Policies for a transition to 100% renewable energy systems in Denmark before 2050

Coherent Energy and Environmental System Analysis

Background Report Part 4

September 2012

A strategic research project financed by

The Danish Council for Strategic Research
Programme Commission on Sustainable Energy and Environment

Authors:
Frede Hvelplund, Aalborg University
Niels I. Meyer, Technical University of Denmark
Poul Erik Morthorst, Risø DTU
Jesper Munksgaard, Pöyry Energy Consulting
Peter Karnøe, Copenhagen Business School
Kirsten Sophie Hasberg

Publisher:
Department of Development and Planning
Aalborg University
Fibigerstræde 13
9220 Aalborg Ø
Denmark

Cover photo: Kristen Skelton

Online access: www.ceesa.dk/Publications

Layout and language support: Pernille Sylvest Andersen/Mette Reiche Sørensen

ISBN 978-87-91404-19-1

Table of contents

Preface

The objective of the CEESA project is to develop scenarios for a future Danish energy system based on renewable energy. The goal is to achieve a 100% *renewable energy system* combined with *energy conservation* by year 2050. This goal is related to the mitigation of global warming and to the problem of Peak Oil. The research project combines scientific knowledge and methods from three areas – 'Energy systems', 'Life-cycle analysis', and 'Market design' – which are usually not integrated into one project.

In this report, the final outcome of the 'Market design' part of the project - work package 4 (WP4) - is described. The objective of WP4 has been to define the policies and market design required to make a complete transition from fossil fuels to renewable energy sources in Denmark before 2050. Results from WP4 have been co-ordinated with the other work packages of the CEESA project.

The project was carried out in the period from 2007 to 2011 and was financed by a grant from the Danish Council for Strategic Research, the Programme Commission on Sustainable Energy and Environment. The International Advisory Committee of the CEESA project has given constructive advice during the project period for which we are very grateful. However, only the working group is responsible for the final content of this report.

The following experts have participated in WP4:

Frede Hvelplund, Aalborg University
Peter Karnøe, Copenhagen Business School
Niels I. Meyer, Technical University of Denmark
Poul Erik Morthorst, Risø DTU (Co-ordinator)
Jesper Munksgaard, Norenergi
Kirsten Hasberg

On behalf of the working group
Poul Erik Morthorst
Risø DTU
September 2012

Reports from the CEESA project:

WP1: CEESA 100% Renewable Energy Scenarios towards 2050
WP2: CEESA 100% Renewable Energy Transport Scenarios towards 2050
WP3: Electric power systems for a transition to 100% renewable energy systems in Denmark before 2050
WP4: Policies for a Transition to 100% Renewable Energy Systems in Denmark Before 2050
WP5: Environmental Assessment of Renewable Energy Scenarios towards 2050

Executive summary

A number of possible policy means of attaining the overall goals of the CEESA scenarios are discussed in this report. It is found that the transition from the present energy system dominated by fossil fuels to a system dominated by renewable energy sources requires significant changes in existing policies, both on the supply and the demand side. This is a change from polluting energy systems that depend on depleting inputs to energy systems that depend on relatively abundant inputs and are relatively non-polluting and intermittent. This change requires a new paradigm. It requires infrastructure which can manage intermittent renewable energy sources in such a way that energy is available at the right time and in the right amount for the consumers. The policy instruments include systems of taxes, subsidies, tariffs, and other economic conditions in order to obtain an optimal effect.

In addition, a number of institutional and regulatory changes are proposed. A central question in this connection is the balance between the role of the market and the role of societal planning and regulation. When the long lifetime of many energy plants and infrastructures, including buildings, is taken into account, it is concluded that the balance needs to change to increase the role of long-term societal planning and regulation. A challenge to the transition planning is how to obtain an efficient co-ordination between investments in electricity, transport, and heating sectors.

A number of macro-economic barriers exist to the transition from fossil fuels to renewables, e.g., in relation to market structures that support "lock-in" to technologies based on fossil fuels. In Denmark, another barrier is the prevalence of high discount rates for the planning of future investments.

Some of the existing barriers can be removed (or reduced) by national changes of tariffs, taxes and other policies, and by changed planning methodologies and priorities at the national level, while others may need changes at the EU level. These changes will require alternative political decisions at high levels in Denmark and the EU. However, the political mechanisms which form the paths to these high-level decisions are not part of this report.

One of the main problems in a future energy system dominated by intermittent renewable sources (e.g., wind and solar energy) is the stability of the electric grid and the security of supply to electricity consumers. In this connection, biomass in different forms plays a central role as a storage element. But, while the amount of Danish biomass, taking into account other uses of the land area, is rather limited, biomass is also in demand in the transport sector and for high temperature industrial process heat (transformed to a liquid fuel or to biogas). Due to the limited biomass resources, the CEESA scenario proposes that the best solution is to let electricity from wind and photovoltaic power replace the demand for biomass, where possible, and to stabilize the grid by other means than biomass, where relevant alternatives are available. This includes the systematic use of large heat pumps and heat storage, eventually combined with electric cars. In addition, new and efficient communication systems between energy suppliers and consumers are required, often described as “intelligent grids” or “smart grids”. The appropriate policy means should be selected in accordance with these technological solutions.

Our proposals for policy instruments are based on a list of criteria in which highest priority is given to the efficient fulfilment of the overall goal of the CEESA project: 100 % renewables in the Danish energy supply before 2050. Other criteria include the consideration of economic efficiency, social balance in the policies, the promotion of Danish employment and industrial production, and policies that support the involvement of the citizens in energy conservation.

We have not attempted to give quantitative numbers of all the proposed economic policy means (taxes, subsidies, tariffs etc.), but we have described the qualitative nature of the schemes supplemented by some quantitative examples. There are not yet many empirical results to indicate the efficiency of the policies. Thus, the policies will have to be adjusted as experience is gained concerning their efficiency. This adjustment is proposed to take place in connection with a bi-annual evaluation of the progress. A general conclusion is that it is not possible to use the same scheme for all sectors and that a democratic and open communication with the energy consumers and producers is important in order to obtain the desired results.

The transport sector has the fastest growing energy consumption and requires the most drastic changes in economic regulation. It is proposed that the taxation of private cars is changed, so that its main component is directly related to the number of kilometres driven per year. This should not await the introduction of an advanced road pricing scheme, but a road pricing scheme should be given high priority. There is an urgent need for investments in improved public transport systems.

Heat and electricity in buildings account for about 40 % of the Danish energy consumption. Stricter building codes have recently been introduced, and they should be updated as improved building designs are developed. The main problem in this sector is that many buildings have a lifetime of 50 to 100 years. Thus, it is not sufficient to wait for the “natural” replacement of the old building mass by low energy buildings. Instead, it is necessary to promote a radical renovation of the existing buildings. This will not be realized in time without significant changes in the present taxation and subsidy schemes. New schemes are proposed in this report. We recommend long-term low interest loans, heat tariffs dependent on consumption (without a fixed part), a graduated building tax related to the energy standard of the building and subsidies for the transformation to low energy houses.

Experience has shown that an efficient reduction of energy consumption by private households requires relatively high levels of energy taxes, but a general high energy tax creates undesired social unbalances. It is proposed to introduce a scheme with a cap on energy consumption where households with consumptions below the defined cap will have a low tax, while households with consumptions above the cap have a strongly increasing tax. In the longer term, this may be supplemented by a Personal Carbon Allowance (PCA) for each individual. The PCA could, in the first phase, be related to the private consumption of fossil fuels per person for heat and electricity, private car driving, and private air transport.

On the supply side, the future energy system will to a large extent rely on renewable sources with an intermittent energy production as wind and photovoltaic power. Offshore wind power has a large role to play and it is increasingly important that tendering procedures for establishing offshore wind farms are improved, especially in relation to economic efficiency and the involvement of citizens as participants. The legal rules for establishing onshore cooperative wind farms should be updated and new partners (e.g., Danish municipalities) should have more favourable possibilities to participate.

District heating systems are expanded, and where this is not possible, efficient individual heat pumps are promoted.

In the long term, the traditional market system (e.g., NordPool) might not be able to handle the large amounts of renewable production in a relevant manner. Today's power markets are mostly based on the marginal pricing principle and large amounts of renewable power production with low or even zero marginal costs reduce the prices on the market to very low levels, thereby creating a barrier to investment in new capacity. Thus, either a totally new market design should be constructed, or the present capacity market for renewable energy should be continued and further developed. A further development of the present system could be based on a flexible feed-in tariff that is adjusted in accordance with the maturing of the technologies and the implementation of the technologies in the energy supply system. The bidding system for offshore wind power projects should be improved to be more competitive.

The investments in the CEESA scenario result in positive socio-economic benefits and in the creation of new "green jobs" – of the order of magnitude of 20,000 new jobs before 2020.

These are some of the most important examples of the subjects treated in the work package on market and public regulation. More details are to be found in the main report and more examples are listed in the following Road Map. The time schedules for the policy changes are illustrated in the Road Map where focus is on the short-term policies as the relevant medium, while long-term policies are more uncertain and depend on the results in the short term.

Road Map for implementing a 100% renewable energy system by 2050:

The following outlines a Road Map related to the policy means of implementing a 100% renewable energy system by 2050. The years indicate the point in time when the proposals are supposed to be in operation. More details are given in the main text. Not all recommendations are included in the Road Map, for practical reasons, and main emphasis has been given to short-term recommendations. The subjects under each period have been listed under subtitles to facilitate the reading. Notice that the road map of this project fulfils the goals indicated in the plan of the new Danish government from October 2011.

2011 - 2015:

Planning, regulations and evaluations

- Completion of a comprehensive energy plan for the Danish transition to 100 % renewable energy supply made and published by the Danish Energy Agency (DEA) - taking into account reports from the IDA Climate Plan 2050 (*IDA´s klimaplan, 2050*), the present CEESA plan 2011, the Danish Commission on Climate Change Policy (2010), etc. Firm national targets and milestones for the short, medium and long term are needed to attract enough investors.
- Establishment of a municipal energy planning procedure obliging all municipalities to set up detailed energy plans, including technical as well as policy measures.
- Enlargement of the existing energy conservation fund by economic contributions from district heating companies and gas companies.
- Ensuring a planning and investment policy that promotes the expansion of low temperature district heating systems.
- Establishment of a new institution with special responsibility for the technical and economic integration of intermittent renewable energy sources.
- Introduction of a bi-annual progress evaluation of the comprehensive energy plan - including new initiatives, if needed.
- Introduction of schemes that make it attractive for municipalities to own and operate energy plants based on renewables, especially onshore and offshore wind farms.
- Organizations that have cogeneration and/or large heat pump/heat storage systems with required abilities to integrate wind power are given ownership priority in wind energy projects.
- For onshore and near-shore wind turbines, the share which a project developer is obliged to offer to local and regional participants is increased from the present 20% to 60%.
- Establishment of a size limit for onshore wind turbines around 80-110 meters (around 1-2 MW) to protect nature value and reduce local opposition. Exemptions from this restriction may be given under special circumstances.
- Revision of the tendering procedure for offshore wind farms to make it more competitive and more attractive to small investors. The project developer should be required to offer a share of 50% to local and regional participants.
- Change of official discount rate in the planning of future energy systems to below 3 % p.a.
- Alternative systems for the regulation of local CHP production based on waste should be implemented if Denmark cannot obtain exemption from the liberalised EU waste market.

Tariff and tax systems

- Change of district heating tariff systems to phase out fixed charges.

- Removal of tax barriers to investment in large heat pumps in the district heating systems.
- Establishment of a policy that supports investment in large heat pump systems linked to district heating.
- Tax policy that promotes the introduction of certified heat pumps and heat storages in private households.
- Improved energy consultancy and long-term, low interest loans for house renovation financed by an enlarged energy conservation fund.
- The economy of intermittent renewables (e.g. wind and solar) should be based on flexible feed-in tariffs - replacing the spot market (NordPool) for these supply systems.
- Introduction of increased taxes on fossil fuels for industrial production combined with a recycling scheme favouring enterprises that promote significant energy conservation.
- Introduction of a new “green taxation” scheme for private households with a relatively low taxation on the consumption of heat and electricity below a specified cap and increasing taxation for consumption above the cap.
- Change of the annual tax on private cars to depend strongly on the kilometres driven. This change should not await an advanced road pricing system.
- A system should be established that compensate for the changed car tax structure in sparsely populated areas with insufficient public transport facilities.
- Extension of reduced tax on electric cars also after 2015 – until the electric cars are competitive in price on market conditions.
- Prohibition against the installation of new oil-fired boilers in private houses after 2015 and of new natural gas-fired boilers after 2020.

Transport sector:

- Systematic promotion of electric cars via purchase policies of municipalities and other public institutions combined with government subsidies for a national electric car charging system.
- Not higher taxes on fuels for buses and rail transport, than on fuels for air transport inside Denmark in order to establish equal competition between the different means of public transport.
- Improved bicycle paths in all cities and in the countryside with heavy traffic. Promotion of electric bicycles.
- Stronger investments in improved public transport, including fast train connections and improved bus and light rail transport.

Buildings:

- Energy labelling of all buildings combined with graduated green taxes on buildings.
- Investment subsidies for building renovation and the installation of renewable energy technologies. This scheme should not allow required building renovations to be replaced by installations of renewable energy technologies.

Smart energy systems:

- The electricity, district heating and gas grids are interconnected and it should be ensured that all the grids are activated on the production and consumer sides.
- The electricity markets in Nord Pool are already able to activate producers and large consumers. Smart metering of electricity should enable electricity buyers to pool small consumer's flexibility and use this in the regulating power market and other markets.
- Smart metering of electricity, heat and gas should ensure that small consumers are aware of their energy consumption and motivate savings by information.
- Establishment of "intelligent metering" (two-way communication) in Danish households (with a yearly demand above a specified level), services and industries, and billing electricity consumers according to an hourly metering.

2015 - 2020:

Taxes and subsidies

- Benchmarking in relation to the energy efficiency of industrial production should be used where possible in connection with green taxes.
- Economic and technological support of the Danish manufacturing industry to promote a change from natural gas to biogas for high temperature processes by appropriate taxation schemes.
- An advanced road pricing system should be introduced before 2020 including the cost of all external social expenses.
- Public subsidies for the replacement of selected old houses by "passive houses".

Research, development and demonstration (some examples)

- A national solar heating research and test station should be established before 2020.
- Development of new types of supplementary organic materials for biogas production, including algae production and special types of beets.
- Development and demonstration of gasification technologies.
- Economic support for the research and demonstration of new PV technology, electrolysis, co-electrolyses, and fuel cells.
- Analysis of costs and technical possibilities of the transmission of biogas and/or gasified biomass in the natural gas transmission system in comparison with alternative solutions.
- Analysis of how the electricity market should be changed in order to handle a large proportion of wind- and PV-based electricity.
- Analysis of the effects of different types of ownership structures for renewable energy systems.

Smart energy systems:

- The electricity, district heating and gas grids are interconnected further by ensuring that all the grids are activated on the production and consumer sides in order to activate all feasible storage options.

Special schemes for mitigation of CO_2:

- A comprehensive analysis of the schemes of Personal Carbon Allowances (PCA) and Tradable Energy Quotas (TEQs) should be carried out before 2020.
- High-speed train connections have been implemented between a number of large Danish cities. Most local airports for national air traffic have been closed down.

2020 – 2030

- General evaluation of the Danish transition from fossil fuels to renewables as compared to official national goals. Establishment of a new comprehensive plan, if needed, for the background of climate development and new technological possibilities.
- Introduction of supplementary policy means, if necessary, to fulfil the specified goals. Examples may be the scheme of Personal Carbon Allowances and Trading Energy Quotas (TEQs).
- Coal is phased out from the Danish energy supply.
- Most domestic air traffic has been replaced by fast trains

2030 - 2050

- Oil and natural gas are phased out from the Danish energy supply system between 2030 and 2050.

1. Setting the scene for a 100% renewable energy system by 2050

1.1 Introduction

In the last couple of years, a number of reports have been published with technological scenarios for a Danish phase-out of fossil fuels during the next 20 to 40 years (e.g., IDA 2009, Danish Commission 2010, Danish Energy Strategy 2011). All these scenarios are based on a switch from technological systems using fossil fuels to technological systems relying on renewable energy sources (RES). It is characteristic of these publications that the scenarios include a detailed description of the technological systems used to accomplish the goal. The attention to the policy means for implementing these significant system changes is, however, much less detailed and expressed in more general terms.

In contrast to this, the CEESA project has given high priority to the proposals of policy means that can promote the proposed transformations in the technological systems in an efficient and timely fashion by combining market regulation and societal planning. This involves a transition from sparse, polluting and stored energy sources to abundant, relatively clean and intermittent renewable sources. As shown in the CEESA scenarios, this paradigmatic transition requires new infrastructures such as flexible cogeneration units, heat pumps, heat storages, electric cars, etc. The goal of this report is to describe policies that make this transition possible.

One important outcome of this analysis is the conclusion that it is necessary to use specific packages of different policy means for the different energy supply and demand sectors. This applies especially to the demand sectors where the policy means must take into account the differences in the existing situation and needs of sectors like industry, private households and transportation.

CEESA has given special attention to the institutional changes and changes in the market regulation and societal planning systems required due to the magnitude of transformations needed in the total energy system to break the addiction to fossil fuels. Without regulations, the incentives in the existing market mechanism cannot facilitate such a paradigm shift. Consequently, without such changes in market regulation and societal planning, the technological CEESA scenarios would have little chance of being implemented.

The choice between potential policy means has given first priority to the efficient promotion of the main goal of phasing out fossil fuels before 2050. This does not imply that considerations to other societal concerns like employment and industrial interests are neglected. It is, however, a necessary change from the traditional priority of Danish political policy in order to accomplish the goal.

The report divides the policy means according to their time of introduction in the short-term (until 2015), the medium-term (2015- 2020) and the long-term time perspectives (2020 –

2050) where this is relevant. We believe that this kind of strategic outline is useful to the decision-makers in the political planning of the necessary changes. More details, e.g., about the desired changes in the economic system are given in appendices of the report.

1.2 Political targets

In 2008, the EU Commission launched a new climate and energy package. The package includes a new CO_2 directive aiming at further reduction in greenhouse gas emissions as well as a renewable energy directive which aims at reaching a share of 20 per cent renewable energy by the year 2020.

Denmark has committed itself to contributing to the fulfilment of the EU 2020 targets. The Danish commitments are among the most ambitious in the member countries:

- 30 per cent renewable energy in final energy consumption by 2020
- 10 per cent renewable energy in transports by 2020, 5.75 per cent in 2012
- 20 per cent reduction in greenhouse gas emissions from non-ETS sectors (agriculture, heating and transport) by 2020 as compared to 2005.

Some additional national targets have been decided by the Danish parliament in the spring of 2009:

- 20 per cent renewable energy by 2011
- Annual energy savings must reach a level of 1.5 per cent compared to 2006
- Gross energy consumption is to be reduced by 2 per cent in 2011 and 4 per cent in 2020 compared to 2009.

Denmark's Kyoto commitment is a 21 per cent reduction in average greenhouse gas emissions in the period 2008-2012, compared to 1990. The EU commitment on greenhouse gas emissions is a reduction of 20 per cent by 2020 compared to the 1990 level.

In 2008, the Danish Prime Minister announced a vision of Denmark being independent of fossil fuels in the long-term time perspective, a vision that led to the establishment of the Danish Commission on Climate Change policy. In September 2010, the Commission launched its report, stating that, by 2050, a Danish energy system independent of fossil fuels is achievable without excessive costs to society.

In February 2011, the Danish Government launched its follow-up report; the official plan entitled Energy Strategy 2050. The Energy Strategy suggests a number of policy initiatives in phasing out fossil fuels in the long term. However, the plan lacks medium-term targets and milestones on how to achieve the long-term target of no fossil fuels. Naturally, such a long-term development requires significant changes in the structure of the energy system, as well as a continued use of strong policy measures.

Having defined the same long-term target of a complete renewable energy system by 2050, this report aims to be more specific on how to implement this target. Consequently, we set up a road map including a portfolio of specific policy recommendations to be carried out in the period up to 2020. We distinguish between short-term policy initiatives from 2011 to 2015 and medium-term initiatives from 2015 to 2020. We stress the importance of immediate and diversified actions if the ambitious target has to be reached by 2050.

1.3 Guideline to the report

Chapter 2 gives a short summary of the objectives of the CEESA project and the results of the technological scenarios. Readers with previous knowledge of the main report of the CEESA project may skip this chapter. To readers with no previous knowledge of the CEESA scenarios, this chapter is relevant to understand the background for the proposed policy measures.

Chapter 3 shortly outlines the most important criteria for the choice of policy instruments and presents a catalogue of the most relevant ones.

A 100 per cent renewable energy system by 2050 is a radical change compared to today's system. Chapter 4 describes a number of barriers and market failures that should be overcome if a renewable system is to be achieved by 2050.

In chapter 5, policies for the integration of renewables are treated explicitly. In the short term, the expansion of wind power requires a more flexible energy system; an intelligent energy system with close interactions between demand and supply. In the longer time perspective, the organisational set-up of the energy market has to be reconsidered. The traditional marginal pricing market might not be able to handle large amounts of renewable energy with low or no marginal costs in a relevant manner.

Two chapters deal with the specific policy proposals for changing energy demand and supply. In chapter 6, policy measures to reduce and change energy consumption are outlined for each of the sectors; industry, households and services, agriculture, transport and buildings.

Chapter 7 deals with supply policies, including the promotion of onshore and offshore wind power, biogas and biomass. Tariff systems for district heating are described in detail.

Finally, chapter 8 sketches a road map related to policy means of implementing a 100 per cent renewable energy system by 2050.

2. The CEESA project

2.1 The objectives of CEESA

The objective of the CEESA project is to develop scenarios for a future energy system with a 100 per cent penetration of renewable energy technologies by 2050. It consists of four interconnected work packages, as shown in Figure 1:

- Future electric power systems
- Renewable energy in transportation
- Market development and public regulation
- Environmental assessment of energy scenarios

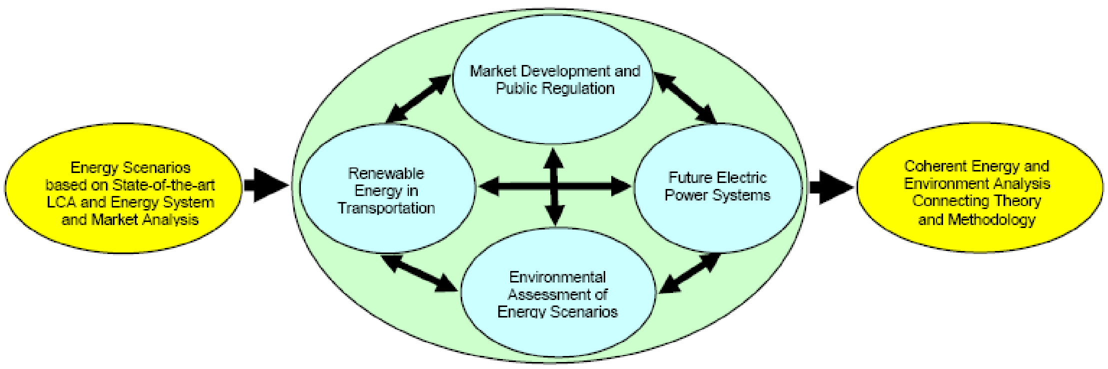


Figure 1: The interconnected work packages in CEESA

As the starting point for the project, an LCA pre-screening was carried out for an existing energy scenario. During the project, this scenario was reworked in detail and considerably expanded in each of the four work packages shown in Figure 1, in a close collaboration and interaction between the work packages. Finally, a number of new coherent scenarios were established based on the results and, especially, taking into account the environmental part of the project. The macro-economic development has been based on official forecasts from the Danish Ministry of Finance.

In the following, these final scenarios will be shortly described.

2.2 The CEESA scenarios

The aim of the CEESA project has been to design a relevant scenario for the transformation of the present energy system based mainly on fossil fuels into a 100 per cent renewable energy system by 2050. The design of such scenario highly relies on the technologies which are assumed to be available within the chosen time horizon. To highlight this issue, the CEESA project has identified the following initial scenarios based on three different assumptions with regard to the available technologies:

> ***CEESA-2050 Conservative:*** *The conservative scenario is created using mostly known technologies and technologies which are available today. This scenario assumes that the current market can develop and improve existing technologies. In this scenario, the costs of undeveloped renewable energy technologies are high. Very little effort is made to push the technological development of new renewable energy technologies in Denmark or at a global level. However, the scenario does include certain energy efficiency improvements of existing technologies, such as improved electricity efficiencies of power plants, more efficient cars, trucks and planes, and better wind turbines. Moreover, the scenario assumes further technological developments of electric cars, hybrid vehicles, and bio-DME/methanol production technology (including biomass gasification technology).*
>
> ***CEESA-2050 Ideal:*** *In the ideal scenario, technologies which are still in the development phase are included on a larger scale. The costs of undeveloped renewable energy technologies are low, due to significant efforts to develop, demonstrate and create markets for new technologies. For example, the ideal scenario assumes that fuel cells are available for power plants, and biomass conversion technologies (such as gasification) are available for most biomass types and on different scales. Co-electrolysis is also developed and the transport sector moves further towards electrification compared to the conservative scenario.*
>
> ***CEESA-2050:*** *This scenario is a "realistic and recommendable" scenario based on a balanced assessment of realistic and achievable technology improvements. It is used to complete a number of more detailed analyses in the project, including the implementation strategy, as well as in a number of sensitivity analyses. Here, however, less co-electrolysis is used and a balance is implemented between bio-DME/methanol and syn-DME/methanol in the transport sector. This is the main CEESA scenario.*

Here, *Conservative* and *Ideal* are used in the sense that different technological developments will have different effects on the extent of the use of biomass resources, as well as the requirements for flexibility and smart energy system solutions. In all scenarios, energy savings and direct electricity consumption are given high priority. In the CEESA scenarios, the *smart energy system* integration is crucial. The scenarios rely on a holistic *smart energy system* including the use of: heat storages and district heating with CHP plants and large heat pumps, new electricity demands from large heat pumps and electric vehicles as storage options, electrolysers and liquid fuel for the transport sector, enabling storage in the form of liquids as well as the use of gas storage.

Such *smart energy systems* enable a flexible and efficient integration of large amounts of fluctuating electricity production from wind turbines and photovoltaics. The gas grids and liquid fuels allow long-term storage, while the electric vehicles and heat pumps allow shorter term storage and flexibility.

