CO_2 emissions by approx. 3.3 million tons of CO_2 per year in IDA 2030. In the reference energy system, reductions amount to approx. 2 million tons of CO_2 per year if electric vehicles are charged at the right times. This difference occurs because the fossil fuels are replaced by more renewable energy in electricity production for the IDA 2030 model than for the reference energy system. The reductions are significantly lower in the reference energy system if the electric vehicles are not charged at the right times. This is due to the fact that power plants have to produce the required electricity using CO_2 intensive fuels such as coal. However, it should be noted that electric vehicles will reduce the CO_2 emissions when using both charging techniques on all energy systems considered.

16.13 Expansion and electrification of the railway network

Expansion and electrification of the railway network creates socio-economic savings of DKK 250 million per year in the reference and DKK 530 million per year in IDA 2030. Once again, these savings are linked to the fact that the large investment of DKK 203 billion is repaid in the form of a more efficient transport system.

Fuel consumption is, to a large extent, replaced by electricity consumption. Again, fossil fuels are replaced by more renewable energy in the IDA 2030 model than in the reference energy system, which also creates larger reductions in the CO_2 emissions. In IDA 2030, emissions are reduced by approx. 0.8 million tons of CO_2 per year, but in the reference thet are reduced by 0.4 million tons of CO_2 per year.

16.14 Bioethanol

The use of bioethanol creates a socio-economic profit of approx. DKK 330 million per year. Even though the volume of biomass required is greater than the volume of petrol required, the socio-economic cost of bioethanol is lower due its production procedure.

Bioethanol reduces the CO_2 emissions by 0.3 million tons of CO_2 per year for both energy systems. However, it ought to be noted that, in the IDA 2030 model, the use of bioethanol is limited and less than in the reference as fuels are linked to a large consumption of biomass

17 Health costs

This chapter estimates the health costs associated with the reference energy systems and the energy systems in IDA's Climate Plan 2050. The health costs are estimated for six different types of emissions. A comparison is made between the costs at an overall level and also, between the costs for the various different sectors.

17.1 Calculation of emissions for individual technologies

The emissions of six different substances were calculated based on the most recent emission coefficients from Denmark's National Environmental Research Institute (DMU). Not surprisingly, emissions were greatest from the energy systems with the largest energy consumption. Emissions declined for the energy systems in the climate plan, primarily due to the fact that fuel consumption is either replaced by cleaner energy such as wind turbines, or is eliminated. The results are shown in Table 28.

Table 28, Emissions by six substances from energy systems in IDA's Climate Plan 2050.

Tons/year		SO_2	NO_x	CO	PM2.5	Mercury	Lead
Reference	2015	19,705	116,713	292,527	30,757	1.2	6.6
	2030	14,122	129,196	271,106	29,676	1.1	7.0
	2050	16,710	151,600	265,365	25,227	1.2	7.4
IDA	2015	18,535	105,358	239,385	20,291	1.1	6.1
	2030	13,221	81,805	98,790	5,327	1.1	6.1
	2050	11,579	55,792	49,378	3,751	0.9	5.9
per cent reduction	2015	5%	10%	20%	35%	5%	5%
	2030	5%	35%	65%	80%	-5%	15%
	2050	30%	65%	80%	85%	20%	20%

In the reference year, 2015, the majority of SO_2 emissions originate from coal that is used for electricity and CHP production (30 per cent) and in boilers (40 per cent). Eventually, by 2030 and 2050, a proportion of these emissions will also come from straw in power plants. In the case of NO_x emissions, the source is primarily diesel from the transport sector (approx. 40 per cent). However, coal for power plants contributes approx. 10 per cent of the emissions in all three reference years. In the reference for 2015, 2030, and 2050, the emission of CO is primarily linked to wood, which is used for heating individual households (approx. 50 per cent), and to emissions from petrol, bioethanol and aviation fuel in the transport sector (approx. 35 per cent). The primary source of small particles is also wood used for heating households (over 80 per cent). In the reference years, mercury comes from the incineration of waste, coal, and wood (each accounts for approx. 20 per cent). Lead originates primarily from the incineration of waste (approx. 70 per cent) and the burning of coal (approx. 10 per cent).

There are fewer SO_2 emissions in IDA 2015 than in the reference, even though the consumption of straw has also increased due to a decline in coal consumption. NO_x emissions also decrease due to the decline in coal consumption. CO emissions fall primarily due to a decline in the consumption of wood in households, which is also the reason for the decline in the emission of small particles (PM2.5). Mercury emissions increase due to an increase in straw and wood, but in overall terms, there is a fall due to the decline in coal consumption. As there is no change to waste incineration in IDA 2015, there is only a marginal fall in lead emisions due to a decline in coal consumption.

In IDA 2030, the SO_2 emission is essentially the same as in the reference: even though coal consumption at power plants and oil consumption in boilers for district heating and industry has fallen considerably, straw consumption has increased significantly. NO_x emissions have also declined, primarily due to the fact that the transport sector consumes fewer diesels and a lot less coal. Waste incineration now accounts for a large proportion of NO_x emissions, even though emissions from incineration remain unchanged and the emissions from straw and wood are on the increase. As far as CO emissions are concerned, a large proportion of the reduction is linked to the lower consumption of wood for the heating of individual households. Petrol consumption is also on the decline, which reduces the CO emissions, but these also increase slightly because more straw and wood are used in boilers for industry and district heating. There is a large decline in small particles, which is due to a reduction in the use of wood for heating purposes. Mercury emissions are falling due to a decline in the consumption of coal, but there are also small increases from both straw and wood boilers. Overall, the mercury level remains unchanged. Lead emissions have fallen slightly due to a decline in the consumption of coal.

In IDA 2050, there is a further decline in emissions, primarily due to drastically reduced consumption of coal at power plants, a reduction in the use of diesel and petrol in the transport sector, a reduced need for oil in industry, and a reduced need for wood in individual households. On the other hand, emissions increase slightly again due to an increase in the use of straw, wood, biogas etc.

17.2 Health costs of the individual elements of the energy systems

Using the above estimation of emissions from the various different sources, health costs can be calculated based on the most recent known costs for the specific fuel, specific technology, and the actual location of the point sources, as well as the number of persons who will be affected by the emission. Thus, the environmental cost of damage to natural habitats and animal species is not included in the calculations, nor is the cost of damage to cultural heritage such as buildings etc.

According to the reference energy systems, in the case of electricity and heat production, health costs to society are primarily linked to emissions of SO_2 and NO_x from the burning of coal in power and CHP stations. In relation to heat-producing boilers, the largest costs originate from the consumption of oil in industry. It is assumed that fuel oil will be replaced by gas oil between 2015 and 2030 for oil consumption in industry. Hence, at the beginning of the period, costs will be due to SO_2 whereas in 2030 and 2050 they will be due to NO_x and SO_2. Wood for the heating of individual households plays a large role in the reference energy systems due to their emission of small particles (PM2.5). The greatest health costs originating from the transport sector are linked to NO_x emissions due to the consumption of diesel.

Costs in the energy systems from IDA's Climate Plan 2050 are lower. In IDA 2015, costs are reduced due to energy savings as they lower the consumption of coal in electricity production. Similarly, the conversion to district heating, geothermal heat pumps, and solar thermal means that there is a reduction in the cost of emissions from the burning of wood in individual households. These trends continue in IDA 2030, but are reinforced by more wind turbines that displace the fossil fuels. Conversely, the costs of emissions from the burning of straw, wood, and biogas increase. These trends continue up to IDA 2050 when there are further conversions to biomass and more renewable energy is introduced into the electricity system, which replaces solid fuels. In addition, health costs originating from the transport sector are further reduced in IDA as there are more electric cars, hybrid cars, and rail transport. The health costs for the six types of emissions are shown in Table 29.

Table 29, Health costs by technology and fuel

Health costs, DKK million/year			Reference			IDA		
Power plants and CHP plants			2015	2030	2050	2015	2030	2050
Coal	Steam turbine	Central plant	944	662	1,081	464	141	-
Natural gas	Steam turbine	Central plant	65	41	65	33	39	-
Natural gas	Gas turbine	Decentralised plant	229	200	204	137	-	-
Biogas	Gas turbine	Decentralised plant	66	74	-	104	108	275
Waste	Steam turbine	Decentralised plant	298	368	368	298	368	368
Biogas	Motor	Decentralised plant	-	-	275	-	-	-
Straw	Steam turbine	Decentralised plant	171	428	428	139	8	-
Whole chips, residues etc.	Steam turbine	Decentralised plant	62	155	155	50	3	134
		Subtotal	*1,834*	*1,927*	*2,575*	*1,225*	*666*	*777*
Heat-producing boilers								
Fuel oil, waste oil	Boiler	District heating plant etc.	1,298	144	144	1,293	144	-
Gas oil	Boiler	District heating plant etc.	502	875	1,054	401	366	-
Straw	Boiler	District heating plant etc.	127	90	90	615	1,357	1,665
Natural gas	Boiler	District heating plant etc.	206	202	148	177	127	-
Wood	Boiler	District heating plant etc.	117	127	158	234	518	212
Natural gas	Boiler	Single dwelling system	51	37	30	16	1	-
Wood etc.	Boiler	Single dwelling system	5,041	4,684	3,706	3,113	373	353
Gas oil	Boiler	Single dwelling system	149	94	75	10	1	-
		Subtotal	*7,492*	*6,254*	*5,404*	*5,860*	*2,887*	*2,229*
Transport								
Diesel	Private vehicles	Average	1,239	1,722	2,109	1,239	877	144
Petrol with cat.	Private vehicles	Average	667	543	666	667	245	-
Bioethanol	Private vehicles	Average	78	84	84	78	38	-
Diesel	Lorries	Average	1,715	2,355	2,858	1,715	1,928	-
Biodiesel	Lorries	Average	-	-	-	-	-	1,467
Diesel	Ships	Average	580	623	623	580	392	-
Biodiesel	Ships	Average	-	-	-	-	-	249
Aviation fuel	Air traffic	Average	1,190	1,028	912	1,190	996	881
		Subtotal	*5,469*	*6,354*	*7,251*	*5,469*	*4,476*	*2,741*
Diesel	Private vehicles	Average	***14,800***	***14,500***	***15,200***	***12,600***	***8,000***	***5,700***

17.3 Total health costs

Health costs are calculated on the basis of six different emissions: SO_2, NO_x, CO, particles (PM2.5), mercury and lead. IDA's Climate Plan 2050 contains, in particular, reductions in emissions of NO_x, CO, and small particles. However, there are also reductions in emissions of SO_2, mercury, and lead. The reductions primarily occur due to smaller volumes of coal being used in the power plants, smaller volumes of diesel and petrol in the transport sector, a reduced need for oil in industry, and a reduced requirement for wood in individual households. On the other hand, emissions increase slightly again due to an increased use of straw, wood, biogas etc.

Total costs can be calculated based on the most recent data on health costs originating from emissions from the various different types of technology, fuel, and location of point sources. Costs are identified by counting the work days lost, hospital admissions, damage to health, deaths etc. The total health costs in the reference energy systems for 2015, 2030, and 2050 amount to approx. DKK 14 to 15 billion per year. These estimates are consistent with other studies. According to a study conducted by Denmark's National Environmental Research Institute (NERI), total costs originating from power plants amount to DKK 3.1 billion and costs from transport are DKK 5.7 billion [26]. As households and industry are not included in the NERI study, the above-mentioned estimates are low by comparison.

In IDA 2015, these costs are reduced to approx. DKK 13 billion, while in IDA 2030 and IDA 2050 costs are reduced to approx. DKK 8 and 6 billion respectively. Thus, if the initiatives in IDA's Climate Plan 2050 are implemented, there will be savings of approx. DKK 2 billion in 2010, approx. DKK 7 billion in 2030 and approx. DKK 10 billion in 2050. As the total costs are based on current emission factors, it must be emphasised that this type of estimate only gives an indication of the total socio-economic costs. Ideally, the energy systems should be analysed using emission models, cf. section 5.8. The health costs by sector are shown in Fig. 31.

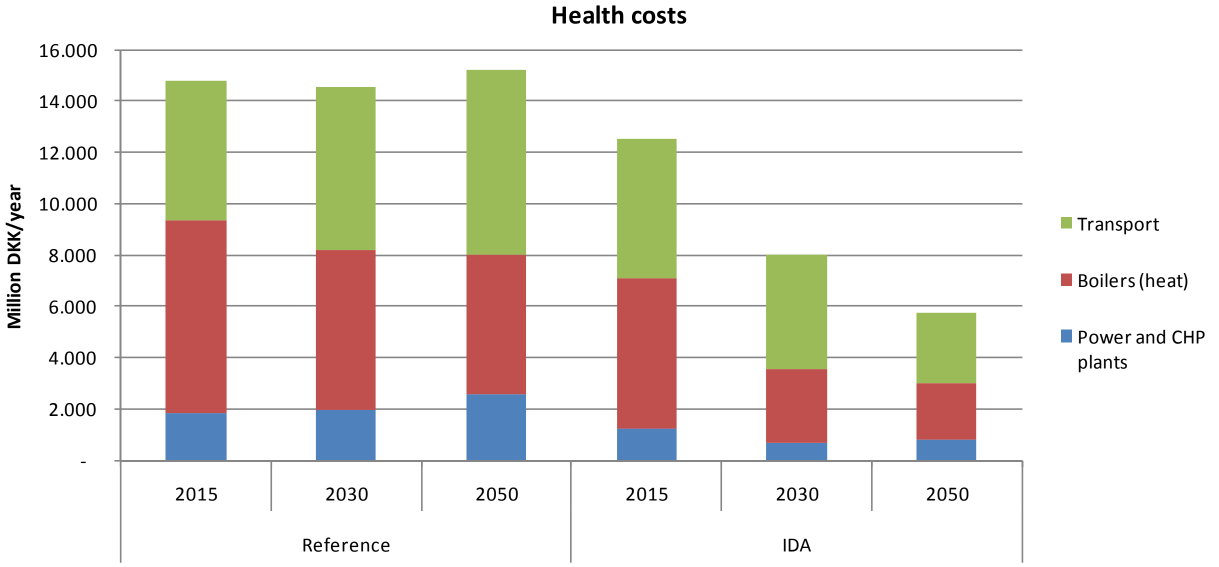


Fig. 31, Total health costs originating from the energy systems, by sector.

The health costs included are exclusively based on the six emissions and do not include the environmental cost of damage to nature and animal life or the cost of mining for fuels and materials overseas, e.g. from a coal mine in South Africa. Thus, the estimate is rather conservative. The difference between the reference energy system in 2015 and IDA 2015 is DKK 0.9 billion in Denmark. Towards IDA 2030 and IDA 2050 the savings that can be related to Denmark increase to DKK 2.3 billion and DKK 2.4 billion respectively. These costs are listed in Table 30.

Table 30, Health costs by technology and fuel in Denmark

Health costs, DKK million/year			Reference			IDA		
Power plants and CHP plants			2015	2030	2050	2015	2030	2050
Coal	Steam turbine	Central plant	83	58	95	41	12	-
Natural gas	Steam turbine	Central plant	4	3	4	2	2	-
Natural gas	Gas turbine	Decentralised plant	14	13	13	9	-	-
Biogas	Gas turbine	Decentralised plant	5	5	-	7	8	20
Waste	Steam turbine	Decentralised plant	63	78	78	63	78	78
Biogas	Motor	Decentralised plant	-	-	18	-	-	-
Straw	Steam turbine	Decentralised plant	14	36	36	12	1	-
Whole chips, residues etc.	Steam turbine	Decentralised plant	80	86	116	54	28	39
		Subtotal	*264*	*279*	*360*	*188*	*130*	*136*
Heat-producing boilers								
Fuel oil, waste oil	Boiler	District heating plant etc.	167	19	19	167	19	-
Gas oil	Boiler	District heating plant etc.	62	108	130	50	45	-
Straw	Boiler	District heating plant etc.	17	12	12	81	179	220
Natural gas	Boiler	District heating plant etc.	17	17	12	15	10	-
Wood	Boiler	District heating plant etc.	15	17	21	31	68	28
Natural gas	Boiler	Single dwelling system	4	3	2	1	0	-
Wood etc.	Boiler	Single dwelling system	2,345	2,179	1,724	1,448	174	164
Gas oil	Boiler	Single dwelling system	25	16	12	2	0	-
		Subtotal	*2,653*	*2,370*	*1,933*	*1,794*	*496*	*412*
Transport								
Diesel	Private vehicles	Average	215	299	366	215	152	25
Petrol with cat.	Private vehicles	Average	72	59	72	72	27	-
Bioethanol	Private vehicles	Average	8	9	9	8	4	-
Diesel	Lorries	Average	206	283	343	206	231	-
Biodiesel	Lorries	Average	-	-	-	-	-	176
Diesel	Ships	Average	62	67	67	62	42	-
Biodiesel	Ships	Average	-	-	-	-	-	27
Aviation fuel	Air traffic	Average	38	33	29	38	32	28
		Subtotal	*602*	*749*	*886*	*602*	*488*	*256*
Diesel	Private vehicles	Average	***3,500***	***3,400***	***3,200***	***2,600***	***1,100***	***800***

Costs originating from CO_2 emissions are not included in the calculation of health costs. As mentioned in section 5.8, it is difficult to estimate these costs. However, environmental and health costs may amount to over DKK 1,000 per ton of CO_2. Thus, the market price for CO_2 quotas is unlikely to cover the full socio-economic cost. As it is difficult to calculate these costs, estimates are often based on markets prices or the expected price of a CO_2 quota which ideally, should reflect the cost of reducing CO_2 emissions.

For the purpose of the estimation of the costs in the energy systems, the CO_2 quota price is included in the Climate Plan, cf. chapter 14. This corresponds to the cost of reducing CO_2 emissions in a market that functions optimally. Two cost levels are applied: DKK 229 and DKK 458 per ton of CO_2. These figures may be somewhat low compared to the cost imposed on society. However, this interval reflects a CO_2 quota price in keeping with the 2-degree target.

