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Danish heat atlas as a support tool for energy system models

Stefan N. Petrovic *, Kenneth B. Karlsson

Department of Management Engineering, Technical University of Denmark, Frederiksborgvej 399, Building 130, 4000 Roskilde, Denmark

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ABSTRACT

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.

1. Introduction

Before 1973, the time of first oil crises, Denmark was totally dependent on the imported oil, with oil making for 92% of the total primary energy consumption. Almost entire transportation sector and residential heating was oil-based, while share of oil in electricity production was 78%; the rest of electricity production was based on coal [1]. Sudden rise in oil prices forced Danish authorities to pursue different energy planning strategies than just building new production, transmission and distribution facilities and thus serving consumption that was increasing from year to year.

Denmark drastically changed appearance of its energy system during past decades – total primary energy supply remained unchanged while total energy used for heating buildings was reduced by 26%. In the same time period, total heated area grew up for more than 50% [2]. This is done by constantly improving energy efficiency and introducing energy saving measures. Wall [3] identified analogous strategy for designing energy systems as the proper direction towards sustainable society, while [4] found that energy conservation is crucial for reducing harmful environmental impacts. Energy efficiency was mainly affected by introducing large number of CHPs (Combined Heat and Power) in the system, technologies which are using waste heat from electricity production as a heating source for residential buildings or industrial processes. Energy savings in buildings were achieved by using materials with smaller heat conductivity in the buildings' envelopes. Along with reduction in the primary energy consumption and fighting the issue of resource depletion, energy savings and efficiency measures have decreased harmful environmental impact of energy systems. Also, use of oil for covering heat demand is reduced from more than 90% in 1972 to about 10% in 2011, thus improving security of energy supply and making complete energy system less prone to changes in oil prices.

The environmental impact of improved energy efficiency is even more evident when considering the current Danish heating system: 52% of the total net heat demand in Denmark is covered by district heating, of which 76% is produced in the CHPs [1]. One third of energy produced in CHP processes in 2007 was based on renewable energy [6] – this fact shows how the environmental impact is reduced by the use of CHPs and district heating technologies. Lund and Andersen [7] observed that CHP-based district heating is essential for implementation of climate change response objectives in many countries. Similarly, positive global environmental effects have been observed in [8]. In line with this, in 2008, Denmark, as one of EU members adopted long term targets in the area of renewable energy and energy efficiency: (1) 20% reduction in emission of greenhouse gasses by 2020 compared with 1990, (2) by 2020, 20% of final energy demand should be covered by renewable energy, such as wind, solar and geothermal

* Corresponding author. Tel.: +45 2465 5732.
E-mail addresses: stpet@dtu.dk (S.N. Petrovic), keka@dtu.dk (K.B. Karlsson).

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energy and (3) 20% reduction in total energy consumption by improving energy efficiency in the whole chain production-transmission-distribution-end-use compared to business-as-usual scenario. Denmark went even further with the renewable energy targets, setting the 2020 goal for share of renewable energy in final energy consumption to 30% [9].

Although it is possible to see energy from many different sides, such as environmental, technical, technological, economical or behavioural, every segment of energy flow from the production to the end-use is spatially distributed and thus geographical in nature. Energy plants can be described by its efficiency, type and amount of fuel used, maximum output and many more and put into the spatial context by assigning spatial coordinates. The same stands for other elements of energy systems, such as sources of energy, transmission and distribution facilities and consumers, such as households and industry - unique spatial coordinates could be assigned to all these elements. Aydin et al. [10] have addressed the lack of solar and wind resources at all geographical locations and proposed GIS based site-selection method for positioning of hybrid wind-PV systems. Spatial nature of energy systems is especially underlined in the case of changes in the collective heat supply, such as expansion of district heating or the implementation of significant heat saving measures. Then, answers to spatial related questions, such as 'Where are the existing DH[1] areas?', 'How far away are these houses from the existing DH areas?' or 'What is the heat density inside this area?' represent starting point in energy system analysis. Finney et al. [11] have answered all these questions about the DH network in Sheffield before analysing economic and environmental consequences of expanding DH in [12].