All three technology scenarios above are designed in a way in which renewable energy sources, such as wind power and PV, have been prioritised, taking into account the technological development in the scenarios and the total costs of the system. Moreover, they are all based on decreases in the demand for electricity and heat as well as medium increases in transport demands. Consequently, none of the scenarios can be implemented without an active energy and transport policy. However, sensitivity analyses are conducted in terms of both a high energy demand scenario as well as the unsuccessful implementation of energy saving measures. These analyses point in the direction of higher costs, higher biomass consumption and/or a higher demand for more wind turbines.

In the *conservative* technology scenario, wave power, photovoltaic and fuel cell power plants are not included and emphasis is put on bio-DME/Methanol and on direct electricity consumption in the transport sector. The electrolysers are based on known technology in this scenario. Smart energy systems are required as well as cross-sector system integration between the electricity system and the district heating sectors as well as into the transport system and gas grid in all scenarios. The integration into the transport system and gas grids is, however, not as extensive in the *conservative* scenario as in the *ideal* scenario. In the *ideal* scenario, wave power, photovoltaic, fuel cell power plants, and a number of other technologies are used to their full potential, while, in the *recommendable* scenario, the technologies are assumed to be developed to a degree in which they can make a substantial contribution. For all technologies, sensitivity analyses are made in which they are replaced with existing technologies. The primary energy consumption for 2050 of the three scenarios and the reference energy system are compared in Fig. 2. Compared to the reference energy system, all the scenarios are able to reduce the primary energy supply to a level of approximately 500 PJ. There are, however, large differences between the structures of this primary energy supply.

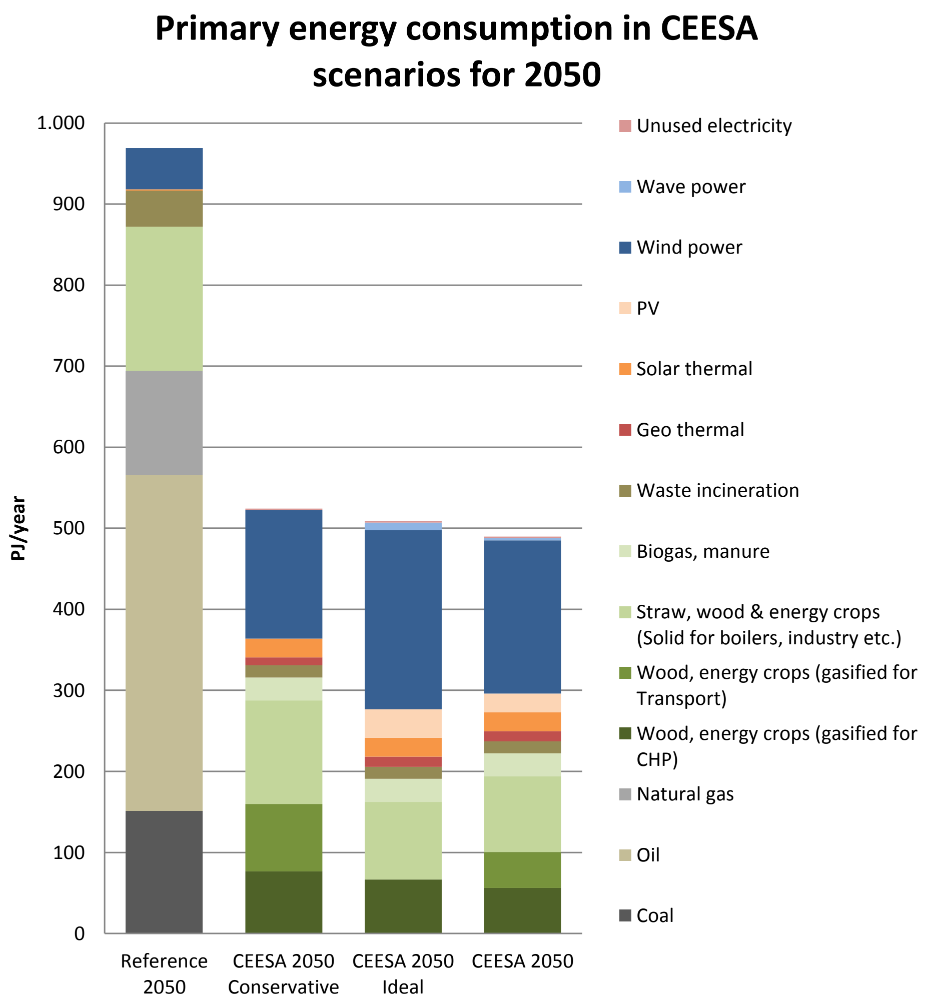


Figure 2: Primary energy supply in the 2050 reference energy system and the three CEESA 100% renewable energy scenarios.

In the *conservative* technology scenario, a 100% renewable energy system is possible with a total biomass consumption of 331 PJ. The *ideal* technology scenario can decrease this consumption to 206 PJ of biomass. In the CEESA 2050 *recommendable* scenario, the biomass consumption is 237 PJ and thus 30 PJ higher than in the *ideal* and 96 PJ lower than in the *conservative* scenario. In all three scenarios, hour-by-hour energy system analyses have been used to increase the amount of wind turbines to an amount ensuring that the unused electricity consumption, also referred to as excess electricity, is lower than 0.5 TWh (1,8PJ). These analyses also ensure that the heat supply and gas supply are balanced. The importance of that is visible in the differences in the installed wind power capacities in the three 100% renewable energy scenarios, i.e., the *ideal* scenario is able to utilise more wind power than the *conservative* scenario.

2.3 The recommended CEESA scenario

The current primary energy supply in Denmark (fuel consumption and renewable energy production of electricity and heat for households, transport and industry) is approximately 850 PJ, taking into account the boundary conditions applied to transport in this study in which all transport is accounted for, i.e., national/international demands and both passengers and freight. If new initiatives are not taken, the energy consumption is expected to decrease marginally until 2020, but then increase gradually until 2050 to about 970 PJ. The reference energy systems follow the projections from the Danish Energy Authority from 2010 until 2030, and the same methodology has then been applied here to create a 2050 reference energy system. The measures of savings, transport as well as renewable energy and system integration between the electricity, heat, transport and gas sectors can reduce the primary energy supply to 669 PJ in CEESA 2020; 564 PJ in CEESA 2030; 519 PJ in 2040, and 473 PJ in CEESA 2050, respectively.

At the same time, the share of renewable energy from wind turbines, photovoltaic, solar thermal, and wave energy, as well as biomass will be increased. The share of renewable energy in the recommended energy system increases from about 20 % in 2010 to 42 % in 2020 and to about 65 % in 2030. If the oil and gas consumption in refineries and for the extraction of oil in the North Sea is excluded, 73 % is the share of renewable energy in the 2030 energy system. Coal is phased out before 2030. In 2050, the entire Danish energy system (incl. transport) is based on 100 % renewable energy. The primary energy supply is illustrated in Figure 3.

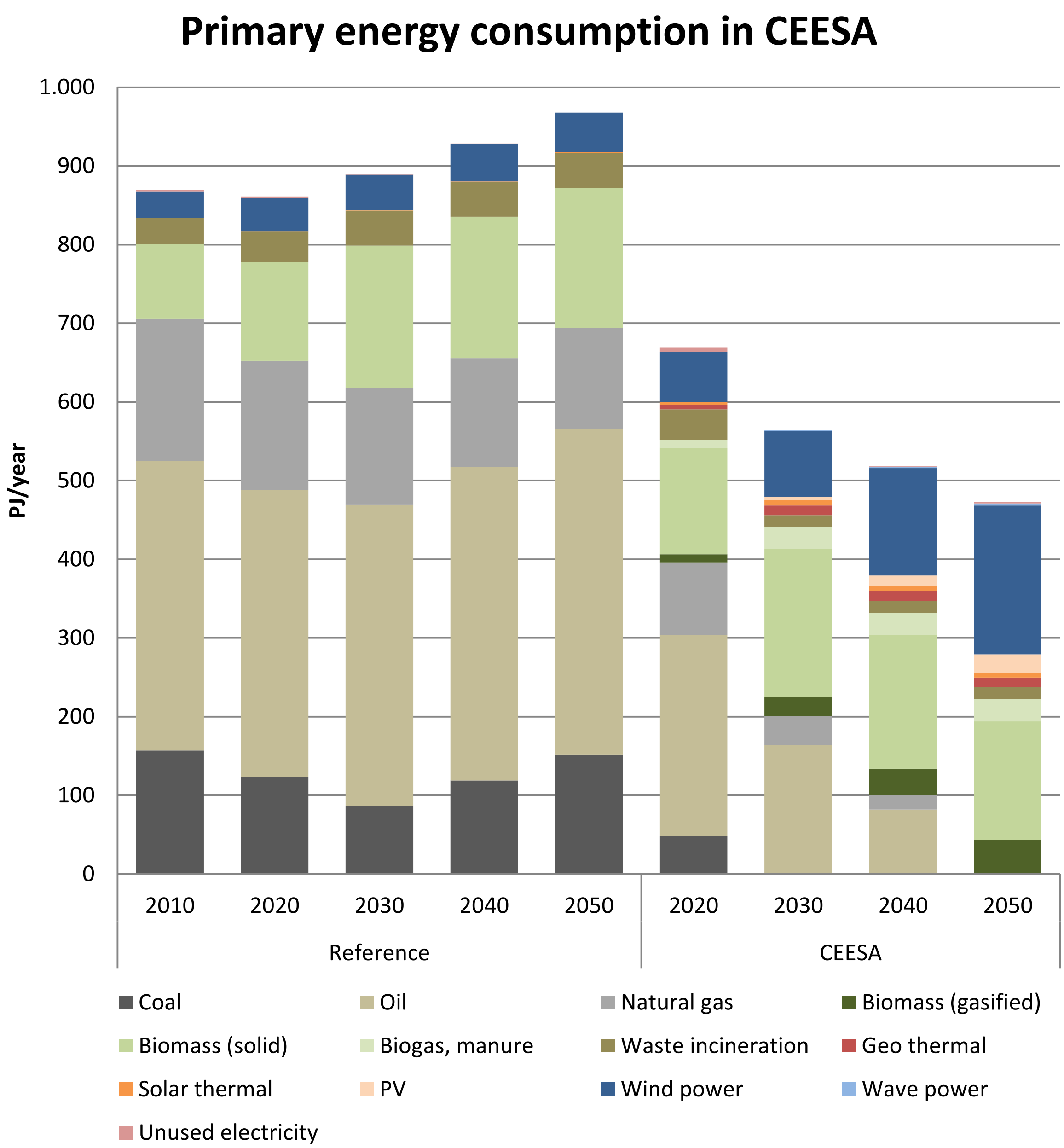


Figure 3. Primary Energy Supply in CEESA.

The energy system in CEESA 2020 is based on measures which can be realised with the current technology; however, some development of battery electric vehicles, hybrid electric and plug-in hybrid electric vehicles is assumed. The main focus in the short term is large heat pumps and heat storages in the district heating sector. In CEESA 2030, large parts of the transport system are changed, district heating systems are heavily expanded, the efficiency of power plants is increased, more mature and new renewable energy technologies are introduced, and further energy savings are implemented in electricity and heating as well as in the transport sector through the introduction of modal shift measures and going from a high increase to a medium increase in transport demand. In general, large parts of the fossil fuel consumption are replaced by electricity demands, especially within transport, with different types of electric vehicles and electrically powered trains. Special emphasis has been put on the transport sector in which the transition to renewable energy poses significant challenges due to the very high demand increases which are forecasted and an almost 100 % dependency on oil.

In CEESA, an energy system is designed which is based on 100 % renewable energy and combined with analyses of the energy system in the transitional years 2020 and 2030. 2040 has been included by interpolating between the 2030 and 2050 energy and transport systems. Savings are implemented gradually and more renewable energy is introduced in these transitional years. Substantial investments are required in savings, renewable energy, district heating, and notably in the transport sector. The transitional years are partly analysed to ensure that these energy systems do not stand in the way of the main objective and partly because of the Danish Government's objective that Denmark shall use 100 % renewable energy in 2050. Hence, the technologies needed in the short term to enable this should be identified.

The CEESA scenarios document that it is possible to find technical solutions for a 100 % renewable energy system. However, a certain technological development becomes essential in the coming years, notably in enabling the efficient direct use of electricity in the transport sector with better electric, hybrid electric and plug-in-hybrid electric vehicles and in biomass gasification technologies (small and large scale). The results also show that, if these technologies are not developed sufficiently, the biomass consumption could be larger than in the CEESA 2050 *conservative* scenario.

In CEESA, the greenhouse gas emissions from fossil fuels are reduced significantly in the energy system. Here the extra contribution from aircraft due to discharges at high altitudes is included. In CEESA 2020, the greenhouse gas emissions are reduced to 30 Mton CO_2-eq./year and in 2030 to 15 Mton CO_2-eq./year. In 2020, the reductions are approximately 45% compared to 2000; in 2030, the reductions are 70% and, in 2040, approximately 85%. In 2050, the emissions are not zero due to aviation, but the emissions have been reduced to 2% compared to 2000 from these sources. Greenhouse gas emissions from industrial processes and from agriculture or land use changes are not included in these figures.

In general, the socio-economic costs are somewhat lower in the recommended CEESA scenario compared to the reference. The CEESA 2050 scenario 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 plan. Therefore, the expenses are calculated as the extra expenses related to the investment in better facilities in comparison with the reference energy system.

The main assumptions are the following: A real interest rate of 3 per cent is used for discounting. 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 April

2010. Three fuel price assumptions are used: 1) A low fuel price development corresponding to an oil price of $60/barrel; 2) A medium price level corresponding to an oil price of $122/barrel; 3) A high oil price of $132/barrel corresponding to the price in the spring/summer of 2008. For CO_2, quota costs of 229 DKK/tonne and 458 DKK/tonne are used for 2030 and 2050, respectively.

3. Choice of policy instruments

3.1 General criteria for the choice of policy means

The goal of the CEESA project is to phase out fossil fuels in the Danish energy supply before 2050. Many different policy means may be used to promote that goal. This section outlines the main criteria for selecting the most relevant policy means from the list of potential schemes.

The following seven criteria are chosen as the most important ones. They are not necessarily listed in order of priority, but the first criteria on the list should be regarded as most important in relation to the goal of the CEESA project. This implies that criteria 2 to 8 should be promoted as long as they do not conflict with criterion 1. It should be noticed that there are couplings between some of the criteria.

1. *Efficiency and certainty* in relation to obtaining the goals of the CEESA scenarios.
2. *Cost-effectiveness* in relation to the scenarios.
3. *Balanced social costs* of the scenarios.
4. Broad *political support* and active participation *by citizens, including NGOs.*
5. Balanced *energy tax burden* between households and industries.
6. Positive influence on Danish *"green industry"* and *employment.*
7. Acceptable impact on *public revenue*.
8. Efficient *monitoring* and *control*.

Regarding 1: A number of different policy means and different technologies may be used to phase out fossil fuels before 2050. Some of these solutions may conflict with other political goals. When possible, these conflicts should be minimized, but the CEESA goals should have highest priority in this project.

Regarding 2: The scenarios should aim at the lowest societal costs over the scenario period in relation to the choice of policy means and technologies.

Regarding 3: Some policy means (e.g., green taxes) are a greater burden on low-income households than on more affluent households. This lack of balance between different social groups should be taken into account when structuring the policy means.

Regarding 4: Without broad political support and active participation by the citizens, the selected scenarios shall be less realistic. In the project, main emphasis is given to the activation of private households as the preferences of the political sector are difficult to predict over such a long scenario period.

Regarding 5: Balance of the tax burden should face the polluter pays principle and the principle to protect the competitiveness of the energy intensive industry.

Regarding 6: Experience from the Danish wind power development has supported the potential for new production and employment based on green technologies. Experience has also shown that the success of new green technologies is strongly dependent on state support and long-range state planning in the period of technology maturing. This should be taken into account when selecting the policy means.

Regarding 7: The impact on public revenue should be considered and balanced in order to obtain sufficient political support.

Regarding 8: Considering the long transition period of 40 years, the monitoring and control of the progress are important. Concrete procedures for this evaluation should be established including a road map with milestones and timing for the implementation of the different policy means.

3.2 Types of policy measures

An important part of the CEESA project is to suggest appropriate policy measures enabling the transformation of Denmark from the present fossil fuel scenario into a long-term scenario of renewable energy from domestic sources. This is done by providing an institutional and regulatory frame for the specific sectors and their market structure.

A catalogue of policy measures has been assembled as a basis for making priorities between alternative measures in accordance with the set of criteria indicated above.

The catalogue is subdivided into the following types of schemes:

a) **Regulating the Formation of Actors**
    i. Property rights and responsibilities
        1. Power companies as private or partnerships.
        2. Renewable Energy Systems as owned by the consumers or owned by power companies.
        3. Transmission System Operator (TSO) owned by the state.
        4. District heating organized as private cooperatives or owned by municipalities.
        5. Regulation of competition.

b) **Economic measures:**
    i. Taxes
        1. Green tax (based on external costs).
        2. Carbon, CO_2, NOx or SO_2 tax.
        3. Energy tax – production or consumption tax; value (per cent) or per energy unit (DKK per GJ).
        4. Tax credit (refund), i.e., as has been practiced in Denmark.

ii. Subsidies
    1. PSO payment from consumers to TSO.
    2. Investment or production grant.

iii. Feed-in tariffs
    1. Technology specific (e.g., wind power onshore, solar, biogas CHP etc.) Flexible tariffs adjusted over time according to maturity of technology.

iv. Tariff design (e.g., fixed or variable energy tariffs).

c) Certificates and quota systems

i. Tradable certificates
    1. EU ETS market.
    2. Markets for SO_2 and NOx.
    3. Grandfathering, auctioning, fund based on revenue from free CO_2 certificates to finance investments in renewable energy technologies.

ii. Non-tradable CO_2 certificates.

iii. Personal quotas for carbon emissions (Personal Carbon Allowances).

iv. Tradable green certificates market (used in, e.g., UK, Sweden, Belgium, Italy, Poland, and Romania).

d) Tendering or bidding systems

i. Bid to supply renewable energy of a particular type on a given location for a certain period in time (has been used in Denmark for offshore wind power).

e) Norms for energy consuming appliances and apparatus decided nationally or internationally

i. Household equipment, cars, building codes.
ii. Limits for environmental effects, e.g., emissions.
iii. Norms for energy efficiency.

f) Information campaigns

i. Labelling of household equipment and cars, information about latest development in energy supply based on renewables.

g) Funding

i. Research, development and demonstration of renewable technologies.
ii. Cheap investment loans for renewable technologies.

iii. ESCO, i.e., third party involvement.

h) Assumptions in economic modelling

i. Discount rates should not downgrade the future.
ii. Portfolio principles in relation to risk of volatility of future fuel prices.

The different schemes are discussed in more detail in connection with the specific demand and supply areas and conclusions are drawn on the priority of different schemes.

4. Structural changes of the existing market design

4.1 The market paradigm

The transformation to 100 % RES involves changes not only of the energy sector but also in a number of other societal sectors. The focus in this section will be on proposed changes in planning methodologies and economic paradigms and priorities, institutional set-up, and taxation systems, in order to promote the efficient phase out of fossil fuels and the creation of a sustainable energy development.

The present market design shall not be seen as a "natural law" but rather as the result of a complex historical development with strong influence from vested interests and varying political priorities. This has resulted in market constructions in the real world that deviate significantly from the theoretical "ideal market", as illustrated by a number of examples below. Even the central market claim of securing an efficient allocation of resources is far from being fulfilled. In addition, the priorities of the present market do not sufficiently include sustainable development.

4.2 Examples of barriers to RES including market failures in the present framework

This section lists some significant examples of institutional and regulatory barriers in the present market system that prevent an efficient path to 100 % RES. There is a relatively strong technological and institutional lock-in that protects and favours existing fossil fuel-based technologies and that makes the provision of space for distributed generation (van der Vleuten and Raven 2006) and renewable energy technologies difficult (see Appendix A). Some Danish and international examples are listed below. In the subsequent text, focus is on the Danish examples.

- Large economic subsidies to fossil fuels in many countries (IEA 2010) leading to artificially low market prices.

- Insufficient inclusion of negative externalities in the price of fossil fuels (EU Commission 2004).

- Too much market power to large utilities with vested interests distorting the efficient allocation of resources. The tendering procedure in connection with the recent Danish offshore wind farm at Anholt is an example.

- No premium to installations based on renewable energy sources (RES) for the lack of risk of increasing fuel prices in contrast to plants based on fossil fuels (Awerbuch 1996a, 1996b, 2003; Awerbuch and Saunter 2006).

- Short time horizon with priority to profitable investments compared to the long time horizon required for the radical transformation of the whole energy system. The short time horizon often leads to investments that block efficient long-term solutions based on RES, e.g., new coal plants without Carbon Capture and Storage (CCS) or the development of tar sand resources.

- Historical development of taxation systems that often counteract energy conservation and the promotion of RES, i.e., the taxation of private transport is not linked to driving distance, but to the car independent of its use.

- Too high discount rate in the government procedure for evaluating alternative technology and savings options. Since 1999, the Danish discount rate has been set to 6% by the Ministry of Finance, while independent economists state that discount rates must be between 1% and 3% if alternative energy sources shall have realistic chances against 'business-as-usual'.

- Government planning based on macroeconomic models and a version of neoclassical economic theories which believe that the present market construction represents an optimum, and the use of high discount rates when comparing alternative solutions. This excludes the necessary promotion of long-term solutions (Daly 2007).

The present dominant belief that the actual market conditions represent an economic optimum, and also generate future optimal solutions, is an significant barrier to making the appropriate policy changes needed to promote the un-locking transition to a 100% renewable energy system. Economists and practitioners continue to make the paradoxical observation that many low- and zero-carbon technologies are ready, but the supposedly free market will not accept them. Therefore, the present institutions and regulations that shape the strong lock-in of high-carbon technologies on the Danish energy markets must be changed.

Present institutions frame different markets for energy technologies in such a way that they support and protect incumbent technologies and provide barriers to the transition to renewable energy systems. See also Appendix A.

Further, there is a need for new long-range planning methodologies. Many tools and instruments from economic theory used in policy analysis are not neutral and objective. For example, the existing conventions of calculation do not to a sufficient degree incorporate pollution costs into fossil fuel prices, and the internal discount rate favours investments with short-term profits and reduces the interest in long-term investments.

The current political preference for exclusively market-based policy tools like the CO_2 quota system with grandfathering has been inefficient in promoting the transition to renewables.

More details are given in the following sections including proposals of efficient policy means in the different energy sectors.

As an illustration, some Danish examples of typical lock-in and un-locking cases are included in this introduction.

4.3 Selected Danish examples

4.3.1 The district heating example

Technical analyses show that it pays to reduce the heat losses in houses by at least 50%. At the same time, the tariff system in the district heating areas is characterized by a fixed charge in the range of 25%- 65% of the total heat bill. Therefore, the economic incentive to invest in long-term heat losses is weak, especially in the large district heating systems in Copenhagen, Århus, Ålborg, Odense, etc., and thus far from strong enough to ensure investments in the long term economical lucrative 50% reduction in heat losses. In addition, there is a lack of consultancy assistance and financial possibilities for long-term investments in improvements of the energy efficiency in the building sector.

These short-comings of the present market characteristics illustrate “lock-in” mechanisms that hinder the implementation of the economically lucrative goal of reducing heat losses by 50%. Thus, the present market construction both results in loss of economic welfare and a high CO_2 emission.

CEESA proposes this “lock- in“ removed by establishing a combination of 100% variable heat tariffs, 30-year 3% loans with public guaranty and improved cheap consultancy services in the area of building renovation (See section 7.4).

4.3.2 The private car example

In the present market construction, the taxation of private cars is mainly linked to the ownership of the car (fixed tax) and relatively less to the use of the car (variable tax). At present, the average total private costs per km, is in the range of 50-60 eurocent, and the marginal costs of driving one km is around 10 eurocent for an average car of the Golf type. This cost structure is a market construction in which the variable tax, mainly on gasoline, will be around 4 eurocents, and the fixed tax on the car around 25-30 eurocents per km. In this market construction, the marginal costs of car driving per km (around 10 eurocents) are far below the long-term societal costs per driven km including environmental costs (36-58 eurocents).

The present taxation system therefore represents an incentive system that furthers a volume of car traffic that exceeds the societal optimum. This is an example of a “lock-in” mechanism that increases the CO_2 emission and simultaneously reduces social welfare.

This “lock-in” mechanism can be weakened or removed by a relative increase of the variable km dependent tax. In this way, the private car traffic volume will approximate the optimum of societal welfare, while reducing energy consumption and CO_2 emission (See section 6.4).

4.3.3 The CO_2 quota example

The EU emission trading system (ETS) has been characterised by free CO_2 quotas to companies based on their historical emission data; the so-called grandfathering system. This system has transferred several hundred million euros to established power companies and (old) large industries, while new renewable energy and energy conservation companies do not have the same benefits.

Thus, the grandfathering principle of allocating CO_2 permits is a “lock-in“ mechanism favouring first-comer companies compared to newcomers. The present design of ETS will be revised for the period 2013-2020. The aim is to reduce the benefits of free emission rights to the industry. The European Commission suggests a new market design based on benchmarking and a stepwise reduction of the share of free emission rights from 80 % in 2013 to 30 % in 2020. Benchmarks will be product-based and reflect the top 10 most efficient industries in the EU member states. A crucial aspect is, however, carbon leakage, i.e., the fact that some industries are facing strong international competition. These industries will be given the privilege of obtaining 100 % free emission rights over the whole period. Still, these industries are due to benchmarking, which means that the allocation of free emission rights will be based on an evaluation of the most efficient industries in Europe. A supplementary cap-and-trade system would introduce Personal Carbon Allowances, where free quotas are distributed to the inhabitants of a country (Fawcett, Hvelplund and Meyer 2010). (See section 6.2.3).

4.3.4 The renewable infrastructure example

The transformation from a fossil fuel-based energy system to a 100% RES system includes an important shift from a system with stored energy to mainly intermittent energy sources. This change requires the establishment of a new technical infrastructure that can coordinate the intermittent RES with the consumption side.

The CEESA project proposes a new intermittency infrastructure consisting of a combination of cogeneration units, heat pumps and heat storage, and, in the longer term, also electric cars. This type of infrastructure is discussed at present, but the current institutional roles of actors do not permit them to promote such a new infrastructure. Thus, the Danish TSO, Energinet.dk, is focused on investment in large grid systems, but has no clear mandate to further the new intermittency infrastructure in a similarly efficient way. In order to avoid suboptimal decisions and investment lock-ins, it is important that a specific institution within Danish energy planning is given the responsibility for the technical and economic integration of intermittent renewable energy sources.