The costs in the reference energy systems are between approx. DKK 10 billion and DKK 25 billion per year. In IDA's Climate Plan 2050, the costs are reduced to DKK 8 - 17 billion per year in IDA 2015, DKK 5 - 10 billion per year in IDA 2030, and they are removed completely by IDA 2050. Thus, there are great savings to be made on the CO_2 quota costs alone. If these costs do not reflect the socio-economic, environmental, and health costs, but instead they are in fact twice as high, the difference between the climate plan and the reference energy systems will be twice as large, cf. results in Fig. 32 reflecting DKK 458 per ton of CO_2.

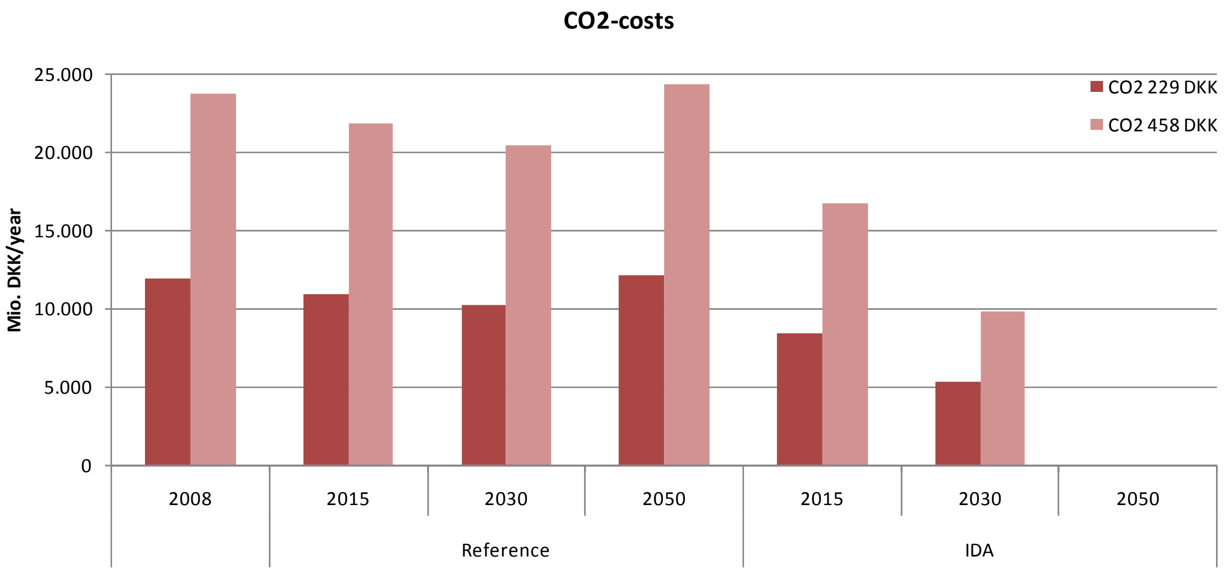


Fig. 32, CO_2 costs in the reference energy systems and the climate plan.

The CO_2 costs are illustrated in Fig. 32 for quota prices of DKK 229 and DKK 458 per ton of CO_2. If calculations are based on the low CO_2 price and the health costs outlined in Table 30, a low estimate of the socio-economic costs from externalities amounts to approx. DKK 5 billion in IDA 2015, approx. DKK 11 billion in IDA 2030, and approx. DKK 22 billion in IDA 2050.

17.4 Sensitivity analyses

It must be emphasised that the analyses above are based on emission data from 2007 and 2008 for fuels and technologies. These emissions will be lowered on a continual basis during the period, so to some extend, overestimations are made. However in the analyses here fuel oil is phased out of the calculations and there are catalytic converters added to vehicles. The emissions from the power and CHP plants are also high in IDA 2030 and IDA 2050. This occurs because the analyses used emission factors from conventional technology, even though fuel cell technology using natural gas, biogas, or synthetic fuels has been introduced. In IDA 2030 approx. 33 per cent of the power plants are based on fuel cells, while in IDA 2050 all of the power and CHP plants are based on fuel cells. A number of sensitivity analyses have been performed in order to investigate this issue. The emission factors were investigated to see if they were too high for the technologies they represented and if so, whether these could be reduced.

It was found that the emission factors for power plants using coal, waste, and natural gas are already rather low and hence, they will probably not be reduced much more. However, fuel oil is replaced by gas oil which has less sulphur, both in the reference and in the climate plan.

According to a calculation made for wood used in households, the NO_x emission coefficient applies to large wood boilers which emit only half of the CO and PM2.5 which was assumed above. If these are adjusted in the health cost calculations, the savings in the IDA Climate Plan are reduced by 36 per cent in 2015, 31 per cent in 2030, and 17 per cent in 2050. Thus, there are still major health gains to be obtained from the climate plan even though emissions from the burning of wood are reduced significantly due to new technology.

If the NO_x emissions from private vehicles and lorries that run on diesel are reduced to the levels of petrol vehicles, savings in health costs are the same in 2015, 10 per cent less in 2030, and 22 per cent less in 2050. Thus, the significant savings in health costs are not changed by this fact either.

Analyses of other emission coefficients and prices were also conducted. It was concluded that there is no current knowledge available that would enable larger changes in savings in health costs than the above two parameters.

18 Commercial potentials

Implementation of IDA's Climate Plan 2050 will result in the development of new competencies and the expansion of production in Danish businesses. Past experiences show that there is a potential to increase exports of these technologies, when converting to a more efficient system and utilising more renewable energy. The commercial potential which can be realised with the implementation of the IDA Climate Plan is assessed in this chapter.

18.1 Different potentials

The method applied in the IDA Energy Plan 2030 [4] was also used to calculate the commercial potential here. The calculations were based on the Danish export of energy technology and consultancy in 2004, which amounted to DKK 32.5 billion and was dominated by wind turbine technology. In the meantime, according to the Danish Energy Authority and the Confederation of Danish Industry, export increased to DKK 64 billion in 2008. Wind turbines accounted for DKK 42 billion of this figure. As was the case for the IDA Energy Plan, the commercial potential has been assessed here up to 2030. Systematic focus on the technologies in the climate plan will increase the potential for export significantly. The following chapter will estimate the size of this potential increase. ***It must be emphasised that, naturally, a high degree of uncertainty is inherent in this type of quantification and the calculation shall be considered an estimate.***

Appendix VII shows a list of the most significant investments in savings and system conversions in IDA's Climate Plan 2050. A total of DKK 330 billion will be invested in these technologies up to 2030: DKK 130 billion will be invested in long term projects such as buildings and the district heating network, while DKK 200 billion will be invested in short-term projects such as vehicles, biofuel plants, and electricity savings. Bioethanol plants account for almost DKK 2 billion of this and biofuel plants (biogas plants and conversion to biomass in industry) account for DKK 13 billion.

In addition to these investments, IDA's Climate Plan 2050 includes investments in a range of supply technologies, such as approx. DKK 11 billion in solar thermal, approx. DKK 33 billion in additional wind power, approx. DKK 6 billion in wave power, approx. DKK 5 billion in photovoltaics, DKK 9 billion in heat pumps, and approx. DKK 20 billion in fuel cells. In any case, there will be investments additional to those in the reference.

Commercial potential is quantified by dividing the initiatives in IDA 2030 into two main groups. Group 1 consists of technologies which, in the form of products, can be compared with wind turbines. Group 2 consists of investments in general improvements to buildings and savings activities.

Group 1 includes: wind turbines, solar thermal systems, wave power, photovoltaic, fuel cells, heat pumps, district heating pipes, district cooling, bioethanol plants, and biofuel plants. This group's export potential is assessed by comparing it with the commercial development of wind power in Denmark.

Group 2 includes: improvements to buildings, electricity savings investments, and fuel savings investments in industry. However, increased investments in the existing building stock and in low-energy construction will also develop new products, which can then be exported. This is assumed because building materials account for such a large proportion of the construction sector i.e. according to the Confederation of Danish Industry and the Building Materials Industry [57], building materials accounted for approx. 25 per cent of the total investment in construction in Denmark for 2004. Therefore, as building materials in the low-energy construction industry have unique export potential, 10 per cent of the investments in improvements to buildings and in BOLIG+ (a zero emission building concept) are handled under group 1. This amount totals approx. DKK 20 billion.

Investments in charging stations for electric vehicles and flexible electricity demand are included under the commercial potential of electricity regulation in group 1. It is concluded that there will be large potential for Denmark to develop the equipment required to integrate these technologies into the electricity network. These investments amount to approx. DKK 10 billion.

Initially, assessments for group 1 are based on the relationship between wind turbine export and the size of the domestic market which, over a period of 20 to 30 years, has contributed to the creation of new exports. In 2004, wind turbine export accounted for approx. DKK 22 billion. The domestic market contained 3,300 MW of wind power which, according to today's installation costs, is worth approx. DKK 16 billion.

Based on the above, a gross potential export in the range of DKK 230 billion per year can be identified for all technologies in groups 1 and 2. However, far from all of these technologies meet the requirements and the development conditions of the wind turbine scenario. All the same, it is important to evaluate these technologies to assess whether they possess what is required to achieve the same export potential as wind power. The development curve of each technology is created by using a complex interaction between these requirements and their unique learning curves and development processes. In addition, it is assumed that the above export effect can only be realised if there are no other foreign competitors who are better during the same period.

Following a consultation with Professor Peter Karnøe, CBS, the driving-forces behind wind power exports so far have been condensed into the following 10 factors and divided into two categories: industrial and political requirements.

Political requirements

- Denmark was early and persistent in the development of wind turbines. There were specific, long-term goals for more wind power combined with sustained support. In addition, development continued, even during periods with low global market prices for fossil fuels.
- Political will to promote wind power, to change the established and competing industries' terms and rights, and to provide new specific terms for wind turbine owners
- Political promotion of public co-ownership and entrepreneurial buyers
- Persistent pressure from coalitions of advocates for the technology
- Establishment of a new model for mutual development, incorporating research, testing stations, and industry.

Industrial requirements

- Denmark was the first to introduce wind power technology to the market.
- Denmark had a flexible company structure that was able to re-combine old production elements into new products. Thus, the skills present in a number of small and medium-sized companies were transferred to the development of components specifically for wind turbines, such as wings, controls, towers etc.
- At the beginning of the period, there were companies that experienced adversity and sought to diversify their product ranges.
- Early on, the global market experienced both steep growth and sharp decline (fluctuating). Denmark was able to maintain its energy policy and wind power development during periods when the global market was in decline.
- Danish industry had a concept of developing technologies from small turbines and applying them to large ones in close collaboration with the market and research institutions.

Calculations are made for the above-mentioned, relevant technologies, indicating the size of the domestic market that can be expected on implementation of IDA 2030. Also, the technologies are assessed in relation to their ability to meet the above requirements. Political requirements can be met if a political decision is made to implement IDA 2030, while the industrial requirements are assessed in Table 31. The estimates in the table are based on the assumption that the political will to implement the climate plan is present and that the above-mentioned requirements are of equal significance.

Table 31, Assessment of the industrial requirements for commercial potential in group 1

	The vision's domestic market, DKK billions in total during the period	First on the market	Suitable business structure	Free capacity	Significant idea and concept	Global market	Total in relation to wind
Special construction components	20	0	1	1	1	1	80%
Wind turbines	33	1	1	1	1	1	100%
Technology for electric cars	11	1	1	1	1	1	100%
Photovoltaic	5	1	1	1	1	1	100%
Solar thermal	11	0	1	1	0	1	60%
Wave power	6	1	1	1	1	1	100%
Fuel cells	20	1	1	1	1	1	100%
Heat pumps	9	1	1	1	1	1	100%
Bioethanol	2	1	1	1	1	1	100%
Biofuel plants	13	0	1	1	0	1	60%

18.2 Total assessment of the commercial potential

Based on the above, the climate plan's commercial potential is calculated as illustrated in Fig. 33. It is estimated that the climate plan will create the potential for the export of energy technology, increasing from approx. DKK 64 billion in 2008 to over DKK 200 billion up to 2030. IDA's Energy Plan 2030 from 2006 assesses the commercial potential to be approx. DKK 160 billion per year. This has now increased as more export capacity has been identified. The DKK 200 billion per year is consistent with an assessment made by the Energy Industry in 2007 under the Confederation of Danish Industry.

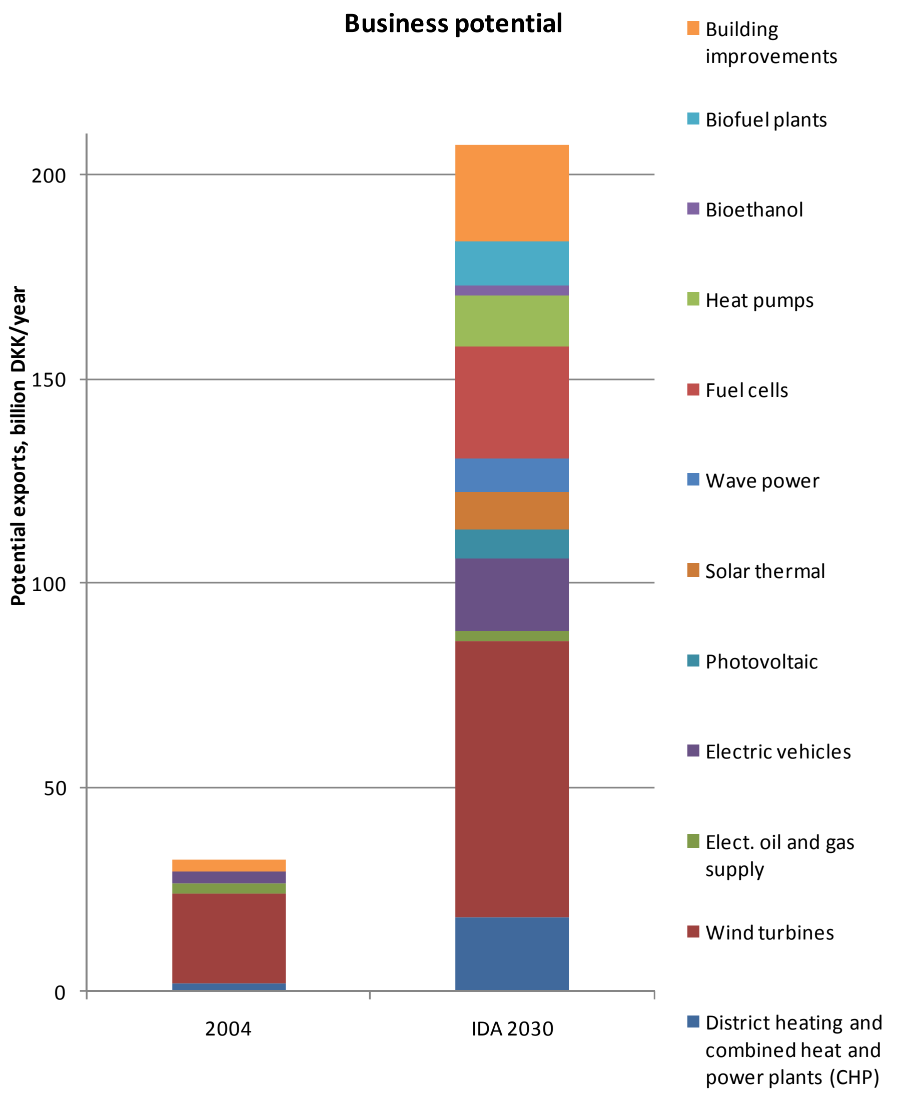


Fig. 33, Commercial potential per year if IDA's Climate Plan 2050 is implemented

Once again, it must be emphasised that a high degree of uncertainty is inherent in this type of quantification and the calculation must be considered an estimate. However, the diagram provides a good summary of the technologies for which IDA's Climate Plan 2050 will create potential and commercial development. It must also be stressed that these potential gains are additional to the gains that have already been discussed chapter 15, which concerned the operation and the structure of the energy systems.

19 Employment effects

Implementation of the IDA Climate Plan 2050 results in a conversion of energy costs: the purchase of fossil fuels is replaced by investments in plant at no additional cost to Danish society. This will result in a higher employment rate and improve the balance of payments at the same time. This can have even further benefits if the plan is implemented while also exploting the above-mention commercial potential due to increased exports.

19.1 Calculation of types of cost

Calculation of the employment effect is based on a breakdown of IDA's Climate Plan 2050 into annual costs and a comparison of these with the reference. The difference in costs can be broken down into investments and operations. The development in operating costs is shown in Table 32. As listed, the energy systems in IDA's Climate Plan 2050 phase out costs for the purchase of fossil fuels, whereas they increase in the reference. On the other hand, costs for biofuels and operations and maintenance increase more in the climate plan than in the reference.

Table 32, Operating costs in IDA 2015, IDA 2030, IDA 2050 and the reference energy systems

	IDA Climate Plan 2050			Reference		
DKK million/year	2015	2030	2050	2015	2030	2050
Coal, oil and gas	60,246	38,577	0	70.217	71.010	79.563
Biomass (DK)	10,973	8,727	21.339	11.557	14.942	14.004
Operations and Maintenance	4,686	8,624	16.836	4.968	4.975	5.391

With respect to investments in plants etc., the extent of the extra investments in the climate plan is calculated for the period up to 2050. The investments are broken down into two sections: construction, including the installation of district heating and railway systems, and other production systems, including wind turbines, solar thermal systems etc.In total, the Climate Plan invests a total of DKK 950 billion more than the reference, distributed over the period between now and 2050.

An import share, as indicated in Table 33 below, is estimated for each type of cost mentioned based on the experience gained from prior compilations of currency and employment data [58;59], which also concerned investments in energy systems. An upward adjustment of the import share has been made in relation to previous data as experience shows that these are increasing.

