Scenarios for sustainable heat supply and heat savings in municipalities - the case of Helsingør, Denmark

Local climate action is not only a domain of large cities, but also smaller urban areas that increasingly address climate change mitigation in their policy. The Danish municipality of Helsingør can achieve a substantial CO2 emissions reduction by transforming its heat supply and deploying heat savings. In this paper, we model the heating system of Helsingør, assess it from a simple socio- and private-economic perspective, develop future scenarios, and conduct an iterative process to derive a cost-optimal mix between district heating, individual heating and heat savings. The results show that in 2030 it is cost-optimal to reduce the heating demand by 20–39% by implementing heat savings, to deploy 32%–41% of district heating and to reduce heating-related CO2 emissions by up to 95% in comparison to current emissions. In 2050, the cost-optimal share of district heating in Helsingør increases to between 38 and 44%. The resulting average heating costs and CO2 emissions are found to be sensitive to biomass and electricity price. Although the findings of the study are mainly applicable for Helsingør, the combined use of the Least Cost Tool and modelling with energyPRO is useful in planning of heating and/or cooling supply for different demand configurations, geographical region and scale.
Identification of Excess Heat Utilisation Potential using GIS: Analysis of Case Studies for Denmark

Excess heat is present in many sectors, such as the industry and utility. The utilization of these heat sources could reduce the primary energy consumption and thus reduce carbon dioxide emissions. This work presents the results of a geographical mapping of excess heat, in which excess heat from the industry and utility sector is distributed to specific geographical locations in Denmark. Based on this mapping, a systematic approach for identifying cases for the utilization of excess heat is proposed, considering district heating, process heat and power generation. The technical and economic feasibility of using this approach is evaluated for four scenarios. Special focus is placed on the challenges for the connection of excess heat sources to heat consumers, as well as tax schemes applicable in Denmark. To account for uncertainties in the model input, Monte Carlo simulations and Morris Screenings are performed to determine the standard deviation of the results and to determine the most important model parameters. The presented method shows how the geographical mapping of excess heat sources can be used to identify its utilization potentials. In combination with the economic model, a fast evaluation and comparison of the feasibility of different matches can be performed. The evaluation of the identified case studies shows that it is economically feasible to connect the heat source to the public energy network or use the heat to generate electricity. However, the uncertainty analysis suggests that the results can only be indicative and are useful for a fast evaluation and comparison of different matches.

General information
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Industrial excess heat for district heating in Denmark

Excess heat is available from various sources and its utilisation could reduce the primary energy use. The accessibility of this heat is however dependent amongst others on the source and sink temperature, amount and potential users in its vicinity. In this work a new method is developed which analyses excess heat sources from the industrial sector and how they could be used for district heating. This method first allocates excess heat to single production units by introducing and validating a new approach. Spatial analysis of the heat sources and consumers are then performed to evaluate the potential for using them for district heating. In this way the theoretical potential of using the excess heat for covering the heating demand of buildings is determined. Through the use of industry specific temperature profiles the heat usable directly or via heat pumps is further found. A sensitivity analysis investigates the impact of future energy efficiency measures in the industry, buildings and the district heating grid on the national potential. The results show that for the case study of Denmark, 1.36 TWh of district heat could be provided annually with industrial excess heat from thermal processes which equals 5.1% of the current demand. More than half of this heat was found to be usable directly, without the need for a heat pump.

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Heat supply planning for the ecological housing community Munksøgård

Munksøgård is a housing community near the city of Roskilde, Denmark. In 2014, Munksøgård's residents have agreed to change the existing heat supply system. The choice of future heat supply was narrowed to heat pumps, new biomass boiler and connection to nearby district heating network. The present paper compares results from techno-economic energy system analysis, simple private-economic analysis and assessment of externalities related to the heat supply and discusses the differences in conclusions - is the economic optimal solution different from a system or private-economic point of view? The techno-economic energy system analysis is done using TIMES-DTU model, which optimizes over all sectors in Denmark and all periods until 2050. The result from this model gives the least expensive solution from the overall system point of view. A spreadsheet model has been developed to do the private-economic analysis and the evaluation of external effects related to the different solutions.