At the same time, the present electricity taxation makes it less economical to invest in heat pumps. Thus, at present, no systematic investments are made in these new infrastructural technologies that can solve the intermittency problem at the local and regional levels.

These organisational and tax conditions represent "lock-in" mechanisms that hamper the introduction of 100% RES, reduce societal welfare and tend to hinder investments in systems reducing CO_2 emissions.

This infrastructural "lock-in" problem could be reduced by giving a higher "feed-in" tariff for wind power from turbine owners that establish a certain heat pump capacity and heat storage capacity per MW of installed wind power. Such a system could be organised by Energinet.dk.

5. Policies on integrating renewable energy technologies

Different policy measures are needed in the short and the long term if a large amount of renewable energy sources, such as wind power and photovoltaics, is to be integrated into the energy system. This is complicated process in terms of technology, regulation and economy, because an increase in the share of intermittent renewable energy technologies does not comply with the dominant logic of operation and load balancing that historically has made the centralized electricity system efficient in one particular way (Karnøe 2010).

At present, two approaches to making sense of this transformation can be seen. One approach adds increasing shares of wind power to an unchanged centralized electricity system, and the result is increasing amounts of discarded electricity and higher total costs. This is due to the fact that intermittent energy sources do not fit into the old hierarchy of base and peak load and spinning reserves (Hookwijk et al 2006). Another approach is the one promoted by the CEESA energy scenario in which increasing shares of intermittent wind power is added to the electricity system, but neither load generation nor load consumption stays constant. In this approach, ongoing reconfigurations of load generation and load consumption reduce discarded electricity, and a new flexible load balancing logic reduces total cost (Lund and Mathiesen 2009, Karnøe 2010).

In the CEESA project, the reconfiguration of the electricity system and the load balancing capacities run as follows:

In the short term, the development of intermittent renewable sources has to go hand in hand with the development of an intelligent, flexible energy system. Emphasis must be given to the development of heat pumps, both for individual purposes (including a hot water storage tank) and for district heating purposes.

In the medium to long term perspective, new technologies, such as electric vehicles, are essential for a 100% renewable energy system. In addition, the development of energy demand flexibility in buildings and industrial processes is important. Finally, in the long term perspective, focus will change from furthering technological development to breaking down institutional barriers, e.g., related to the functioning of the liberalised power market. In the long term, the existing organisational set-up of energy markets, with many low marginal cost technologies being the rule rather than the exception, might not be able to handle investments in these technologies.

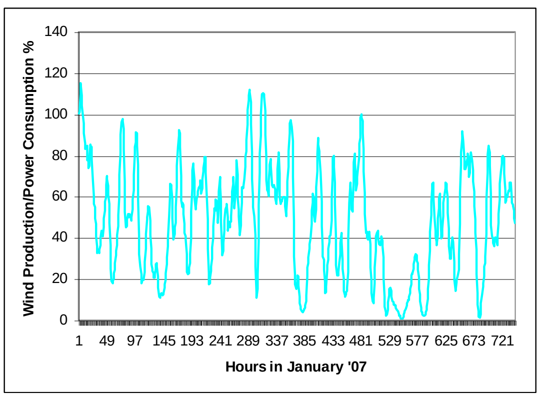
In the following, both the short-term and the medium- to long-term issues will be discussed in more detail with a main focus on the short-term policies.

5.1 Integration of wind power into the Danish power system

5.1.1 The present role of wind power in Denmark

Denmark has, at present, the world record for wind power share in the power system: On average, approx. 20% of the Danish power consumption is covered by wind power and, in the Western part of Denmark[1], this share is even higher – 25% on average. From time to time, wind power covers more than 100% of the power consumption of Western Denmark (see Figure 4, left). In their new report, the Danish Commission on Climate Change Policy has illustrated that the capacity until 2050 will multiply by five from the present 3.1 GW to approx. 16 GW, offshore wind farms being the main contributor to this increase. However, at present, the spot market is pressed to the limit when the share of wind power in the system is large (see Figure 4, right). Therefore, a share of 50% of wind power in the Danish power supply will require a much closer integration of wind power into the energy system.

Seen from a system viewpoint, it is a challenge to integrate a large share of wind power into the system. Wind is a variable source of power production. Thus, the amount of wind power produced changes rapidly with the variability of the wind resource. This puts constraints on the conventional part of the power system in terms of regulation capabilities.



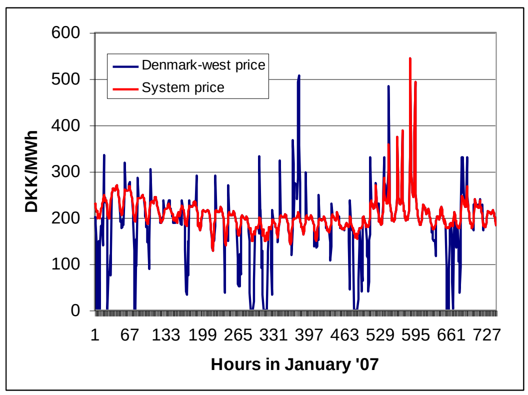


Figure 4: Left: Wind power as a percentage of the power consumption in Western Denmark for January 2007 and right: Spot prices for the same area and time period.

5.1.2 Interactions with energy consumption

Today's energy system is the result of decisions made during more than a century. The specific fit between base and peak load, cogeneration of electricity and heat, grid structure, and the patterns of consumption has evolved through time and the elements of this fit have adapted to each other. Further, this technological development is intertwined with

[1] From 2010, a 600 MW DC-cable connects the Eastern and Western areas of Denmark.

[2] Large companies are defined by a minimum consumption of 50 GWh. Small companies are defined by a

institutional regulations of price, investment, national priorities, forms of exchange, and rules for competition. Therefore, the energy system must be seen as a specific Techno-Institutional-Market-Complex – in short, a TIMC with its own developmental dynamics of stability and transformation.

This applies to the Danish energy system as it does to other European systems. The long-term development is reflected in the energy system structure, which, in most cases, is developed according to basic engineering requirements: Energy is produced to fulfil the needs of energy consumers and should be made available according to these needs. However, a new supply structure based on intermittent energy resources, such as wind power, will require a much more flexible energy system, including the flexibility of energy consumers. Thus, the core of an intelligent system should include an efficient communication between energy producers and energy consumers, e.g., based on real-time pricing, where the cost of energy is disseminated to the consumers, thus, influencing their demand for energy. In this way, an abundant supply of wind power-based energy produced at low prices could be absorbed by consumers, responding to the low prices of an increased energy demand. Correspondingly, consumers are expected to lower their energy demand, when supplies are sparse and prices high.

The combined utilisation of the three different grids - the power grid, the district heating grid and the natural gas grid - has supported an efficient supply system with a high share of combined heat and power. The increased production of renewable energy in the future, primarily wind energy, must interact efficiently with these grids in order to contribute as much as possible to the displacement of fossil fuels in the electricity, heat and transport sectors. In this respect, flexibility will be a key concern.

Thus, an intelligent energy system must fulfil the following objectives:

- To integrate a large amount of intermittent renewable energy sources in an efficient way in the power and heating systems and in the transport system.
- To ensure that the energy demand is covered in an efficient and appropriate way without compromising the security of supply and the comfort of consumers.
- To facilitate the implementation of energy conservation and efficiency measures.
- To ensure reasonable costs of energy for the consumer.

5.1.3 Options for flexibility

Seen in this perspective, a higher degree of flexibility in the energy system – and especially the power system - is called for. This can be achieved by a number of different means:

- A closer interplay between the power system and the district heating system might be a solution. Large heat pumps may be utilised to absorb excess power supply in times of heavy wind power production and convert electricity to heat at a high efficiency. Hot water heating storages are available as part of the district heating grid and may serve as a cheap buffer for power balancing in an optimised heat and power system.

- Small individual heat pumps equipped with hot water storage facilities and replacing existing oil-fired burners could in a similar way absorb the excess supply of wind power when needed. These could either act autonomously according to a real-time price signal or be subject to a coordinated bidding on the balancing market.
- The introduction of electric vehicles could be an efficient solution using car batteries for storing excess power from wind turbines;
- It is possible to interrupt some industrial processes for hours or even for days (e.g., cold stores) by communicating the right price signals to the consumers.
- In general, a certain degree of flexible demand exists in households, services and industry, especially in relation to cooling and heating processes. To activate this flexibility, real-time metering and relevant price information to the consumers are required. At present, flexibility potentials in households, services and industry does not seem to be sufficiently large. Continued technological development in the future might, however, increase these potentials significantly.

Hence, the main question to be answered in this part of the project is: Which policy incentives can increase the integration of renewable electricity into the grid and create the economic basis for an intelligent energy system?

One way of achieving this goal is to change the tax tariff on electric power. In Denmark, the electricity tax is a per unit tax adding to the electricity price (except VAT, which is an ad valorem tax), with multiple exemptions to companies.

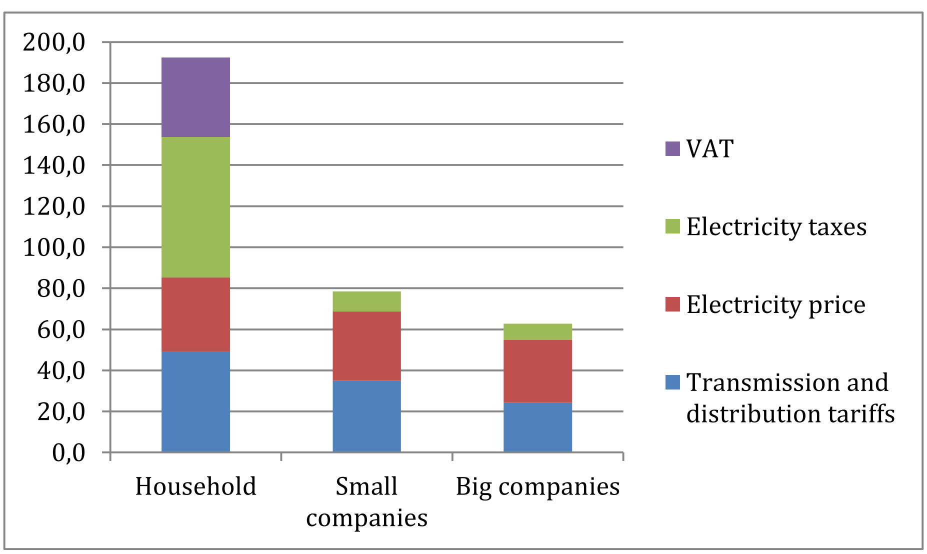


Figure 5: Composition of electricity price, October 2009, øre/kWh. Source: DERA 2010 and own calculations[2]

As shown in Figure 5, the price of electricity as given by the power market, NordPool, constitutes a major part of the price paid by companies, owing to their insignificant payment of tax and no VAT. However, this is certainly not the case for households which pay a heavy tax on electricity and VAT on top of the electricity cost.

If the volatility of the power prices increases, a response is to be expected from companies and, to a minor extent, also from households. However, neither households nor companies have shown demand response of any significance (Andersen 2009). This indicates that the market fluctuations are too small to create an incentive for demand response at end-user level for both companies and households. This is partly due to the lack of incentive transfer (hourly metering and billing), but also because price fluctuations are too small to give consumers a significant gain. The average welfare gain is estimated at less than 0,5 % of the electricity bill paid by consumers (Andersen 2009).

5.1.4 Conclusions and recommendations

In the *short term*, a number of initiatives are prerequisites for promoting an intelligent energy system. These include billing the customers according to an hourly metering and implementing standards for communication and technologies in an intelligent energy system. This is especially needed for heat pumps connected to district heating plants, but also individual heat pumps are highly prioritised in this respect. It is important that the relevant technologies are chosen by the consumers. Thus, new policies include:

- The introduction of a subsidy scheme for high-efficiency heat pumps (earth to water or water to water). This scheme may include an investment subsidy (upfront subsidy) or a variable tariff on the use of electricity.
- For large heat pumps connected to district heating plants, a tendering scheme could be relevant, if possible including a variable tariff on the use of power.

In the *medium to long term*, electric vehicles should cover a significant part of the car transport. A prerequisite for this is the settlement of standards for communication and regulation for these electric vehicles. This could also include a reversible use of the vehicle's batteries as a storage facility that is able to both charge and recharge. The following policy measures should be introduced:

[2] Large companies are defined by a minimum consumption of 50 GWh. Small companies are defined by a maximum consumption of 100.000 kWh. Households are assumed to have a consumption of 4000 kWh.

The electricity price of large companies is calculated from the Nord Pool price with a mark-up. Differences in assumptions are the reason for the difference in electricity prices for companies and households.

- Implementation of a subsidy scheme for electric vehicles, ensuring that these are charged at the right times; that is, when there is a surplus of wind electricity in the system and the power price is low. A dynamic electricity tariff should reduce potential bottlenecks in the distribution grid.
- Analyses of coordinated bidding (pooled bidding) on the power markets (day-ahead and regulating power market) as a viable option for technologies such as heat pumps and electric vehicles.
- Promotion of flexibility in industrial processes by relevant economic incentives.
- Promotion of demand flexibility in individual households by relevant economic incentives.
- Introduction of relevant changes on the power market in order to promote a further development of a flexible and intelligent power and energy system.

5.2 Reconsidering the electricity market in a long-term perspective

A 100% renewable energy system will, in the long term, require significant changes in the organisational and regulatory set-up. One century ago, the actors behind the centralised power system in Denmark began to create the changes in power production, grid structure, organisation, and institutional regulation that gave it complete dominance by 1980. In the following, focus is on the pricing of electricity on the liberalised power market.

5.2.1 The liberalised power market and the marginal pricing rule

Liberalised power spot markets reflect a particular institutional and technological pricing arrangement. In the Nordic power exchange, NordPool, the power price is determined according to the marginal pricing rules.

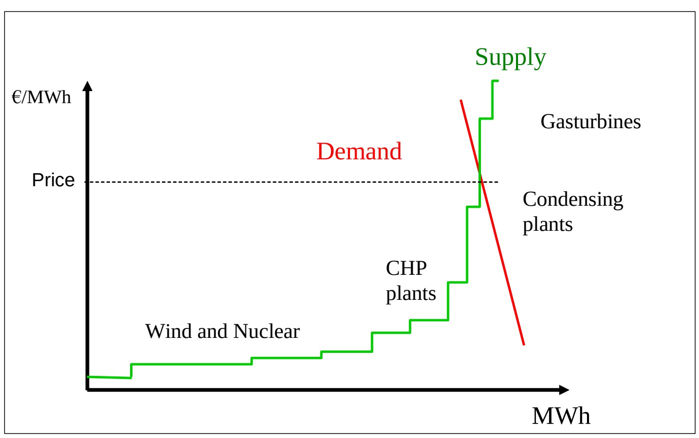


Figure 6: Supply and demand curves for the Nord Pool power exchange

Figure 6 shows a typical example of annual supply and demand curves for the Nordic power system. As shown, the bids from nuclear and wind power enter the supply curve at the lowest level, owing to their low marginal costs, followed by combined heat and power plants, while condensing plants and gas turbines have the highest marginal costs of power production. Hydro power is not included in the figure, because the bids from hydro tend to be strategic depending on precipitation and level of water in their reservoirs. In general, the demand for power is highly inelastic, while Norwegian and Swedish electro-boilers and power intensive industry are the main contributors to price elasticity in the power demand.

Power producers and consumers give their bids to the market 12 to 36 hours in advance, stating the quantities of electricity supplied or demanded and the corresponding price.[3] Then, for each hour, the price that clears the market (equalizes supply with demand) is determined in the NordPool power exchange. In principle, all power producers and consumers can trade in the exchange, but in reality, only big consumers (distribution and trading companies and large industries) and generators act on the market, while the small ones form trading co-operatives (as is the case for wind turbines) or engage with larger traders to act on their behalf. Approximately 45% of the total electricity production in the Nordic countries is traded on the spot market. The remaining part is sold on long-term contracts, but the spot prices have a considerable impact on the prices agreed in these contracts. In Denmark, the share sold on the spot market is as high as 80%.

Today, the market works well in the daily operations. The NordPool power market is one of the major reasons that Denmark has managed to integrate a large amount of wind power into its power system. However, until now, the NordPool market has not proved any ability to generate new investments in the power system. Moreover, with a strongly increasing amount of wind power in the future energy system the market may become incapable of generating the required revenues to make new power investments commercially profitable.

This problem is associated with the principles of marginal pricing. The marginal cost curve or the Merit-Order-Curve in Figure 6 stems from the old and existing centralised electricity system in which production units are characterized as base-, high- and peak-load units. Thus, price-making in the Nordpool power exchange is designed to handle the pricing of power from centralised power producers with higher marginal cost. The marginal pricing principle is a critical element in the institutional regulations of the existing electricity system.

On a market on which the price is set by marginal pricing, the marginal producing unit (see figure above), in which demand is equal to supply, is the one that determines the price of power. *And this price is paid to all producers even though they have given a lower bid. The problem for the market is to be found in the difference between total and marginal costs.*

[3] The 12 to 36 hours bidding procedure is not a problem for power plants that can be turned up and down depending upon their activation. However, due to the relative unpredictability of the wind the requirement to make bids 12 to 36 hours in advance makes it more difficult to deliver the promised production. Shortening of the bidding procedure to 6-8 hours wil improve wind power to deliver as promised which will be important with increased share of wind power, and as the margin of error is largest in the medium wind regime.

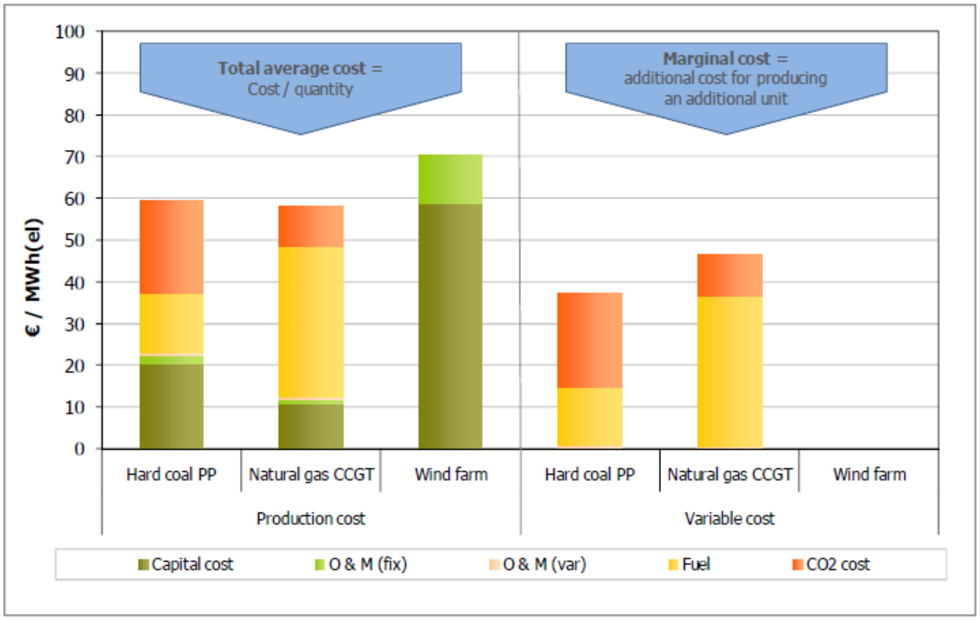


Figure 7: Different types of costs of different relevance to investments. Source: (Bode 2008)

Marginal costs and total average costs for different production units are shown in Figure 7. Whereas total average costs are decisive for investment decisions, marginal costs are decisive for market supply decisions. When bidding on a marginal pricing market, the bid is given by the marginal costs. If you as an owner get at least this price, you will cover your variable costs (marginal costs) and therefore it is worthwhile to produce. If you get a higher price than your marginal cost, it will cover part of the fixed costs. Over the lifetime of the plant, all your fixed and variable costs should at least be covered to make the plant profitable.

The left and right side of Figure 7 show two fundamental decisions on the energy market: Investment decisions versus operational decisions. The left side displays the fact that the total average cost of renewables today is larger than in the conventional production. Therefore, public support schemes are in place to create an incentive for investments in renewable generation capacities.

The right side shows the operational decisions for existing plants. The producer supplies to the market, if marginal costs are equal to or smaller than the market price. Figure 7**:** clearly shows the background of the merit order on the electricity market, where wind power isat a price close to zero, because marginal costs are close to zero.

If fuel costs and CO_2 quota costs increase over time, renewable energy sources become more competitive. Thus, it is often expected that renewables will not need any support schemes, e.g., feed-in tariffs, in the longer time perspective.

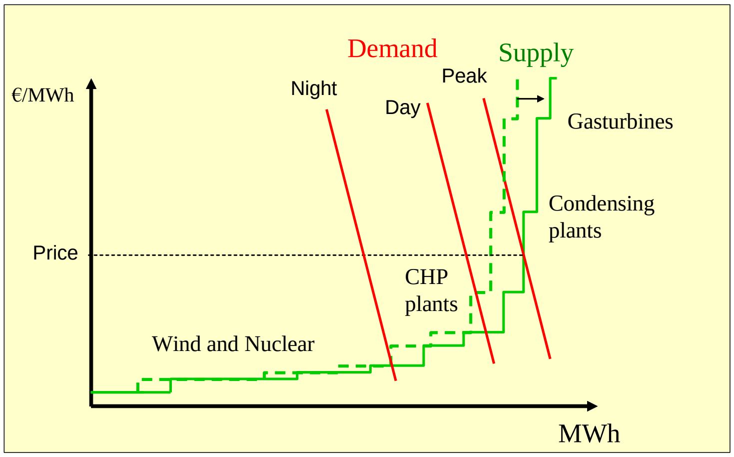


Figure 8: How wind power influences the power spot price at different times of the day.

The problem of the marginal price setting market in the future, if plenty of wind power is introduced, is shown in Figure 8.When the supply of wind power is increased, the power supply curve moves to the right. At a given demand, this implies a lower spot price on the power market. The more wind power on the market, the lower the power price. Therefore, the marginal price setting cannot guarantee that investments in new plants are profitable.

Consequently, the average revenue of wind farms also decreases. During hours with strong wind and weak demand, the power price goes towards zero, and as a consequence, the wind farm owner may not receive any revenue.

The characteristics of renewables, their close-to-zero marginal costs and fluctuating production, result in an inherent revenue problem not only for renewable installations but for all installations on the market. This drives the electricity price towards zero in the long run, if the share of renewables is still increasing.

Thus, the dilemma is: The incentive to invest in additional renewable installations decreases with increasing market penetration on liberalized markets. That is, the higher the share of renewables, the less profitable is the installation (of any generating capacity, not only renewables). With the current market structure, renewables are dependent on support schemes, also in the long run. This is contrary to conventional wisdom, according to which, learning curves and technological development result in increasing competitiveness over time. The current market structure makes the penetration of renewables beyond a certain point nearly impossible; hence, goals of 100 % renewable energy systems of the future seem implausible with the current electricity market design.

5.2.2 Conclusions and recommendations

The principle of marginal pricing in the NordPool power exchange was originally designed to handle the pricing of hydro power plants; but it also works well for conventional power producers that can turn the power generation up and down. Thus, in the *short term*, the liberalised power market can fulfil its function in handling the daily dispatch of power generation. However, already by now, it is doubtful whether the price-making mechanisms on the NordPool market can initiate the required new investment in power capacity, especially in new quick-reacting capacity as a supplement to the strong development of wind power. Thus, there is a pressing need to analyse which mechanism can ensure that the future capacity of quick-reacting power plants is available to back-up intermittent sources such as wind power? New designs for price making must be considered to ensure investments in new quick-reacting capacity.

In the long term, the marginal price principle seems to be in contradiction with a 100% renewable energy system, unless most of this system is based on the utilisation of biomass. If a major part is supplied by wind power and PVs, the marginal price setting will probably not work. Thus, new price-making designs on the electricity market should be considered, may be bysplitting the market into two or more segments, separating the daily operations from the long-term investments.

Analyses should clarify whether alternative new price-making market designs can handle the production from intermittent renewables and technologies with low or even zero marginal costs. A relevant solution would be to take intermittent renewables out of the NordPool market and rely on a flexible feed-in tariff.

A key conclusion is that existing price-making arrangements on the NordPool electricity market cannot accommodate the increasing shares of intermittent energy sources. Thus, new price-making arrangements must be developed and implemented. This is crucial to facilitate the un-locking of the fossil fuel lock-in in the electricity system.

6. Consumption policies

In this chapter, the effect of different policy means on the energy consumption in the main sectors is described. The main sectors are industry, service & households, agriculture, transport, and buildings.

Energy consumption is partly regulated using national policy instruments, partly combined with EU policies. The national instruments comprise energy taxes and tariffs, regulation including building codes and other standards, research into new materials and low energy housing and, finally, different kinds of information.

At the EU level, the Emission Trading System (ETS) for CO_2 emissions covers the power industry and other selected heavy industries. This implies that all electricity consumption is subject to a cap on CO_2 emissions and that the quota price of CO_2 is reflected in the NordPool spot market price of electricity. The higher spot power price including a CO_2 component impacts all Danish branches when electricity is used.

At the EU level, this is the major regulation impacting energy consumption, notwithstanding the transport sector in which a number of specific EU regulations are introduced. It is left to individual Member States to regulate energy consumption and emissions in other energy consuming sectors. At present, the Danish policy means of reducing the energy use and the associated emissions are based on “green taxes” on electricity, oil and gas for heating and hot water.

6.1 Industrial energy consumption

At present, the Danish industry is not burdened with heavy “green” energy taxes. This is very clearly shown in Figure 5, where only a small tax is levied on the price of power for large companies compared to private households. There are a number of reasons for not burdening the industry with energy taxes, especially considerations on the industry’s international competitiveness. However, a tax on energy consumption in industry would create an incentive for introducing more energy conservation measures. Thus, it is proposed to introduce a higher energy tax on industrial energy consumption, combining such a tax with the possibility of compensating those industrial branches that are in strong international competition, and/or to recycle the tax to companies that promote energy conservation, as it was done in Denmark in the nineties. Such a tax would be in line with the one suggested by the Danish Commission on Climate Change policy (in Danish: Klimakommissionen), i.e., a fossil fuel tax gradually increasing over time; however, including the possibility of compensating specific industrial branches.

Besides that, a wide range of policy measures will be needed in order to make possible a transition from fossil fuels to renewable energy in the Danish manufacturing industry.

It is proposed to roll-out policy measures at two stages; in the short term and long term.

Energy regulation is most effective when the framework is stable and predictable, as stability and transparency can help directing investments in the desired direction.

6.1.1 Policy measures to be implemented in the short term

Green taxes: A gradually increasing tax on fossil fuels (as proposed by the Commission on Climate Change policy) should be introduced to signal to industrial consumers that the price on fossil fuels will increase in the future and to promote the transition to renewables.