Table 33, Import share by type of cost

Type of cost	Import share in percent
Investment - Buildings, construction incl. district heating network	30 per cent
Investments - machinery and production units/plants	40 per cent
Operations and maintenance	20 per cent
Fossil fuels (Coal, oil and gas)	90 per cent
Biomass fuels	20 per cent
Average costs per job of the amount excl. import share: DKK 500,000 /job year	

After removing the import share, it is assumed that two jobs will be created for every DKK 1 million remaining. This includes derivative jobs in the finance and service sectors. Again, the figures are adjusted in relation to previously collected data. This time a downward adjustment of the figures is made in order to account for general price developments. Naturally, it must be emphasised that the figures are estimates.

19.2 Total employment effect

After applying the above-mentioned method and assumptions, the employment effects for the reference were compared to the IDA Climate Plan. From the results, it is evident that approx. 30 - 40,000 extra jobs can be created if IDA's Climate Plan 2050 is implemented. As Table 34 shows, jobs handling fossil fuels are lost whereas jobs relating to investment in energy technology are created. In the long term, employment will fall in line with the implementation of investments in the actual conversion to a 100 per cent renewable energy system. For example, Table 34 shows that from 2050 to 2051, employment will fall from approx. 40,000 jobs to approx. 15,000 jobs when investments reduce. In practice however, this will probably be spread over a number of years. By comparison, the Danish Energy Authority and the Confederation of Danish Industry have calculated that currently, the energy industry employs almost 30,000 people.

Table 34, Additional jobs due to the implementation of IDA's Climate Plan 2050, compared with the reference

	2010	2030	2050
Fuels	-2,929	-16,431	-4,177
Operations and Maintenance	-451	5,838	18,312
Inv. (Building construction)	23,450	22,190	20,930
Inv. (Prod. & Machinery)	9,420	9,300	9,180
Total	29,490	20,898	44,245

It is crucial that the main employment effort takes place as close to the beginning of the period as possible. There are two reasons for this. Firstly, the workforce as a share of the total population declines during the whole period up to around 2040 and hence, more working capacity is available to make changes to the energy system at the beginning of the period. Secondly, Danish North Sea resources will run out during the period. Hence, it is important to develop an energy supply based on renewable energy as early as possible and therefore, increase the export of energy technology to replace the export of oil and natural gas that will diminish and cease altogether over the next 10 to 20 years.

Table 34 does not include the job creation resulting from the increase in exports of energy technology. This is an additional benefit. Assuming an import share of 50 per cent, an annual export of DKK 200 billion will generate up to 200,000 jobs. Of course, this depends on the rate of export that would have been possible without the climate plan, the extent of unemployment, and the extent to which the unemployed workforce can be employed in other export industries. It should be noted here that a proportion of the Danish workforce will become available as the extraction of oil and gas from the North Sea is phased out.

Appendix I – Conversion from the Danish Energy Authority's data and results from the reconstruction in EnergyPLAN

The conversion of the Danish Energy Authority's figures to input data for the EnergyPlan model for 2030 is shown below. The principles used to convert the references for other years are identical to the method indicated below. The Danish Energy Authority's background tables and the key figures for 2030 are summarised in Table 35. The converted data that are used as input to the EnergyPlan model are summarised in Table 36. Other heat (collected by heat pumps) is not included as a separate input in the EnergyPlan's calculations. Therefore, this has been omitted.

Table 35, Background data from the Danish Energy Authority's forecast, broken down by type of consumption and electricity producer.

From the Danish Energy Authority 2030 (PJ/year) - projection											
Coal	Oil	Natural gas	Biomass	Renewable	Other heat	Total	Fuel	Electricity	District heating	Key fig.	
69.82	2.64	7.47	61.81			141.74	141.74	-60.04		81.70	Power plants
				41.33		41.33	41.45	-41.45		0.00	Onshore wind
				0.11		0.11				0.00	Hydro power
34.67	0.98	4.50	34.24			74.39	74.39	-26.36	-40.73	7.30	CHP central
0.63	0.18	9.57	11.20			21.58	21.58	-8.04	-10.36		CHP cdecentral
0.00	9.36	15.20	13.72	0.03		38.30	38.30	0.41	-36.24	2.47	District heating boilers
0.07	2.56	7.72	2.84			13.20	13.20	-4.37	-7.54	1.29	Industriel CHP
			44.14			44.14	44.14	-9.93	-27.54	6.67	Waste CHP
			0.26			0.26	0.26	0.00	-0.21	0.05	Waste district heating
10.78	67.90	28.99	8.77	0.00	1.61	118.05	118.05			118.05	Industry
0.00	3.28	10.07	0.84	0.08	0.00	14.27	14.27			14.27	Service
	116.27					116.27	116.27			116.27	Transport Diesel et.c
	67.89		10.46			78.35	78.35				Transport Petrol etc..
	39.14					39.14	39.14			39.14	Transport jet fuel
0.00	9.42	17.25	41.53	1.73	12.18	82.10	82.10			82.10	Households
								4.06		4.06	Households and heat pumps
						0.00		145.73		145.73	Electricity demand
						0.00			123.59	123.59	District heating demand
					0.00	0.00	0.00	0.00	0.00	0.00	Geothermal
		0.07				0.07	0.07			0.07	Ngas grid losses
	13.23					13.23	13.23			13.23	Non Energy
	16.95					16.95	16.95			16.95	Refinery
		33.04				33.04	33.04			33.04	North see
	0.00	0.13				0.13	0.13			0.13	Household gas
								0.00			Net-export
											Sum various
115.97	349.79	134.01	229.82	43.29	13.78	886.66	886.66	0.00	0.96	806.10	Sum

Table 36, Input from the Danish Energy Authority converted to input to the EnergyPLAN.

Input EnergyPLAN (TWh/year)												
	Efficiency		Fuel									
	Electricity	Heat	Coal	Oil	Ngas	Biomass	Waste	Solar thermal	Elec. prod.	District heating	Elec. Demand	Distr. Heat demand
Power plant	42.36%		19.39	0.73	2.07	17.17			16.68			
Onshore wind									11.51			
Hydro power												
CHP central	35.43%	54.76%	9.63	0.27	1.25	9.51			7.32	11.31		
CHP decentralised	37.25%	48.02%	0.17	0.05	2.66	3.11			2.23	2.88		
District heating boilers		94.62%	0.00	2.60	4.22	3.81		0.01		10.07		
Industriel CHP	33.15%	57.10%										
Waste CHP	22.50%	62.40%	0.00	0.00	0.00	0.00	12.26		2.76	7.65		
Waste district heating		79.76%	0.00	0.00	0.00	0.00	0.07			0.06		
Industry sum (gr 3)			3.02	20.48	13.00	3.46			1.22	2.09		
Transport Diesel etc.				32.30		0.00						
Transport Petrol etc.				18.86		2.91						
Transport jet fuel				10.87		0.00						
Households			0.00	2.62	4.79	11.54		0.50				
Households/heatpumps											1.13	
Elec. Demand											40.59	
District heating Gr 1												2.64
District heating Gr2												9.90
District heating Gr 3												21.52
District heating demand												*34.06*
Geothermal (COP)		1.00								0.00	0.00	
Ngas grid losses												
Non energy												
Refinery												
North see												
Household gas												
Net-export											0.00	
Sum various			0.00	8.38	9.23	0.00						
Sum			32.21	97.16	37.22	51.50	12.33	0.51	41.72	34.06	41.72	34.06
Control (PJ/year)			115.97	349.79	134.01	185.42	44.40	1.84	150.19	122.62	150.19	122.62

The results from the reconstruction of the 2030 energy system are presented in chapter 6. The reconstruction of the 2015 system is presented in Table 37, while the reconstruction for 2050 is presented in Table 38. The assumptions for the 2050 energy system are presented in chapter 6. Please note that the 2050 energy system is not compared with any of the Danish Energy Authority's reference systems, but is based a separate forecast conducted in this report.

Table 37, Reconstruction of the reference in the EnergyPLAN model for 2015.

2015		**The reference**		**EnergyPLAN calculations**	
		Forecast	**Identical electricity market exchange**	**Reconstruction**	**Identical electricity market exchange**
Input:					
Electricity demand	TWh/year	36.4	36.6	36.4	36.4
District heating demand	TWh/year	35.3	35.3	35.3	35.3
Individual heating boilers	TWh/year	23.3	23.3	23.3	23.3
Industry incl. service & refineries	TWh/year	34.8	34.8	34.8	34.8
Transport (incl. aircraft and ships)	TWh/year	62.0	62.8	62.8	62.8
North Sea, losses, etc.	TWh/year	16.8	16.8	16.8	16.8
Avg. efficiency decentralised -CHP (elec./heat)	Per cent	36 / 47	36 / 47	36 / 47	36 / 47
Avg. efficiency central CHP (elec./heat)	Per cent	32 / 52	32 / 52	32 / 52	32 / 52
Avg. efficiency condensation power plants	Per cent	41	41	41	41
Primary energy supply					
Wind, waves, solar, hydropower	TWh/year	10.4	10.4	10.4	10.4
Solar thermal	TWh/year	0.2	0.2	0.2	0.2
Coal	TWh/year	36.4	37.3	39.2	36.6
Oil	TWh/year	94.8	94.9	94.8	94.9
Natural gas	TWh/year	41.6	39.6	45.6	46.4
Biomass	TWh/year	41.8	39.7	39.6	39.7
Total, incl. electricity export	TWh/year	225.2	222.1	229.9	228.2
Key figures					
Net export (excess electricity)	TWh/year	-2.1	-2.2	1.6	0.3
Total adjusted for electricity export	TWh/year	233	227	226	228
Condensing PP electricity in per cent of electricity demand	Per cent	31	21	22	22
Boilers in per cent of district heating demand	Per cent	26	12	9	15
CO_2 emission	Ton/year	49.7	46.2	48.1	47.4
Adjusted CO_2 emission	Ton/year	52.2	46.5	45.9	46.0

Table 38, Construction of the reference in the EnergyPLAN model for 2050.

2050		EnergyPLAN calculations		
		Identical electricity market exchange		Identical electricity market exchange
Input:				
Electricity demand	TWh/year	51.5	51.5	51.5
District heating demand	TWh/year	34.1	34.1	34.1
Individual heating boilers	TWh/year	15.6	15.6	15.6
Industry incl. service & refineries	TWh/year	51.6	51.6	51.6
Transport (incl. aircraft and ships)	TWh/year	75.7	75.7	75.7
North Sea, losses, etc.	TWh/year	8.4	8.4	8.4
Avg. efficiency decentralised - CHP (elec./heat)	Per cent	37 / 48	37 / 48	37 / 48
Avg. efficiency central CHP (elec./heat)	Per cent	35 / 55	35 / 55	35 / 55
Avg. efficiency condensation power plants	Per cent	42	42	42
Primary energy supply				
Wind, waves, solar, hydropower	TWh/year	14.0	14.0	14.0
Solar thermal	TWh/year	0.5	0.5	0.5
Coal	TWh/year	51.5	42.3	41.9
Oil	TWh/year	117.5	117.5	117.5
Natural gas	TWh/year	36.4	35.5	35.8
Biomass	TWh/year	55.2	55.2	55.2
Total, incl. electricity export	TWh/year	275.2	265.0	264.8
Key figures				
Net export (excess electricity)	TWh/year	4.6	0.2	0.1
Total adjusted for electricity export	TWh/year	264	264	265
Condensing PP electricity in per cent of electricity demand	Per cent	34	35	35
Boilers in per cent of district heating demand	Per cent	9	9	10
CO_2 emission	Ton/year	56.5	53.2	53.1
Adjusted CO_2 emission	Ton/year	53.1	51.6	51.6

Appendix II – Costs of the technologies in IDA's Climate Plan 2050

The costs estimated in the table below are supplementary to the data in the technology catalogue for electricity and heat-producing plants used by the Danish Energy Authority [14], as well as to the technology descriptions above.

Reference technologies	Unit	Inv. (DKK million/unit)	Lifetime (year)	Fixed operations and maintenance costs as per cent of inv./year	Variable operations & maintenance	Notes / sources
Small CHP plants	MW-e	5.00	20.00	1.50	20.00	[14]
Large CHP plants	MW-e	10.00	30.00	2.00	20.00	[14]
Power plants	MW-e	8.00	30.00	2.00	15.00	[14]
Large heat pumps	MW-e	20.00	20.00	0.20	2.00	[14]
Large heat storage systems	GWh	10.00	20.00	1.00	0.00	[7]
Wind, onshore	MW-e	8.00	20.00	2.40	0.00	[8] [30]
Wind, offshore	MW-e	12.00	25.00	3.00	0.00	[9] [31]
Individual boilers	MW-th	5.00	15.00	2.50	10.00	[10] [32]
Individual heat pumps	MW-e	28.00	15.00	0.70	0.00	[11] [32]

[7] PlanEnergi: Steel tank DKK 18 million for 30,000 m^3, equivalent to approx. 1.6 GWh

[8] However, for IDA 2015 the investment costs for onshore wind turbines are DKK 8.5 million/MW, while operations and maintenance costs are 1.8% of the total investment per year.

[9] However, for IDA 2015 the investment costs for offshore wind turbines are DKK 15.5 million/MW, while operations and maintenance costs are 3% of the total investment per year.

[10] Average for oil boilers: DKK 45,000 DKK/system, biomass boilers: DKK 50,000 DKK/system, and natural gas boilers DKK 30,000 DKK/system. In addition, average operations and maintenance costs of 2.5%, 2.8%, and 2.1% respectively of the total investment per year.

[11] Average for geothermal heat pumps: DKK 100,000 DKK/system and air/water systems: DKK 50,000 DKK/system. In addition, average operations and maintenance costs of 0.9% and 0.6% respectively of the total investment per year. It is assumed that half of the investment in geothermal heat plants has a lifetime of 40 years.

IDA (production)

	Unit	Inv. (DKK million/unit)	Lifetime (year)	Fixed operations and maintenance costs as per cent of inv./year	Variable operations & maintenance	Notes / sources
Small fuel cell CHP plants	MW-e	6.00	20.00	10.00	20.00	[12]
Large fuel cell CHP plants	MW-e	6.00	30.00	6.00	20.00	[12]
Fuel cell power plants	MW-e	6.00	30.00	6.00	15.00	[12]
Photovoltaic	MW-e	7.50	25.00	0.25	0.00	[13]
Wave power	MW-e	14.00	30.00	1.13	0.00	[14] [14]
Individual solar thermal	GWh/y	5.00	20.00	1.00	0.00	[15]
Large solar thermal	GWh/y	3.20	25.00	0.05	0.00	[16]
Dam heat storage systems	GWh	5.00	25.00	0.50	0.00	[17]
Electrolysis plants	MW-e	1.88	20.00	2.00	0.00	[18]

IDA 2030 (savings)

	Unit	Inv. (DKK million/unit)	Lifetime (year)	Fixed operations and maintenance costs as per cent of inv./year	Variable operations & maintenance	Notes / sources
Buildings						
Electricity savings	TWh	4000	10.00	0.00	0.00	[19]
Heat savings	PJ	2000	50.00	0.00	0.00	[20]
Industry						
Electricity savings	TWh	1500	15.00	0.00	0.00	[21]
Fuel savings	TWh	930	30.00	0.00	0.00	[22]

[12] Data relating to the cost of fuel cells for CHP plants from 2015 onwards is supplied by Topsoe Fuel Cells.
[13] Expected price after 2016. Further information is available in section 8.2.
[14] Expected price after 2020. Further information is available in section 8.3.
[15] PlanEnergi/Arcon: 10 m^2 + 500 litres costs DKK 30,000 + 15,000 and produces 5 MWh (DKK 500/year in operating costs).
[16] PlanEnergi/Arcon: DKK 1,600/m^2 all inclusive for 500 kWh/m^2 (DKK 2/MWh in operating costs).
[17] PlanEnergi: DKK 250/m^3 for dam heat storage systems over 100,000 m^2.
[18] See Appendix IV.
[19] Based on input from the Danish Electricity Saving Trust. Further information is available in section 9.1.
[20] IDA 2015 applies a figure of DKK 1,000 million/PJ. Further information is available in section 9.4.
[21] See section 10.1.
[22] See section 10.3.

Appendix III – Forecast of economic development and energy demand from 2030 to 2050

Kenneth Karlsson, Risø-DTU, May 2009

This memorandum presents forecasts of the energy demand in different sectors based on IEA 2008 for the Danish Society of Engineers' climate plan for the year 2050, IDA's Climate Plan 2050. The forecast should be seen as a reference scenario and is similar to the Danish Energy Authority's basic forecast that was completed in April 2009, for each year until 2030 [6]. After 2030 up until 2050, continued energy savings are expected in line with the 2010 to 2030 period, i.e. a continued active policy to reduce the energy consumption has been included in the reference scenario.

The Danish Energy Authority's basic forecast from June 2008 was based on the Ministry of Finance's 2015 plan, "Towards new goals – Denmark 2015" from August 2007. This 2015 plan forecast was created before the financial crisis began and has therefore not taken into account the economic fall that is expected in 2009 and for some years into the future.

Hence The Ministry of Finance (MF) has prepared an ADAM forecast, "Convergence Programme 2008", from December 2008 that runs until 2100. The Convergence Programme 2008 contains a picture of the Danish economy with a fall in the gross domestic product for 2009, a weak growth in 2010, and then the growth returns to the level from the previous forecast. The economic crisis is thus expected to be straightened out during the course of the next 2 years, with the long-term "equilibrium growth level" staying between 1½ and 2 per cent per year. Following a very low level of unemployment in 2008, unemployment is expected to be on a level with the structural unemployment of around 3½ per cent. The conditions for this development are a 0-rate growth in the GDP for Denmark's trading partners in 2009, partial normalisation in 2010, and a growth of 2.1 per cent per year after 2010. It should be noted that the Convergence Programme is based on IEA´s 2007 oil price forecast, which ends at 66 $/bbl in 2030, while IEA´s 2008 price forecast anticipates a long-term real oil price of 122 $/bbl in 2030. The economic growth in the ADAM forecast is therefore high in comparison, as lower fuel prices were taken into account. FM's Convergence Programme 2008 (CP2008) is what forms the basis for the Danish Energy Authority's April 2009 basic forecast used in this report. Figure 1 shows the annual growth in GDP and the private consumption in CP2008.