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Residential heat pumps in the future Danish energy system

Denmark is striving towards 100% renewable energy system in 2050. Residential heat pumps are expected to be a part of that system. We propose two novel approaches to improve the representation of residential heat pumps: Coefficients of performance (COPs) are modelled as dependent on air and ground temperature while installation of ground-source heat pumps is constrained by available ground area. In this study, TIMES-DK model is utilised to test the effects of improved modelling of residential heat pumps on the Danish energy system until 2050. The analysis of the Danish energy system was done for politically agreed targets which include: at least 50% of electricity consumption from wind power starting from 2020, fossil fuel free heat and power sector from 2035 and 100% renewable energy system starting from 2050. Residential heat pumps supply around 25% of total residential heating demand after 2035. The improved modelling of residential heat pumps proved to have influence on the results. First, it would be optimal to invest in more ground-source heat pumps, but there is not enough available ground area. Second, the total system costs are higher when COPs are modelled as temperature-dependent compared to fixed COPs over a year.
Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock

Ringkøbing-Skjern municipality aims to be 100% self-sufficient in renewable energy supply starting from 2020. It is expected that the building sector will contribute by reducing energy demand by 25-50%. Technical, economic, environmental and geographical aspects need to be considered when analysing such drastic change of municipality's energy system. For that purpose, GIS-based Ringkøbing-Skjern Energy Atlas has been developed. The present paper utilises Ringkøbing-Skjern Energy Atlas together with the Heating Model to calculate potentials and costs of heat saving measures. The results show that the reduction of heating demand by 25% and 35% can be achieved at the annuitized full cost lower than 1.7 and 2 DKK/kWh, respectively. The results also show that significant heat saving potential lies in farmhouses and detached houses as well as in buildings built before 1950. Over 75% of very cheap heat saving potential can be harvested by insulating floors, while majority of heat saving potential cheaper than 2 DKK/kWh can be utilised by insulating floors and installing mechanical ventilation systems. After heat savings and heat supply options are compared from a private-economic perspective, it is concluded that heat savings should be directed towards buildings supplied by oil boilers, natural gas boilers and ground-source heat pumps.

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Heat supply planning for the ecological housing community Munksøgård

Munksøgård is a housing community near the city of Roskilde, Denmark. In 2014, Munksøgård's residents have agreed to change the existing heat supply system. The choice of future heat supply was narrowed to heat pumps, new biomass boiler and connection to nearby district heating network.

The present paper compares results from techno-economic energy system analysis, simple private-economic analysis and assessment of externalities related to the heat supply and discusses the differences in conclusions - is the economic optimal solution different from a system or private-economic point of view?

The techno-economic energy system analysis is done using TIMES-DTU model, which optimizes over all sectors in Denmark and all periods until 2050. The result from this model gives the least expensive solution from the overall system point of view. A spreadsheet model has been developed to do the private-economic analysis and the evaluation of external effects related to the different solutions.
Optimal development of the future Danish energy system – insights from TIMES-DTU model

After a long period of transition, Danish energy system is half-way towards completely renewable in 2050. Drastic changes happened in the last forty years – the imported oil has been replaced by a mix of coal and natural gas, energy efficiency and conservation have been improved by extensive use of CHP-based district heating and heat saving measures. In the same period Denmark became well-known by integration and export of wind turbines. In line with the changes in the past, Denmark currently has very ambitious renewable energy targets, most ambitious being the 100 % renewable energy system in 2050. To achieve this, it is obvious that the present energy system needs to change, but the open question is how this should be done. In order to answer this question, the present paper uses TIMES-DTU model. TIMES-DTU is technology-rich, bottom-up, optimisation model covering all sectors of the Danish energy system, assuming full foresight and perfect competition. It simultaneously optimises investments and operation across all sectors and all time periods. Three different scenarios have been described in the present paper: (i) Base scenario without any policy constraints imposed on the model, (ii) WLP with the constraint that 50 % of electricity production should come from wind starting from 2020, and (iii) WLP-NFE scenario with the constraint that power and heat sector should be fossil fuel-free starting from 2035 and Denmark should be 100 % renewable starting from 2050. In all scenarios, Denmark was constrained to be a net exporter of electricity. The results imply that heat demand in future Danish energy system will be significantly reduced as a result of significant heat saving measures within the building stock, especially in rural and sub-urban areas. In urban areas, large district heating networks will supply between 55 and 73 % of heat supply in the years close to 2050. Electricity demand will be largely increased mainly due to transition to large scale heat pumps in the district heating networks. More than 90 % of increased demand for electricity will be based on on-shore and off-shore wind energy. WLP scenario implies less than 1 % higher total system costs compared to Base scenario, while WLP-NFE scenario implies 5-6 % higher total system costs compared to Base scenario. An additional conclusion from the current study is that Denmark has sufficient resources to achieve self-sufficiency in energy supply.
Residential heat pumps in the future Danish energy system