Public-Private Partnerships: In order to successfully address energy efficiency shortcomings, information on actual energy technologies used in the industry as well as the Best Available Technology (BAT) must be provided. However, information about industrial processes, energy use, national and international competition, etc., is asymmetrically distributed and possibly hard to gather for a regulating entity. Therefore, we suggest the formation of sector-specific Public-Private Partnerships (PPP), which should outline the most efficient policy measures needed to fulfil the targets for renewables and monitor the future implementation.

Voluntary agreements: Previously, voluntary agreements have been used as one of the policy measures to improve energy efficiency in the Danish industry (see, e.g., Krarup & Ramesohl, 2000). However, ambitions have been reduced significantly, due to both the introduction of the EU ETS and the significant administrative costs involved, as made visible by evaluations (Ericsson, 2006). In 2008, the latest changes completely eliminated the voluntary agreements regarding fuel use[4]. However, instead of the negotiation with single firms, a new effort should concentrate on negotiation on a sector-wide basis (this is similar to the Dutch Long-Term Energy Agreements scheme, see Rietbergen et al. 2002). This could happen in accordance with the newly created PPPs.

Energy Demand Management: A number of energy demand management schemes should be put in place. This involves strengthening the **energy audits** which were previously mandatory for companies signing a voluntary agreement (VA). The costs involved were a major reason for the changes made to the VA system, but the costs of the energy audits could also be seen as an important argument for the state to provide incentives to perform the audits, e.g., by establishing a subsidy for energy audits (e.g., 50%). **Energy audits** should be combined with the promotion of a regular **ESCO industry** in Denmark. Following international experiences with ESCOs (e.g. Ürge-Vorsatz et al, 2007; Bertoldi et al., 2007), the following proposals are made:

- Establishment of an accreditation scheme.
- Standardisation of contract procedures.

[4] Rules still exist regarding electricity and space heating.

- Establishment of a preferential loan scheme for investments as a result of VA/energy audits.
- Establishment of a state-owned fund which would decrease the risk of investment losses of ESCOs due to, e.g., bankruptcies. Focusing on ESCOs could have the added benefit of creating a niche – ESCOs working with the manufacturing industry – with a significant export potential.

White Certificate Market: Another aspect of improving the energy demand management is the establishment of a White Certificate Scheme (see Child et al., 2008; Oikonomou et al, 2009). Today, the energy distribution companies have a responsibility to improve the energy efficiency. Annual energy savings of 6.1 PJ are planned for the period 2010-2020, but the success of the current scheme is being debated[5]. We propose an analysis of the potential for obtaining more efficient results by a white certificate market based on experiences from the UK, France and Italy.

Soft public loans to SMEs: Empirical studies show that a major barrier to energy efficiency is the fact that firms tend to give priority to investment costs rather than to recurrent energy costs. Therefore, innovative financing solutions are needed. One solution could be soft public loans in which interest rates are not paid if certain specified energy efficiency targets are not realized. A loan scheme could be tied to an energy audit scheme, but should be presented in such a way that it will not reduce the turnower ofe ESCO companies.

Two-way communication between electricity producers and electricity consumers: The introduction of the two-way communication (sometimes labelled smart grids) should be accelerated, so that the industrial production can adapt as well as possible to intermittent renewable energy sources.

6.1.2 Policy measures to be implemented in the medium and long term

Specialised road maps, monitoring and targeting. Energy Performance Standards: The Public-Private Partnerships should develop specialised road maps which point out Best Available Technologies within their field. They should also address key barriers to fuel substitution and energy efficiency improvements within their sector. This monitoring and targeting exercise should lead to focused RD&D efforts where the noted issues are addressed. At the same time, the road maps should outline certain Energy Performance Standards which ensure that inefficient technologies are phased out. Ambitious, but realistic timelines should be given for the phase-outs.

Benchmarking: Benchmarking is a process of comparison which serves to highlight potential unnecessary differences in performance. Benchmarking industrial performances is not an easy task, as industrial processes are of a very heterogeneous nature and companies may be against providing the information needed. However, the benchmarking of energy efficiency in the manufacturing industry has been successfully introduced in a number of countries, including the Netherlands and Norway (see, e.g., Phylipsen et al, 2002 for details). Moreover, product benchmarking is included in the recent suggestion by the European Commission for the new ETS market design up to 2020. Following the Dutch model, a relevant target could be that companies need to be in the top 10% of their sector worldwide (this number is to be examined by the PPP in collaboration with a special Benchmarking Unit), or face certain yet-to-be-decided economic sanctions.

Research, development, and deployment: The single most important factor in improving the industrial use of renewable energy will most likely be the further development of the relevant technologies. Based on the road maps' monitoring and targeting, key processes should be identified as the basis of focused R&D efforts. Public funding and the involvement of public research establishments are important, but close collaboration with related firms is a necessity for success. At the same time, a relatively tough energy regulation (benchmarking, energy performance standards) should provide the private companies with incentives to collaborate. Government supported R, D and D on RES technologies should be promoted in co-operation with Danish industry.

6.1.3 Conclusions and recommendations

Short-term recommendations:

- Introduce an energy tax on fossil fuels that is gradually increased. The tax level is to follow the energy content of the fuel; however, in the short run, natural gas should be taxed at a lower level because of its usefulness in replacing other fossil fuels in industrial processes. For Danish companies that are in strong competition with companies abroad, an economic compensation might be needed.
- Utilise the concept of best available technologies (BAT) to strengthen the development towards more energy efficient processes in industry.
- Enhance the use of energy audits to improve energy demand management, e.g., by subsidising these energy audits.
- Introduce soft public loans to SMEs in order to remove the barriers to investments in new energy efficient technology.
- Analyse the potential of a market for tradable White Certificates, i.e., an auction scheme or a pool.
- Accelerate the introduction of two-way communication between producers and consumers (smart grid).

In the *longer time perspective*:

- Benchmarking should be introduced where possible to increase energy efficiency in connection with green taxes.
- Research and development promoting efficient industrial energy applications and processes should be supported.

6.2 Electricity consumption in services and households

This chapter treats in more detail the use of electricity in the service and household sectors. The use of heat in these two sectors is not addressed here, as the technological potential for reducing energy consumption in buildings, especially existing buildings, is described in section 6.6 including proposals for policy means. Thus, in this section, we shall only discuss more general policy means of reducing the electricity consumption of private households and services. This consumption is mostly related to the use of different appliances, such as televisions, refrigerators, computers, etc.

6.2.1 Green taxes

Experience has shown that a very high tax level is needed to convince private households and the service sector to reduce their energy consumption. Most households give high priority to a convenient and pleasant lifestyle, which often implies a lower priority to energy conservation. This is a general political barrier.

Another problem is that high energy taxes are unbalanced socially and economically. The taxes constitute a much higher burden on low-income households than on high-income households. Several proposals have been made to compensate for this unbalance. One possibility is to introduce a general reduction in the tax of low-income households. However, this type of scheme has broader economic implications than energy policy and is expected to meet serious political barriers.

A scheme with more direct energy policy implications is based on the introduction of a specified level of energy consumption per household (a cap) below which the green tax is low (or even zero). Above this level, the tax may increase progressively. The administration of this *level-dependent tax system* may be left with the energy suppliers already billing the households for the present green taxes.

6.2.2 Regulation of the energy consumption of appliances in households

The total Danish electricity consumption in 2009 amounted to approx. 36 GWh including grid losses. The consumption in households and services was approximately 19 GWh, or 60% of the total consumption. During the past ten years, the electricity consumption of households and services has been slowly increasing (by approximately 0.5 % per year).

In general, the number of appliances in households and services are increasing fairly rapidly. However, in terms of electricity consumption, a number of the most important appliances have reached their saturation level as these exist in most Danish households today. But new appliances keep popping up in the marketplace and, therefore, the overall number of appliances is still increasing.

In the following, two approaches to regulating power consumption in households and services will be discussed: *Standards and public green procurement* and *Quotas on electricity use.*

Standards and public green procurement

For the most energy consuming appliances, such as refrigerators/freezers and cookers/ovens, standards have been used to limit the electricity consumption, followed by energy labelling (A+ and A++ labels, etc.)

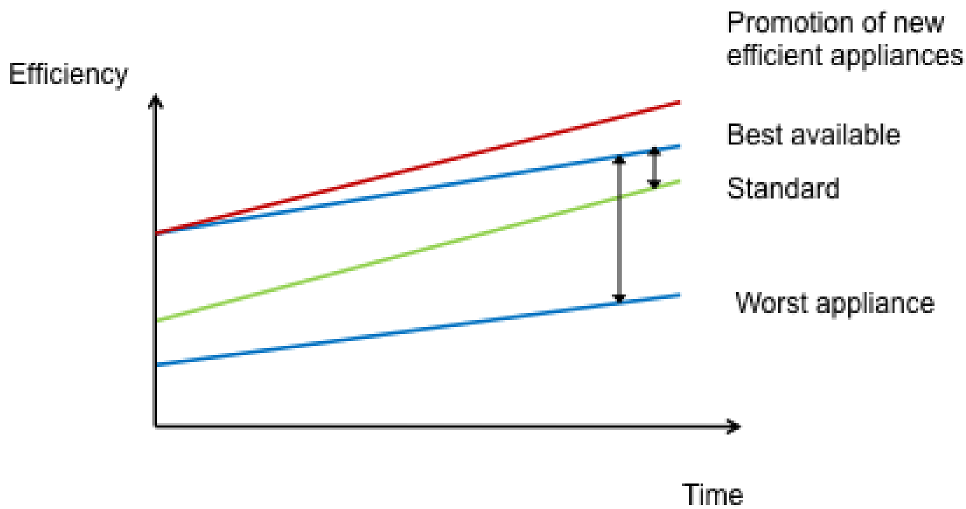


Figure 9: Standards for appliances in households, services and industry.

Generally, the efficiency of appliances is spread over a broad range. In terms of efficiency, appliances tend to develop in a parallel manner, as shown in Figure 9. The least efficient appliances increase their efficiency at the same rate as the most efficient ones, because the least efficient appliances are often the oldest ones in the production line and are therefore phased out. This preserves the large spread between the least and most efficient appliances. A progressively increasing efficiency standard would eliminate the least efficient appliances at an earlier stage in time and force producers to a quicker phasing in of new models (as shown by the green line in Figure 9). This would have the additional effect of removing the cheapest appliances from the market, but considering the lower energy costs of more efficient appliances, the increased investment costs would be recovered over the lifetime of the appliance.

Existing standards function well, but need an upward adjustment to ensure a quicker development of energy efficient appliances.

Long-term announcements of progressive standards enable producers to plan efficiency increases ahead. Simultaneously, the market becomes more homogenous, i.e., the spread between the least and the most efficient appliances decreases.

Furthermore, there is a need for a concentrated effort to increase efficiency beyond the market development. A few years ago, the Swedish government experimented with technology development programmes.[6] For example, competitions for the development of more efficient refrigerators were launched, in which producers were invited to present new highly efficient products; and the winner was not only awarded a prize, but was also given a certain market share of public procurement (kindergartens, day care etc.). As shown in the upper red line in Figure 9, such initiatives promote the most efficient technologies and increase the phasing out of the least efficient appliances. Unfortunately, technology development programmes seem to have come to a halt (also in Sweden), perhaps as a consequence of barriers in the EU regulations. But technology development with built-in incentives for producers is a potential tool for increasing efficiency.

It is important to note that standards are most effective when applied to homogenous products with a clearly defined service, as for example refrigerators/freezers and washing machines. Typically, these relatively energy intensive appliances have increased their efficiency at faster rates than other appliances.

New, smaller appliances are not taking part in standard schemes, and it may take time before they are added to the scheme, if at all. Stand-by consumption is also a relatively large problem, amounting to approximately 10 % of the total electricity consumption of households. This stand-by consumption is typically attributed to smaller appliances such as computers, TVs and DVD players and especially internet connections and satellite dishes. Therefore, there is a need for a concentrated effort to improve the efficiency of smaller appliances.

The establishment of a working group at the EU level would solve this task. The working group could evaluate new, smaller electrical appliances on a continuous basis, and present quick suggestions on their standardisation. The evaluation is relevant whether the appliance is a big electricity consumer or not, since the widespread use of an appliance will lead to a significant electricity consumption under all circumstances. The working group should have strict rules regarding the speed of the standardization process, as well as the competence to initiate negotiations with producers, including the authority to dismiss products from the market if these do not comply with the decided standards.

Standards and labelling can also be combined with other incentives, e.g., a quota system for electricity consumption (see the next section), or more comprehensive CO_2 quotas for private households and services. It is important to support consumers in adjusting their consumption and life style, if strict measures such as personal CO_2 quotas are introduced. These options can be promoted through standards and energy labelling.

[6] Reference: Nilsson, Hans (2003): Experiences with Technology Procurement as an Instrument for Changes on the Market. 4-Fact

Advantages:

- The ”free” choice of the least efficient appliances is eliminated while the energy service level is maintained.
- Most consumers will not experience a limitation of their choices.
- The use of long-term announcements of progressive standards gives producers time to develop new models.

Disadvantages:

- Because of the EU trade regulations, the development of standards needs to be coordinated at the EU level. This can be bureaucratic and take time.
- It is difficult to include new and especially smaller appliances.

Quotas on electricity for households

As described, standards can act in combination with other instruments, e.g., electricity quotas for private households. A quota can be defined by a certain consumption level per person in the household plus a basic consumption[7], i.e.:

Quota = basic consumption + N*consumption per person

where N is the number of residents in the household.

In this way, it is taken into account that, in households with one resident, the electricity consumption per person is higher than in the household of a large family. The household quota can be based on the Danish Civil Registration System (CPR), in which the number of individuals in each household is registered. When relocation is registered in the CPR, the size of the quota for the given year is regulated.

As shown in Figure 10, the idea is to offer a lower electricity price, as long as the household stays within the quota limit (the cap).

This ensures the social balance of the system. However, electricity consumption beyond the quota must be priced at an increasing marginal price (cf. Figure 10).

The regulation to obtain lower electricity consumption can be implemented in several ways:

- If the appliances of the basic consumption level (e.g., refrigerator/freezer) are becoming more efficient, the cap is reduced.

[7] The idea of a basic consumption quota has also been put forward in “En vej til flere og billigere energibesparelser. Evaluering af samtlige danske energispareaktiviteter” by Ea Energianalyse, Niras, RUC og 4-Fact for the Danish Energy Authority. December 2008, p. 25

- Alternatively, the consumption per individual in the household can be reduced, if other forms of appliances become increasingly efficient.
- The marginal price of the electricity consumed and its progressivity can be increased.
- The price of the basic consumption of electricity can be increased. However, this will probably not have any significant effect on the electricity consumption.

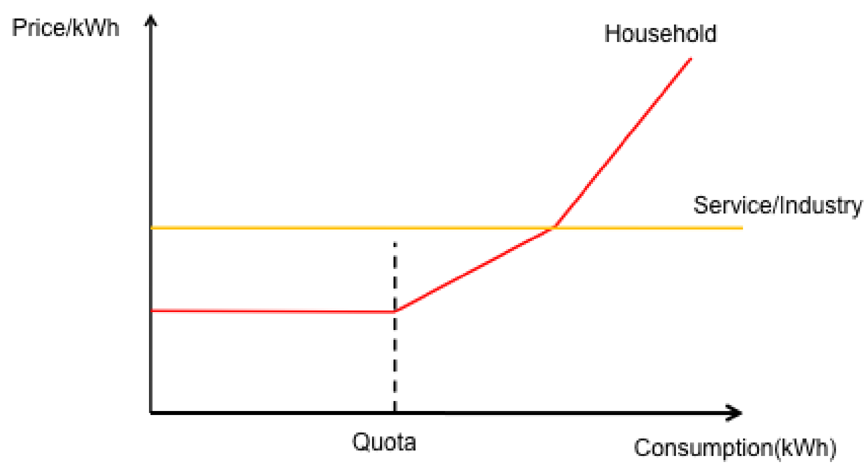


Figure 10: Electricity price as a function of the household electricity consumption.

Other types of electricity consumption can also be handled in this model, e.g., electric heat pumps used for heating purposes. The quota equation can be expanded to incorporate this as a new electricity consumption unit:

Quota = basic consumption + N*consumption per person + m^2*heat pump consumption

where N is the number of residents in the household.

The consumption of the heat pump is defined per square meter of the household (cf. the Danish Building and Housing Register, BBR). This serves as an incentive to energy retrofitting.

The way in which additional consumption of electricity for a heat pump is added in the quota equation means that the consumption saved in the household appliances can be transferred to the consumption of, e.g., the electric car.

The idea is to include those forms of electricity consumption that are required in a 100% renewable energy- based future i.e., pure electric heating (or supplementary electric heating) is not included, since this is not an energy efficient technology. Households using these technologies must use their basic quota or pay a higher marginal price for inefficient appliances. There may, however, be borderline cases, in which it might be difficult to determine whether the basic quota equation should be extended with a particular technology or not.

Advantages:

- Low energy consumption is encouraged and rewarded economically; – a high consumption (beyond the cap) is expensive.
- The basic consumption plus the consumption per person can be adjusted continuously to reflect the development in energy efficiency and energy saving options – this applies to additional components of the equation (e.g. electric cars), as well.
- Billing and payment according to the cap can be handled of the electricity distribution company – if the company is continuously updated with changes from the CPR-register.

Disadvantages:

- The decisions of what goes inside and outside the cap can be complicated and might result in arbitrary choices.
- Unwanted substitution from electricity to other energy types may appear (e.g. individual biomass for heating purposes). However, this can be handled using taxes and tariffs of the fuels in question.
- The model might be static, that is, the average treatment of all households might create too weak incentives for some households. A more gradual model might lead to more effective results.

Two way communication between producers and consumers (smart grids)
Introduction of direct communication between producers and consumers of electricity should be accelerated for consumers above a specified demand level (for instance 1500 kWh/year).

6.2.3 Personal Carbon Allowances

Personal Carbon Allowances (PCA) is a policy which would introduce a national cap on household and personal transport energy use by directly allocating a carbon cap to each citizen. All adults would receive an equal carbon allowance, which would be adjusted/reduced periodically to achieve stated goals. These allowances would be tradable and enrolment in the PCA scheme would be mandatory. To pay an energy bill, put fuel into a private car or buy a personal plane ticket, the citizen would have to surrender carbon 'credits' from their allowance, as well as pay the financial cost. They would keep track of their carbon allowances by a carbon credit card and carbon account in the same way they keep track of their money by a money credit card and bank account.

If they had used up all their initial allocation of carbon credits they could buy more at the market price. This market price could be high in situations where most people had little surplus left on their PCA card or low if the majority significantly reduced their emissions. As the national carbon cap and personal allowance are reduced over time, people would have to adopt progressively lower carbon lifestyles, via a combination of technology choices and behavioural changes.

For practical reasons PCA would cover only 'direct' energy use by the householder for residential purposes and personal travel. At present these energy consumptions are responsible for 30-50 % of total CO_2 emission in Denmark and the UK (Fawcett, Hvelplund and Meyer 2010). The PCA would not cover all other 'indirect' uses of energy embodied in goods or services. The carbon impacts of direct energy use are well known – with the exception of the debate about the global warming impact of air travel – whereas the energy and carbon embodied in everyday goods and services depends on a large number of varying parameters in a complex way. It would simply be too difficult at present to label food, clothing and other goods with a carbon 'price'. Indeed, in an age of globalized and fast-changing supply chains, it might never be possible to have reliable carbon labels on most products, let alone services. Therefore, while it might initially seem an attractive and effective idea, there is no suggestion that goods and services should be included within a PCA scheme. Instead the carbon used in their manufacture, transport, retail and so on should be regulated via existing or new policies. These carbon emissions are outside the scope of the proposed PCA.

The ability to trade emissions is a key feature of a PCA scheme. Without trading a considerable proportion of the population would immediately have to drastically change their lifestyles to live within their ration – this is unlikely to be either possible or democratically acceptable. Additionally, if trade were not allowed, experience with rationing systems has demonstrated that an illegal "Black Market" would quickly emerge. Trading is likely to lead to a transfer of money in general from richer to poorer individuals, and a transfer of carbon allowances in the opposite direction. Richer people travel more have bigger cars and homes, etc., resulting in bigger carbon footprints.

Introducing PCA would signal a permanent commitment to a mechanism for reducing carbon emissions in the total emission reduction of CO_2 in the household sector in relation to "direct" energy consumption. To enable people to reduce their emissions over time, extensive supportive information and advice policies would be required. In addition, the current suite of policies designed to reduce electricity and energy use / carbon emissions – labels, standards, subsidies, information etc. – would need to be enhanced. If PCA was introduced, everyone would explicitly take part in reaching society's goal of reducing carbon emissions. Individuals would need to understand both their emissions and the options which they have to reduce them; and society would need to prioritize enabling low carbon lifestyles for this policy to succeed. More details in (Fawcett, Hvelplund and Meyer 2010).

An alternative and more comprehensive proposal including the whole energy system is called Trading Energy Quotas (TEQs). The details of this proposal are discussed in a recent British report (Fleming and Chamberlin 2011).

6.2.4 Conclusions and recommendations

Without new and/or stricter policy means in relation to private households, it does not seem possible to achieve the necessary reductions in the Danish consumption of fossil fuels and emissions of CO_2. In order to avoid an unbalanced economic burden on Danish households and industry, it is important that low-energy consumption groups are handled cautiously.

- In the *short term*, a general increase in green taxes should be considered in combination with a scheme that favours low consumption. This scheme could be based on a certain quota of energy taxed a reasonable low price and a strongly increasing marginal price for consumption above this level. The low-price quota is determined according to the size of households and also adjusted regularly in relation to the development of new low-energy appliances.
- In the *medium to long term*, a new and more radical policy would be to introduce the scheme of *Personal Carbon Allowances* (PCAs). This personal cap-and-trade scheme will need more time to be further developed and find its practical form. It is recommended that a more detailed analysis is performed with the aim of evaluating experiences abroad with PCA and similar personal quota systems like Trading Energy Quotas (TEQs), e.g., in the UK.

6.3 Agriculture

6.3.1 Energy consumption and emissions

Gross energy consumption in primary agriculture was 43 PJ in 2006. This is about 5% of the Danish gross energy consumption. The consumption of fossil fuels in primary agriculture is linked to the specific activities undertaken and is associated with the use of machines and vehicles (process energy), and heating and electricity (stables and houses). The emissions of methane and nitrous gases from agricultural production have a significantly stronger contribution to the greenhouse effect, but that is outside the framework of this project, which is focusing on CO_2 from fossil fuels.

In this report, the energy consumption of the primary agriculture covers only the primary production, which means that energy consumption in slaughterhouses, dairies, etc., is not included. As the consumption of fossil fuels in agriculture is a relatively small fraction of the total Danish consumption, the following analysis will not go much into detail.

Energy consumption was 43PJ in 2006, and has fallen by 7% from 1995 to 2006. This reduction can mostly be attributed to the decline in horticulture. The highest energy consumption is related to pig production (34%), cattle (24%), and crops (18%).

Organic farming has been expected to have lower energy consumption than traditional farming, but a report from the Research in Organic Farming (Jørgensen and Dalgaard 2004) shows that organic farming has only marginally lower energy consumption than traditional farming.

Almost half of the energy consumption (49%) is oil-based products; one third (30%) is electricity. Renewable energy stems mainly from the use of straw in straw burners on individual farms. CO_2 emissions linked to fuels have been reduced by 16% since 1995.

6.3.2 Contextual conditions in the sector

The last two decades have shown a strong development towards large-scale industrial farming in primary agriculture. However, this development strategy has not resulted in improved earnings according to some studies (Kjeldsen-Kragh 2010). In contrast, many large farms were heavily indebted by 2010 and have little free cash for investment. As a consequence, it is unlikely that primary agriculture will give high priority to investments in energy conservation without government subsidies.

In the medium and longer term, it is not clear if this kind of centralization will continue or there will be a new trend in medium-sized farming. Over-centralization of cattle farming will imply that cattle cannot be put out to pasture or will have to be transported to the grassland.

There are more positive prospects for the agricultural sector in exploiting the unused potential for biogas production from animal manure. In addition, the new bio-energy crops may become an important new generator of income opportunities.

6.3.3 Conclusions and recommendations

The 5% share of Danish gross energy consumption in agriculture is relatively small, and the potential for energy conservation is mainly dependent on the technological development in other sectors. The policies for energy conservation in agriculture may use some of the same elements as proposed for private households and industry.

There is a relatively large unused potential for producing biogas from animal manure. It is recommended that this potential is realized by introducing sufficiently high feed-in tariffs for biogas plants.

Agriculture may also support the transition to an energy system based on RES through energy crops. This may to some extent conflict with land use for food crops. Before an extensive promotion of energy crops can take place, a first step should be to make a comprehensive and balanced plan for land use in Denmark.

Short-term recommendations:

- The potential for biogas from animal manure is to be promoted by favourable feed-in tariffs and official targets for biogas production.
- Research funds should be made available for the development of new types of transmission lines for biogas from farms to consumers.
- A comprehensive analysis of advantages and disadvantages of energy crops on selected farming areas should be carried out.

Medium to long-term recommendations:

- The promotion of energy crops at preserved areas should be supported if the CO_2 balance is favourable and the negative environmental consequences are negligible.

6.4 Transport

6.4.1 Transport in CEESA

Assumptions in CEESA's transport scenarios:

1. The high forecasted increase is reduced. In the *reference* scenario, passenger transport is expected to increase by 80% between 2010 and 2050, while freight transport is expected to almost double. In CEESA, passenger transport increases by approximately 40% in 2050 compared to 2010. The major reduction is implemented from 2030. No major changes in the demand for freight are included.
2. The efficiency of conventional cars is increased. Only the efficiency of cars is improved since there are already significant energy efficiency improvements in the reference energy system for other vehicles.
3. Focus is on electric vehicles and they are implemented where possible.
4. Vehicles are utilised more, e.g., each truck carries more goods.
5. Different modes of transport which are more efficient and use more sustainable fuels are utilised more in CEESA. For example, rail is a particularly suitable replacement for long road journeys, since it is very efficient and it can be completely electrified; hence, railways are expanded and electrified. Also domestic aviation can be reduced by such a measure.

This change will not happen without significant market reforms.

This report does not go into detail with regard to the regulation of total transport, the implementation of electric rail; roads or the regulation of truck transport. The focus here is on private car transport. However, a few suggestions are made in relation to points 1 to 3 above.

1. A tax per kilometre driven should be introduced on truck transport in the range of 13 to 33 eurocents, as in countries like Germany, Switzerland and the UK.