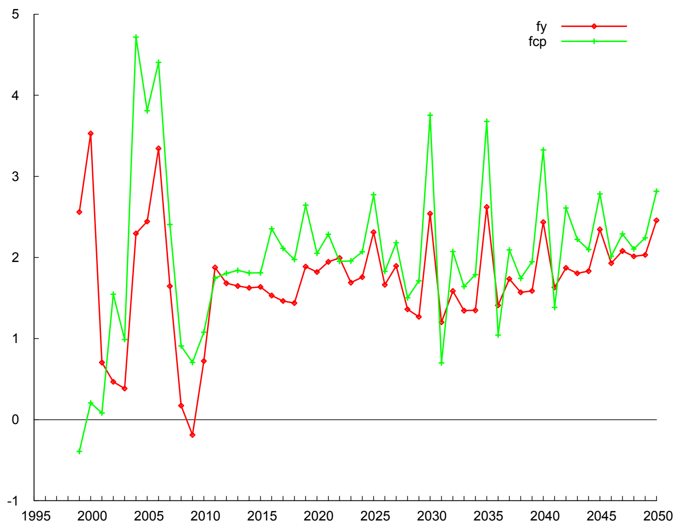


Figure 1 Annual percentage growth in GDP (fy) and private consumption (fcp).

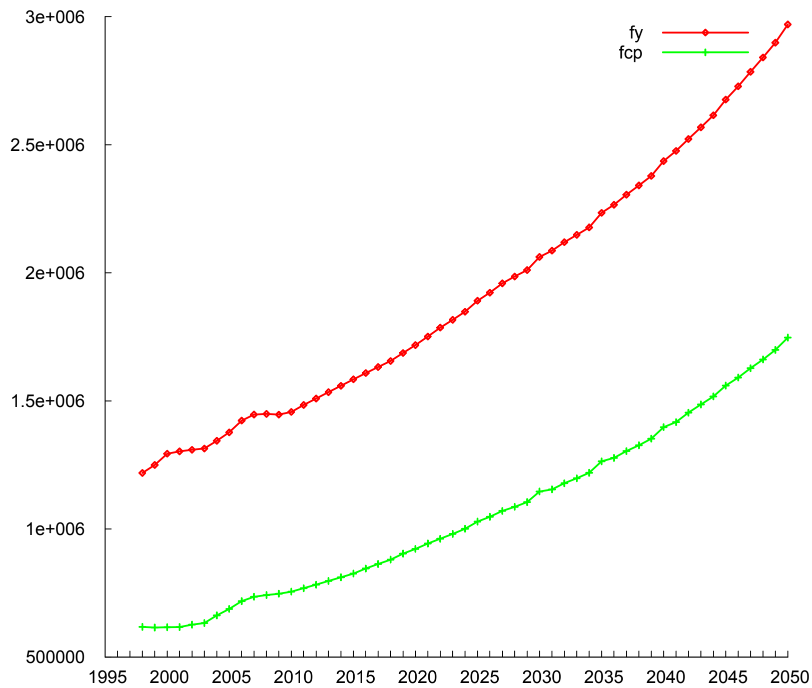


Figure 2, The development in GDP (fy) and Private Consumption (fcp) in fixed prices (in 1,000 2000-DKK prices)

Figure 2 shows the development in the GDP and private consumption in fixed prices. It can be seen from this that the GDP doubles in the 2008 to 2050 period from 1400 billion 2000-DKK to 3000 billion 2000-DKK.

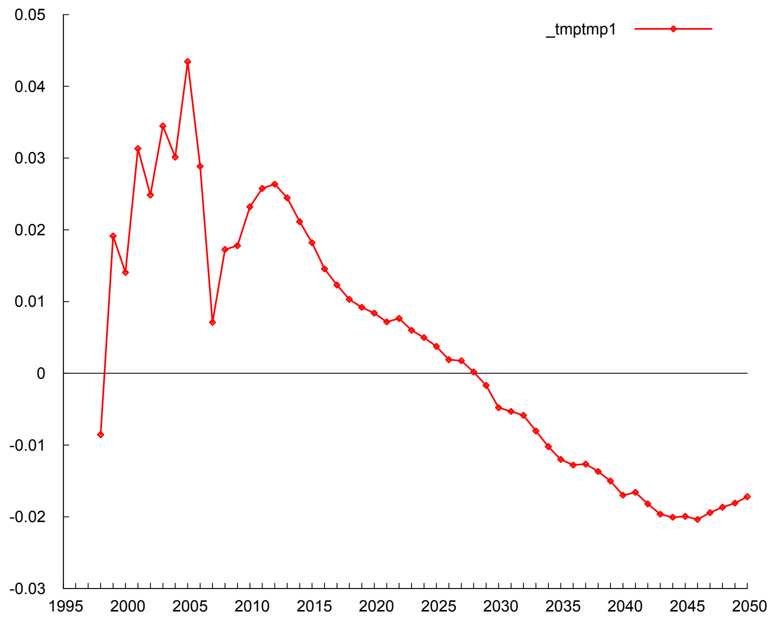


Figure 3, The balance of payments in relation to the GDP. For example, the balance of payments deficit is 2per cent of the GDP in 2045.

One problem with the current Convergence Programme is that after 2030, Denmark builds up an increasing foreign debt due to a negative balance of payments from 2029, which creates a risk of overestimating the economic growth and the energy demand.

This constant deficit in the balance of payments from 2029 means that the foreign debt is up to 20 per cent of the GDP in 2050.

The forecasts for the IDA Climate Plan scenarios are based on the Danish Energy Authority's forecast from April 2009 until 2030, where the economic development is based on the Ministry of Finance's "Convergence Programme 2008", which includes the financial crisis and is run until 2100. Therefore, it is also used as the basis for the economic development until 2050 in the IDA scenarios.

Changes to fuel prices affect the economy through industries' energy expenses. If the prices rise, energy-intensive industries will be affected more severely than those that are less energy-intensive, i.e. there will be a shift between the industries. Higher energy prices will also mean that the industries will concentrate more on manpower and investments in production plant rather than energy (what are known as production factors). These changes/effects can be captured by running ADAM with the changed prices, although this has not been done here.

The scenarios should in principle therefore be based on an updated version of the Convergence Programme that takes new fuel prices into account and that handles the problem with the balance of payments.

In order to ensure "semi" consistency between the economic development, society's demand for energy services, and the Danish energy system of the future, a combination of macroeconomic models and an energy system model has been chosen.

Figure 4 illustrates the sequence of calculations in the models used.

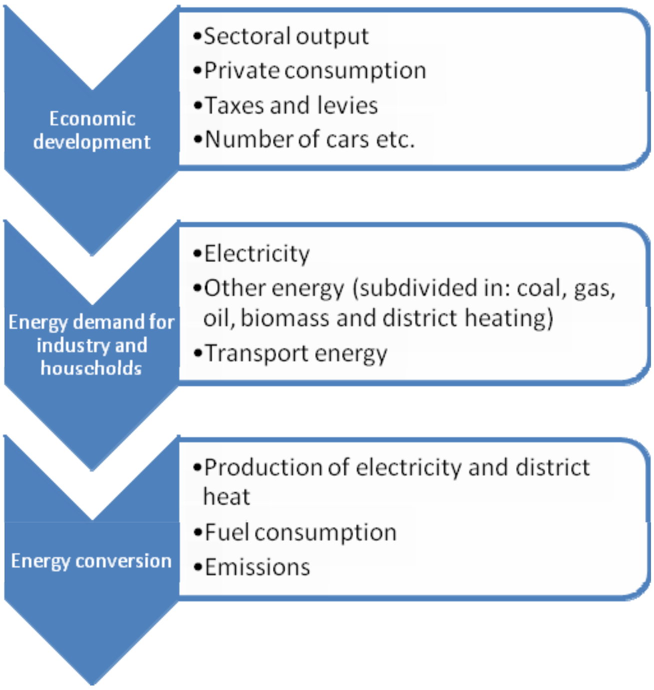


Figure 4 Models that are included in IDA's scenarios.

EMMA determines the individual industries' demand for electricity, other energy, and transport energy. Electricity is substituted for other energy for some industries, while other industries do not have the option of changing between these. For other energy, a certain degree of substitution is assumed for the industries between oil, coal, gas, district heating, and biomass, while exogenously fixed shares are used for the households.

ADAM is a macroeconomic model of the Danish economy. It has 19 industry sectors, including private and public consumption. ADAM is an econometric model that can in the short term be used as an economic cycle model, but that in the long term (more than 5-10 years) has characteristics of a general equilibrium model (a balance in the public budgets and balance of payments is of course ensured). It is used by the Ministry of Finance for their official economic forecasts for the Danish economy and thereby also constitutes the basis of other Ministries' analyses, including the Ministry of Climate and Energy. ADAM is maintained by Statistics Denmark.

EMMA is an energy and emissions module for ADAM, developed as a Research project with cooperation between Risø DTU, DMU, and Statistics Denmark. It is an econometric model that, on the basis of a forecast of the economic activity for the individual industries from ADAM, calculates the associated energy consumption divided among electricity, other fuels, and transport. EMMA is used by the Danish Energy Authority to forecast the industries' and households' demand for electricity, district heating, and fuels. EMMA is maintained by the Danish Energy Authority and Risø DTU. The documentation for the ADAM and EMMA models can be found on the following homepage: www.dst.dk/adam

EnergyPLAN is a simulation tool that describes an energy system using parameters such as plant capacities, levels of efficiency, and a regulation strategy. On the basis of such inputs, the model can perform a range of technical analyses,which define how the energy system should operate hour by hour over the space of a year. The result includes calculations of the balance between consumption and production over the year in the energy system analysed, plus the associated annual fuel consumption, CO_2 emissions, and economic consequences. EnergyPLAN was developed at Aalborg University and can be downloaded from the homepage: www.energyplan.eu

The ADAM and EMMA models are only used in the IDA scenarios to form the basic forecasts based on the Danish Energy Authority's April 2009 forecast [6]. They are not used to calculate the consequences of the investments and changes made to the energy system until 2030 and 2050. So, ADAM and EMMA are used here in the same way that the Danish Energy Authority uses them for the Government's official forecasts. Therefore, if the economic development in Denmark and the development in the energy system are consistent within the scenarios created, changed investments in the energy system and assumptions regarding changes in the tax system will require new runs of ADAM and EMMA. This will create new demand levels that change the need for investment in the energy sector and that also affect the economy. Using iteration between the macroeconomic models and the energy system models allows consistent scenarios to be created.

Consequuently, forecasts for Denmark's energy system should be created in close cooperation between the macro economists and energy system analysers, i.e. in practice a call for the Ministry of Finance, the Danish Energy Authority, universities, and others to work closely together in the future in an iterative process where forecasts are concerned.

Results of the forecast

Until 2030, IDA's reference scenario follows the Danish Energy Authority's basic forecast for April 2009. For details on the conditions regarding energy savings and other assumptions until 2030, please refer to the Danish Energy Authority's memorandum on the Basis Forecast for April 2009 [6].

The following briefly shows the assumptions used and the forecast for the energy demand using EMMA from 2030 to 2050.

Important conditions/inputs for the EMMA calculations include the future price of electricity, trend in private consumption, the industries' production, the development in energy levies, housing areas, and efficiency improvements. Most of these come directly from the ADAM model through FM's CP2008, while the level of efficiency improvements will be assessed externally.

From 2030 to 2050, EMMA counts on an average price of electricity of 85 øre/kWh (incl. a load distribution supplement, PSO contribution, mains electricity tariff, etc.), corresponding to a spot market price of 63 øre/kWh.

The industries' total production and private consumption are shown in Figure 5. It shows that the growth in the industries' production is higher than the growth in private consumption. This means, that the industries represent an increasingly larger share of the energy demand.

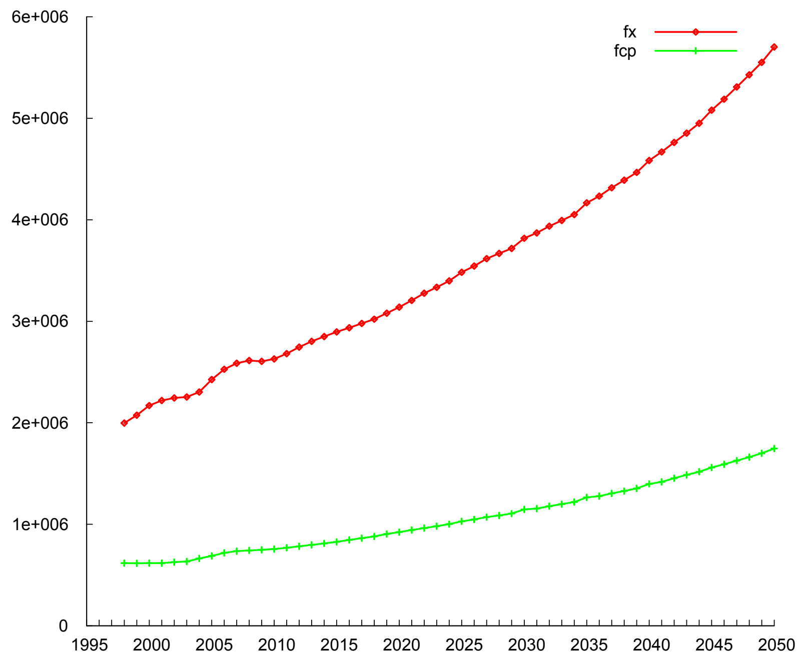


Figure 5, Development in the industries' production value and private consumption in fixed prices (in 1.000 2000-DKK prices).

With regard to taxes and levies, no new changes have been assumed in addition to those which have already been included in CP2008. From 2030 and onwards, the energy levies are simply assumed to increase with inflation.

The housing area is assumed to continue to increase by 0.86 per cent per year as assumed by the Danish Energy Authority from 2010 until 2030.

EMMA's energy equations include an efficiency index called a trend, which describes both the change in energy demand within the industry as a consequence of structural changes and also the technological improvements. In the forecast from 2030 to 2050, the efficiency development and structure effects are assumed to follow the level from the period until 2030, i.e. the industries increase their energy efficiency in electricity consumption by a total of 1.3 per cent per year (however, there is a major difference between the industries, as displayed in Table 1). The energy consumption goes the opposite way to the structural effects. Taking an average over all of the industries indicates that they use 0.2 per cent more energy a year per value increase as a consequence of a changed industry structure. This means that the total trend regarding the industries' electricity consumption in relation to the value of their production is 1.3 per cent minus 0.2 per cent, i.e. 1.1 per cent per year.

Table 1, The industries' developing energy trend (per cent annual efficiency change) for electricity consumption and other energy consumption (processing and heating) from 2030 to 2050.

Sectors Annual %-changes	Electricity demand (GJ)	Structural changes last 10 years in model	Changes 2030-2050	Other energy (GJ)	Structural changes last 10 years in model	Changes 2030-2050
Fishery	215	0	-1.3	32	0	-1.35
Garden/greenhouses	947	0	-1.4	6147	0	2.8502
Agriculture	6491	-0.31	0.98	26261	-0.16	-0.808
Nutrients and stimulants	8198	0.43	-0.27	24217	0.30	0.1072
Iron and metal	8595	-0.79	2.5	10013	-0.79	1.2742
Steel	270	0	2.8	1624	0	-2.65
Chemical	6560	-1.79	4.5	7566	0.15	4.0602
Other production	6809	0.24	-0.14	17100	1.22	0.471
Cement	1559	0	-1.2	17417	0	0.9502
Glass	722	0	-1.6	1353	0	-1.15
Construction	1133	0.29	0.5	5715	0.04	-0.114
Trade	12716	-0.59	3.53	11947	0.17	2.6476
Offices	1728	1.28	0.94	2163	0.71	3.3502
Hotel etc.	3549	-0.41	1.48	5464	-0.16	-0.75
Other private service	5935	0.3	-0.36	9110	0.07	0.1021
See transport	101	0	1.51	4646	0	1.0202
Aviation	79	0	1.62	72	0	1.1302
Road transport	4854	-1.57	1.59	1439	-1.93	1.4602
Railroads	1282	0	1.56	3099	0	1.0702
Public service	8936	0.33	1.94	16544	-0.16	1.3102

For processing energy and heating, the technical efficiency improvement is an average of 0.2 per cent per year, while there is largely no structural effect on energy consumption for processing and heating. Therefore, the economic growth and efficiency improvements assumed are used to forecast industries' final energy consumption with EMMA, shown in Figure 6.

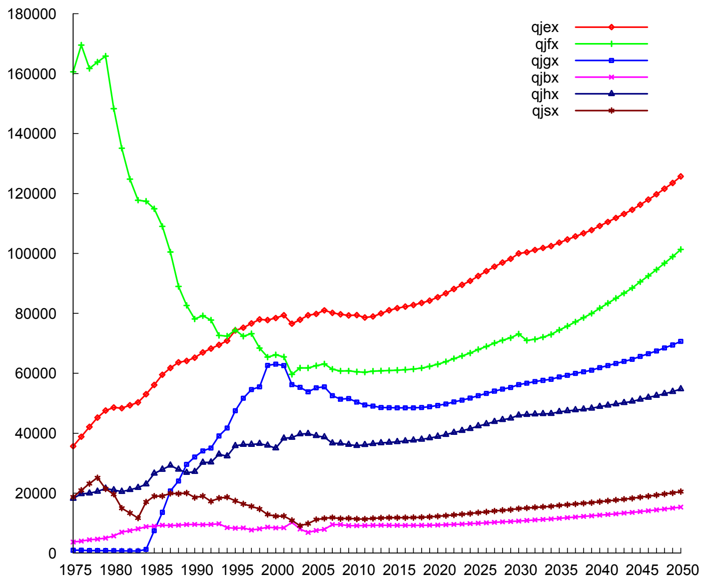


Figure 6 Forecast of industries' final energy consumption. Until 2030, the development follows the Danish Energy Authority's basic forecast from April 2009. From 2030, it is assumed that a similar policy will continue.