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Ringkøbing-Skjern Energy Atlas for municipal energy planning
Ringkøbing-Skjern is Denmark's largest municipality, located in the west part of Central Denmark Region. Its medium-term goal is to achieve 100% self-sufficiency in renewable energy supply by 2020. To achieve this ambitious goal, future courses of action have been outlined in the municipality's energy strategy "Energy2020" and divided into five groups: increasing production from wind, bioenergy and other renewable energy sources, reducing heat demand in buildings and converting transportation sector to renewable energy. The analysis of technical, economic and environmental impacts of such a variety of technologies on the municipality's energy system requires highly detailed decision support system. For that purpose, GIS-based energy atlas has been developed for Ringkøbing-Skjern municipality. The data about energy supply and demand, transmission and distribution infrastructure, energy resources, societal and other energy data have been geographically referenced and combined with the tools built in ArcGIS software.
The data have been collected from various sources: freely accessible public databases, the municipality, district heating and electricity companies, Danish transmission system operator, etc. The focus in the energy atlas is put on the geographical level of details, such as locations of district heating pipes and wind turbines, but the objects have been described with technical parameters and historical values as well. The applicability of the energy atlas is elaborated in the present paper and it is concluded that it can be used for analysis of heat saving measures in the building stock, district heating expansion and site-selection analysis for new wind turbines or biogas plants. In addition to that, it has proven to be useful as a data container and pre-analysis tool for energy system models and as a visualization tool. The continuous updating of the atlas while maintaining the sufficient level of data confidentiality is considered crucial for its long-term value; the strategy for continuous updating is presented in a separate section. Finally, since the methods and procedures used to create the atlas are irrespective from administrative boundaries, neither obstacle is observed towards creating the GIS-based energy atlases for other Danish municipalities or for Denmark as a whole.

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Danish heat atlas as a support tool for energy system models
In the past four decades following the global oil crisis in 1973, Denmark has implemented remarkable changes in its energy sector, mainly due to the energy conservation measures on the demand side and the energy efficiency improvements on the supply side. Nowadays, the capital intensive infrastructure investments, such as the expansion of district heating networks and the introduction of significant heat saving measures require highly detailed decision-support tool. A Danish heat atlas provides highly detailed database with extensive information about more than 2.5 million
buildings in Denmark. Energy system analysis tools incorporate environmental, economic, energy and engineering analysis of future energy systems and are considered crucial for the quantitative assessment of transitional scenarios towards future milestones, such as EU 2020 goals and Denmark's goal of achieving fossil free society after 2050. The present paper shows how a Danish heat atlas can be used for providing inputs to energy system models, especially related to the analysis of heat saving measures within building stock and expansion of district heating networks. As a result, marginal cost curves are created, approximated and prepared for the use in optimization energy system model. Moreover, it is concluded that heat atlas can contribute as a tool for data storage and visualisation of results.

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Global and national TIMES models: Use of IEA-ETSAP TIMES models in Denmark

An important part of the cooperation within the IEA (International Energy Agency) is organised through national contributions to "Implementing Agreements" on energy technology and energy analyses. One of them is ETSAP (Energy Technology Systems Analysis Programme), started in 1976. Denmark has signed the agreement and contributed to some early annexes. This document is the final report of the project "Danish participation in IEA-ETSAP, Annex XII, 2011-2013" under the Danish Energy Technology Development and Demonstration Programme (EUDP) 2010. A first complete draft of the ETSAP final report for Annex XII will not be released until January 2015. A new project, "Danish participation in IEA-ETSAP, Annex XIII, 2014-2016" was granted by the EUDP 2013. The current report from the Annex XII project is final edition of the preliminary edition Risø-R-1774, which was published in March 2011. The use of the ETSAP tools is linked to many other projects focusing on model application worldwide. This includes the organisations and institutions gathering in the annual International Energy Workshops (IEW), which are held back-to-back with one of the ETSAP semi-annual workshops. In recent years the ETSAP modelling tools have contributed to several projects under the various European research programmes.

Heat savings and district heating in TIMES-DTU model

Heat savings and district heating in TIMES-DTU model

Heat savings and district heating in TIMES-DTU model
Since the global oil crisis in the 1970s, Denmark has followed a path towards energy independency by continuously improving its energy efficiency and energy conservation. Energy efficiency was mainly tackled by introducing a high number of combined heat and power plants in the system, while energy conservation was predominantly approached by implementing heat saving measures. Today, with the goal of 100% renewable energy within the power and heat sector by the year 2035, reductions in energy demand for space heating and the preparation of domestic hot water remain at the top of the agenda in Denmark. A highly detailed model for determining heat demand, possible heat savings and associated costs in the Danish building stock is presented. Both scheduled and energy-saving renovations until year 2030 have been analyzed. The highly detailed GIS-based heat atlas for Denmark is used as a container for storing data about physical properties for 2.5 million buildings in Denmark. Consequently, the results of the analysis can be represented on a single building level. Under the assumption that buildings with the most profitable heat savings are renovated first, the consequences of heat savings for the economy and energy system have been quantified and geographically referenced. The possibilities for further improvements of the model and the application to other geographical regions have been discussed.