2. A tax on jet fuel for aviation should be introduced taking into account the heavy greenhouse effect from fuels burned at an altitude around 10 kilometres. In the first phase, this tax can be applied to national Danish aviation, eventually to all aviation from the EU.

3. The railway system in Denmark should be electrified as quickly as possible through increased public investments. The present energy tax refund on diesel trains should be abolished.

Reforms of private car taxation:

The reforms should support:

a. An optimal development of transport, including a reduction of the present excessive growth of car transport. The present transport growth does not represent an optimal development seen from a welfare economic viewpoint, as it is based on prices and price structures that do not sufficiently include the costs of noise, air pollution and use of scarce fossil fuel resources.
b. A shift to more energy efficient cars.
c. A shift from gasoline cars to electric cars
d. A system that makes it uneconomical to drive with only one person in a car, where public transport possibilities represent an alternative. At present, the taxation structure results in very low marginal costs of car driving, which makes it economical for a single person to drive by car instead of using public transport.

In Denmark, around 80 % of the present car taxation is fixed and does not depend on the number of driven kilometres. This includes taxes on the price of cars, on ownership, on car insurance and, to some extent, on the use of roads and other traffic infrastructure. As a consequence, it is relatively expensive to buy a car, but cheap to use it once you have it. The consequences of this system are illustrated by a detailed Danish case study in Appendix B. The main results of this case study are summarized below.

6.4.2 Main results of Danish case study for an average diesel car

Our analysis shows that the societal costs of driving one kilometre by car is around 27 eurocents with the present car and petrol prices, and excluding external environmental costs such as air pollution, noise, accidents, etc. A conservative estimate of the total societal costs including external costs results in a figure between 35 and 60 eurocents /km. At the same time, the private marginal costs for a car driver in the Danish incentive system are between 3 eurocents/km (commuting with tax reduction) and 11 eurocents/km (non-commuting).

If Danish car owners are acting in an economically rational way, they will, once they have a car, not avoid taking a job in a distant city, if the extra driven kilometres give them a welfare increase that is higher than the marginal costs of commuting (3 eurocents per kilometre). But as mentioned above, the societal costs are marginally between 27 and 60 eurocents. So the marginal societal welfare loss of commuting will, in this case, be between 24 and 57 eurocents per driven kilometre. The marginal welfare loss linked to non-commuting car traffic will, in this case, be between 16 and 49 eurocents. If we take an average between these two figures, the present short-run *private* marginal costs per kilometre of car driving are around 30-40 eurocents below the short-run *societal* marginal costs of car driving. This illustrates very clearly the short-comings of the present economic scheme in relation to car driving.

The development of private car transport is, to a large extent, driven by a multitude of individual car owner decisions based upon a marginal cost of, in this case 11 eurocent per kilometre. And based on these decisions, a certain amount and distribution of car transport evolves. This development founded in individual short-term tactical decisions forms the basis for traffic prognoses and strategic long-term decisions concerning investments in roads, bridges and public transport. This illustrates the strategic problem of making many traffic-related decisions within a short time horizon, when alternative traffic system planning requires a much longer time horizon.

The above discussion also implies that a cap and trade system extended to car transport would have very limited effects compared to the market failures in the tax system already in place. The CO_2 tax will only be 0.7 % of the total car expenses per kilometre, and it amounts to only 0.5% of the total effects from the tax system. Instead, the system should be changed to a tax per kilometre in which the cost of driving one kilometre should approach the total societal costs per kilometre including all environmental costs.

6.4.3 Proposed change of tax structure

As mentioned at the beginning of this section, the change of the car tax system should support a more optimal transport development, e.g., the introduction of energy efficient cars including electric cars, and make it relatively more economical to use public transport.

In the above discussion, we have estimated that the present private short-term marginal costs are between 30 and 40 eurocents below the long-term societal costs per kilometre.

Ideally the tax system should secure that the private costs are equal to the social costs of car transport. This means that we should establish a tax system, in which the private short-term marginal costs are increased by between 30 and 40 eurocents per kilometre.

The first step in a car tax reform could be to make insurance costs and annual car tax directly dependent on the kilometres driven. See example in Appendix C. This step should be supplemented by a reduction of the present tax deduction benefits of commuting.

1. The above general change in the marginal kilometre costs can be supplemented with a road pricing system. However, it is important to be aware that it should not be replaced by the road pricing system, but supplemented by this system.

The above change in private short-term marginal costs has the following supportive effects in relation to our goals:

a. It represents a tax structure in which private costs are closer to societal costs, and therefore leads to a transport system that is closer to a welfare optimum than the present tax and incentive system. At the same time, it reduces the growth in private car transport.

b. It furthers the use of electric cars, as the tax payment per kilometre should be dependent upon the level of external societal costs of the car.

c. It improves the competitiveness of public transport, as the private short-term marginal costs of car transport are increased considerably.

   The proposed reform may, however, give rise to economic problems for citizens living far from their work when the commuter subsidy is reduced (or abolished).

6.4.4 Conclusions and recommendations

The present Danish transport policy is not able to secure the transition to renewable energy in time. The tax system for private car transport must be changed in such a way that it becomes more expensive to drive a personal car. The competition between private cars and public transport must be changed to the advantage of public transport based on buses and trains.

Short-term recommendations:

- The annual tax on private cars should depend on kilometres driven and cover all externalities that are created. This should not await an advanced road pricing system.
- The present tax refund for private car commuting should be reduced. People living far from their work with limited access to public transport may receive temporary tax refund.
- Investment in public transport (trains and buses) should be significantly increased. Preparations for high-speed trains should be accelerated.
- Introduction of electric cars should be promoted by tax exemptions and the construction of the necessary infrastructure.
- The construction of an extensive net of cycle lanes should be accelerated and electric bicycles should be promoted, e.g., by reduced VAT.
- The introduction of an advanced road pricing system should be accelerated.

6.5 Energy conservation in buildings

The consumption of heat and electricity in buildings accounts for about 40 % of the total final energy consumption in Denmark. 55 % of the final heat consumption goes to one-family houses.

In "Varmeplan Danmark 2010", it is assumed that the heated building area will increase by 20% from 2010 to 2050. As a consequence, the area of the building stock in 2050 will consist of around 70-80% of today's buildings, and around 20-30% new buildings built in the period 2011-2050.

As basic building renovation such as better insulated walls, roofs, floors, windows, etc., will last for 40-60 years, one should make sure that renovation standards already in 2011 are tightened up compared to present standard requirements. This is also important in order to synchronize house improvements and investments in new supply technologies, as described in chapter 7.2.

The following text analyses the potential for reducing energy consumption in the existing building stock in Denmark with focus on the policy means for realizing this potential. The analysis takes its point of departure in a recent Danish report on this subject (Jensen 2009).

If we take our point of departure in "Varmeplan Danmark 2010", it is assumed that the average heat demand per square metre is reduced by around 50% from 2010 to 2050, while the total heat demand is reduced by 25%, as the total heated area is increased in the period.

6.5.1 Present Danish policies for energy savings in buildings

The government has initiated a so-called action plan for energy conservation in 2005. In relation to the building sector, this plan includes the following demands:

- Maximum U-values for single building elements in connection with renovation (e.g., in relation to windows). The U-values must be consistent with the regulations on new buildings.
- When more than 25 % of a building is renovated, the total building after renovation must fulfil the regulations on new buildings.

In addition, the Danish Electricity Savings Fund has campaigned for more efficient household appliances and circulation pumps, etc. This has resulted in a shift to more energy efficient equipment. The Electricity Savings Fund has now been closed down and replaced by an Energy Saving Unit in the Danish Energy Agency. It remains to be seen whether this change will give rise to an overall improved promotion of less energy intensive equipment.

These policies have so far not resulted in significant reductions in the energy consumption. On the contrary, the energy consumption for heat and electricity in buildings has showed a small *increase* during the latest years. This is explained by a higher level of comfort and more energy consuming equipment with higher user intensity.

6.5.2 Barriers to energy renovations

Investments in the renovation of private houses may be based on a number of different considerations other than the mitigation of global warming and the conservation of energy, e.g., the wish for a modern kitchen, a new organization of rooms, larger panorama windows, etc.

In the district heating areas, the following barriers can be considered as important:

The district heating companies have tariffs with a different, but often very high fixed share. This is illustrated in Figure 11. The figure shows that, in some parts of Copenhagen, the fixed share of the total heat bill is between 50% and 62%.

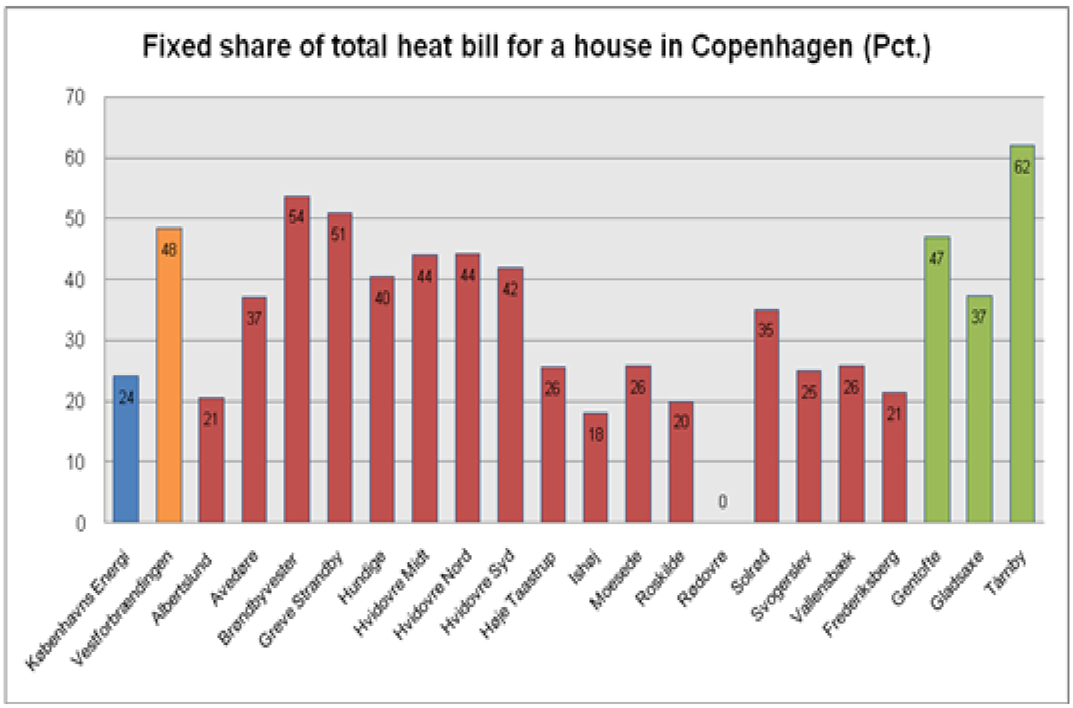


Figure 11: Fixed share of total heat bill for a house in Copenhagen. Source: Larsen 2009,

	Annual heat payment Dkr.	Annual variable payment Dkr		Annual saving in case of 25% house improvements Dkr.	Break even investment (6% discount rate/15 year lifetime- 25% house improvement.
Tårnby	13.000	**4.949**	(38%)	1.235	**11.994**
Gentofte	10.000	**5.300**	(53%)	1.325	**12.868**
Albertslund	13.800	**10.902**	(79%)	2.725	**26.465**
København Energi	13.500	**10.260**	(76%)	2.565	**24.911**
Brøndby Vester	10.000	**4.600**	(46%)	1.150	**11.169**
Frederiksberg	10.000	**7.900**	(79%)	1.975	**19.181**

Table 1. Break-even investment for 25% reduction in heat consumption per m^2 in parts of Copenhagen. Source: Calculations by Frede Hvelplund based upon data from Larsen, 2009

Table 1 shows that, in Tårnby, Brøndbyvester and Gentofte, where the fixed tariff is relatively high, it only pays to invest around 12,000 DKK in a reduction of the heat consumption of 25%. We consider 15-year loans on average to be realistic with the present situation on the housing market, with decreasing prices and also reduced possiblities of getting long-term loans. If we had calculated with 30-year loans, it would pay to invest up to 17,000 DKK. At the same time, we know that, on average, a 25% reduction will cost around 30,000 DKK, when implemented as a part of a house renovation. And more than the double, if a 50% reduction of the heat demand per m^2 is required. In this case, only Albertslund is close to have tariffs according to which it pays to invest in 25% heat reductions. The tariff situation in other district heating cities is very similar to the average situation in Copenhagen.

Although, from a societal point of view, it seems to pay to reduce the heat consumption per m^2 up to 50%, in accordance with the goal in "Varmeplan Danmark 2010", this will not happen if people react economically to the present tariff conditions.

As a conclusion, at least the following economic problems can be found in the district heating areas with regard to the implementation of house improvements beneficial to society:

1. The high fixed tariff.
2. The financial problems in the present situation with low house prices.

SBI has, furthermore, added a number of negative investor considerations:

3. Too long pay-back times.
4. The reservation of money for other purposes.
5. The position that it may be better to wait until a major renovation is necessary.
6. The fact that private comfort is disturbed during renovations.

7. The lack of detailed knowledge concerning economic and comfort advantages of energy renovations.
8. The position that major renovations may harm the original architecture.

Altogether, these barriers give rise to serious delays of investments in energy renovations. As a consequence, there is a strong need for efficient policy means.

6.5.3 Policy means for promotion of energy reductions in buildings

The SBI report lists a number of proposals for policy means, e.g.:

1. Green building tax graduated according to the energy intensity of the house.
2. Labelling of all houses according to energy intensity as a basis for green building taxes.
3. Tax reductions and other forms of investment subsidies as a support for strong energy renovations and installations of renewable energy sources, combined with proposal 2.
4. Introduction of a new scheme in which old houses unsuited for an efficient total renovation are demolished and replaced by "passive houses".
5. Introduction of Personal Carbon Allowances including heat and electricity for private houses.

Comments on SBI recommendations:

Graduated green building tax (cf. 1 above): This scheme could be combined with the proposed labelling of houses according to energy intensity (number 2 above). A short cut may be to simply register the total consumption of heat and electricity in the house and divide it by the area of the house to obtain a measure of energy intensity. A strong tax graduation could have a substantial positive influence on new investments in the energy efficiency of old buildings. A social problem is related to *"energy poverty"* in which low income families live in apartments and houses with relatively high energy intensity. This may be compensated by other policy means, but could complicate the scheme.

Labelling of energy intensity (cf. 2 above): This scheme should include proposals for relevant reductions in energy intensity as a support for new investments. Such a scheme is under negotiation in the Danish Parliament.

Investment subsidies (cf. 3 above): This scheme will need a precise description of the requirements to obtain the investment subsidy. This may include a condition that the renovation must increase the energy efficiency of the house by a specified number of places on the scale.

Replacement by a passive house (cf. 4 above): This scheme needs further investigation in order to evaluate the potential for replacement of old houses by passive houses and to evaluate the investment subsidy needed to motivate the house owners. Other practical questions include housing of the house owner during the building period.

Personal Carbon Allowances (cf. 5 above): This is a new scheme which is proposed to include heat and electricity from fossil fuels for private houses, gasoline for private cars and private air travel. While the four other recommendations above may be introduced within the time scale of a year or so, the PCA scheme may take five to 10 years to be fully implemented for political reasons. Thus, the PCA scheme should be considered as a long-term supplement to the other four recommendations.

6.5.4 Conclusions and recommendations

There is an urgent need for new policy means to promote energy efficiency investments in old buildings. The potential energy savings are of the order of magnitude: 70 PJ/y for heat and 20 PJ/y for electricity.

In the *short term*, the following policies are proposed:

- A reform assuring 100% variable energy tariffs depending only on energy consumption. This may give economic problems for some district heating companies with very high heat costs. Therefore, a moderate version of the proposal could be that any heat cost below 80 øre/kWh or 10,5 Eurocent per kWh, should be based on a variable tariff allowing a 50% fixed tariff for the heat cost above 80 øre/kWh. The level of 80 øre/kWh should be regulated annually, following the consumer price index.
- A legislation regarding a municipal energy planning procedure. Including energy scenarios, feasibility studies and policy measures.
- An energy conservation fund financed by district heating companies and by companies selling oil and gas, similar to the PSO arrangement in the electricity sector. All subsidies and other expenses are paid by this fund and are therefore independent of public finances.
- An investment subsidy for building renovation and renewable energy technologies of 20% in 2011-2015; 15% in 2015-2020, and 10% from 2020 to 2030.
- A financial reform giving 30-year 3% loans plus public guaranty. This guaranty should be financed by the district heating company.
- An energy conservation consultancy service, which is subsidised with 50% by the district heating company.
- Energy labelling of all buildings combined with graduated green taxes on buildings.

From the analysis above and Varmeplan Danmark 2010, we recommend:

- Make sure that district heating systems, which to a large extent are technical monopolies, remain municipally owned.
- Compensation of the increased costs of commuting proposed in chapter 6.4 by a reform in which the maximum heat price per kWh of non-fossil fuel heat systems outside the large cities including tax is 30% below the oil price including tax. This may be done without subsidies by introducing low-cost heat pump systems based on wind energy and by making sure that houses in these areas are not taxed higher per delivered heat unit than houses in the district heating areas in the large cities. A 30% reduction in heat prices compared to oil-based heating will encompass a reduction in the heat bill of around 10.000 DKK (1.300 Euro) annually for an average household. .

Medium to long-term policy:

- Replacement of selected old houses by "passive houses"
- Introduction of a scheme based on Personal Carbon Allowances.

7. Supply policies

To achieve a 100% renewable energy system, radical changes have to be introduced in the energy supply system. The recommended CEESA-scenario mainly relies on a massive introduction of onshore and offshore wind power and biomass. Approx. 40% of the total primary energy consumption is covered by intermittent renewable resources, such as wind power, thermal solar and photovoltaics. A large amount corresponding to approx. 40% is supplied by biomass; that is, straw, wood and energy crops. Biogas contributes with approx. 10% of the total primary energy consumption. Finally, waste has a small contribution as well and hydrogen also plays a smaller role in 2050. In the following, each of the above-mentioned renewable technologies will be addressed in order to find appropriate policy measures to ensure the implementation.

7.1 Wind power

In a European as well as a global perspective, wind power develops rapidly and, at the end of 2010, wind turbines of a total of approx. 194 GW were installed; of this almost 50% in Europe. However, wind power is at present competitive only on sites with relatively high wind speeds (disregarding externalities). Thus, a continued development of the wind power technology improving its cost-competitiveness is still recommended – combined with the inclusion of externalities in the determination of fossil fuel prices.

In this section, the Danish development of offshore and onshore wind power will be addressed.

7.1.1 Tendering of offshore wind farms

Denmark was one of the early movers in establishing offshore wind farms. The first offshore farm was installed in 1991 and, since then, a great deal of planning efforts have been devoted to a comprehensive offshore development. At the end of 2010, approximately 2040 MW offshore capacity was installed world-wide and of this approximately 640 MW is sited in Danish waters (31%). A large part of the existing Danish offshore capacity is established in accordance with an agreement between the Danish government and the power companies. This applies to the two offshore wind farms Horns Reef I and Nysted I. These two wind farms are paid a feed-in tariff of 6.1 c€/kWh, including a compensation for balancing of 0.3 c€/kWh, for 42,000 full load hours. When the number of full loads hours is reached, the turbine owners receive the spot price plus a premium of 1.3 c€/kWh[8] plus the balancing compensation of 0.3 c€/kWh until the wind farm has reached the age of 20 years.

[8] With a maximum of 4.8 c€/kWh. If the spot price plus the premium exceeds 4.8 c€/kWh, the premium is lowered. Balancing compensation is added on top of the maximum of 4.8 c€/kWh.

Following that, only the spot price will be paid for the power production from the wind farms.

The privately established offshore wind farms at Middelgrunden and Samsø have similar, although not identical, economic conditions. These wind farms are paid a feed-in tariff of 6.1 c€/kWh, including a compensation for balancing of 0.3 c€/kWh, for the first 10 years of operation. From the eleventh year, the turbine owners receive the spot price plus a premium of 1.3 c€/kWh[1] plus the balancing compensation of 0.3 c€/kWh until the wind farm has reached the age of 20 years. Following that, only the spot price will be paid for the power production from the wind farms.

In recent years, the Danish government has adopted the tendering procedure to introduce competition in relation to the development of offshore wind farms. The Danish tendering strategy is characterised by a strong planning procedure for those offshore areas found suitable for tendering. Specific areas are pre-screened and allotted for establishing offshore wind turbines. In this way, the risks of the investors are decreased. The capacity of the wind farm is predetermined in the tendering requirements, while the size of turbines is to be chosen by the winning investor. Thus, technical improvements, e.g., the utilisation of larger turbines, can be fully exploited by the investor. For the two large offshore wind farms, Horns Reef I and Rødsand I, it was required that a comprehensive environmental monitoring programme was carried out as part of the demonstration projects. The results of these projects have made Denmark an international leader in this aspect of the marine environment and have attracted considerable international interest.

In Danish waters, two offshore farms exist today that have been tendered by the Danish government: Horns Reef II and Rødsand II, both with a capacity of approx. 200 MW. According to the agreement obtained in the tendering process for Horns Reef II, a feed-in tariff of 7.0 c€/kWh is paid for 50,000 hours of full load operation, including a compensation for balancing of 0.3 c€/kWh. After the number of full load hours has been reached, the turbine owners receive the spot price plus a premium of 1.3 c€/kWh[9] plus the balancing compensation of 0.3 c€/kWh until the wind farm has reached the age of 20 years. Following that, only the spot price will be paid for the power production from the wind farm. For Horns Reef II, the bidding procedure encompassed 3-4 bidders; thus, a reasonable competition was ensured.

For Rødsand II, the conditions are very similar, except from the fact that a feed-in tariff of 8.4 c€/kWh is paid for 50,000 hours of full load operation, including a compensation for balancing of 0.3 c€/kWh. The tendering process for Rødsand II was at first won by the Danish company DONGenergy, but the company decided to step out of the deal and Eon assumed responsibility for the Rødsand II.

Recently, the Anholt offshore wind farm was tendered, with a capacity of 400 MW becoming one of the largest offshore wind farms in the world. But the tendering procedure of this offshore wind farm has not created appropriate competition. For the Anholt wind

[9] Observe that for new offshore wind farms there is no maximum limit on spot price and premium.

farm, there was only one bidder, resulting in a unsatisfactorily high feed-in tariff of 14.0 c€/kWh being paid for 50,000 hours of full load operation, including a compensation for balancing of 0.3 c€/kWh.

7.1.2 Policy recommendations for tendering of offshore wind farms

The tendering procedure has to be improved if large amounts of offshore wind power are to be used. This could be done in several ways:

- The tendering procedure should be more attractive to investors. Offshore wind farms as large as Anholt (400 MW) could be partitioned into a number of smaller farms of a size of 150 to 200 MW. This might make it easier for smaller companies to participate.
- New investors as Danish municipalities should be allowed to enter into the establishment of offshore wind farms. E.g., the municipality of Copenhagen has shown strong interest in participating in offshore wind farm development.
- Developers of offshore wind farms should be obliged to offer 50 % of the shares to local and regional investors.
- The "open door" approach should be made more attractive to offshore development. Today the tariff for open door offshore wind farms is at the same level as for onshore turbines.

7.1.3 Onshore wind power

In the 1980s and 1990s, the capacity of onland wind turbines in Denmark developed relatively fast and Denmark was highly ranked on the European list of wind power implementation. As in other countries, wind power and renewable energy was at that time supported by the government in Denmark. Subsidies to renewable energy were introduced in Denmark in 1979. The aim was to subsidize investments in developing renewable technologies (e.g., wind power, solar heating, biogas and biomass), which were not yet prepared to compete with traditional technologies on the market. During the last 20 years of the 20th century, a general feed-in tariff combined with the prioritisation of wind power in dispatch was driving the fast wind power development in Denmark.

In 2000, the Danish Parliament approved a power sector reform liberalising the power market. At the same time, the subsidy to wind power producers included in the feed-in tariff was transformed from a fiscal subsidy into a subsidy paid by electricity consumers. Moreover, the fixed feed-in tariff was changed to a feed-in premium and the price paid to wind turbine owners was linked to the power price paid on the spot market, introducing a higher uncertainty for wind power producers.

The higher uncertainty combined with the fact that the premium was fixed at a fairly low level resulted in the stagnation of wind power development in Denmark for a number of years, in which only the offshore development was adding to the wind power capacity.

Although the density of wind turbines is rather high in some geographical areas of Denmark, analyses show that there still is room for a considerable increase of onshore wind power. It has, however, to be taken into account that siting new onland turbines has shown to be increasingly difficult, because of, amongst others and in some cases, the so-called NIMBY effect (not in my backyard). One way to reduce the local opposition against large wind turbines would be to regulate the allowed capacity of onshore turbines to a maximum of, e.g., 2 MW, except in special cases, and to support local and regional ownership. Larger size wind turbines are also difficult to fit into the nature of the vulnerable Danish landscape.

In recent years, the premium has been increased, thus improving the conditions of onshore wind turbines. If the legal rules were changed to promote local ownership of wind farms, e.g., in the form of cooperatives, this would benefit local development and acceptance of onshore wind power.

In order to establish the needed intermittency infrastructure, it is proposed that organisations with certified cogeneration and/or heat pump/heat storage systems are given ownership priority in wind energy project shares.

7.1.4 Policy recommendations for onshore wind farms

Short-term recommendations:

- Updating of the legal rules for establishing cooperative wind farms in accordance with the large turbines of today. Previously, cooperative wind farms were very successful and, back in the 1990s, a large share of onshore capacity was owned by cooperatives.

- Increasing the share which a project developer is obliged to offer to local and regional investors from the present 20 % to 60 %.

- Introduction of ownership priority in wind energy projects by which organizations that have cogeneration and/or heat pump/heat storage systems with required abilities to integrate wind power are prioritised.

- The municipal spatial planning should make sufficient room for new onshore turbines, including simple administrative procedures that do not act as barriers to onshore wind power development.

- Introduction of a size limit on onshore wind turbines of around 110 meters (around 2MW), with possibility of dispensation in specific cases, to protect nature values and to reduce local opposition to wind power.
- Municipalities should have favourable possibilities as owners of local wind farms.
- Permissions to larger onshore wind farms may be coupled with investments in certain infrastructures that assist the grid balance.

7.2 Photovoltaics

Photovoltaic cells (PVs) convert solar radiation into electricity. With the present technology, the efficiency of commercial PVs is approaching 20 %. In theory, the PV efficiency may approach 30 % at the expense of more complicated structures and higher production costs. The present PV market is dominated by cells based on pn-junctions in silicon (about 90 % of the market), but a number of other types are under development.