The forecast has assumed substitution between the fuels in other energy (oil, gas, biomass, district heating and coal), i.e. the distribution between these fuels depends on their price, incl. levies and the individual industries' opportunity for substitution.

The forecast for the households' electricity and heat consumption is based on EMMA's household model. The households' electricity consumption is divided up into some groups of devices where the model needs assumptions regarding the efficiency improvements within these groups. The electricity consumption for households is divided up into "Household machines", "TV, etc.", "Lighting", "Various", and "PCs". The forecast from 2030 to 2050 assumes the following annual efficiency improvements:

- Household machines 0.63 per cent per year
- TV, etc.: 0.85 per cent per year
- Lighting: 0.26 per cent per year
- Various: 1.27 per cent per year
- PCs: 2.53 per cent per year.

These improvement rates are based on an "ELmodel Bolig" [electricity model, housing] forecast of the Danish composition of devices. The "Various" group has a negative efficiency improvement, which is attributed to the fact that this group, as well as containing circulation pumps and ventilation, also covers new devices that do not come under the other categories.

With regard to the heating of homes, the continuous improvement of building materials until 2030 that is included in the Danish Energy Authority's basic forecast for April 2009 is expected to continue in the 2030 to 2050 period. This means that the heat loss from buildings per m^2 is lowered by 2 per cent per year. Figure 7 shows the resulting forecast of the households' energy consumption. "Other energy" is divided between gas, oil, district heating, and biomass.

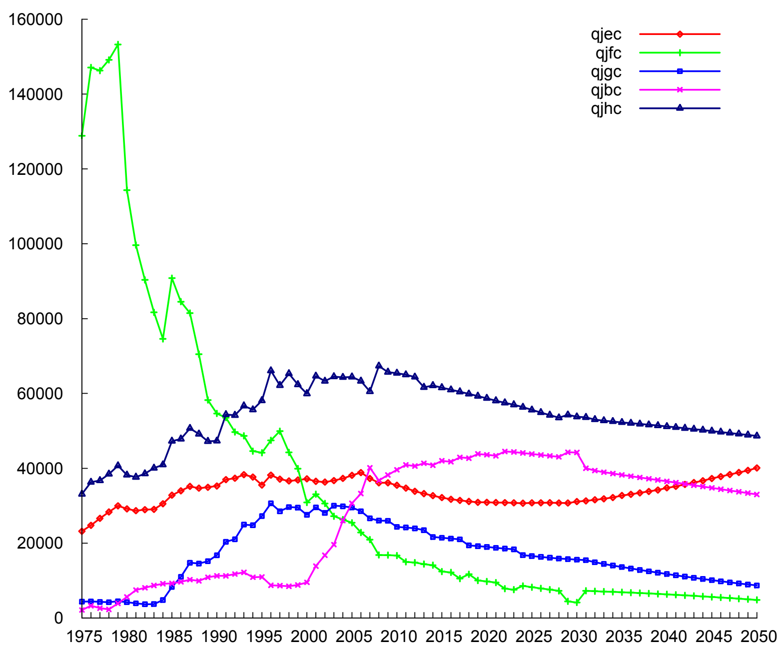


Figure 7, Historical figures and forecast for the households' final energy consumption (TJ/year). [qjec=electricity, qjfc=oil, qjgc=gas, qjbc=biomass, qjhc=district heating].

When forecasting the transport energy consumption, a 0.5 per cent annual efficiency improvement is assumed for all means of transport. EMMA models the industries' own transport, transport in private cars, and the transport industries' (air, road haulage, train, bus and ship/ferry) energy consumption for transport.

Figure 8 thus shows the total Danish demand for electricity, "other energy", district heating, and finally the transport energy consumption.

The Danish district heating consumption is thereby assumed to be almost constant from today, while other energy grows by 0.5-1 per cent per year, and the electricity consumption and transport energy consumption grows by 1-1.5 per cent per year.

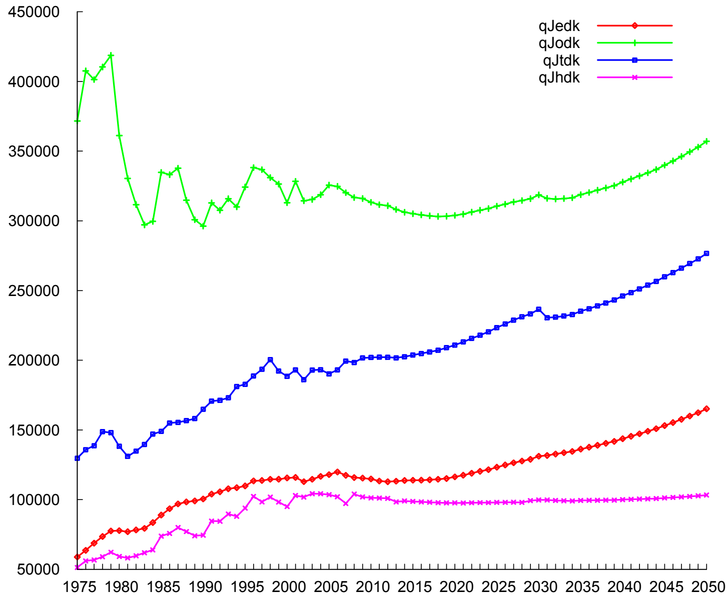


Figure 8, Result of the forecast for the final Danish energy consumption (TJ/year). [qjedk=electricity, qjodk=other energy, qjtdk=transport, qjhdk=district heating].

The forecasts presented here for the final Danish energy consumption are used as a basis forecast for IDA's scenarios until 2030 and 2050.

Appendix IV – Technology data for future high temperature solid oxide electrolyser and current alkali electrolysers

Brian Vad Mathiesen, Aalborg University, January 2009 in [60].

High temperature electrolyses are not yet developed. In this technology sheet an estimate of the technology data for such future technology is presented. All values presented on the efficiency of the cells are based on the lower heating value (LHV).

The data presented here represents an update and expansion of the data sheet used by the Danish Energy Authority from March 2005. [14]. The updates are mainly based on input from Professor Mogens Mogensen and Scientist Søren Højgaard Jensen from the Fuel cells and Solid State Chemistry Department at Risø National Laboratory for Sustainable Energy – Technical University of Denmark.

Two sets of data are presented for high temperature solid oxide electrolyser cells (SOEC). One which represents the theoretical maximum efficiency with ideal conditions and one with electrolysers where 10 per cent heat losses are included, as a proxy for including balance of plant consumption and losses. The data are presented for hydrogen and CO_2 electrolysers. For use in energy system analyses the second set of data which includes these losses are recommended. The technology is still in the early development stage. It is anticipated that commercial electrolyser plants will be available from 2020. It should be noted that such technology and cost data are connected to considerable uncertainties.

For comparison data for a current and future alkali electrolyser is presented. Based on different publications state-of-the art data for alkaline electrolysers is presented.

The results are listed in table 1.

Theoretical maximum for high temperature electrolysers

Energy balance based on ideal theoretical conditions for SOEC is based on the production of 1 mole of hydrogen and illustrated in Fig. 34. 1 mole of hydrogen represents 242 kJ.

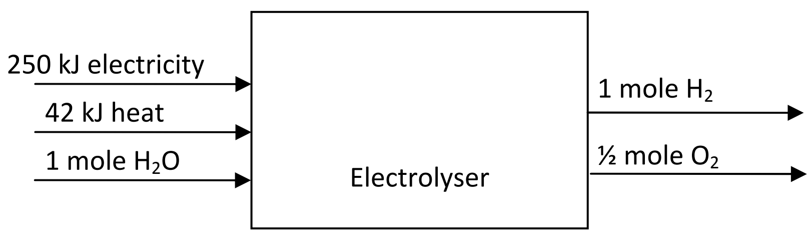


Fig. 34, Theoretical optimal operation conditions in high temperature hydrogen electrolyses

The inlet heat is used by evaporating water. The inlet heat should be delivered at ~250°C at ~40 atm. considering that the heat is "free" the electricity to fuel efficiency is 96.8 per cent. Considering that the heat is not "free" the electricity and heat to fuel efficiency is 82.9 per cent with ideal operation conditions (assuming that the heat origins from electricity). For CO_2 electrolyses the same ideal theoretical conditions are illustrated in Fig. 35.

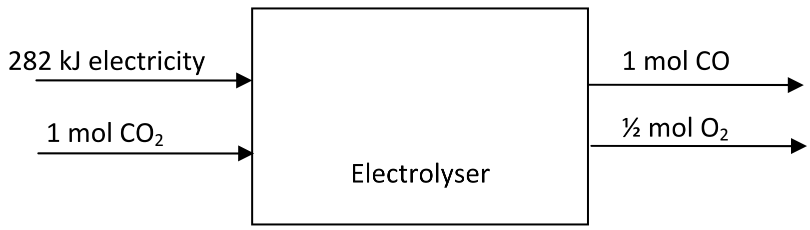


Fig. 35, Theoretical optimal operation conditions of high temperature CO_2 electrolyses

The electricity to fuel efficiency is 99.3 per cent with ideal operation conditions in the case of CO_2 electrolysis. In this case totally pure CO_2 has to be delivered.

Future possible high temperature electrolysers

High temperature electrolyses cannot be expected to operate with ideal operation conditions. For energy system analyses it is recommended that the following data are used, in which 10 per cent heat losses have been included. Such low value heat however can be used in district heating systems, where other fuel can be replaced. The 10 per cent heat losses are losses to the surroundings. For larger units the losses may be smaller. Another possibility in the future is that the losses are lower than the 10 per cent, because the heat can be utilized for preheating water.

In Fig. 36 the operation conditions for high temperature hydrogen SOEC is presented. Considering that the heat is "free" the electricity to fuel efficiency is 88.0 per cent and the electricity to low value heat efficiency is 9.1 per cent. Considering that the heat is not "free" the electricity and heat to fuel efficiency is 76.3 per cent and the electricity and heat to low value heat efficiency is 7.9 per cent.

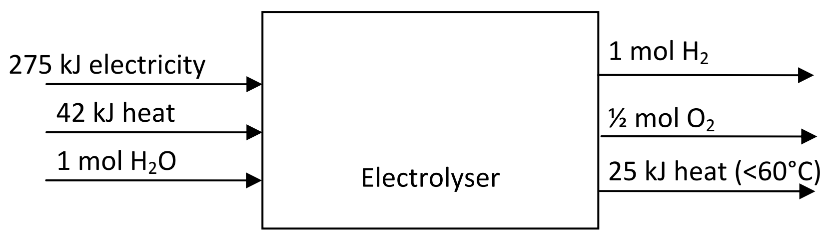


Fig. 36, Potential future operation conditions of high temperature hydrogen electrolyses

High temperature CO_2 electrolyses is presented in Fig. 37. In this case it is recommended to use 90.3 per cent electricity in fuel out efficiency and 9.0 per cent electricity in low value heat out efficiency. Losses due to the purification process in the procurement phase of CO_2 have to be added.

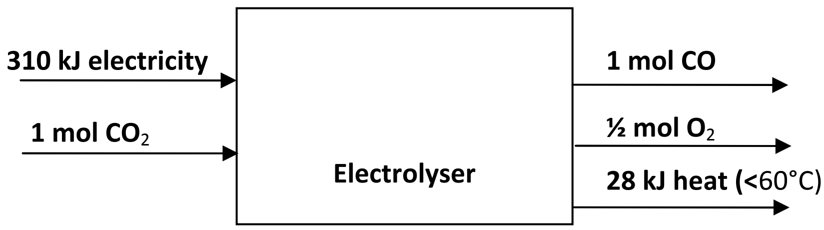


Fig. 37, Potential future operation conditions of high temperature CO_2 electrolyses

The H_2O and CO_2 electrolyses can be combined and the electricity and heat consumption can be calculated linearly by combining the operation parameters presented above. This has been tested at Risø National Laboratory at 850°C and the cell performance seems to change quite linear from pure H_2O/H_2-performance over mixed H_2O/H_2-CO_2/CO-performance to pure CO_2/CO-performance.

The cells have fast regulation abilities (from 0% to 100% power in less than a few seconds) if the cell temperature is kept at the maximum operating temperature. If the cell is operated below 100 % power a heat supply is needed to keep the cell temperature at the maximum operation temperature. The heat-supply-device can be fairly simple and is not considered a significant cost component. Operation below 100% power (or below thermo-neutral-potential (E_{tn} = 1.3 V) does not affect the electricity-to-fuel-efficiency. That is because the heat supply equals the reduction of the electricity consumption in the cell (i.e. the total voltage (cell + heat supplier) is 1.3 V regardless of the power ratio).

The start-up time of SOEC is a challenge; however different operation and insulation strategies can be applied in the SOEC-plant in order to keep the plant at operation temperature. If the SOEC is cold the start-up time is several hours.

When using the electricity to fuel efficiencies the DC/AC inverters also has to be considered as well as the potential losses in the fuel storages. For the inverters 5 per cent losses should be added.

The costs of future high temperature electrolysers

According to the Danish Energy Authority [14], the costs of solid oxide electrolysers is 0.18 M€/MWe, with a lifetime of 20 years. However there are extra costs of connection electrolysers to the grid, because normally the grid is designed to move electricity to larger transmission lines. Here we need to use significant amounts of electricity. Larger electric boilers between 8-15 MWe are between 530,000 and 800,000 € based on initial Danish experiences. Smaller electric boilers are considered too expensive. The cost of grid connection is between 260,000 and 1,000,000 € for these depending on location and local connection possibilities for these boilers. The costs are estimated to be 66,000 €/MWe electric boiler and 66,000 €/MW grid connection of other technologies such as electrolysers. The lifetime is assumed to be 30 years for the grid connection. The total investment costs of grid connected electrolysers is thus 0.25 M€/MW [61]. The fixed operation and maintenance (O&M) costs are 5,400 €/MW/year which is approx. 3 per cent of the initial investment annually [14]. The replacement of cells in the lifetime of these electrolysers is included in the fixed O&M costs. With such assumptions the total annual costs are 0.021 M€/MW using a socio-economic interest rate of 3 per cent.

At Risø National Laboratory for Sustainable Energy a total investment of between 0.23 and 0.37 M€/MW is expected. Here one third of the investment is the electrolyser cells, which has a lifetime of 10 years. The rest is assumed to be the BoP equipment/plant and has a lifetime of 30 years. Here the fixed O&M cost are estimated to be 0.5 per cent of the initial investment. Including grid connections the total annual cost are between 0.021 and 0.031 M€/MW.

In the cost estimates recommended, the total plant including grid connection is based on the estimate from the Danish Energy Authority and on the low estimate from Risø. The investment cost are assumed to be 0.25 M€/MW for grid connected electrolysers with a 20 year lifetime and 2 per cent fixed O&M costs. These cost estimates are based on future large-scale production of electrolysers and is an estimate for the socio-economic costs from between 2020 – 2030.

Current and future alkali electrolysers

The alkali electrolysers are already well developed, and no significant improvements can be expected. It is a 100 year old technology used in the chemical and metallurgic industry and for production of fertilizer in the form of ammonia (NH_3).

The data listed here is based on state-of-the art atmospheric pressure alkaline electrolysers. Some operate at atmospheric pressure, and some with pressurised operation between 4 and 30 bar.

The cost of alkaline electrolysers is heavily dependent on the size of the plant. Here only large scale production plants are included. Here the costs from the Danish Energy Authority [14] is used for large scale plants (>2 MWe). The costs are estimated to be at least 0.2 M€/MW with fixed O&M costs of 3 per cent of the initial investment. The lifetime is 20 years with major services every 6 years.

The start-up time of current large scale alkaline electrolysers is approx. 2 hour to 100 per cent and they are not designed for fast regulation abilities. Regulating up and down tears the cells whereas turning the stack on or off does not affect the lifetime of the cells significantly. The stacks often have the maximum lifetime (in hrs) when used at 80 – 90 % of their maximum capacity. If stacks are used for up- and down regulation the overall lifetime can be expected to be reduced by an average of app. 30 per cent. The actual number heavily depends on the actual electrolyser. Cooling systems may be developed to make the plants more flexible. Downward regulation can be achieved within a few seconds.

The efficiency of alkaline electrolysers can be very high, however this would increase the costs significantly as the current density would be lowered.

The LHV for alkaline electrolysers has been calculated from [14] by converting from 71-75 per cent based on the HHV to the LHV and adding 5 percent losses in the inverter. The same LHV occurs if calculated from the cell current density of 1.3 V for SOEC to 1.8 V for alkaline electrolysers combined with inverters. The LHV for commercially available technology is confirmed in the CONCAWE project [62] from march 2007.

It is assumed that it is technically possible to utilize 90 per cent of the excess heat for district heating. Here it is assumed the 30 per cent of the input electricity can be used as heat in district heating systems.

Table 1 – Potential operation conditions of high temperature electrolyses and current alkali electrolysers

Technology		High temperature electrolysers (SOEC)		Alkali electrolysers[23]
Production of		Hydrogen	CO	Hydrogen
Available from		2020-2030	2020-2030	2008
Capacity	MW	0,5-50	0,5-50	0.9-2.0
Output	Bar	40	40	1
Operating temp.	°C	850	850	70-90
Electricity to fuel efficiency [24]	% (LHV)	73	86	58-61 [25]
Electricity to heat efficiency	% (LHV)	7.5	8.6	30
Other input		Steam[26]	Pure CO_2	Ambient air, water
Start-up time	Hours	0,2[27]	0,2[27]	
Regulation ability				
Fast reserves	MW per 15 min.	Full capacity	Full capacity	Full capacity (in 10 min.)
Regulation speed	% per second	3 down / 0.1 up	3 down / 0.1 up	0.004
Minimum load	% of full load	1	1	20
Economy				
Investment costs[28]	M€/MWe	0.25	0.25	0.26-1.4
Fixed O&M costs	% of inv./year	2	2	2.3-3.0
Variable O&M cost[29]	€/MWh	-	-	-
Lifetime[30]	Years	20	20	20

23 The alkaline electrolyser data are modified from [14].
24 Including 5 per cent losses in inverters
25 The LHV has been calculated from [14] by converting to the LHV and adding inverter losses. The same LHV occurs if calculated from the cell current density of 1.3 V for SOEC to 1.8 V for alkaline electrolysers combined with inverters. The LHV for commercially available technology is confirmed in the CONCAWE project [62].
26 The energy consumption for steam is included in the efficiency.
27 The start-up time is several hours if started from cold.
28 Including improvements in grid connection of 66,000 €/MW for large plants.
29 No variable costs assumed other than electricity.
30 The lifetime indicated for SOEC and the investment and O&M costs includes a replacement of cells and the BoP/plant. See explanation above.

