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Comparison of district heating expansion potential based on consumer-economy or socio-economy

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A B S T R A C T

Recent studies show that a high share of district heating is an important part of a future sustainable energy system or smart energy system with a high renewable energy penetration. These studies also show socio-economic benefits of expanding the district heating coverage. However, in order to implement such an expansion, district heating needs to be economically feasible for the heat consumers. This aspect is often not investigated and hence it is unknown if calculations based on consumer-economy, where tax payment is included, will yield the same potential of expansion. This study identifies the differences in the expansion potential of district heating calculated with a socio-economic and a consumer-economic approach, respectively, in a case study of Denmark. By also investigating the consumer-economy of expanding district heating, a deeper insight is obtained of possible locations for expanding district heating under the current framework conditions.

1. Introduction

District heating is often considered as one of the methods for reducing the climate impact both nationally and internationally in, for example, the European Union and China [1–6]. District heating consists of central heat production distributed through a pipe network to the consumers. This gives some economy-of-scale benefits compared to individual heating and enables the usage of waste heat from the industry and electricity production [7,8]. District heating networks can also include storage of heat on a larger scale, which facilitates the integration of fluctuating energy sources, such as solar heating. Also, heat pumps can be connected to an electricity grid with a high renewable energy penetration [9]. Increasing the district heating coverage is also in line with the transformation towards a Smart Energy System, see Refs. [10–12], where a high degree of integration between the heating sector, the transport sector and the electricity sector is needed in order to incorporate a high amount of fluctuating energy sources. Several studies show that the coverage of district heating in Denmark and internationally should expand [5,13–15]. In the case of Denmark, the potential of district heating coverage is estimated to increase from 50% to 63–70% of the heat demand [15]. On a European level, Heat Roadmap Europe estimates a potential district heating coverage of 50% of the heat demand [16]. This district heating expansion is expected to be concentrated in the urban zones.

With the district heating coverage expected to increase, this calls for a way of defining the geographical boundary between individual heating and district heating. Spatial analysis based on a heat atlas can assist in defining zones for district heating and individual heating. Currently, the heat atlas developed at Aalborg University is among the most detailed in the world with the single building as the smallest unit [17]. The heat atlas from Aalborg University is based on data from the Danish Building and Dwelling Register and a heat demand model from the Danish Building Research Institute. The heat atlas uses the age, size and type of each individual building to estimate the heat demand. The heat atlas further contains information about the spatial location of each building as well as the current form of heat supply.

Recent research in the field of geographical heat and energy planning has been done in Refs. [4,18–20]. The methodical approach differs. In Ref. [4] the methodology is based on a combination of GIS and energy system modelling. GIS is utilized to develop a heat atlas for the EU27. The heat atlas is reflecting the local conditions for district heating, such as quantities of heat that can be recycled, local renewable energy resources and local heat

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demands. A heat atlas is created at a 1 km^2 resolution and is used to highlight areas with high heat density and a surplus of heating resources. In Ref. [18] data on the heat consumption in the US is divided per capita for residential and commercial buildings. The division is based on statistics and projections of the total final energy demand. These values are multiplied with raster data sets representing the spatial distribution of residential and commercial consumers. The output is a heat demand density map in a spatial resolution between 0.56 km^2 and 0.78 km^2. In Ref. [19] climate information and spatial information are combined to create a map on the single building level for a subject area in South Korea. The urban GIS integration model creates a database of buildings, land cover and altitude information for an existing and a planned city in detail in both 2D and 3D. The resulting spatial level of detail is very high. However, the model only covers a very limited land area of 8 km $\times$ 12 km. Further, a mesh is created on a scale of 200 m $\times$ 200 m reflecting the temperature and heat load based on indoor heat load. In Ref. [20] a GIS map is produced for the area of Sheffield City Council in the UK. Existing and emerging heat sources and sinks are identified and areas, where expansion of the existing district heating networks is possible, are found.

The approach in the studies differs largely, where [4] and [18] are based on a top-down approach using aggregated numbers to create a large-scale heat atlas for the US and the EU27 [19], and [20] use a more bottom-up approach giving more detailed information but for a smaller area of interest. The Danish heat atlas has also been used in recent studies [8,21,22].