The cost of electricity from commercial PVs has been decreasing over the last decades, but is still a factor of about five higher than the cost of electricity from land-based wind turbines. The decrease in price has been slowed down in the years up to 2009, due to the lack of raw silicon and the resulting lack of market competition.

This bottleneck seems to be eliminated resulting in a strong drop of about 35% in the PV price during 2009. The decrease in price is assumed to continue due to a rapid increase of PV on the global market (about 40 % per year) and improved production methods.

Denmark is not an obvious country for the early introduction of PVs in the energy supply system, as the total solar radiation per m^2 is about half of the influx in, e.g., southern Europe. However, Germany is a pioneering country in the promotion of PVs globally, despite the fact that its influx is somewhere between that of Denmark and southern Europe.

Danish potential for electricity from PVs

In the beginning of 2010, the total Danish PV capacity amounted to about 4.5 MW, corresponding to 0.8 watt per capita. This may be compared to the corresponding German number of about 120 watt per capita. The drop in price of PV installations has, however, started a dynamic development of PVs on the Danish market, especially in relation to small installations at private households. Thus, the total Danish PV capacity increased by about 40 % in 2009 and has continued to increase rapidly during 2010.

This development is due to several factors in addition to the drop in market price. One important factor is the Danish indirect government subsidy through a system in which a private household may cover its electricity consumption by its own PV installation and export surplus electricity to the grid, as its electricity meter runs backwards. This so-called net-metering system means that the private household is paid a tariff for its export to the grid, corresponding to the household electricity price *including all taxes.* In this way, the estimated tariff corresponds to about 1.5 to 2 DKK per kWh (0.20 to 0.27 €/kWh) at present, but the system is limited to installation capacities up to 6 kW.

The annual radiation influx in Denmark is about 1000 W/m^2 and, with the present technology, a PV installation of 1 kW of rated power can produce up to 1000 kWh/year, corresponding to 1000 hours at rated capacity. This number of annual hours is about a factor of two higher for onshore wind turbines and up to a factor of four higher for offshore wind farms. This is partly reflected in the cost relations. Other factors promoting PVs in Denmark are the new building codes and increasing electricity prices.

After the recent drop in production costs, PVs installations in Denmark are estimated to produce electricity at a cost of around 1.4 DKK/kWh (0.19 €/kWh), neglecting financial costs. This is below the indirect tariff from the net-metering system and may be part of the explanation for a present increasing interest in PVs for private households.

It is possible in theory to install enough PV capacity on buildings to cover half of the present Danish electricity consumption [Ahm 2010].

7.2.1 Conclusions and recommendations

The theoretical potential of PV installations in Denmark is significantly larger than required to fulfil the CEESA scenarios. The societal economy of large investments in PV installations depends, however, on the future development of electricity cost from PVs compared to costs of wind power and general electricity prices. These figures are inherently quite uncertain but this should not prevent the development of the PV option in the Danish context. Danish industry is already active in relation to electronic converter systems for PV installations. This may well lead to significant Danish export articles.

Short-term recommendations:

- A comprehensive plan should be set up for the inclusion of PV installations in the Danish electricity supply system, including considerations of synergy effects in combining wind power with solar power.
- The present net-metering system should be continued in order to obtain further Danish experience with the practical use of PV installations. The limitation of this system to 6 kW of rated power should be increased to at least 20 kW of rated power in order to include larger apartment houses and service institutions.

Medium to long-term recommendations:

- Demonstration projects should be sponsored by government money to obtain practical experience with the efficient combination of wind power and solar power.
- The net-metering tariff system should be supplemented by a flexible feed-in system for larger PV installations.

7.3 Wave power

The production of electricity from wave power is still in the development phase. So far, a convincing and economic wave power technology has not been demonstrated. Wave power technology is lacking behind offshore wind technology by 20 to 30 years.

A government sponsored project on wave power development was initiated in Denmark in 1997 administrated by the Wave Power Committee (WPC) under the Danish Energy Agency (DEA). The project was allotted 40 million DKK (5.3 million €) for a first project period of four years.

During the four-year period, a wide range of wave power technologies were tested in small-scale sizes sponsored by the WPC. At the end of this period, the WPC was focusing on a couple of promising technological proposals and applied to the government for a continuation of the project based on demonstration and testing of the selected pilot projects.

However, in November 2001 a liberal-conservative government took over in Denmark, and the new government decided to close down the Danish wave power project.

Since then, a small number of Danish wave power development projects have continued on a private basis, while the main development efforts have taken place in other industrial countries (the UK, Portugal, Norway, Japan). On this background, the prospect of a Danish industrial adventure in the field of wave power is rather modest.

7.3.1 Potential of Danish wave power

The final report from the WPC estimates the Danish potential of electricity from wave power at about 5 TWh/year, provided that efficient wave power plants are successfully developed. This should be compared to a long-term contribution from offshore wind power of about 20 TWh/year in the CEESA scenarios.

The Danish potential of wind power is significantly greater than the consumption of electricity in Denmark, foreseen in the CEESA scenarios. It is, thus, a main question whether there is a relevant need for a Danish investment in wave power. One argument for this investment may be based on the possible synergy effect between wave power and power from offshore wind farms. The waves develop later than the wind and continue for some time after the wind has stopped. A combined system may thus reduce the variations in the total output from the system. A preliminary analysis of the advantages of a combined system is published in [Brix et al 1999]

7.3.2 Conclusions and recommendations

The main development efforts related to wave power take place in other industrial countries than Denmark. At the same time, the wave power technology is lacking behind the wind power technology by a couple of decades, while Denmark is a pioneering country in offshore wind with sufficient potential in the future Danish electricity consumption. It is, thus, a central question whether the investment in wave power for the Danish electricity system is relevant.

Short-term recommendations:

- An analysis of the possible synergy effects between offshore wind and wave power should be initiated in order to evaluate the relevance of further Danish investment in wave power. If this result confirms significant long-term advantages of the combination of wave power and offshore wind, the earlier wave power programme may be continued.
- The interest of commercial companies in establishing first generation wave power units may be tested by an official programme as follows: A tender for a wave power plant of a capacity of up to 40 MW is announced based on a maximum tariff of 25 eurocents/kWh. The best offer below this maximum tariff will be accepted. The extra cost compared to the average market price should be covered by the power consumers via Energinet.dk. With no bids below the maximum tariff, no plants are built in connection with this programme.

Medium and long-term recommendations:

- Provided that the synergy analysis is sufficiently positive, a number of demonstration projects should be sponsored combining offshore wind with wave power, eventually leading to wave power being an element in the Danish electricity system.

7.4 Heating

The CEESA policy proposals for the heating sector are, to a large extent, based on the "Varmeplan Danmark 2010" and its appendices.

7.4.1 Scenarios for heating in Denmark

In "Varmeplan Danmark 2010", it is assumed that:

- The consumption of heat and hot water per m^2 is reduced by 50% from 2010 to 2050. This is further discussed in chapter 6.

- The district heating market share will grow from 50% to around 70% of the total heat market. As the heated space area is expected to grow by 20%, this means an expansion of the district heating system by more than 50% from 2010 to 2050.

- The supply system in 2050 is 100% based on renewable energy technologies such as geothermal, biomass/biogas, wind power in combination with heat pumps, and heat storage systems.

- The market share of individual houses is expected to be reduced from 50% to around 30% in 2050, and the heat supply is assumed to be based mainly on heat pumps and wind power.

This scenario represents a fundamental change of both the demand side and the supply side of heat and it introduces a need to ***synchronize*** heat conservation with the investment in a new renewable energy-based supply side system. This is analysed in detail in Appendix B and the main results are quoted in the following.

The analysis shows that, from a societal point of view, it pays to reduce the heat consumption per m^2 in houses by 35%-40%. If supply security and the scarcity of wind turbine sites are taken into consideration, it pays to reduce heat consumption per m^2 by up to 50% before 2050. With the long lifetime of houses, it would pay to renovate the houses to an even better energy standard.

As a consequence, new investments in the supply system should be based on the heat demand for houses, which is at least 50% lower compared to today's standard. The time perspective is of central importance as renovated houses will last to 2050-2080. Thus, from a supply and demand side optimization point of view, "2050 begins in 2011", when considering the renovation of an existing house. Already in 2011, house renovation should encompass a 50% reduction in heat losses. If this way of thinking and planning is not implemented from 2011 and onwards, we risk building uneconomical large supply systems that will also use too many sparse and expensive wind sites. This is the case both for houses within and outside district heating systems.

The present tariff system for district heating customers are one of the important barriers to the implementation of the proposed scenario as summarized below (and also discussed in section 6.5). A detailed analysis is given in Appendix B.

7.4.2 Tariff policy for district heating systems

For the time being, the tariffs in the district heating systems are set according to *the average*[10] short-term marginal costs in the present supply system. Large variations may be seen from one locality to another, but a 50/50 distribution between fixed and variable tariff is a reasonable estimate of the present average distribution (see chapter 6.5.).

The basic problem that has to be solved is that decisions made in the district heating companies have a short time horizon compared with the time horizon needed, when changing the energy system fundamentally. The district heating networks are well suited for the infrastructure function in a coming renewable energy-based supply system. But the present way of setting the tariffs is a barrier to the transition to a system based upon energy conservation and renewable energy.

Due to the short time horizon and the calculation rules in the district heating companies, the tariffs are usually an average of the *short-term marginal costs* in the existing supply system. But in a long-term perspective, in which the goal is an economical strategic optimization of demand and supply activities, the price should be set according to the *long-term total costs* per extra heat unit supplied by a future supply system. Already today, the tariffs should be set according to the price of the future renewable energy-based system. The problems and solutions in relation to this proposal are discussed in Appendix B.

The conclusion of the analysis in Appendix B is that, from a strategic supply and demand optimization point of view, the tariffs should be set already today according to the long-term total costs per extra heat unit produced by the future renewable energy-based supply system. The desired change of the system will not happen if the present tariff system based on short-term marginal costs is not replaced.

7.4.3 Governance and the change to renewable energy-based heating systems

In addition to the tax system, the public regulation should be designed to efficiently promote the change to the future renewable energy supply system. Members of the CEESA team have been actively involved in the report "Varmeplan Danmark 2010", and CEESA has adopted most of the policy means described in chapters 6.5 and 7.4 of this report.

The most important general proposal is that municipalities should establish strategic energy planning as an obligation rooted in the energy legislation. All municipalities should create energy scenarios including analyses of consequences for environment, employment, public finances, etc., as defined by the Parliament.

Other proposals involve:

1. A change of the procedures for socio-economic feasibility studies including a *reduction of the discount rate* from the present 6% p.a. to 3% p.a. (or below). The proposed changes are described in detail in Appendix 5B, in " Varmeplan Danmark 2010- forudsætningskatalog."

2. The establishment of an *innovation fund.* This may be realized by a PSO fund for heat, financed by the district heating systems.

3. The establishment of a *transformation fund* financed by a tax on fossil fuels and contributions from the district heating companies.

4. Subsidies for individual heat systems, including economic support for the transformation to combined wind and heat pump systems. This subsidy may cover 25% of the investment cost in the period 2011-2015 with a subsequent gradual decrease up to 2030.

5. The establishment of a certification procedure for heat pumps and solar heat systems.

6. The establishment of a cost-based compensation procedure for the decoupling of households from the natural gas network.

7. 20% subsidy for investment in large heat pumps in 2011 with a subsequent gradual reduction to zero in 2014.

8. The regulations of large heat pumps installed at CHP plants in order to match the need for grid balance in periods without wind.

9. Supply companies should remain municipally owned in order to establish the needed transformation coordination.

10. Private households and firms wanting to sell wind and solar-based heat to the network should have open access to the district heating system – like in the present system of electricity sale to the public grid.

11. Restrictions should be put on the use of individual biomass-based heating in district heating systems.

12. 20% subsidy for investment in certified small heat pumps with a subsequent gradual reduction to zero in 2014.

7.5 Solar heating systems

Theoretically, solar energy is the largest renewable energy source in the world as well as in Denmark. The annual solar radiation on Denmark's land area is about 180 times larger than Denmark's total annual energy consumption.

Today, four types of solar heating systems are used in Denmark:

- Solar domestic hot water (SDHW) systems.
- Solar combination systems.
- Solar heating plants for heating a whole town or a part of a town by means of a district heating system.

- Air collectors for the dehumidification of houses.

Today, simple financial payback times of solar heating systems in Denmark are 7-15 years. Technological improvements are expected to reduce the payback time by 50 % before 2020. A large effort is presently made in China in this field.

The main problem of solar heat in Denmark is the fact that most of the solar influx appears during the summer months in which the demand for heat is low, while the solar influx is low during the winter months when the demand for heat is high. This makes the efficient and low-cost storage of solar heat from summer to winter an important element in the future development of solar heat systems. Early experiments with large heat storage systems have been carried out in Sweden and new projects are planned in Germany (Heup 2010, Janzing 2010).

Danish production of systems for solar heating

A number of Danish manufacturers and companies are active on the European solar heating market. For example in the following fields:

- Marketing of solar heating systems in many European countries.
- Production and marketing of large solar collector panels for about 50% of Europe's solar heating plants.
- Production of antireflection treated glass for a large number of Europe's leading solar collector manufacturers.
- Production of selective coating for absorbers for a number of European solar collector manufacturers.
- Production of circulation pumps for many solar collector manufacturers of the world.
- Marketing of patented air solar collectors for summer houses.

Recommendations:

Denmark has been pioneering large solar heat installations in connection with district heating, e.g., on the island of Ærø. It is uncertain, however, whether this type of systems solution is optimal in a future comprehensive Danish energy supply system. This has to be clarified before the strength of further Danish efforts in this field is decided.

A number of Danish manufacturers and companies are active on the expanding solar heating market. From an employment point of view, this could give grounds for government support to these commercial activities.

Research and development in the field of small solar heating systems should concentrate on hot water tanks and the interplay between solar collectors and other renewable energy sources. The development of larger systems should concentrate on solar collectors and seasonal heat storage.

Short-term recommendations:

- A comprehensive plan should be set up for the role of solar heating in the total Danish supply system.
- The present Danish scientific experience in the field of solar heating should be preserved and supported by educational programmes and development projects. Research and development in the field of small solar heating systems should concentrate on hot water tanks and the interplay between solar collectors and other renewable energy sources. The development of larger systems should concentrate on solar collectors and seasonal heat storage.

Medium-term recommendations:

- A solar heating test station should be established if solar heating is given a significant role in the Danish comprehensive energy planning. In addition, Denmark should establish educational programmes for the key players in the field, and large solar heating systems should be given favourable feed-in tariffs.

7.6 Natural gas

7.6.1 Phasing out natural gas

The goal of CEESA is to phase out all fossil fuels in Denmark before 2050. This includes natural gas, which is in a special condition as Denmark has been a *net producer* of natural gas for a couple of decades. During the next decade, Denmark will change into a *net importer* of natural gas with the present energy policy. The CEESA project has sought to determine the optimal strategy for the phase-out of natural gas, seen from the point of view of societal economy and environmental effects and including considerations of the consequences for present natural gas customers and for present natural gas companies.

The resulting policy means and strategies are discussed in detail in the report "Varmeplan Danmark 2010" ("Heat Plan Denmark 2010") and the main results are summarized in the following.

Main strategies for the phase-out of natural gas in Denmark:
The first phase in the transition from natural gas to renewable energy sources (RES) is concerned with policy means for phasing out natural gas for the heating of individual houses. This requires the presence of economically attractive alternatives, especially for houses without access to district heating. One way to promote the transition from natural gas to RES will be to introduce taxes on investments in new natural gas installations in individual houses. A more radical scheme would be to prohibit such investments by law.

A second phase is concerned with promoting alternatives to natural gas in a number of industrial processes. This is a complex problem as many industrial productions involving high temperature processes are presently utilising natural gas. One solution may be to replace natural gas by biogas from animal manure, as described in the section on biogas.

The potential biogas production is estimated to be sufficient to meet the need of the manufacturing industry.

Conclusions and recommendations
In order to phase out natural gas, the existing scheme with restrictive ruleshas to be reformed in such a way that natural gas heating is replaced by district heating and heat pumps. This transformation can be promoted by investment subsidies to households switching from individual gas boilers to district heating or heat pumps.

The shift of CHP plants from natural gas to heat pumps, solar heating and geothermal energy should be promoted.

The shift of the manufacturing industry from natural gas to biogas should be promoted.

Short-term proposals:

- A tax should be introduced on future investments of private households on natural gas boilers. An alternative or supplementary solution would be to subsidize the shift in private households from individual natural gas boilers to heat pumps or to district heating where this is a possibility.

- The regulatory rules in the Danish heating plan scheme should be changed in order to allow natural gas customers to disconnect from the natural gas grid.

Medium-term proposal:

- Economic and technological support should be given to the manufacturing industry in order to promote a change from natural gas to biogas for high temperature processes.

Three potential renewable substitutes for natural gas exist: Biogas, bio-SNG and hydrogen. These are treated in the following three sections

7.7 Biogas

Biogas production is based on the following main sources: Animal manure, sewage treatment plants, landfills, and cleaning of organic industrial waste streams. The production of biogas from animal manure is a mature technology well established in many European countries, including Denmark. In Denmark, animal manure has the largest potential, but only about 4 % of this potential is utilised at present. If biogas is to play a significant role in the Danish energy supply, it is important to find the optimal production and transmission systems for biogas, and to analyse the structural development of Danish agriculture. The main feature is that cows and pigs will be assembled in fewer and larger production units which will decrease the production and transmission costs of biogas. The development in the total number of cows and pigs is, however, more uncertain.

The official Danish goal in the political agreement ("Green Growth") from June 2009 is that 50% of the animal manure is used for the production of biogas by 2020. This will require a rapid expansion of the biogas production facilities in the coming decade. It is, furthermore, estimated that it is possible to expand the production to 90 % of the biogas potential by 2030. Most of the plants are using a combination of animal manure and organic waste from, e.g., fishery and slaughterhouses. 10 to 20 % of organic waste is boosting the production of biogas, and the biogas plants receive a subsidy for accepting the organic waste. The production of biogas based purely on animal manure is not economical at present. It is a problem, however, that the traditional organic waste resource is rather limited and much too small, if the biogas production is increased in accordance with official Danish plans. As a consequence, other forms of boosting materials should be considered like energy maize, energy beets, grass from preserved nature areas, and biomass waste from gardens and park areas. This is further elaborated below.

Historical Promotion of Danish Biogas

The modern development of Danish biogas started in the beginning of the 1980s with governmental support from the so-called Steering Committee for Renewables. This was, to a large extent, an experimental period with a number of unsuccessful biogas projects due to inefficient technologies and the lack of expert knowledge. Both mesophilic and thermophilic technologies were developed in this early phase. During the 1980s, some 15 so-called "village plants" were developed based on manure from cows and pigs on a number of Danish farms, where the biogas was used in local co-generation plants. A similar number of individual biogas "farm plants" were implemented, e.g., based on manure from large pig farms. This development stagnated, however, in the 1990s due to the lack of technological development and an unsatisfactory economy.

Today, around 80 biogas plants based on animal manure are operating in Denmark. This includes small plants with input from only 2 m^3/manure per day to the largest plants (Lemvig and Linkogas) with an input per day of about 550 m^3 manure plus organic waste. About 30 of these plants are coupled to local district heating systems. Biogas production in Denmark currently amounts to approximately 4 PJ annually (about 100 million Nm^3 gas).

Economic Prospects of Danish Biogas

In 2010, the average production cost of Danish biogas was about 110 DKK/GJ. This should be compared to a price of Danish natural gas of about 50 DKK. Thus, biogas is not competitive with natural gas, e.g., as fuel for local co-generation plants without significant economic support. However, this situation is estimated to change during the next 20 years due to decreasing costs of biogas and increasing prices of natural gas. Taking into account the changes in Danish agriculture to larger production units, the production and transmissions costs of biogas may decrease as much as 25 % before 2030. At the same time, the official forecast for the natural gas price is an increase of about 75 % which would make biogas competitive by 2030 without government subsidy.

In the period from now to 2030, the promotion of biogas should be based on a feed-in system with sufficiently high tariffs to accelerate the expansion of biogas production and to include demonstration projects with new forms of transmission line from the biogas plants to the consumers. The tariffs should be reduced along with the technological progress and the improved competitiveness of biogas.

Future Systems Changes for Danish Biogas
As mentioned above, it is expected that cows and pigs will be assembled at fewer and larger farms. This will make it economically possible to invest in separate transmission lines for the biogas from these large farms to the consumers in the nearest larger cities.

Another possibility is to couple these biogas transmission lines from large farms to the national natural gas system. In the present situation, this will require an upgrading of biogas in order to reduce the content of CO_2. At present, the upgrading is estimated to cost about 1 DKK per m^3 of methane for large installations and even more for smaller units. Preliminary analyses indicate that this cost is so high that it would be less costly to build a parallel national transmission system for biogas only. It is too early, however, to draw final conclusions concerning further cost reductions of upgrading technologies, including new processes for the chemical transformation of the content of CO_2 into methane.

Potential Energy Contribution from Danish Biogas
As one possible scenario, the boosting of biomass production can be provided by grass from preserved areas and other types of biomass for energy to the extent that 25 % of the input to the biogas plants is boosting material supplementing 75 % of manure. The total energy from biogas will amount to about 45 PJ, if it is further assumed that 90% of the manure from the large animal farms is exploited for biogas by 2030. This would amount to roughly 1 billion Nm^3 of natural gas, which would more than adequately replace the natural gas currently used by the manufacturing industry[11].

Institutional and Political Barriers to the Promotion of Biogas
The input of biogas to existing local co-generation plants operating on natural gas is a possible strategy for reducing CO_2 emissions in Denmark. Such a development is, however, competing with a strategy promoting large solar energy plants in connection with these local co-generation plants. Analyses by Klaus Illum have shown, however, that the solar solution is not optimal, when the goal is to reduce the emissions of CO_2 in a cost-effective way. The solar solution seems, nevertheless, to have full support from the natural gas companies that are present fuel suppliers to the local co-generation plants.

Conclusions and recommendations
Biogas from animal manure is a significant resource for the mitigation of Danish CO_2 emissions, especially when it is used to replace natural gas in local co-generation plants in a system with a high coverage by wind power.

The most urgent challenge is to provide a comprehensive plan for the inclusion of the biogas potential in the Danish energy system. At present, a number of unsolved planning

[11] This is based on estimations of currently available resources. However, within the next decades, additional resources for producing biogas might become available and hopefully be cost-effective. A number of studies have suggested the use of, e.g., algae as a biomass source.

questions can be seen, including the provision of boosting materials for the biogas plants; how to choose the optimal system of biogas transmission lines; and how to find a balanced solution in relation to competing systems based on solar energy.

Short-term recommendations:

- A comprehensive plan should be set up for the inclusion of a long-term biogas potential of about 40 PJ/y. This plan is urgently needed in order to avoid serious barriers to the future exploitation of the Danish biogas potential. Such a plan should preferentially be worked out . Detailed analyses are needed to compare the biogas solution to other solutions based on renewable energy, when replacing natural gas in local co-generation plants.
- There is also an early need for demonstration projects with different systems of transmission lines from biogas plants to the primary consumers. Proposals from suitable Danish regions should be sponsored by the government.
- Favourable feed-in tariffs are needed to promote new biogas plants during the coming decade.

Medium and long-term recommendations:

- New types of supplementary organic materials should be developed for biogas production. The possibility of algae production should be included in this connection.
- Feed-in tariffs for biogas may be reduced as the production process becomes more efficient.
- The natural gas system may be prepared for the distribution of biogas as the supply of natural gas is running out if this turns out to be an economical solution and the amount of manure is high enough.
- The biogas production plants may be developed to yield higher efficiency related to the use of animal manure so that less (or no) supplementary organic input is required. This involves new research and development.

7.8 Hydrogen and energy systems

Hydrogen is not a primary energy source such as coal and oil. Hydrogen is an energy carrier in line with the power grid and district heating networks and therefore other sources of energy have to be converted to produce hydrogen. Today, hydrogen is usually produced either by electrolysis or by steam reforming of natural gas. However, hydrogen can be produced in a number of ways, as illustrated in Figure 12. Different kinds of biomass can be liquefied or gassified and reformed to hydrogen. Solid fossils, such as coal, can be gassified and reformed to hydrogen, may be combined with CO_2 capture and sequestration.

The storage of hydrogen is an important element of the hydrogen system. The most commonly used storage today is high-pressure composite tanks, steel tanks and cryogenic storage of liquid H_2. However, new approaches are being developed including the use of solid materials as metal hydrides and nanoporous materials, such as active carbon or metal organic frameworks. Compressed hydrogen storage in very large quantities in underground caverns (mined cavities in salt domes) is, however, a relatively cheap and well-known technology.

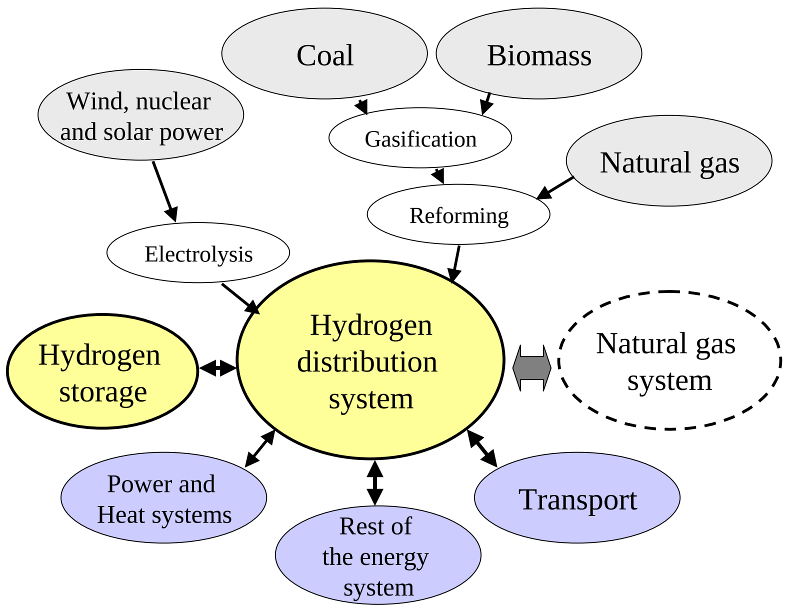


Figure 12: A hydrogen system could provide linkages between the different parts of the total energy system.