Appendix V – External costs of emissions from energy systems

External costs cover the economic expenses that are not part of the market price of something such as a fuel like coal. If the energy sector, and also obviously the power plant owners, operates in a liberalised market, all external expenses should be internalised to ensure that the development is optimal for society. The fact that there are externalities can be regarded as a market failure that should be corrected. The problem is simply that it can be fairly difficult to determine the magnitude of the external expenses. Environmental charges can be seen as an attempt to internalise the external expenses, but the level of environmental charges does not necessarily match the actual external expenses.

External expenses can be many things: they can be the expenses associated with environmental impacts in the place from which the fuel was extracted (e.g. a coal mine in Southern Africa), or they may be health and environmental effects at the place where the fuel is used. The expenses used here are based on the effects from fuel conversion in Denmark and therefore, they do not include the environmental and health expenses at the time of extraction and transportation of the fuels to the country.

Health externalities

There are a number of studies concerning the pricing of health effects as a consequence of different contamination components being emitted. The best known is ExternE (www.externe.info), an EU project that was started in 1996 and that is continuously being updated. The National Environmental Research Institute in Denmark (DMU) has also updated these figures several times in relation to Danish conditions, while also using a more advanced air pollution model than the one that was originally used in ExternE [19]. The official DMU figures for the health expenses associated with various different types of emissions are used by the Danish Energy Authority, among others, when evaluating the economic value of projects [1], which is listed in Table 39. DMU has made some updates for the health expenses in relation to the figures recommended by the Danish Energy Authority. These can be found on DMU's homepage (www.dmu.dk), and is reproduced in Table 40.

Table 39, Economic expenses per kg of emitted substance used by the Danish Energy Authority [1].

DKK/kg	Outside urban areas	Urban areas
NO_x	50	50
SO_2	79	121

Table 40, Economic expenses per kg of substance emitted [25].

DKK/kg	Outside urban areas	Urban areas
PM2,5	95	152
NO_x and nitrates	52	52
SO_2 and sulphates	82	127
Lead	10,016	10,406
Mercury	1,658	1,906

When the DMU determines the health expenses for NO_X emissions, for example, it uses its EVA system (Economic Valuation of Air Pollution) (see Fig. 38). Emissions data for the whole of the northern hemisphere is used as a basis (e.g. from the year 2005), and meteorological data are used from a "normal year", e.g. the year 2000. The DEHM emissions to air and dispersion model identifies the annual average concentration of the various substances over Denmark, using a 16X16 km grid. By crossing the concentrations found with population data, it is possible to quantifythe exposure of the population and consequently, use exposure/response functions to find how many instances of health damage and death are attributed to the pollution. The total expenses can thus be calculated in the form of instances of health damage by counting lost working days, hospital admissions, etc. and multiplying them by a unit price for each of these instances. To find the expenses for the individual types of emission, the method has until recently been based on placing an "artificial" point source (e.g. a power plant) in different places throughout the country, outside and within towns. The air pollution model has thus been run again and changes in concentrations due to the new point source have been registered. These are the changes that are used to determine the expenses for emitting NO_X in urban areas or outside urban areas. The method of using an "artificial" point source is the basis for calculating the expenses that are reproduced in Table 39 and Table 40 and that is recommended by the Danish Energy Authority and DMU for economic calculations.

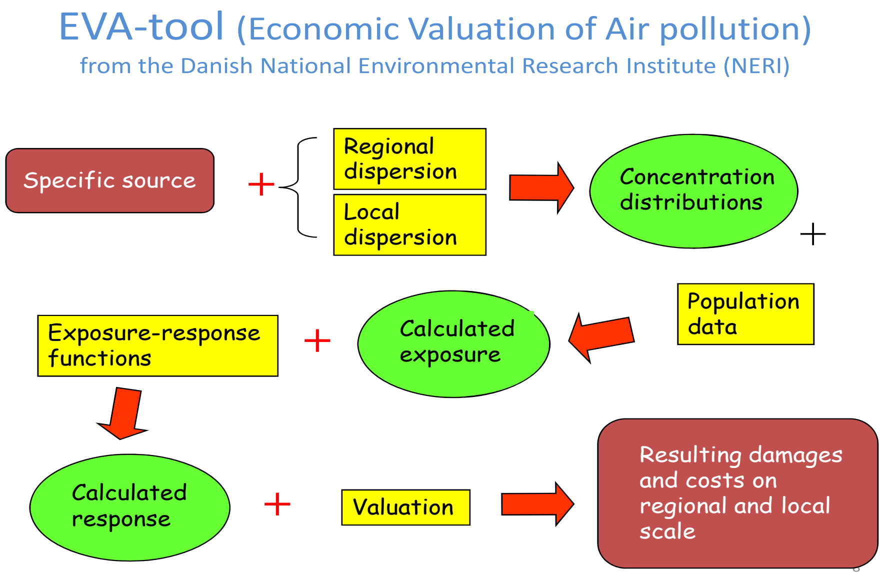


Fig. 38, The work flow in the EVA system [23;24].

Fig. 39 graphically illustrates the way in which the exposure of the population is determined. A map of annual average concentrations for different emission components is placed over a map showing the population density, from which the exposure can be calculated.

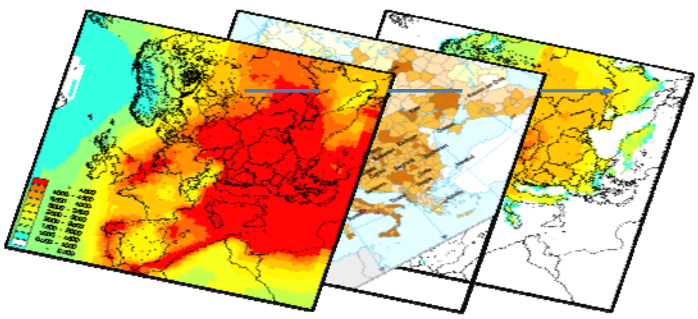


Fig. 39, Human exposure is calculated by crossing the annual average concentrations of different pollution substances with population data. This can calculate how much the population is exposed to pollution in different areas.

One of the aims of the Centre of Energy, Environment, and Health, www.ceeh.dk, CEEH, is to produce a better evaluation of the expenses for health effects as a consequence of emissions from energy conversion in Denmark. Part of the Centre's work is therefore also based on the existing air pollution models from DMU (DEHM – Danish Eulerian Hemispheric Model). The centre is currently trying to increase the model's resolution (to 5 X 5 km) and at the same time, enable the model to isolate the emissions from the different industry sectors so it can follow their specific emissions, which means their influence on the health of the population can be calculated. Model changes and greater computer power have made it possible to increase the level of detail.

This new method means that instead of positioning an "artificial" point source and following the contribution thereof, it is now possible to remove all emissions from things such as power plants and thus, calculate how much they have contributed to the annual average concentrations in each grid and thereby the exposure they are attributed to. This can be done not just for the power plant sector but for all sectors: fishing, agriculture, industry, households, transport, etc., and as a result, it is possible to determine the share of the exposure and corresponding expenses associated with each sector. This also means that individual health externalities can be determined for each sector instead of using the same value for all sectors.

The higher resolution in the models, together with sector-classified analyses, makes it easier to identify the sectors which contribute to the exposure of the population in a given area. The transport sector's externality expenses increase with the new method since the emissions take place at street level (see Table 41), while the externialty costs for the power plants reduces slightly since the calculation now considers their actual location and not a single "artificial" power plant.

At this moment in time, only figures for power plants, transport, and ship traffic (presented at international conferences – not yet in papers) have been published (see Table 41). However, health expense values for emissions from a broad range of sectors should come during the course of 2009. DMU has also listed lead and mercury values, which are reproduced in Table 40.

Table 41, Provisional results from CEEH (www.ceeh.dk). Economic expenses per kg substance emitted [26].

DKK/kg	Power plants	Road traffic	Ship traffic
PM2,5	81	159	Na.
NOx and nitrates	43	69	80
SO2 and sulphates	68	243	146
CO	0.00596	0.1639	0.0067

Externalities from the emission of greenhouse gases

When it comes to evaluating the costs of greenhouse gases, it is very difficult to evaluate the level of the externalities. Up to a certain level there are not necessarily any expenses, since the natural carbon cycle has a certain buffer. However, if this buffer is used (which is very clearly close to happening), this can have devastating consequences such as climate changes which affect the water supply, alterations to arable land preventing the growth of some crops, and the movement of climate zones. These effects have very different timeframes and their externality expense will therefore depend heavily on future events which are factored in, i.e. which discount interest is used to calculate the expenses.

The costs of the emission of greenhouse gases can be approached from two sides: 1) it can be assessed as a damage cost, i.e. the economic loss as a result of climate changes that will occur if action is not taken, or 2) marginal reduction costs, i.e. the price of the marginal technology or change that is needed to keep greenhouse gases at an acceptable level.

In theory, option 2) will be the expense that a well-functioning CO_2 market will bring, while option 1) will be considerably higher since it illustrates the effects of the worst conceivable situation, i.e. that greenhouse gases continue to increase in the atmosphere.

The technical résumé from IPCC's work group III presents a broad range of model calculations of what it will cost to stabilise the atmosphere's CO_2 content at different levels. These are shown in Fig. 40. The expenses listed are based on marginal reduction costs and correspond in method to 2).

Fig. 40 shows that if there is a future stabilisation at 500 ppm, the price per tonne CO_2 in 2030 is between 0 and 170 $/tonne CO_2, with the majority of model results around 100 $/tonne CO_2 (around 530 DKK/tonne CO_2). The equivalent for 2050 is a distribution from 25 to 270 $/tonne CO_2, but with an even distribution of the results between these extremities, the median is around 150 $/tonne CO_2 (around 800 DKK/tonne CO_2). These prices apply only if the whole world works to stabilise the atmosphere's CO_2 content. If Denmark acts on its own, the CO_2 prices will be lower. The results stated are in line with the EU Commission's expectation for a CO_2 quota price of 35€/tonne CO_2 (260 DKK/tonne CO_2) through implementation of the renewable energy Directive in 2020 (20% renewable energy in 2020).

The Stern report arrives at even higher CO_2 prices after considering the global damage expenses if the atmosphere's CO_2 content is not stabilised or are is stabilised at a high level [21]. The Stern report concluded that the damage expenses may cause a loss for the global GDP of 2 to 20 per cent where the marginal reduction expenses are from 0 to 4 per cent. The distribution of these losses between countries and regions is not even. The Stern report simply says that if people fail to do anything to reduce greenhouse gas emissions, they will probably have very expensive problems.

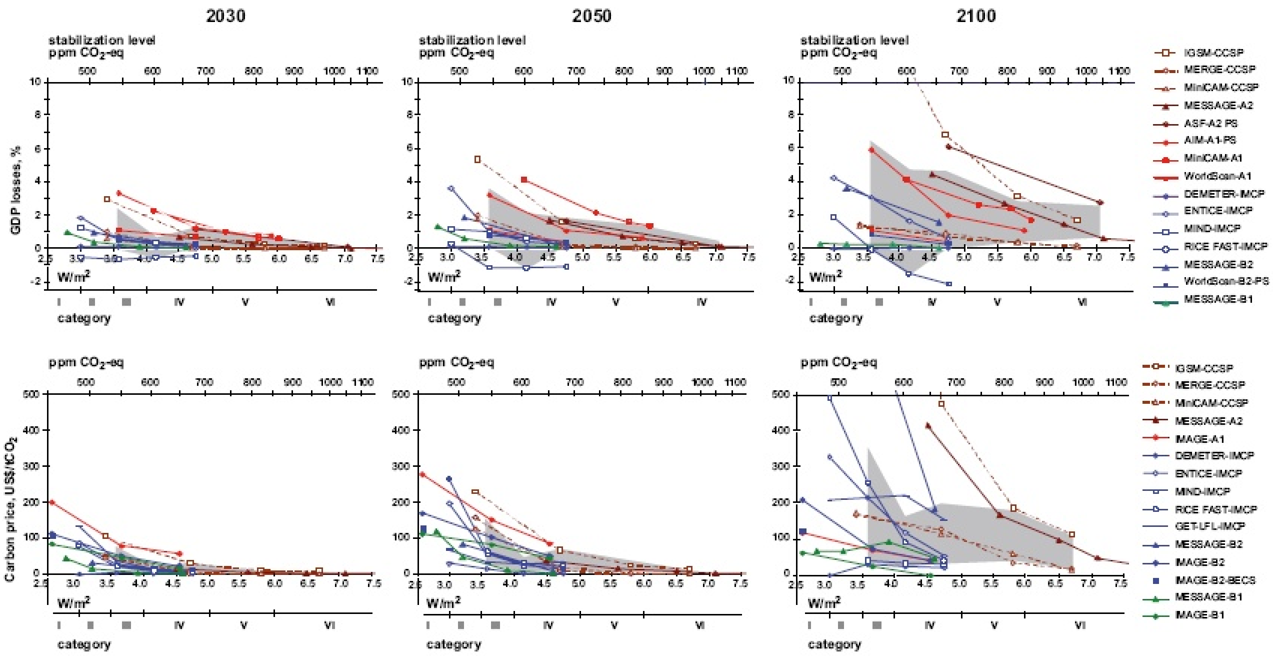


Fig. 40, Model results from IPCC's work group III. The results are based on an examination of stabilisation scenarios on 15 different model systems. The graphs at the top show the expected loss in GDP by stabilising the atmosphere's CO_2 content at different levels. The lower graphs show this expense converted to a price per tonne CO_2 [27].

Other externalities

As well as health effects and climate changes, nature and buildings are also being damaged due to emissions. No expenses have been found for these effects for this project, although the expenses may be significant. There are also considerable uncertainties in this area: for example, what does it cost if the frontage of an historic building is damaged and what is the value of life in a Swedish forest lake?

Calculation of external expenses for the energy system

On the basis of the studies examined, Table 42 collates the external expenses that are used here. The figures in Table 42 are based on the most advanced calculations from CEEH if they were available and if they were not, then DMU's latest official figures were used.

The costs of different emissions and sectors in Table 42 are based on emissions, the specific placement of point sources, and the populations from the year 2000. In a future energy system the emission pattern, i.e. amount of emissions, placement etc. may change as may the population density in different areas. In the long term climate change can influence the meteorology and therefore, also influence how the emissions to air are transported and spread in the atmosphere. In addition, the chemical reactions in the atmosphere are not linear and for that reason, it cannot be concluded that the costs are valid under all circumstances. The costs are valid for the specific sources and year for which they are calculated and should be used with caution for other scenarios.

However there is no doubt that the values used here represent the best possible data available at the moment. More precise costs may be identified by analyzing the emissions from the IDA scenarios using the emissions to air models. To make such calculations is the specific aim of the CEEH (www.ceeh.dk), which is headed by Prof. Eigil Kaas at the University of Copenhagen.

Table 42, Economic expenses per kg substance emitted.

DKK/kg	Power plants	Road traffic	Industry[31]	Households/ Trade & services[32]	Ship traffic
PM 2,5	81	159	120	159	81[33]
NO_x and nitrates	43	69	56	69	80
SO_2 and sulphates	68	243	155	243	146
CO	0.00596	0.1639	0.0849	0.1639	0.0067
Lead	10,016	10,406	10,211	10,406	10,016[33]
Mercury	1,658	1,906	1,782	1,906	1,658[33]

Hence the following precaution should be mentioned in connection with the calculation of health costs here: if the same costs pr. kg emitted is assumed for the health costs of different polluting components in future scenarios (i.e. as in *Table 42) – then the calculations here are an indication of the related costs.*

It is possible to show the health costs using parameters such as the number of dead, the number of sick days, the occurrence of asthma etc. for the year the emissions to air models have calculated the costs. However, in 2030 and 2050 too many parameters have changed and an estimation of these effects would have to be found by operating the emissions to air models with such scenarios.

It is also important to note that the health costs assumed here include all areas also outside Denmark, where Danish emissions may have an effect. According to DMU only some of the costs affect the Danish national budget. The rest of the emissions would be part of international negotiations about mitigation obligations. As such models are used in international negotiations, Denmark will also be held responsible for these emission effects in the other countries.

Including the health costs in other countries due to Danish emissions corresponds to paying for CO_2-qoutas which cannot be said to cover damages in Denmark directly, but in principle in the entire world. In Table 43 the part of the global socio-economic costs that can be related to Denmark is defined.

Table 43, Part of expenses in Denmark

DKK/kg	Power plants	Road traffic	Industry[31]	Households/ Trade & services [32]	Ship traffic
PM 2,5	0,125	0,321	0,516	0,516	0,125
NO_x and nitrates	0,063	0,079	0,096	0,096	0,029
SO_2 and sulphates	0,104	0,129	0,154	0,154	0,037
CO	1,000	0,679	0,358	0,358	0,061
Lead	1,000	1,000	1,000	1,000	1,000
Mercury	1,000	1,000	1,000	1,000	1,000

Greenhouse gases are a global problem and it makes no sense to divide the expense between sectors or towns and country. Also, the expense may vary over time since there will be an increase in the displacement of greenhouse gases over time to ensure stabilisation. The IPCC's scenarios show that a stabilisation of 500 ppm of the atmosphere's greenhouse gas content, measured in CO_2 equivalents, gives a central estimate of a CO_2 price in the year 2030 of 300-530 DKK/tonne CO_2, and in 2050 of 500-800 DKK/tonne CO_2.