Spatial aspect of energy planning played an important role in the transition of Denmark's energy system from polluting and inefficient imported-oil-based to modern, efficient energy system primarily based on renewable energy, CHPs and district heating. The first major policy statement was published in 1976 by Ministry of Trade and it has declared aims for Danish energy policy. The energy efficiency was addressed by the use of CHPs and district heating, energy savings by improving insulation on buildings, while dependency on imported fuels was addressed by switching to use of coal, renewable energy, natural gas and nuclear power. The ideas about using nuclear power were abandoned later. Heat Supply Act, passed in 1979, required that communes, in cooperation with regional public utility companies, map present and future energy needs at the local level on the basis of small heat districts, the so called energy districts. A national, geo-based system for energy planning was created – information about number of houses supplied by different fuels and supply technologies was easily accessible. Then, on the basis of energy districts, counties drew up their own heat supply plans, which had to contain fuels that will be prioritised in the future, locations of future investment in collective heating and locations of specific activities that are producing or consuming large quantities of heat. For the newly developed areas, a collective heat supply was prescribed. Later, each commune had to draw up own heating plan in agreement with the counties' heating plan [13]. Creation of heat plans and delineation of energy districts denoted beginning of regional energy planning. In the same time, due to geographical nature of energy districts, same process could be interpreted as a first use of spatial decision support tool, a heat atlas. In 1970s and 1980s heat atlases were based on hand drawn paper maps, while in 1990s they started being incorporated in computerised GIS software. Today, heat atlas can be seen as highly precise, data-intensive decision support tool that provides huge possibilities for data storage, analysis and visualisation.

[1] If not stated otherwise, acronym DH is used for district heating throughout the paper.

The current paper investigates how Danish heat atlas can be used as a support tool for energy system models. It is shown how detailed data from heat atlas together with GIS tools can be used to create cumulative cost curves for DH expansion and heat savings in building stock. Later, these curves have been approximated and prepared for the use in the TIMES model for Denmark. Finally, use of GIS based heat atlas for representing results from energy system models has been discussed.

2. Methodology

2.1. Danish heat atlas

If not specified otherwise, current paper tends to describe use of a heat atlas developed at Aalborg University and presented in [5]. It is designed as File Geodatabase in ESRI's ArcGIS 10 software. This software has been chosen, because it is capable of efficiently storing and operating huge datasets and it offers variety of analytical tools and good connectivity.

A heat atlas contains spatially referenced data for about 2.5 million buildings in Denmark. Each building is represented as single point within GIS software. Heat supply data include heat installations (individual boilers, electric heating, district heating, etc.), fuel used in individual heating (natural gas, wood chips, straw, etc.) and means of supplementary heating. Non-energy related data, such as construction year and building type, heated area, conservation status, region, address, commune, postal and parish code, etc. are also included in a heat atlas and comprise a sound basis for computation of specific building parameters using empirical formulas. Further socio-economic parameters, such as levels of income or education, property values, number of inhabitants or similar could be included in the future [5]. Even when taking privacy issues into account, these data are publicly available with high resolution. With all-time progress of computer hardware and GIS software, storing and operating huge amounts of data does not seem to be a problem either, but problem seems to be on empirical side. Heated area of buildings, age and type accompanied with empirical data about specific heat losses and DHW[2] consumption were used in a spread sheet model developed by Wittchen [14] to calculate net heat demand for total of 175 types of residential buildings. Another approach, developed by Karlsson and Næeraa [15] was used for calculating net heat demands in commercial and public buildings. Net heat demand calculated in Heat Atlas was adjusted to Danish Energy Statistics data [1] and validated in study Heat Plan for Denmark [16]. It surely is not the matter of coincidence that GIS based heat atlas of such high detail was created for Denmark. Denmark has a relatively small population of around 5.5 million and about 2.5 million buildings. In the same time, highly developed statistical office (Statistics Denmark) keeps track on people's residence, age, income, education and employment while national register of buildings and dwellings (BBR) maintains records about physical properties of buildings, construction year, area and many more. Thus, publicly kept registers with high level of detail, containing data specified by geography, along with big experience in using heat supply plans, comprise a solid fundament for creation of GIS based decision-support tool – a heat atlas.

2.2. GIS based heat atlas for calculations of district heating expansion and heat savings

Heat atlas was used in [17] to recalculate heat demand for DHW and space heating and assess potentials and costs of different heat saving measures for 360 types of buildings. GIS based heat atlas

[2] Acronym DHW is used for domestic hot water throughout the paper.