Hydrogen can be utilised in a large number of different applications, including transport, power generation (central or dispersed) and industrial processes. In general, the end-use of hydrogen has a very low impact on the environment, having no emissions of greenhouse gases or most other pollutants. Seen over the total lifecycle, the environmental impact of hydrogen of course depends on how hydrogen is produced. If renewable sources as wind and solar power are utilised, hydrogen-based systems are considered to be among the most environmental benign systems known today.

The transport and dispersion of hydrogen is an important but often partly overseen issue. If large amounts of hydrogen are to be utilized across the World, a comprehensive infrastructure has to be developed. A hydrogen distribution system could be developed locally, regionally or nationally. A hydrogen system could also be linked to the natural gas system, which, with some changes, can carry hydrogen[12]. Hydrogen could provide the linkage between renewable energy and the transport sector, making biomass, solar and wind available as a fuel for transport purposes (e.g., automotive, maritime, rail and air transport), which otherwise are heavily dependent on the supply of oil. In CEESA, hydrogen is primarily used for boosting gasified biomass and making bio-DME/methanol; thus, creating a cheaper way of storing energy than hydrogen and enabling the use of

[12] In most conventional natural gas systems, the pipelines are capable of carrying hydrogen, though pumps and valves may have to be adapted or replaced.

existing storage options. Co-electrolysers are used in the long term with which DME/methanol can be produced without a direct biomass input.

Conclusions and recommendations
Hydrogen is to be considered as a *long-term option* of replacing fuels in the transport sector with liquid fuels.

Thus, we recommend that:

- Research and development are prioritised focusing on more efficient hydrogen production and co-electrolyser technology.

7.9 Waste

Waste is a renewable energy resource and is also considered as such in national energy statistics. Danish waste from households and industries is utilized for combustion in CHP production (waste incineration). However, waste also has an influence on the potential for biogas and biofuel production.

When considering the position of waste in future energy supply scenarios for Denmark, the implications of future market design for the treatment of waste are of importance to the analysis. EU regulation has a strong influence on the framework conditions for waste management in the member countries. Most important is the liberalisation of energy markets and the waste directives given by the EU.

Compared to most EU countries, a fairly high share of waste is used for energy production in Denmark. As energy markets have been liberalised, the economy of waste CHP in Denmark is increasingly influenced by the electricity market prices given by NordPool.

7.9.1 Cost-of-service regulation

Local CHP production in Denmark is presently under the cost-of-service regulation, as district heating is a local monopoly market in which heating customers are tied to only one local heat supplier.

Cost-of-service regulation implies that the costs of production have to balance the sales on three independent markets for

- Electricity, where the price is given by the NordPool market
- District heating, where the price is regulated by Energitilsynet
- Waste management, where the price is determined so that costs and sales revenue are balanced.

7.9.2 EU waste directive

The EU intends to liberalise the waste market. One step in the liberalisation process is to make an EU market for industrial waste incineration. This implies the right to import and export industry waste used for incineration across national borders where the market forces determine the prices for industry waste management. Thus, waste can no longer be considered as an isolated national resource but has to be seen as a commodity in an international market.

In a longer perspective, one might expect that the prices on the international market are the driving forces for the import and export of waste. If the prices of waste management are lower in Germany than in Denmark, there will be an incentive for Danish industries to export waste to Germany. Thereby, Danish waste CHP production plants will lose a market share and will face a challenge to meet the market prices due to the cost-of-service regulation paradigm. If the price of waste can no longer be set to meet the costs, but has to meet the market price, there is a need for revising the Danish cost-of-service regulation model.

Another EU initiative is the decision made by the EU Parliament to target 50 per cent recycling without taking into account electricity and heat produced by waste. This initiative is a challenge to Denmark, where the share of waste used for CHP production is much higher than in the average EU member country.

7.9.3 A competitive waste market

The future competition on the EU market for waste management will make it difficult to maintain the existing Danish cost-of-service regulation paradigm for CHP production based on waste. It will also be difficult to make forecasts for the waste resources available for CHP production in a scenario in which Danish CHP plants are competing nationally and internationally for the waste resources.

So far, the EU only intends to liberalise industrial waste used for incineration. Industrial waste used for deposits and household waste are presently not considered relevant for liberalisation. Thus, the regulation has to take into account the existence of two different categories of waste. This is further complicated by the presence of waste incineration plants owned by the municipalities primarily to manage household waste and the presence of privately owned incineration plants operating on a commercial market, including all categories of waste (and even energy resources) of relevance to the CHP production. This gives rise to a complicated situation for the future regulation of Danish CHP production based on waste.

7.9.4 Conclusions and recommendations

The Danish system for the energy use of waste is different from most other EU member states, as a much higher percentage of the waste is used for CHP production in Denmark. This has not been a problem so far, as the Danish regulation of CHP production based on waste has not been influenced by the situation in other member states. However, this will change with new EU directives for the liberalisation of the waste market. It is, thus, an urgent problem to find alternative solutions for the Danish CHP production based on waste, if Denmark cannot be exempted from the commercial waste market in the EU.

New EU targets for the recycling of waste (50 % target) will also influence the present Danish waste policy in which the CHP production utilises a significantly higher proportion of the Danish waste.

Short-term proposal:

- If Denmark cannot obtain exemptions from the liberalised EU waste market, then alternative systems for the regulation of local CHP production based on waste should be implemented. The goal of the regulation is the same as before: to protect the district heating consumers from unfair pricing due to the monopoly situation of the local district heating system.

7.10 Biofuels for transport

7.10.1 The use of biofuels

A general treatment of the transport sector is presented in section 6.4. The present section adds some brief notes on the potential and problems of using bio-fuels for transport.

In principle, Denmark has a resource and an industry potential to become a producer of bio-fuels for parts of the transport sector. Straw from Danish agriculture is a potential source for second-generation bio-fuel production based on enzymes produced by Danish industries, as illustrated by a demonstration plant located in Kalundborg (INBICON).

The claimed benefits for the Danish society are CO_2 reductions, increased employment, increased security of energy supply, and positive synergetic effects between Danish agriculture, the green-tech industry and the energy sector.

The EU transport energy directive demands each EU member country to implement a target of 10 per cent renewable energy in the transport sector by 2020 with some restrictions in relation to environmental concerns.

The extensive use of biomass for transport is, however, a controversial issue even when limited to second generation bio-fuel based on agricultural waste like straw. Thus, a number of Danish CHP plants compete for the straw, and ecological farming claims the straw for other purposes including the preservation of soil quality. Further, new green-city alliances between DONG and larger cities prepare for the increased use of biomass in centralized power plants.

On this background, the CEESA project proposes to make market regulations that will concentrate the use of Danish bio-fuels to a few transport types: heavy commercial transport and air traffic. At the same time, it is important to reduce the need for these types of traffic by promoting alternative solutions like fast trains and electric cars.

7.10.2 Conclusions and recommendations

Denmark has a potential of agricultural waste that may be transformed into bio-fuels for the transport sector. There are, however, competing demands and uses for this agricultural waste. For this reason, it is concluded that agricultural waste for transport should be restricted to special transport demands like air traffic and heavy commercial transport.

Short-term recommendations:

- A comprehensive analysis should be initiated in order to determine the optimal use of Danish agricultural waste from a societal point of view. The analysis should include the requirements of a future energy supply system based on renewables in addition to considerations of societal economics, environmental impact and competing demands for biomass.
- Biofuel production capacity for heavy-weight transport should be promoted.
- Regulation should prevent biomass from becoming earmarked for inappropriate Green-City concepts extending the lifetime of existing power plants that may better be phased out.

Medium term recommendations:

- If the above analysis concludes that there are overall positive effects of using parts of agricultural waste for bio-fuels in the heavy transport sector, technological demonstration projects should be promoted.

8. List of references

Chapter 1:

Danish Commission on Climate Change Policy (2010): ”Green energy – the road to a Danish energy system without fossil fuels”, Copenhagen, Denmark.

Danish Energy Strategy 2050 (2011), Ministry of Climate and Energy, Copenhagen, Denmark.

Mathiesen, BV, Lund, H & Karlsson, K (2009), ”IDA´s klimaplan 2050: Tekniske energisystemanalyser og samfundsøkonomisk konsekvensvurdering” - Baggrundsrapport, Ingeniørforeningen i Danmark, IDA, København V.

Chapter 4:

Awerbuch, S. (1996a), “Capital budgeting, technological innovation and the emerging competitive environment of the electric power industry”. *Energy Policy,* 24(2): 195-202.

Awerbuch, S. (1996b), “The Problem of Valuing new energy technologies”, *Energy Policy,* 24(2)

Awerbuch, S. (2003), “Determining the real cost – why renewable power is more cost-competitive than previously believed,” *Renewable Energy World,* 6 (2): 52-61.

Awerbuch, S. and Sauter, R. (2006), “Exploiting the oil-GDP effect to support renewable deployment”. *Energy Policy* 34(17): 2805-2819.

Daly HE (2007), “Ecological Economics and Sustainable Development”, in Advances in Ecological Economics, Edward Elgar Publishers, Northhampton, MA, USA.

EU Commission (2004): “Extern E, final reports”, www.externe.info

Fawcett T, Hvelplund F and Meyer NI (2010), “Making It Personal: Per Capita Allowances”, Chapter 4 in “Generating Electricity in a Carbon-Constrained World”, edited by F.P. Sioshansi, Elsevier Publishers, the Netherlands.

IEA, OPEC, OECD, WORLD Bank (2010): ”Analysis of the Scope of Energy Subsidies”, Joint report for G-20 Summit Meeting, Toronto, Canada.

Karnøe, P. (2010), "Material disruptions in electricity systems: can wind power fit in the existing electricity system?", in M. Akrich, Y. Barthe, f. Muniesa, P. Mustar (eds.)(2010), Melanges offerts a Michel Callon, Paris: Presse des Mines

Karnøe, P. (2010), Material Grounding of Valuation: How disruptions from wind power leads to re-framing of valuation processes in electricity systems, Working paper, Scandinavian Consortium for Organizational Research, Stanford University, July 27, 2010

Karnøe, P. and Buchhorn A. (2008) Path creation Dynamics and winds of change in Denmark, in Lafferty et al. (2008), Promoting Sustainable Electricity in Europe, Edgar A.

Meyer NI (2010), "New Systems Thinking and Policy Means for Sustainable Energy Development", chapter 16 in book with the title "Sustainable Energy", Intech Open Access Publisher, Vienna, www.intechweb.org (2010).

Meyer NI, Hvelplund F and Nørgård JS (2011), "Equity, Economic Growth and Lifestyle", chapter 4 in book with the title "Energy Sustainability and the Environment", edited by F.P. Sioshansi, Elsevier Publishers, the Netherlands, 2011.

Van der Vleuten E and Raven R (2006): "Lock-in and change: Distributed generation in Denmark in a long-term perspective", *Energy Policy* 34: 3739-3748.

Chapter 5:

Andersen, FM, Jacobsen HK, Larsen HV, and Jensen SG (2009), "End-user behaviour, incentives and measures". In Risø energy report 8., eds. Hans Larsen, L. S. Petersen, 51.

Bode S (2008), "Renewable energy and power prices – incentives to invest under different support schemes". Arrhenius – Institut für Energie- und Klimapolitik.

DERA (2010): "Electricity prices in Denmark", in Danish: Energitilsynet. Elprisstatistik, oktober 2009. [cited 02/02 2010]. Energitilsynet, Copenhagen, Denmark. Available from http://www.energitilsynet.dk/prisstatistik/elektricitet/statistik-efter-januar-2007/elprisstatistik-oktober-2009/.

Karnøe P (2010), "Material Grounding of Valuation: How disruptions from wind power leads to re-framing of valuation processes in electricity systems", Working paper, Scandinavian Consortium for Organizational Research, Stanford University. Available at Copenhagen Business School, pka.ioa@cbs.dk

Hoogwijk et al. (2007), "Exploring the impact on cost and electricity production of high penetration levels of intermittent electricity in OECD Europe and the USA, results for wind energy." *Energy* 32: 1381-1402.

Lund H and Mathiesen BV (2009), "Energy system analysis of 100% renewable energy systems-The case of Denmark in years 2030 and 2050", *Energy* 34: 524-531.

Mathiesen, B.V., Lund, H., and Karlsson, K. (2010), 100% Renewable energy systems, climate mitigation and economic growth, Applied Energy, forthcoming 2010.

Chapter 6:

Bertoldi P, Boza-Kiss B and Rezessy S (2007), ”Latest Development of Energy Service Companies across Europe – A European ESCO Update”. Institute for Environment and Sustainability. JRC Scientific and Technical Reports. See: http://energy.eu/publications/LBNA22927ENC_002.pdf

Child R, Langniss O., Klink J and Gaudiose D (2008), “Interactions of White Certificates with other Policy Instruments in Europe”. *Energy Efficiency* 1 (4): 283-295.

Ericsson K (2006), ”Evaluation of the Danish Voluntary Agreements on Energy Efficiency in Trade and Industry”. AID-EE. See: http://193.88.185.141/Graphics/Energibesparelser/alle_initiativer/tilskud_CO2_afgift/danish_agreement,%20Karin%20Ericson%202006.pdf

Fawcett T, Hvelplund F and Meyer NI (2010), “Making It Personal: Per Capita Carbon Allowances”, Chapter 4 in the book: *Generating Electricity in a Carbon-Constrained World.* Elsevier Publishers, Amsterdam, Holland.

Jørgensen U and Dalgaard T (2004), ”Energy in Ecological Farming”, in Danish: ”Energi i økologisk landbrug – Reduktion af fossil energiforbrug og produktion af vedvarende energy”. Forskningscenter for Økologisk Jordbrug. Rapport no. 19

Fleming D and Chamberlin S (2011), ”TEQs – A Policy Framework for Peak Oil and Climate Change”, House of Commons, London, UK.

Jensen OM (2009): ”Policy means for the Promotion of Energy Conservation in Buildings”, in Danish: ”Virkemidler til fremme af energibesparelser i bygninger”, SBI, Copenhagen, Denmark.

Kjeldsen-Krag S (2010), ”Has Danish Farming Chosen the Wrong Track?”, In Danish: ”Har dansk Landbrug valgt et forkert spor?”, Tidsskrift for Landøkonomi, nr. 2, juni

Krarup S and Ramesohl S (2000), ”Voluntary Agreements in Energy Policy – Implementation and Efficiency”. Final Report from the project Voluntary Agreements – Implementation and Efficiency (VAIE). AKF, Amternes og Kommunernes Forskningsinstitut. See: http://www.sei.ie/uploadedfiles/InfoCentre/voluntaryagreementsfinalreport.pdf

Larsen, Anders 2009, “Towards a Sustainable District Heating System in Copenhagen”, Master Thesis Department of Development and Planning, Aalborg University June, 2009.

Oikonomou V, Patel MK, van der Gaarst W and Rietbergen M (2009), “Voluntary Agreements with White Certificates for Energy Efficiency Improvement as a Hybrid Policy Instrument”. *Energy Policy* 37 (5): 1970-1982.

Phylipsen D, Blok K, Worrell E and de Beer J (2002), "Benchmarking the Energy Efficiency of Dutch Industry: An Assessment of the Expected Effect on Energy Consumption and CO2 Emissions". *Energy Policy* 30 (8): 663-679.

Rietbergen MG, Jacco CM, Blok F and Blok K (2002), "Do agreements enhance energy efficiency improvement?: Analysing the actual outcome of long-term agreements on industrial energy efficiency improvement in The Netherlands". *Journal of Cleaner Production* 10 (2): 153-163.

Togeby M, Dyhr-Mikkelsen K, Larsen A, Juel Hansen M and Bach P (2009), Danish Energy Efficiency Policy: Revisited and Future Improvements". ECEEE 2009 Summer Study. See: http://ea-energianalyse.dk/papers/2009_june_eceee2009_togeby.pdf

Ürge-Vorsatz D, Köppel S, Liang C, Kiss B, Nair GG and Celikyilmaz G (2007), "An Assessment of on Energy Service Companies (ESCOs) Worldwide". WEC ADEME project on energy efficiency policies. See: http://89.206.150.89/documents/esco_synthesis.pdf

Chapter 7:

Ahm P (2010), Background paper to the Danish Climate Commission, 2010.

Brix M, Kristensen K, Pedersen K, Quisman S, Steen-Andersen M and Sørensen M (1999), "Wave Energy in Denmark", in Danish: "Bølgeenergi i Danmark", rapport fra 3-ugersprojekt ved BYG, DTU, januar 1999.

Heup J (2010), "From sun boxes to solar neighbourhoods", *new energy* 6: 63-66.

Janzing B (2010), "Summer heat for the winter", *new energy* 6: 55-63.

Meyer NI (2000), "Implementation of Renewable Energy in Denmark from 1975 to 2000" (in Danish) and Boldt J: "Energy from Agriculture and Forestry" (in Danish), Two chapers in the book "Renewable Energy in Denmark: 1975-2000" (in Danish), published by OVE, ove@orgve.dk, Denmark, 2000.

ForskEL. 2009. "Analysis of Power Balancing with Fuel Cells & Hydrogen Production Plants in Denmark". CanDan1,5 Project Report. Web: http://vbn.aau.dk/fbspretrieve/-18119749/010110CanDan15Analysisogpowerbalancingwithfuelcellsandhydrogenproductionplants.pdf

ForskNG. 2008. ForskNG indsatsområder 2009. Web: http://www.energinet.dk/NR/-rdonlyres/BC2CC9C5-9084-4A53-AA80-4B07CC80A61B/0/ForskNGindsatsomr%C3%A5-der2009.pdf

Heyne S and Harvey S (2009), "Production of Synthetic Natural Gas from Biomass – Process Integrated Drying". 22nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. Web: http://publications.lib.chalmers.se/records/fulltext/local_98037.pdf

Lund H and Mathiesen BV (2009), "Energy system analysis of 100% renewable energy systems – The case of Denmark in years 2030 and 2050". *Energy* 34 (5): 524-531.

Weiland P (2010), "Biogas production: Current state and perspectives". *Applied Microbiology and Biotechnology*. Vol. 85 (4).

Zwart RWR, Boerrigter H, Deurwaarder EP, van der Meijden CM and van Paasen SVB (2006), "Production of Synthetic Natural Gas (SNG) from Biomass – Process Development and operation of an integrated bio-SNG system". Energy research Centre of the Netherlands. Web: http://www.ecn.nl/docs/library/report/2006/e06018.pdf

9. Appendices

A. Markets and regulation for unlocking the carbon lock-in

By Peter Karnøe, CBS.
Email: pka.ioa@cbs.dk

Introduction
The aim of the CEESA WP 4 project is to propose a range of changes in the market regulation and societal planning in order to phase out fossil fuels in Denmark before 2050. Phasing out fossil fuels requires drastic changes in the technological systems used for the generation of electricity, transport, and heating. These technological systems emerged and stabilized in Denmark as in other industrialized countries during the last 100 years, and became the centres for what has been labelled the 'carbon-lock-in' (Unruh, 2000).

Markets come in multiple forms with different characteristics such as forms of pricing, forms of competition, types of economic actors, as well as specific physical and technological infrastructures and regulatory forms (Callon, 1998a, Knorr-Cetina and Bruegger, 2002, Callon and Caliskan, 2009). Specific markets develop in specific historical processes, and it is particular important to pay attention to *which* of the many possible forms of market becomes the realized one for a particular technology. This is important with respect to understanding how markets are part of the carbon lock-in, as well as addressing the challenges and controversies when designing new markets that can facilitate carbon unlocking.

Rather than neutral market forces responding to marginal changes in prices, lock-in is made from associations of many heterogeneous elements, such as vested interest, sunk cost, conventions of calculations, cultural identities of consumption, the technology standard, and a dominant cultural discourse on its efficiency. The interlocking of these elements makes unlocking difficult. Unlocking is more likely to happen when shifts happen in several of the lock-in elements at the same time (Callon, 1991, Cowan and Hultén, 1994, Karnøe, 2007, Karnøe and Buchhorn, 2008).

To facilitate and possibly accelerate the unlocking of the carbon lock-in, there is a need for a paradigm shift.

Increasing returns and technological lock-in at the sector level

The sector level corresponds to certain technologies in use like combustion engines for transport, the primary mode of electricity generation by centralized power plants, or the types of heating systems for buildings.
The central question is whether the existing technologies are the most efficient ones because they have been selected by perfect and efficient market processes?

The neoclassical model assumes constant and decreasing returns to scale. The latter means that the technical qualities and cost advantages of a product derive solely from pre-market development, and that the perfect market process selects the best among a number of alternatives. An understanding building upon perfect markets and rational actors with perfect knowledge will assume that the most efficient technologies are selected. And consequently, the price equilibrium in the market represents the optimal solution.

Contrary to constant returns to scale, increasing returns to scale mean that technical qualities and cost advantages derive from various learning effects linked to the increased volume of the production and use of a technology. The theory of increasing returns economics (also labelled path dependency economics)(David, 1985, Arthur, 1989, 1994) argues that the prevailing and dominant technological designs are not necessarily the best and optimal ones, seen from a technical or economic point of view. This view essentially stresses that technological development is a process – usually a lengthy and untidy one – and it is not reduced to some abstract market force. When new technologies emerge, there is typical competition between several technical options, but very soon only a few of the options prevail. The winning technologies do not result from optimal or perfect market processes, because volume and learning effects result from the specific process of timing, strategic manoeuvring (marketing and lobbying), producer-user interaction, and (enactment of) historical circumstances (Hughes, 1983, Arthur, 1989, Utterback, 1996, McGuire, P. and Granovetter, M. (1998), Unruh, 2000). The increasing returns economic argument is that the relative lock-in state has a strong exclusion effect on alternative technological designs, because it is supported by operational routines and training, industry standards, socialization and cultural preferences, and regulation.

Danish examples of lock-in and lock-out

The district heating example

Technical analysis shows that it pays to reduce the heat losses in houses by at least 50%. At the same time, the tariff system in the district heating areas is characterized by a fixed charge in the range of 25%- 65% of the total heat bill. Therefore, the economic incentive in especially the large district heating systems in Copenhagen, Århus, Ålborg, Odense etc. is far from strong enough to ensure investments in the long-term economically lucrative 50% reduction in heat losses. In addition, there is a lack of consultancy assistance and financial possibilities of long-term investments in the improvements of energy efficiency in the building sector.

These shortcomings of the present market characteristics illustrate “lock-in” mechanisms that hinder the implementation of the economically lucrative goal of reducing heat losses by 50%. Thus, the present market construction both results in the loss of economic welfare and a high CO_2 emission.

It is proposed that this “lock-in “ is removed by establishing a combination of 100% variable heat tariffs, 30-year 3% loans with public guaranty, and improved cheap consultancy services in the area of building renovation.

The private car example

In the present market construction, the taxation of private cars is mainly linked to the ownership of the car (fixed tax) and relatively less to the use of the car (variable tax). At present, the average total private costs per km are in the range of 50-60 eurocent, and the marginal costs of driving one km are around 10 eurocent for an average Golf type car. This cost structure is a market construction in which the variable tax, mainly on gasoline, will be around 4 eurocents and the fixed tax on the car around 25-30 eurocents per km. With this market construction, the marginal costs of car driving per km (around 10 eurocents) are far below the long-term societal costs per driven km including environmental costs (36-58 eurocents).

The present taxation system therefore represents an incentive system that furthers a volume of car traffic which exceeds the societal optimum. This is an example of a “lock-in” mechanism that increases the CO_2 emission and simultaneously reduces social welfare. This “lock-in” mechanism can be weakened or removed by a relative increase of the variable km dependent tax. In this way, the private car traffic volume will get closer to the optimum of societal welfare; at the same time, reducing energy consumption and CO_2 emission.

The CO_2 quota example

The EU emission trading system (ETS) has been characterised by free CO_2 quotas to companies based on their historical emission data; the so-called grandfathering system. This system has transferred several hundred million euros to established power companies and (old) large industries, while new renewable energy and energy conservation companies do not have the same benefits. Thus, the grandfathering principle for the allocation of CO_2 permits is a “lock-in“ mechanism favouring first-comer companies compared to newcomers. The present design of ETS will be revised for the period 2013-2020. The aim is to reduce the benefits of free emission rights to the industry. The EU Commission suggests a new market design based on benchmarking and a stepwise reduction of the share of free emission rights from 80 % in 2013 to 30 % in 2020. Benchmarks will be product-based on the top-10 most efficient industries in the EU member states. A crucial aspect is, however, carbon leakage; i.e., the fact that some industries are facing strong international competition. These industries will be given the privilege of obtaining 100 % free emission rights over the whole period. Still, these industries are regulated by benchmarking, as the allocation of free emission rights will be based on the most efficient industries in Europe.

The renewable infrastructure example

The transformation from a fossil fuel-based energy system to a 100% RES system includes an important shift from a system with stored energy to mainly intermittent energy sources. This change requires the establishment of an infrastructure that can coordinate the intermittent RES with the consumption side.

The CEESA project proposes a solution with a combination of cogeneration units, heat pumps and heat storage, and, in a longer term, also electric cars. This type of system is discussed at present, but not implemented by the system responsible organisation, Energinet.dk, apparently giving higher priority to investments in large grid systems. At the same time, the present electricity taxation makes it less economical to invest in heat pumps. Thus, at present, no systematic investments are made in these new infrastructural technologies that can solve the intermittency problem at the local and regional levels. These organisational and tax conditions represent "lock-in" mechanisms that hamper the introduction of 100% RES, reduces societal welfare and tends to hamper investments in systems reducing CO_2 emissions.

This infrastructural "lock-in" problem could be reduced by giving a higher "feed-in" tariff for wind power from turbine owners that establish a certain heat pump capacity and heat storage capacity per MW of installed wind power. Such a system could be organised by Energinet.dk.

These examples demonstrate the different sources that preserve lock-in.

The consequence of this lock-in is that markets are not seen as 'natural and objective' and renewable energy and low-carbon technologies do not compete against objective cost and prices. The newcomers must compete against technological standards, organizational routines, rules of the game, laws and regulations, training, competences, and research-based technical and economic models and knowledge.

Unlocking is possible; for example the new agencies behind the Danish wind power and decentralized combined heat and power plants have unlocked the relatively strong lock-in of the centralized electricity system. But the important point is that these transformations did not only come from new technologies; indeed the deployment of the new technologies required drastic shifts in policies, like granting property rights that allowed new economic actors to be formed; market subsidies that supported the new technologies; the coercive regulation of utilities that forced them to act; national planning and priorities, and the organization of new and skilled actors in plant operation and policy governance agencies (Karnøe and Buchhorn, 2008, Meyer, 2000).

The role of economic tools and instruments in the framing of markets

This section presents four calculative instruments: 1) The lack of internalizing externality costs; 2) the level of discount rate used; 3) the approach which energy planners use to estimate the value of the composition of energy technologies in the energy system, and 4) the status hierarchy of energy technologies.