[31] Industry is placed both in urban areas and in the countryside, hence it is assumed that the costs of emissions from industry are an average of power plants and road traffic.
[32] Household, trade, and services are found mainly in urban areas, hence it is assumed that the cost of these emissions are similar to those for road transport.
[33] For ship traffic some values are missing, hence the values from power plants have been used.

Appendix VI – Adjustments of IDA 2030 and IDA 2050.

Results of the adjustments in IDA 2030:

		The reference	Step 1	Step 2	Step 3	Step 4	Step 5	IDA 2030
Input:			Starting Point	CHP regulation	Large Heat Pumps	Flexible electricity demand	Smart charge of BEV	FC regulation
Electricity consumption	TWh/year	41.7	29.7	32.0	33.5	33.6	33.2	33.0
District heating consumption	TWh/year	34.1	40.6	40.6	40.6	40.6	40.6	40.6
Individual heating	TWh/year	19.5	1.0	0.7	0.7	1.0	1.0	1.0
Industry incl. service & refineries	TWh/year	40.0	31.0	31.1	31.1	31.0	31.0	31.0
Transport (incl. aircraft and ships)	TWh/year	66.0	41.7	41.7	41.7	41.7	41.7	41.7
North Sea, losses, etc.	TWh/year	17.6	9.2	9.2	9.2	9.2	9.2	9.2
Avg. efficiency decentralised CHP (elec./heat)	%	37 / 48	47 / 41	47 / 41	47 / 41	47 / 41	47 / 41	47 / 41
Avg. efficiency central CHP (elec./heat)	%	35 / 55	46 / 45	46 / 45	46 / 45	46 / 45	46 / 45	46 / 45
Avg. efficiency condensation plants	%	42	50	50	50	50	50	50
Primary energy supply								
Wind power	TWh/year	11.5	25.6	25.6	25.6	25.6	25.6	25.6
Solar thermal	TWh/year	0.5	5.4	5.4	5.4	5.4	5.4	5.4
Coal	TWh/year	25.7	25.3	12.0	13.2	12.1	9.9	5.5
Oil	TWh/year	101.8	58.5	58.5	58.5	58.5	58.5	58.5
Natural gas	TWh/year	41.2	24.9	20.0	17.9	17.6	17.1	17.3
Biomass	TWh/year	56.8	47.7	46.7	41.0	40.8	40.9	41.9
Total, incl. electricity export	TWh/year	237.4	187.3	168.2	161.7	160.1	157.4	154.2
Key figures								
Net export (excess electricity)	TWh/year	0.1	23.0	6.7	6.3	5.3	3.8	1.8
Total adjusted for electricity export	TWh/year	237	141.5	154.8	149.2	149.6	150.0	150.7
Electricity from condensing power plants in % of electricity demand	%	27	2%	2%	4%	3%	1%	2%
Boilers in % of district heating demand	%	12	10%	36%	15%	16%	20%	23%
CO_2 emission	Million tonnes	44.4	29.3	23.8	23.7	23.3	22.5	21.0
Adjusted CO_2 emission	Million tonnes	42.9	13.7	18.3	18.5	18.7	18.8	18.6

Results of the adjustments in IDA 2050:

		The reference	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	IDA 2050
Input:			Starting Point	CHP regulation	Large Heat Pumps	Flexible electricity demand	Smart charge of BEV	FC regulation	Electrolyses and H_2-storage
Electricity consumption	TWh/year	51.5	44.4	47.6	49.1	49.2	48.2	48.0	50.1
District heating consumption	TWh/year	34.1	40.8	40.8	40.8	40.8	40.8	40.8	40.8
Individual heating	TWh/year	15.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Industry incl. service & refineries	TWh/year	51.6	23.6	23.6	23.6	23.6	23.6	23.6	23.6
Transport (incl. aircraft and ships)	TWh/year	75.7	24.1	24.1	24.1	24.1	24.1	24.1	24.1
North Sea, losses, etc.	TWh/year	8.4	-	-	-	-	-	-	-
Avg. efficiency decentralised CHP (elec./heat)	%	37 / 48	54 / 36	54 / 36	54 / 36	54 / 36	54 / 36	54 / 36	54 / 36
Avg. efficiency central CHP (elec./heat)	%	35 / 55	64 / 26	64 / 26	64 / 26	64 / 26	64 / 26	64 / 26	64 / 26
Avg. efficiency condensation plants	%	42	64	64	64	64	64	64	64
Primary energy supply									
Wind power	TWh/year	14.0	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Solar thermal	TWh/year	0.5	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Coal	TWh/year	41.9	-	-	-	-	-	-	-
Oil	TWh/year	117.5	-	-	-	-	-	-	-
Natural gas	TWh/year	35.8	-	-	-	-	-	-	-
Biomass	TWh/year	55.2	116.2	94.2	87.3	85.8	82.6	80.2	79.0
Total, incl. electricity export	TWh/year	264.8	160.1	138.0	131.1	129.7	126.4	124.1	122.9
Key figures									
Net export (excess electricity)	TWh/year	0.1	27.0	7.5	7.3	6.3	4.1	2.3	0.3
Total adjusted for electricity export	TWh/year	265	117.8	126.4	119.8	119.9	120.1	120.6	122.5
Electricity from condensing power plants in % of electricity demand	%	35	3%	3%	4%	4%	1%	2%	2%
Boilers in % of district heating demand	%	10	26%	39%	18%	19%	23%	25%	26%
CO_2 emission	Million tonnes	53.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Adjusted CO_2 emission	Million tonnes	51.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix VII – Other costs used in IDA 2015, IDA 2030 and IDA 2050

	2015					2030					2050				
	Investments	Life time	Annual O&M	Annual inv.	Annual O&M	Investments	Life time	Annual O&M	Annual inv.	Annual O&M	Investments	Life time	Annual O&M	Annual inv.	Annual O&M
	Mill. DKK	Years	% of inv.	Mill. DKK/år	Mill. DKK/år	Mill. DKK	Years	% of inv.	Mill. DKK/år	Mill. DKK/år	Mill. DKK	Years	% of inv.	Mill. DKK/år	Mill. DKK/år
Electricity savings in households	10200	10	0.0%	1,196	-	16920	10	0.0%	1,984	-	24480	10	0.0%	2,870	-
Charging stations		10	0.0%			11250	10	0.0%	1,319		20000	10	0.0%	2,345	
Sum part 1	10200	10	0.0%	1,196	-	28170	10	0.0%	3,302	-	44480	10	0.0%	5,214	-
E85 - vehicles	400	13	8.2%	38	33	170	13	8.2%	16	14		13	0.0%	-	-
Battery electric vehicles		13	0.0%			20968	13	11.2%	1,972	2,340	37085	13	11.2%	3,487	4,139
Hydrogen vehicles		13	0.0%				13	1.0%			22207	13	6.0%	2,088	1,332
Sum part 2	400	13	8.2%	38	33	21138	13	11.1%	1,988	2,354	59292	13	9.2%	5,575	5,471
Electricity savings in industry and service	18885	15	0.0%	1,582		37109	15	0.0%	3,108	-	57074	15	0.0%	4,781	-
Sum part 3	18885	15	0.0%	1,582	-	37109	15	0.0%	3,108	-	57074	15	0.0%	4,781	-
Flexible electricity demand		20	0.0%			500	20	0.0%	34		500	20	0.0%	34	
IBUS plant	4443	20	6.4%	299	284	2188	20	6.4%	147	140	0	20	0.0%	-	-
Sum part 4	4443	20	6.4%	299	284	2688	20	5.2%	181	140	500	20	0.0%	34	-
Improved waste incineration		25	2.0%			1400	25	2.0%	80	28	1400	25	2.0%	80	28
Sum part 5		25	2.0%			1400	25	2.0%	80	28	1400	25	2.0%	80	28
BOLIG+		30	0.0%			12500	30	0.0%	638	-	25000	30	0.0%	1275	-
District cooling		30	0.0%			9440	30	0.5%	482	47	9440	30	0.5%	482	47
Fuel savings in industry and service	6441	30	0.0%	329	0	11867	30	0.0%	605	-	23553	30	0.0%	1202	-
Geothermal plants		30	0.0%			3944	30	2.5%	201	99	3944	30	2.5%	201	99
IDAs Transport vision/rail		30	0.0%			53000	30	0.0%	2704	-	328000	30	0.0%	16734	-
Extra costs of biogas		30	0.0%			12000	30	0.0%	612	-	15000	30	0.0%	765	-
Sum part 6	6441	30	0.0%	329	-	102750	30	0.1%	5,242	146	404937	30	0.0%	20,660	146
Expansion of district heating	20500	40	1.0%	887	205	55,500	40	1.0%	2,401	555	55,500	40	1.0%	2,401	555
Sum part 7	20500	40	1.0%	887	205	55500	40	1.0%	2,401	555	55500	40	1.0%	2,401	555
Heat savings in district heating areas	17119	50	0.0%	665	-	49022	50	0.0%	1,905	-	48455	50	0.0%	1,883	-
Heat savings outside district heating areas	11766	50	0.0%	457	-	28206	50	0.0%	1,096	-	7619	50	0.0%	296	-
Sum part 8	28885	50	0.0%	1,123	-	77229	50	0.0%	3,002	-	56075	50	0.0%	2,179	-
Conversion to biomass cons. in industry	497	0	0.0%	497	-	1162	0	0.0%	1,162	-	1516	0	0.0%	1,516	-
Sum part 9	497	0	0.0%	497	-	1162	0	0.0%	1,162	-	1516	0	0.0%	1,516	-
SUM	90251	-		5,949	522	327146	-		20,466	3,223	680774	-		42,440	6,200

Appendix VIII – List of expenses for individual measures in IDA 2030

Below are the calculations for the individual measures described in IDA 2030. It should be noted that fuel prices and CO_2 prices are also included in the calculations with the stated conditions. The expenses indicated concern only the technical changes.

Individual measures	Description	Expense
Wind power – onshore	• Expansion from 2,350 MW to 4.454 MW	• 8 million DKK/MW, lifetime 20 years, O&M 2.4 per cent
Wind power – offshore	• Expansion from 1,239 MW to 2,600 MW	• 12 million DKK/MW, lifetime 25 years, O&M 3 per cent
Photovoltaic	• Expansion to 683 MW	• 7.5 million DKK/MW, lifetime 25 years, O&M 0.25 per cent
Wave energy	• Expansion to 400 MW	• 14 million DKK/MW, lifetime 30 years, O&M 1.13 per cent
Waste combustion	• Transfer of 0.07 TWh from pure heat production to CHP production. • 1.233 TWh flexible, 0.617 TWh both decentralised and central waste combined heat & power plant. • Electricity efficiency from 22.5 per cent to 26.7 per cent • Heat efficiency from 62.4 per cent to 77.3 per cent	• 1.4 billion DKK, lifetime 25 years, O&M 2 per cent
Geothermal	• District heating efficiency 0.487, Electricity efficiency, 0.218, steam efficiency 0.317, COP 1.6541	• 3.944 billion DKK, lifetime 30 years, O&M 2.5 per cent
Combined heat & power fuel cells, decentralised	• 50 per cent or 973 MW • Average electricity efficiency from 37.3 per cent to 46.6 per cent • Average heat efficiency from 48.0 per cent to 41.0 per cent	• 6 million DKK/MW, lifetime 20 years, O&M 10 per cent
Power and combined heat & power fuel cells, central	• 33 per cent or 2,526 MW • Average electricity efficiency CHP from 35.4 per cent to 45.6 per cent • Average heat efficiency from 54.8 per cent to 44.5 per cent • Average electricity efficiency power plant from 42.4 per cent to 50.2 per cent • But in the reference, electricity efficiency to 49.0 per cent	• 1.4 billion DKK, lifetime 25 years, O&M 2 per cent
Electricity savings in households	• Electricity saving 4.31 TWh • Saved power plant capacity: 757 MW	• 16.92 billion DKK, lifetime 10 years, O&M 0.0 per cent • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
BOLIG+	• Electricity saving 0.53 TWh • Saved power plant capacity: 93 MW • Heat saving district heating 0.26 TWh • Saved district heating boilers: 125 MW • Heat saving ind. 0.26 TWh • Saved ind. boilers: 147 MW	• BOLIG+: 12.5 billion DKK, lifetime 30 years, O&M 0.0 per cent • District heating boilers: 1 million DKK, lifetime 20 years, O&M 3 per cent • Ind. boilers: 5 million DKK, lifetime 15 years, O&M 2.5 per cent • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent

Individual measures	Description	Expense
Heat savings, district heating areas	• From 20 per cent heat savings included in the reference to 50 per cent • 0.53 TWh saved in district heating area equipped with boiler • 2.00 TWh saved in decentralised combined heat & power areas • 4.27 TWh saved in central combined heat & power areas • Changed heat consumption distribution • Saved district heating boilers: around 3,400 MW in the reference and 3,700 MW in IDA 2030 (lower peak load) • Saved combined heat & power plants: around 1,350 MWe in the reference and 1,450 MW in IDA 2030 (lower peak load) • Power plants adapted, incl. average efficiency levels	• 49.022 billion DKK, lifetime 50 years, O&M 0.0 per cent • Decentralised CHP: 5 million DKK/MW, lifetime 20 years, O&M 1.5 per cent • Central CHP: 10 million DKK/MW, lifetime 30 years, O&M 2 per cent • District heating boilers: 1 million DKK, lifetime 20 years, O&M 3 per cent
Heat savings outside district heating areas	• From 20 per cent heat savings included in the reference to 50 per cent • Greater need for heat, natural gas: 0.91 TWh • Greater need for heat, oil: 0.47 TWh • Greater need for heat, biomass: 1.94 TWh • Greater need for heat, heat pumps: 0.68 TWh • In even greater heat consumption: 4.00 TWh • Changed distribution	• 28.206 billion DKK, lifetime 50 years, O&M 0.0 per cent • Ind. boilers: 5 million DKK, lifetime 15 years, O&M 2.5 per cent • Ind. heat pumps: 28 million DKK/MWe, lead time (sic) 15 years, O&M 0.7 per cent (55 million DKK/MWe input to EnergyPLAN)
Conversions to district heating	• Heating Plan Denmark is used in the reference, incl. 25 per cent heat savings acc. to the same principle described in the section re. conversion to district heating (between sc. 2 and 3) • Greater total consumption in the reference of around 14 TWh in district heating strict removed from the ind. supply • Greater total consumption in IDA 2030 of around 11 TWh • More district heating boilers: around 4,630 MW in the reference and 2,950 MW in IDA (changed peak load) • More combined heat & power plants: around 1,870 MW in the reference and 1,170 MW in IDA (relation between changed district heating consumption) • Power plants adapted, incl. Average efficiency levels	• 55.50 billion DKK, lifetime 40 years, O&M 1.0 per cent • Decentralised CHP: 5 million DKK/MW, lifetime 20 years, O&M 1.5 per cent • Central CHP: 10 million DKK/MW, lifetime 30 years, O&M 2 per cent • District heating boilers: 1 million DKK, lifetime 20 years, O&M 3 per cent • Ind. boilers: 5 million DKK, lifetime 15 years, O&M 2.5 per cent • Ind. heat pumps: 28 million DKK/MWe, lead time (sic) 15 years, O&M 0.7 per cent (55 million DKK/MWe input to EnergyPLAN)
Conversion to district heating with savings	• Heating Plan Denmark is used in the reference, incl. 50 per cent heat savings acc. to the same principle described in the section on conversion to district heating (between sc. 2 and 3). • Greater total district heating consumption around 4 TWh (after 50 per cent heat savings and reorganised consumption in ind. boilers) • More district heating boilers: around 2,650 MW in the reference and around 230 MW in IDA (changed peak load) • More combined heat & power plants: around 1,050 MW in the reference and around 100 in IDA 2030 (lower peak load) • Changed distribution	• District heating expansion: 55.50 billion DKK, lifetime 40 years, O&M 1.0 per cent • Saving in decentralised combined heat & power area: 49.022 billion DKK, lifetime 50 years, O&M 0.0 per cent • Decentralised CHP: 5 million DKK/MW, lifetime 20 years, O&M 1.5 per cent • Central CHP: 10 million DKK/MW, lifetime 30 years, O&M 2 per cent • District heating boilers: 1 million DKK, lifetime 20 years, O&M 3 per cent • Saving in decentralised combined heat & power area: 28.206 billion DKK, lifetime 50 years, O&M 0.0 per cent • Ind. boilers: 5 million DKK, lifetime 15 years, O&M 2.5 per cent • Ind. heat pumps: 28 million DKK/MWe, lead time 15 years, O&M 0.7 per cent (55 million DKK/MWe input to EnergyPLAN)

Individual measures	Description	Expense
Ind. heat pumps outside district heating	• Converted to ind. heat pumps from 2.58 TWh need for heat covered in the reference to 8.22 TWh in IDA 2030 • Greater power plant capacity: 600 MW	• Ind. heat pumps: 28 million DKK/MWe, lead time (sic) 15 years, O&M 0.7 per cent (55 million DKK/MWe input to EnergyPLAN) • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
Ind. solar thermal outside district heating	• Total of 2.15 TWh used instead of 0.5 TWh in the reference • COP increased by use of solar thermal from around 2.6 to around 4.6 through heat pumps.	• 5 million DKK/GWh, lifetime 20. O&M 1 per cent
Solar thermal in district heating areas	• Total of 0.01 TWh in district heating area without combined heat & power in the reference. • Total of 3.33 TWh solar thermal input. From this, it is possible to use 3.25 TWh in IDA 2030 and 3.05 TWh in the reference • In district heating without combined heat & power 1.33 TWh, with around 10 days' steam storage of 80 GWh, 0.01 per cent/hour loss. Established in 90 per cent of the plants. • In decentralised combined heat & power area 1.39 TWh, 8 GWh storage (already exist and in the reference). Established in 50 per cent of the plants. • In central combined heat & power area 0.61 TWh, does not need storage. Established in 50 per cent of the plants.	• 3.2 million DKK/GWh, lifetime 25 years, O&M 0.05 per cent • Steam heat storage in district heating area without combined heat & power: 5 million DKK/GWh, lifetime 25 years, O&M 0.5 per cent • Large heat store in other areas: 10 million DKK/GWh, lifetime 20 years, O&M 1 per cent
Electricity savings in industry and service	• Electricity saving 15.5 TWh • Saved power plant capacity: 3,258 MW • Power plants adapted, incl. average efficiency levels	• 37.1 billion DKK, lifetime 15 years, O&M 0.0 per cent • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
District cooling	• 0.41 TWh electricity consumption to 1.65 TWh cooling replaced by 0.91 TWh district heating consumption • This corresponds to 1.10 TWh from plants, incl. 21.4 per cent net loss • Consumption assumed in central areas • Saved power plant capacity: 86 MW • Power plants adapted, incl. average efficiency levels	• 9.44 billion DKK, lifetime 30 years, O&M 0.5 per cent • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
Fuel savings	• 12.7 TWh saved fuel, coal: 1 TWh, oil: 9.5 TWh, natural gas: 0.8 TWh, biomass: 1.3 TWh. • Greater electricity consumption in industrial heat pumps 0.7 TWh • Lower industrial heat production for district heating: around 0.56 TWh • Changed power plant capacity: 148 MW • Power plants adapted, incl. average efficiency levels	• 11.9 billion DKK, lifetime 30 years • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
Biomass in industry	• 21,5 TWh converted to biomass, coal: 1.48 TWh, oil: 12.57 TWh, natural gas: 7.47 TWh • Lower electricity production 0.3 TWh	• 1,162 million DKK/year
Less growth in need for transport	• 9 per cent less growth in passenger and commercial vehicle transport, i.e. from 18 per cent growth in the period from 2008 to 2030 to 9 per cent. • Saved fuel in alt: 3,37 TWh, Diesel: 1.42 TWh, Petrol: 1.96 TWh.	