The economic approach differs in the articles. In Ref. [19] a model is developed to assist in planning by, among other things, predicting the energy consumption. The model is not used for specific economic calculations. In Ref. [18] the economic approach is techno-economic, calculating the cost of establishing and running the district heating system. In Refs. [4,8,20–22] a socio-economic approach, calculating the cost of expanding and running the district heating system without including taxes is used. They all have in common that they do not calculate the consumer-economic consequences. However, both [21] and [22] acknowledge the necessity of such calculations. This means that the results of the calculations done in these studies are all valid from a societal or business perspective. However, the results do not include an investigation of whether the consumer-economic costs in the areas are affected positively or negatively by the changes suggested in the papers.

This study investigates the potential of expanding existing district heating networks to surrounding towns, villages and urbanized zones with Denmark as a case study. The calculation of the expansion potential is based on an economic comparison between district heating and an alternative of individual heating for the buildings in the urban zones. The calculation uses both a socio-economic approach as well as a consumer-economic approach. The main finding is not only the potential of expanding district heating but also the differences in this potential depending on the economic approach. In this paper, socio-economy is narrowly defined as the cost for society, using socio-economic cost of investment and fuel without profit and taxes, and without indirect effects on the environment, on GDP, and on levels of employment, etc.

2. Methods

The spatial analyses using Geographical Information Systems (GIS) is carried out in ArcMap 10.2. PlansystemDK and Kortforsyningen supply the publicly available spatial data used in the project [23,24]. Further, the current edition of the Danish Heat Atlas from Aalborg University is used to calculate the heat demand [17].

The analyses carried out in this study are divided into a spatial analysis and an economic analysis. Both are described in the following.

2.1. Spatial analysis

The purpose of the spatial analysis is to prepare for the economic analysis. This is done by identifying the zones currently supplied with district heating and the zones currently not supplied by district heating. The potential of supplying district heating to the zones currently without district heating can then be investigated.

The existing district heating networks are delimited using the polygons defining the supply zones of district heating, derived from local heat plan zoning. The purpose of these heat plan areas is to define the zones, where consumers according to municipal planning can be connected to district heating, now and in the future. The polygons often expand further than the current urban zones and thereby further than the presently existing district heating networks. Polygons delimiting the built up urban zones within the supply zones are used to remove areas without buildings from the district heating polygons. In this way, the coverage of the existing district heating networks is defined to only include urban zones where buildings currently exist. The extent of the coverage is validated using the heat atlas to check that the majority of buildings within the district heating zones are currently supplied with district heating. All urban zones outside the district heating supply zones are identified using the urban zone polygons. The heat atlas is used to find the number of buildings and the heat demand inside the polygons. The information is spatially joined to the polygons, summarizing the heat demand and number of buildings as a parameter.

To identify the distance between each of the urban zones without district heating and existing district heating networks, a near analysis using Euclidean, straight line distances is performed between the two datasets. This analysis identifies the distance to the nearest district heating network for each of the urban zones outside the district heating supply zones. In the economic analysis, it is assumed that the nearest district heating zone is the one that the urban zone can potentially connect to.

2.2. Economic analysis

The economic analysis of expanding the district heating networks follows the same overall approach for both consumer-economy and socio-economy and is divided into the following steps:

- The cost of establishing a transmission line to the nearest district heating network is calculated with a capacity matching the heat demand in the urban zone.
- The cost of the distribution network is calculated based on the area of the urban zone.
- An installation cost per building is added to cover the district heating unit and the branch connection.
- The cost of heat is assumed to be the same as for the existing customers in the nearest district heating network although the marginal cost may be higher than the present average cost.
- All of the above costs are summarized on a yearly basis for each urban zone and divided by the heat demand to get the cost per MWh of heat.
- The resulting cost of district heating is compared to an alternative of individual heating options.

For both analyses, it is assumed that 80% of the heat demand within each of the urban zones is connected to the district heating.