Spatial issues when optimising waste treatment and energy systems – A Danish Case Study
This study addresses the challenge of including geographical information related to waste resources, energy demands and production plants, and transport options in the optimization of waste management. It analyses how waste may serve as an energy source through thermal conversion and anaerobic digestion. The relation to the energy sector is taken into
account. The geographically specific potentials and utilization possibilities of waste are taken into account. Thus, the relative location of the resources (in this study waste and manure for codegation) is accounted for. Also the location of the resources relative to their utilization (in this study mainly the location of district heating networks) is considered. The temporal dimension is important for the energy sector which displays distinct variations over the year, week and day, and this is reflected by a subdivision of the extension of the year. The study provides an analysis of the Danish waste and energy systems with a spatial and temporal resolution.

Use of Danish Heat Atlas and energy system models for exploring renewable energy scenarios
In the past four decades following the global oil crisis in 1973, Denmark has implemented remarkable changes in its energy sector, mainly due to energy conservation measures on the demand side and energy efficiency improvements on the supply side. Nowadays the optimal expansion of district heating networks in relation with significant heat saving measures that are capital intensive infrastructure investments require highly detailed decision - support tools. The Heat Atlas for Denmark provides a highly detailed database and includes heat demand and possible heat savings for about 2.5 million buildings with associated costs included. Energy systems modelling tools that incorporate economic, environmental, energy and engineering analysis of future energy systems are considered crucial for quantitative assessment of transitional scenarios towards future milestones, such as (i) EU 2020 goals of reducing greenhouse gas emissions, increasing share of renewable energy and improving energy efficiency and (ii) Denmark's 2050 goals of covering entire energy supply by renewable energy. Optimization and simulation energy system models are currently used in Denmark. The present paper tends to provide a comprehensive insight into the use of the Heat Atlas for Denmark in recent studies dealing with municipal strategic energy planning and main scientific papers addressing those issues. A literature review of current advancements and discoveries in linking the Heat Atlas and energy system models will be presented, while special attention will be given to treating competing investments between heat supply and savings using optimization models. Main scientific contributors, their methodologies and areas for future research will be identified.
in line with the objectives of the Renewable Energy Directive and the Energy Performance of Buildings Directive that require Member States to develop ambitious policies as regards the use of renewable energy sources and energy efficiency in heating and cooling networks. progRESsHEAT is intended to support the market uptake of existing and emerging renewable electricity, heating and cooling technologies. More specifically, the project helps policy makers develop integrated, effective and efficient policy strategies aimed at achieving a fast and strong penetration of renewable and efficient heating and cooling systems. This includes the analysis of cross-sectoral effects between renewables and energy efficiency measures in industrial heat and cold, waste heat, heating and cooling in buildings and district heating. Together with six local authorities in six target countries across Europe (Austria, Germany, Czech Republic, Denmark, Portugal, Romania), heating and cooling strategies will be developed through a profound analysis of (1) heating and cooling demand and future developments, (2) long-term potential of renewable energies and waste heat in the regions, (3) barriers & drivers and (4) a model-based assessment of policy intervention in scenarios up to 2050. The established local energy advisory tool EnergyPRO will be used for the local studies and further developed to appropriately reflect district heating and cooling. The final versions for the investigated regions will be handed over to the authorities. In the target countries, progRESsHEAT will support the implementation of national heating and cooling plans which have to be released by member states by the end of 2015. The plans will include a policy outlook on how the potentials identified by the comprehensive assessment will be achieved. progRESsHEAT will assist national policy makers in implementing suitable policies with a model-based quantitative impact assessment of local, regional and national policies up to 2050. Policy makers and other stakeholders are strongly considered in the process. They will be offered the opportunity to learn from the experience of other players and gain deep understanding of the impact of policy instruments and their specific design. They are involved in the project via policy group meetings, workshops, interviews and webinars dedicated to policy development assistance, capacity-building and dissemination. The project is supported by the Horizon 2020 programme of the European Union.

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Relations
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