Individual measures	Description	Expense
Electric vehicles with and without intelligent charging	• 50 per cent electric vehicles and hybrid vehicles for passenger vehicle and commercial vehicles, counted as 45 per cent pure electric vehicles. Total of 1.125 million vehicles • Total saved fuel: 13.83 TWh, Diesel: 5.8 TWh, Petrol: 8.03 TWh. • Greater electricity consumption for electric and hybrid vehicles: 4.61 TWh • Greater power plant capacity: 2,520 MW • Power plants adapted, incl. average efficiency levels	• Marginal extra expenses for electric vehicles: 20.5 billion DKK, lifetime 13 years, O&M 11.2 per cent • 2 charging stations per electric vehicle: 11.25 billion DKK, lifetime 10 years • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
Expansion of the railway	• 9 per cent growth for passenger vehicles and commercial vehicles transferred to the railway • Railway electrified and a share of the growth in HGV traffic transferred and domestic flights minimised • Total saved fuel: 5.3 TWh, Diesel: 3.13 TWh, Petrol: 1.84 TWh. • Greater electricity consumption on the railway: 1.71 TWh • Greater power plant capacity: 360 MW • Power plants adapted, incl. average efficiency levels	• Marginal extra expenses for railways: 53 billion DKK, lifetime 30 years • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent
Streamlining of ships	• Reduced diesel electricity consumption of 1.07 TWh	
Biofuels	• Reduced petrol consumption: 1.31 TWh • Greater biomass consumption: 1.70 TWh • Greater power consumption: 0.09 TWh	• IBUS plant: 2,188 million DKK, lifetime 20 years, O&M 6.4 per cent • Marginal expenses for E85 vehicles: 170 million DKK, lifetime 13 years, O&M 8.2 per cent
Large heat pumps	• In decentralised combined heat & power areas: 150 MWe large heat pumps • In central combined heat & power areas: 300 MWe large heat pumps • COP: 3.5	• 20 million DKK/MWe, lifetime 20 years, O&M 0.2 per cent
Flexible electricity consumption	• 15 per cent of electricity consumption in households, industry and service is flexible, corresponding to a total of 2.7 TWh • Half of one day and half within one week • Reduced power plant capacity: 569 MW	• 500 million DKK, lifetime 20 years • Central power plants 8 million DKK/MW, lifetime 30 years, O&M 2 per cent

References

[1] Danish Energy Authority, "Forudsætninger for samfundsøkonomiske analyser på energiområdet (Premises for socio-economic analyses within energy)," Danish Energy Authority (Energistyrelsen), Copenhagen,May2009.

[2] DONG Energy, "Markedsindsigt, Uge 3 - 2009 (Market Information news letter)," DONG Energy, Gentofte,Jan.2009.

[3] Danish Energy Authority, "Forudsætninger for Samfundsøkonomiske beregninger på energiområdet (Premises for socio-economic calculations within energy)," Danish Energy Authority (Energistyrelsen), Copenhagen,Feb.2008.

[4] H. Lund and B. V. Mathiesen, "Ingeniørforeningens Energiplan 2030 - Tekniske energisystemanalyser, samfundsøkonomisk konsekvensvurdering og kvantificering af erhvervspotentialer. Baggrundsrapport (Danish Society of Engineers' Energy Plan 2030)," Danish Society of Engineers (Ingeniørforeningen Danmark), Copenhagen,Dec.2006.

[5] K. Vogt-Nielsen and P. Hagedorn-Rasmussen, "Grøn fremtid - brikker til en bæredygtig udvikling," Danish Society of Engineers (IDA, Ingeniørforeningen Danmark), Copenhagen, Denmark,Jan.2008.

[6] Danish Energy Authority, "Notat - Energistyrelsens basisfremskrivning, april 2009 (Forecast the Danish energy system)," Energistyrelsen (Danish Energy Authority), Copenhagen,Apr.2009.

[7] H. Lund, "EnergyPLAN - Advanced Energy Systems Analysis Computer Model - Documentation Version 7.0 - http://www.energyPLAN.eu," Aalborg University, Aalborg, Denmark,Mar.2007.

[8] IPCC, "IPCC Fourth Assessment Report, Climate Change 2007 Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change," Intergovernmental Panel on Climate Change, Geneva, Switzerland,Nov.2007.

[9] J. Hansen, M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D. L. Royer, and J. C. Zachos, "Target Atmospheric CO2: Where Should Humanity Aim?," *The Open Atmospheric Science Journal*, vol. Volume 2, pp. 217-231, 2008.

[10] H. D. Matthews and K. Caldeira, "Stabilizing climate requires near-zero emissions," *Geophysical Research Letters*, vol. 35, no. 4 2008.

[11] R. Monastersky, "A Burden Beyond Bearing," *Nature*, vol. 458, no. 7242, pp. 1091-1094, 2009.

[12] H. Lund and B. V. Mathiesen, "Ingeniørforeningens Energiplan 2030 - opdaterede samfundsøkonomiske beregninger (Danish Society of Engineers' Energy Plan 2030 – updated socio-economic calculations)," Danish Society of Engineers (Ingeniørforeningen Danmark), Copenhagen,May2008.

[13] Danish technology council, "Det Fremtidige Danske Energisystem – Teknologiscenarier (The future Danish Energy System - Technology Scenarioes)," Danish technology council (Teknologirådet), Copenhagen,2006.

[14] Danish Energy Authority, Elkraft System, and eltra, "Technology Data for Electricity and Heat Generation Plants," Energistyrelsen (Danish Energy Authority), Copenhagen, Denmark,Mar.2005.

[15] Danish Energy Authority, "Appendiks: Forudsætninger for Samfundsøkonomiske beregninger på energiområdet (Premises for socio-economic calculations within energy)," Danish Energy Authority (Energistyrelsen), Copenhagen,July2006.

[16] Danish Energy Authority, "Forudsætninger for samfundsøkonomiske analyser på energiområdet (Premises for socio-economic analyses within energy)," Danish Energy Authority (Energistyrelsen), Copenhagen,Feb.2009.

[17] H. Lund, P. A. Østergaard, A. N. Andersen, F. K. Hvelplund, H. Mæng, and E. Münster, "Lokale Energimarkeder (Local Energy Markets),"2004.

[18] Danish Energy Authority, "Vejledning i samfundsøkonomiske analyser på energiområdet (Guidelines for socio-economic analyses within the energy sector)," Danish Energy Authority (Energistyrelsen), Copenhagen,Apr.2005.

[19] European Commision, "ExternE. Externalities of Energy - Methodology annexes, Appendix V: Assessment of the global warming damages," European Commision, Brussels, Belgium,2002.

[20] M. S. Andersen, "Responsum angående samfundsøkonomiske analyser af vedvarende energi (Expert opinion on socio-economic analyses of renewable energy)," National Environmental Research Institute (Danmarks Miljøundersøgelser - DMU), Aarhus, Denmark,May2007.

[21] N. H. Stern, "The Economics of Climate Change: The Stern Review," Cambridge University Press, Great Britain,2007.

[22] Miljøstyrelsen, "Nøgletal for samfundsøkonomiske beregninger på miljø- og naturområdet (Key figures for socio-economic calculations within environment and nature)," Danish EPA (Miljøstyrelsen),Miljøprojekt nr. 1199, 2007.

[23] M. S. Andersen, L. M. Frohn, J. S. Nielsen, M. Nielsen, S. S. Jensen, J. H. Christensen, and J. Brandt, "A Non-linear Eulerian Approach for Assessment of Health-cost Externalities of Air Pollution," Gothenburg, Sweden:
European Association of Environmental and Resource Economists 16th Annual Conference, 2008.

[24] L. M. Frohn, J. Brandt, O. Hertel, J. H. Christensen, C. Geels, M. S. Andersen, J. S. Nielsen, J. Frydendall, M. Hvidberg, S. S. Jensen, J. Petersen, and P. V. Madsen, "Assessment of air pollution related damages on human health – and the subsequent costs," The Netherlands: 3rd GLOREAM/EURASAP Workshop, Modern developments in modelling and chemical data analysis, 2005.

[25] M. S. Andersen, "Nye forudsætninger for samfundsøkonomiske analyser på energiområdet (New conditions for socio-economic analyses within energy)," 2009.

[26] J. Brandt, J. H. Christensen, L. M. Frohn, C. Geels, K. M. Hansen, G. B. Hedegaard, T. Hvid, M. Hvidberg, and C. A. Skjøth, "THOR – an operational and integrated model system for air pollution forecasting and management from regional to local scale," Istanbul, Turkey: 7th International Conference on Air Quality - Science and Application (Air Quality 2009), 2009.

[27] P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou, R. Schock, P. Shukla, R. E. H. Sims, N. Nakicenovic, H.-H. Rogner, J. Roy, J. Sathaye, O. Masera, B. Metz, L. Meyer, G.-J. Nabuurs, A. Najam, S. Kobayashi, M. D. Levine, D. L. Martino, K. Halsnæs, B. Heij, S. K. Ribeiro, O. Davidson, B. S. Fisher, S. Gupta, J. E. Bogner, P. Bosch, R. Dave, T. arker, I. Bashmakov, and L. Bernstein, "Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change," Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland,2008.

[28] Energinet.dk, "Effektiv anvendelse af vindkraftbaseret el i Danmark, samspillet mellem vind, varmepumper og elbiler (Efficient use of wind power using heat pumps and battery electric vehicles)," Energinet.dk (Danish TSO), Fredericia, Denmark,Mar.2009.

[29] Energinet.dk, "Kabelhandlingsplan - 132-150 kV (Cable action plan)," Energinet.dk (Danish TSO), Fredericia, Denmark,Mar.2009.

[30] Danish Energy Authority, "Basisfremskrivning af Danmarks energiforbrug frem til 2025 (Forecast of the Danish Energy Supply until 2025)," Energistyrelsen (Danish Energy Authority), Copenhagen,Jan.2008.

[31] J. Lemming, P. E. Morthorst, and N.-E. Clausen, "Offshore Wind Power Experiences, Potential and Key Issues for Deployment," Risø National Laboratory for Sustainable Energy - Technical University of Denmark, Roskilde, Denmark,Risø-R-1673(EN), Jan.2009.

[32] A. Dyrelund, H. Lund, B. Möller, B. V. Mathiesen, K. Fafner, S. Knudsen, B. Lykkemark, F. Ulbjerg, T. H. Laustsen, J. M. Larsen, and P. Holm, "Varmeplan Danmark (Heat plan for Denmark)," Ramboll Denmark, Virum, Denmark,Project no. 2008 - 01, Oct.2008.

[33] Ramboll, "Vurdering af mængden af forbrændingsegnet affald i Danmark (Assessment of waste amounts for incineration)," Affald Denmark, Copenhagen Danmark,Jan.2008.

[34] B. V. Mathiesen, "Fuel cells and electrolysers in future energy systems - PhD Dissertation." Department of Development and Planning, Aalborg University, 2008.

[35] OECD/IEA, "Do energy saving appliances cost more?," OECD/IEA, Paris, France,Oct.2006.

[36] S. Aggerholm, "Skærpede krav til nybyggeriet 2010 og fremover - Økonomisk analyse (Increased demands for buildings standards from 2010)," Statens Byggeforskningsinstitut (Danish Building Research Institute), Hørsholm, Denmark,Apr.2009.

[37] K. B. Wittchen, "Potentielle energibesparelser i det eksisterende byggeri Skærpede krav til nybyggeriet 2010 og fremover - Økonomisk analyse (Increased demands for buildings standards

from 2010)," Statens Byggeforskningsinstitut (Danish Building Research Institute), Hørsholm, Denmark,May2009.

[38] H. Tommerup and S. Svendsen, "Energy savings in Danish residential building stock," *Energy and Buildings*, vol. 38, no. 6, pp. 618-626, June2006.

[39] M. Johansen, M. W. Hansen, and J. Mikkelsen, "Energibesparelser i erhvervslivet (Energy savings within industry and service)," Dansk Energi Analyse A/S og Weel og Sandvig Aps, Copenhagen, Denmark,Mar.2009.

[40] Danish Energy Authority and dan, "Fjernkøling i Danmark (District Cooling in Denmark)," Danish Energy Authority (Energistyrelsen), Copenhagen,June2007.

[41] B. V. Mathiesen, H. Lund, and P. Norgaard, "Integrated transport and renewable energy systems," *Utilities Policy*, vol. 16, no. 2, pp. 107-116, June2008.

[42] Danish Transport Research Institute DTU, "Transportvaneundersøgelsen 2006 (National Travel Survey)," DTU, Kgs. Lyngby,Dec.2007.

[43] Danish Energy Authority, "Alternative drivmidler i transport sektoren (Alternative fuels in the transport sector)," Danish Energy Authority (Energistyrelsen), Copenhagen,Jan.2008.

[44] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark," Energinet.dk (Danish TSO),May2009.

[45] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark (draft-version)," Energinet.dk (Danish TSO),May2009.

[46] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark (draft-version)," Energinet.dk (Danish TSO),May2009.

[47] B. Sørensen, H. Petersen, C. Juhl, T. Pedersen, H. Ravn, C. Søndergren, K. Jørgensen, L. Nielsen, H. Larsen, and F. Sørensen, "Scenarier for en samlet udnyttelse af brint som energibærer i Danmarks fremtidige energisystem (Hydrogen as an energy carrier in Denmark)," Roskilde University, Roskilde, Denmark,390, Feb.2001.

[48] O. A. Nielsen, A. Landex, and J. Rørbech, "Fremtidsscenarier for transport i Danmark (Future scenarios for transport in Denmark)," Ugebladet Ingeniøren, Copenhagen,Apr.2006.

[49] Københavns Kommune, HUR, Københavns Universitet, Vejdirektoratet, DTU, and COWI A/S, "Projekt Trængsel, resumé (Project Congestion)," COWI A/S, Kgs. Lyngby,Aug.2004.

[50] L. Christensen and T. C. Jensen, "Korte ture i bil - Kan bilister ændre adfærd til gang eller cykling? (Behavioural changes towards walking and cykling)," DTU Transport (Danish Technical University), Copenhagen, Denmark,Dec.2008.

[51] Danish Energy Authority, "Biomasseressourcer, Ressourcer til energiformål i Danmark," Energistyrelsen (Danish Energy Authority), Copenhagen,2006.

[52] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark (draft-version)," Energinet.dk (Danish TSO),May2009.

[53] H. Lund and W. Kempton, "Integration of renewable energy into the transport and electricity sectors through V2G," *Energy Policy*, vol. In Press, Corrected Proof 2008.

[54] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark (draft-version)," Energinet.dk (Danish TSO),May2009.

[55] Miljøstyrelsen, "Denmarks Fourth National Communication on Climate Change," Danish Ministry of the Environment, Copenhagen, Denmark,May2005.

[56] N. Müller and J. Harnisch, "A blueprint for a climate friendly cement industry," WWF, Gland, Switzerland,2007.

[57] Dansk Industri and Byggematerialeindustrien, "Byggeprognose - Byggematerialeindustriens udsigter for 2006 og 2007 (Construction forecast)," Dansk Industri og Byggematerialeindustrien (Confederation of Danish Industry), Copenhagen,Oct.2005.

[58] G. Winther, "Dansks Energianlægs Importindhold og beskæftigelseskonsekvenser," Institut for Samfundsudvikling og Planlægning, Aalborg Universitet, Aalborg, Denmark,June1998.

[59] H. Lund, F. Rosager, and F. K. Hvelplund, "Valuta- og beskæftigelsesoplysninger for 60 energiteknologier. Importkvoter, beskæftigelsestal og prioritetsanalyser," Aalborg Universitetsforlag, Aalborg Universitet,1984.

[60] P. Koustrup and B. V. Mathiesen, "Analysis of power balancing with fuel cells & hydrogen production plants in Denmark (draft-version)," Energinet.dk (Danish TSO),May2009.

[61] B. V. Mathiesen and H. Lund, "Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources," *Submitted for IET Renewable Power Generation (Status: accepted)*, Nov.2008.

[62] R. Edwards, J.-F. Larivé, V. Mahieu, and P. Rouveirolles, "Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context," CONCAWE, European Council for Automotive R&D, JRC Joint Research Centre of the European Commission,Version 2c, Mar.2007.