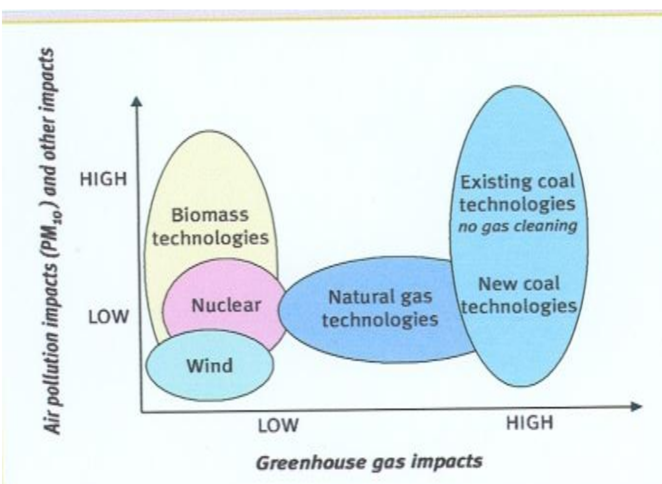
All represent systematic forces that shape the policy debate and the role of economic instruments that should facilitate the transition towards a low-/zero-carbon society, and the calculative instruments are directly involved in shaping the choice of technologies and the shaping of markets.

Lack of internalizing externalities into fossil fuel cost, and accounting for subsidies

The failure to adequately internalize the environmental impacts into prices is a very important distortion of the market prices of fossil fuels that makes it difficult for low-/zero-carbon technologies to make headway. Thus, the inclusion or exclusion of externalities in market prices is seen as a crucial part of the boundary conditions of markets; i.e., it is a crucial element of the TIMC of the existing incumbent technology or the newcomer.

This discussion implies that negative externalities (such as pollution) are *more than* merely an ethical problem. The problem is a disjuncture between marginal private and social costs that is not solved by the market. Pollution is not something that is automatically solved by competitive markets. Some *collective* solution is needed, such as a court system to allow the parties affected by the pollution to be compensated, government intervention banning or discouraging pollution, or economic incentives such as taxes or cap-and-trade programmes.

The EU study on the externality cost from energy production has become a kind of reference study of this problem (ExternE 2005, IEA, 2006,). Figure 1 shows how the ExternE study separates the externalities into air pollution and greenhouse gas impacts. Neuhoff and Twomey (2008) build upon this study, but add new numbers to the pollution from coal power plants. The externality cost of air pollution is estimated at between 8.7 – 25 Euro/MWh, whereas the greenhouse gas impact is estimated at between 10-23 Euro/MWh.



Air pollution from coal	**Greenhouse gas impacts of coal-generated electricity**
8.7 – 25 Euro/Mwh	10 – 23 Euro/Mwh
65 - 187 dkr/Mwh	75 – 172 dkr/Mwh

Source: ExternE, 2004.

Source: Neuhoff and Twomey (2008)

Figure 1: Externalities from energy production by air pollution and greenhouse gas impacts.

The cap-and-trade system is supposed to put a price on the pollution cost from greenhouse gas emissions in such a way that electricity prices reflect the true environmental cost.

The CO_2 cap and trade system can be an important construction of a market instrument if it puts a price on CO_2 that reflects the true environmental cost. Even if there is no agreement about the true cost, it is highly questionable whether this mechanism is efficient. The EU CO_2 quota system is characterised by free CO_2 quotas based on historical emission data, the so-called Grandfathering system. This Grandfathering system transfers hundreds of million Euros to the established power companies and old large industries, and no money to new renewable energy and energy conservation companies. In that way, it supports the first-comer companies linked to the use of fossil fuels and without any special knowledge or economic incentive to the introduction of new green technologies. Therefore, it is a "lock-in" institution giving money to first-comer companies, and nothing to newcomers.

More importantly, the risk associated with the carbon price is mainly political, because the cap-and-trade system is a constructed market that puts a price on greenhouse pollution. The regional and global negotiations about emission targets and therefore the scarcity price have been both politically volatile and below the levels suggested by IPCC and Stern. For incumbents as well as newcomers, the investment cycles in the energy sector are long-term (20-40 years), and the combination of long-time scales and policy risk is damaging to investment in low-/zero carbon technologies.

The examples demonstrate how the institutional framing of existing energy technologies tends to protect them and to become barriers to the transformation to low-carbon technologies.

The policy of the Discount rate when status quo is not an option

The level of the discount rate influences directly how the future cost/benefit ratio in 5, 10 or 20 years from now is converted into present values. Mathematically, the calculative formula works in such a way that a higher discount rate lowers the value of future benefits or increases the demands on future positive benefits. The word dis-counting points exactly to the fact that this calculative formula is down-grading the future.

In Denmark, the Ministry of Finance has, since 1999, recommended that a discount rate of 6% is used in policy evaluations for the state and for municipalities. That means that alternative investments in new energy technologies or energy savings must generate benefits that with a 6% discount rate can beat the net present value of business as usual.

Ackerman (2007:7) cites the work of Cline (2004) to conclude that the cost-benefit justification for an active climate policy diminishes rapidly with higher discount rates, and essentially vanishes at a rate of 3.5% or more. At a discount rate of 5%, only the most trivial climate initiatives survive. The choice of discount rate highly influences the outcome, and economists argue that the far distant future should be discounted at the lowest possible rate. The Stern report used a 1.4% discount rate; this low rate is supported by

(Hope and Newbery, 2008), but economists also claim that the appropriate discount rate is that of after-tax risk free investments which is close to zero (Howarth, 2003, in Akerman, 2007,p. 9).

The choice of a low discount rate reflects a choice of giving high value to action now as an insurance against unlikely future climate change related disasters, in which the probability and scale of that disaster are both unknown (Hope and Newbery, 2008:46).

The global warming effect may lead to negative discount rates because the future generations in financial terms will be poorer than the present population (Arrow 1999, and Dasgupta 1999 in Ackerman 2007).

New research has demonstrated that the present configuration of the energy system creates a financial risk which is associated with the vulnerability to future fuel price fluctuations. An energy system configured by fossil fuel-based technologies is highly vulnerable to fluctuations in future fuel prices, and investors cannot know these prices. By contrast, an energy system configured with increased shares of renewable energy technologies will reduce the price fluctuations and increase the financial certainty about future energy prices. Awerbuch pioneered this understanding (Awerbuch 1996, 2000) by showing that the calculation methods used to put a value on different energy technologies did not take that important factor into account. The reduction of the uncertainty about the volatility of future fuel prices is central to investment decisions. One of the important actions is to make Danish energy planners shift from the old 'least-cost calculative method' to the new calculative method that builds upon financial portfolio thinking to make the (e-)valuation of energy technologies depend upon the risk of rises in fuel prices.

The reduction of the risk of price fluctuations involves a cost or some premium for reducing the risk. Wind power is reducing the risk and therefore needs a premium in the sense that it must have a lower price compared to fossil fuels that increase the risk and must be priced higher accordingly.

Table 1 shows that the risk-based valuation method results in a large adjustment of the fuel prices.

	Coal boiler	Coal IGCC	Gas CC	Gas GT	Nuclear	Wind
Traditional estimate	3,1	3,1	3,0	3,4	4,0	4,0
Risk-adjusted estimate	6,7	6,0	7,0	9,4	5,5	3,6

Source: Awerbuch, S. (2003), "Determining the real cost – why renewable power is more cost-competitive than previously believed," *Renewable Energy World*, 6 (2), 52-61.

Table 1: Risk-adjusted cost of electricity estimates (Europe/IEA countries) based upon historical fuel price risk (US cents/kWh)

For fossil fuels like coal and gas, the risk component as a minimum doubles the cost, whereas wind power cost should be reduced with 10%. This new calculation of the 'real' cost of energy technologies should be taken into account in the valuation of the specific technologies in the energy system.

Policy actions in the context of lock-in and unlocking

This report has provided a basis for thinking about the policy regulation of markets in relation to the climate change challenge. The CEESA market design group has, in the main report, proposed a set of new market regulations that can unlock the existing energy system and facilitate a transition towards the scenario involving transformations in the Danish energy system to reach a zero-carbon energy system by 2050.

This report has highlighted two important conditions of the approach to policy regulation of markets:

First, at the sector level, it is important to understand how specific technological systems are co-created with specific institutions and regulations that become constructed in the historical process of their formation. The developmental dynamics are subject to increasing return economics and the institutional and regulatory framing of the markets for that technology. Therefore, there is no perfect market competition to make the fair selection of new low/zero-carbon technologies, but the existing technological systems include central fossil fuel lock-in barriers that support the existing technologies.

Second, it is critically important that economic theory and calculative instruments and devices are not seen as neutral and objective. As we have demonstrated with the examples such as the externalities and the discount rate, it is important to have a critical view on the calculative instruments as they are directly involved in shaping the choice of technologies and the shaping of markets. Among economists, there is debate and disagreement about this, but these issues are too important to leave this discussion to the monopoly of the economists. These economic models and instruments have an important role in decision-making on market design (Callon, 1998, MacKenzie, 2007).

There are no natural barriers that separate 'economy' and 'politics'; the choice between a strong or weak regulation of market politics is part of an ongoing struggle to open or close the linkages. With the climate challenge (and the financial crisis fresh in mind), the central question is not if politics participates in making markets, but how politics participates in making markets. We do not follow the stylized sequence of rational policy-making - define objectives, set targets, choose instruments, and evaluate outcome. We extend uncertainty to policy-makers. Political science and decision theory have added conflicting interests, conflicting means-ends; and the problem of ambiguity and evolving preferences among decision-makers. Politics is not perfect, but is biased and informed by (more or less contested) expertise and scientific knowledge at the same time. Because of complexities and uncertainties, intended and unintended effects may emerge from regulations, and new economic models and instruments may also lead to a revision of the goals and preferences if the first course of actions does not deliver the results relative to the definition of the problem situation (March and Olsen, 1989, March, 1994, Fligstein, 2001). In relation to climate change, status quo is not an option despite the uncertainties and political challenges in changing regulations.

References

Ackerman, Frank (2007), Economics for a Warming World, *post-autistic economics review*, issue no. 44 (now renamed to Real-World Economics Review)

Ackerman, Frank (2008), The Economics of Collapsing Markets, *real-world economics review*, issue no. 48.

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-in by historical events. Economic Journal 99, 116–131.

Arthur, W.B., 1994. Increasing Returns and Path Dependence in the Economy. University of Michigan Press, Ann Arbor.

Awerbuch, S. (1996), Capital budgeting, technological innovation and the emerging competitive environment of the electric power industry. *Energy Policy*, 24(2), 195-202.

Awerbuch, S. (1996b), The Problem of Valuing new energy technologies, *Energy Policy*, 24(2)

Awerbuch, S. (2003), "Determining the real cost – why renewable power is more cost-competitive than previously believed," *Renewable Energy World,* 6 (2), 52-61.

Awerbuch, S. and Sauter, R. (2006), Exploiting the oil-GDP effect to support renewable deployment. *Energy Policy*, 34(17). 2805-2819.

Caliskan, K. and Callon (2009), Economization, part 1: a research programme for the study of markets, *Economy and Society*, vol. 38, 3, 369-98

Callon, M. (1998a), Introduction: The embeddedness of economic markets in economics, in Callon, M. (1998), The Laws of the Markets, Blackwell Publishers.

Callon, M. (1998b), An essay on framing and overflowing: economic externalities revisited by economic sociology, in Callon, M. (1998), The Laws of the Markets, Blackwell Publishers.

Callon, M. (1991), 'Techno-Economic networks and irreversibility', in J. Law (eds), *A Sociology of Monsters: Essays on Power, Technology and Domination*, London, UK: Routledge

Cowan, R. and Hultén, S. (1994), Escaping Lock-in: The case of the electric Vehicle, *Technology Forecasting and Social Change*, Vol. 53, Issue 1

David, P., 1985. Clio and the economics of QWERTY. American Economic Review 72 (2).

Fligstein, N. (2001), The Architectures of markets: An Economic sociology of twenty first century capitalist societies, Princeton, NJ: Princeton University Press.

Garud, R. and Karnoe, P. (2003), 'Bricolage versus Breakthrough: Distributed and embedded agency in technological entrepreneurship', *Research Policy*, 32, pp: 277-300.

Garud, R. and Karnoe, P (2001), 'Path Creation as a process of Mindful Deviation', in R. Garud and P. Karnøe (ed.) *Path Dependence and Creation*, Lawrence, Earlbaum Associates

Garud, R., Kumaraswamy, A. and Karnøe, P. (2010), Path Dependence or Path Creation, in *Journal of Management Studies*, vol. 47, 4.

Garud, R., Gehman, J., & Karnøe, P. 2010. Categorization by association: Nuclear technology and emission-free electriticty. In W. D. Sine, & R. David (Eds.), Research in the Sociology of Work, Vol. 21: 51-93. Bingley: Emerald.

Geels, F.W., 2002, 'Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study', *Research Policy*, 31(8/9), 1257-1274

Geels, F.W., Hekkert, M. and Jacobsson, S., 2008, 'The micro-dynamics of sustainable innovation journeys: Editorial', *Technology Analysis & Strategic Management*, 20(5), 521-536

Hughes, T. (1983). *Networks of power*. Baltimore, MD, The John Hopkins University Press.
Irwin, A. And Michael, M. (2003), Science, Social Theory and Public Knowledge, Open University Press

March, J. (1994), A Primer on Decision Making, Free Press.

McGuire, P. and Granovetter, M. (1998), "The Making of an Industry: Electricity in the United States". With Patrick McGuire. Pp. 147-173, in Michel Callon (ed)(1998), The Laws of The Markets, Blackwell Publishing

Grubb, M. and Newbery, D. (2008), Pricing carbon for electricity generation: National and international dimensions, in Grubb, M., Jamasb, T., and Pollitt, M. (eds.)(2008), Delivering a Low-Carbon Electricity System – Technologies, Economics and Policy, Cambridge University Press.

Hargadon, A. B. and J. Y. Douglas (2001) "When Innovations meet Institutions: Edison and the Design of the Electric Light," *Administrative Science Quarterly*, 46:476-501

Hargrave, T. and van de Ven, A. (2006), A Collective Model of Institutional Innovation, *Academy of Management Review*, 2006, Vol. 31, No. 4, 864–888.

Hepburn, Cameron (2009), Carbon Taxes, Emissions Trading, and Hybrid Schemes, in Helm, Dieter, and Hepburn, Cameron (eds.)(2009), The Economics and Politics of Climate Change, Oxford University Press.

Helm, Dieter, and Hepburn, Cameron (eds.)(2009), Introduction, The Economics and Politics of Climate Change, Oxford University Press.

Helm, Dieter (2009), Nuclear Power, Climate change, and Energy Policy, in Helm, Dieter, and Hepburn, Cameron (eds.)(2009), The Economics and Politics of Climate Change, Oxford University Press.

Hogdson, G. (2007), Evolutionary and Institutional Economics as the New Mainstream? *Evolutionary Institutional Economic Review*, 4(1): 7–25.

Hope, C., and Newberry, D. (2008), Calculating the social cost of carbon, in Grubb, M., Jamasb, T., and Pollitt, M. (eds.)(2008), Delivering a Low-Carbon Electricity System – Technologies, Economics and Policy, Cambridge University Press.

Karnøe, P. (2010), "Material disruptions in electricity systems: can wind power fit in the existing electricity system?", in M. Akrich, Y. Barthe, f. Muniesa, P. Mustar (eds.)(2010), Melanges offerts a Michel Callon, Paris: Presse des Mines.

Karnøe, P. and Buchhorn, A. (2008) *Path creation Dynamics and winds of change in Denmark,* in Lafferty et al. (2008), Promoting Sustainable Electricity in Europe, Edgar A.

Karnøe, P. (1999), *When low-tech becomes high-tech: The social construction of Technological learning processes in the Danish and the American Wind turbine industry*, in Peter Karnøe, Peer Hull Kristensen, Poul Houman Andersen (Eds.)(1999), Mobilizing Resources and Generating Competencies: The Remarkable Success of Small and Medium Sized Enterprises in the Danish Business System. Copenhagen Business School Press.

Knorr Cetina, K. and U. Bruegger (2002), Global Microstructures: The Virtual Societies of Financial Markets, *American Journal of Sociology* 107(4): 905–950

MacKenzie, D. (2003), An equation and its worlds: Bricolage, Examplars, Disunity and Performativity in Financial Economics, *Social Studies of Science* 33:831-868.

MacKenzie, D, (2006), An Engine not a Camera: How financial models shape markets, Cambridge, MA, MIT Press.

Meyer, N. I. (2000), chapters in 'Vedvarende Energi i Danmark – En Krønike, OVE's Forlag.

Neuhoff, K. and Twomey, P. (2008), "Will the market choose the right technologies?", in Grubb, M., Jamasb, T., and Pollitt, M. (eds.)(2008), Delivering a Low-Carbon Electricity System – Technologies, Economics and Policy, Cambridge University Press.

Newell, R.G. and W. A. Pizer (2004), "Uncertain Discount Rates in Climate Policy Analysis", 32(4) Energy Policy.

Otting, Karoline (2010),"How Wind Power Blows off the existing valuation of electricity", Master Thesis at Copenhagen Business School, supervised by Liliana Doganova and Peter Karnøe.

Sobel, J. (2005),"Interdependent Preferences and Reciprocity," 43, Journal of Economic Literature, 392

Stiglitz, J. et al (2009), Report by the Commission on the Measurement of Economic Performance and Social Progress, www.stiglitz-sen-fitoussi.fr

Swedberg, R. (2003), Principles of Economic Sociology, Princeton University Press, Princeton, NJ

Unruh, G.C. (2002), Escaping carbon lock-in, Energy Policy 30, p. 317-325

Unruh, G. C. (2000), Understanding Carbon Lock-in, Energy Policy 28, p. 817-830

Utterback, J. (1996), Mastering the Dynamics of Innovation. Harvard Business School Press.

Weitzman, M. L. (1998), "Why the Far-Distant Future should be discounted at its lowest Possible Rate", Journal of Environmental Economics and Management

B. Solving the tariff dilemma - the Aalborg case

By Frede Hvelplund

Aalborg University

An in-depth study of the Aalborg district heating system has led to the results described in the following.

First of all, it seems to pay to insulate the houses in Aalborg to achieve a reduction in heat and hot water consumption of between 40% and 50%. This is illustrated by a combination of figure 1 and the comments in the following.

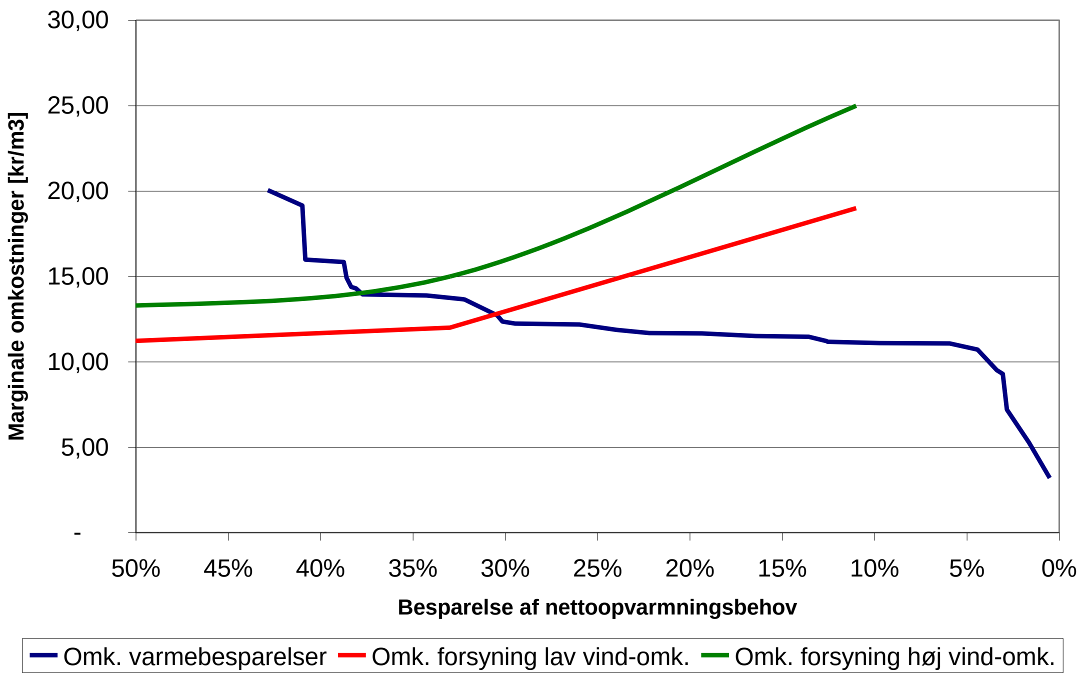


Figure 1. Optimum conservation level in the Aalborg district heating system. Source: Baggrundsrapport for energistrategi for Aalborg municipality.

The figure shows an optimal insulation standard at 38%, when realising that it is necessary to use more expensive wind power locations, if a too low insulation level is introduced. The insulation level at 30% is optimal, if there are no limits at all to good wind power locations. If we add to this that even more expensive offshore wind locations are scarce, which is a reasonable assumption, an insulation level at 44%, as used in our calculations, is socio-economically reasonable. It should be underlined that the costs of insulating the houses are costs linked to the extra costs of improving the energy standard, linked to a renovation of the house.

From the above discussion in combination with figure 1, we can say that a tariff of between 15 and 20 DKK per m^3 of hot water is a reasonable tariff that will motivate the houses to an insulation standard of around 40%-45%. We believe that tariffs close to 20 DKK per m^3 are preferable for two reasons. Firstly, because the scarcity costs of wind turbine locations should be taken seriously. Secondly, because more transaction costs (that are not necessarily social costs) are linked to the *present* organisation of houses and house insulation than linked to building new supply systems.

But how is this discussion to be linked to the present tariff policy in Aalborg? Figure 2 is useful for this discussion.

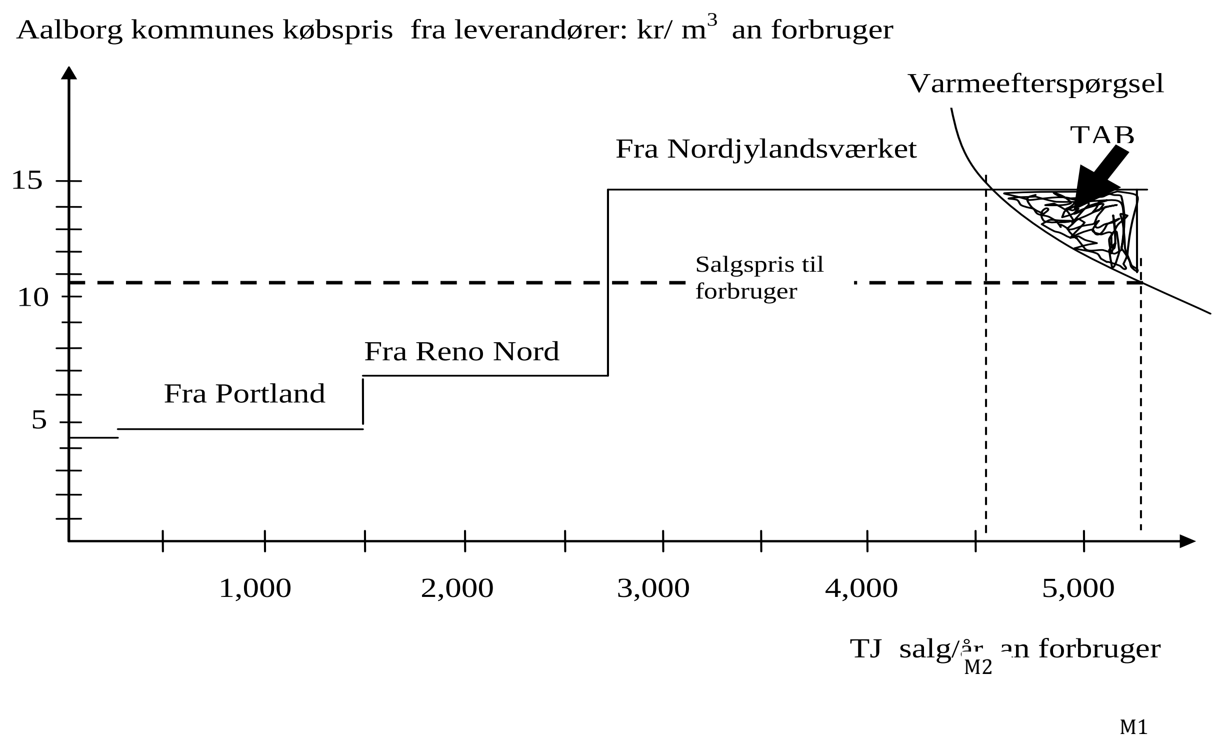


Figure 2. Tariff policy and costs in the Aalborg district heating system.

The "staircase" curve shows that we are in a situation, in which the cost per m^3 of hot water for Aalborg district heating company is progressive. The cheapest heat is bought from the cement factory Portland at 6 DKK per m^3 of hot water. The most expensive heat is bought from the power plant "Nordjyllandsværket" at 14.77 DKK per m^3. To this should be added a reduction in heat consumption which reduces the investment by marginally 1.2 DKK per m^3 of hot water and a CO_2 quota for Aalborg District heating company amounting to marginally 1 DKK per m^3 of hot water. Furthermore, a coming change in the energy taxation will increase the marginal costs of coal-based cogeneration by around 2.5 DKK per

m^3 of hot water. All in all, the marginal cost of buying hot water will be 14.77+ 1.2+1+2.5= **19.47 DKK** per m^3 of hot water.

The tariff in 2009 is 10.75 DKK per m^3 of hot water, and based upon the average costs illustrated by the horizontal dotted line.

Thus, at present, Aalborg has a tariff policy based upon the ***average*** costs of buying 1 m^3 of hot water and not on the marginal costs of the whole system of buying one m^3 of hot water. As a result of this, there is an inbuilt loss in the present tariff policy, indicated by the black hatched area.

The loss is even larger, if we calculate with the marginal cost of 19.47 DKK.

Thus, even at present, the tariff setting is wrong seen from an economical viewpoint, and the right price would be a little less than 20 DKK per m^3, which is close to the right price calculated on the basis of the long-term costs of a future supply system based on renewable energy.

In the Aalborg case, there is no conflict between the right price in the present 2010 energy system and the right price in a future renewable energy-based system. The problem is that the price today is set according to the average costs and not according to the marginal costs in the system.

If the heat prices in Aalborg were set according to the marginal supply costs of the present supply systems, the present fixed part of the tariffs should be abolished, and the tariffs should be 100% variable.