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Research Paper

Choice of insulation standard for pipe networks in 4th generation district heating systems

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HIGHLIGHTS

- New method for assessment of the insulation level for district heating is suggested.
- It combines a detailed heat loss analysis with an integrated energy system analysis.
- The method can be used to evaluate socioeconomic and energy system consequences.
- The method is presented and its application demonstrated for the case of Denmark.

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ABSTRACT

Reducing heat losses from the pipe networks in district heating (DH) systems is one of the main challenges when developing DH in the future. Fourth generation DH is a concept that defines the role of DH in future smart energy systems as an integrated part together with smart electricity grids and smart gas grids. Improving DH pipes by improving the insulation standard results in decreasing the heat and temperature losses from the pipe networks. When reducing heat losses from DH pipes, there is a trade-off between the increasing cost of pipe insulation and the associated savings in the heat supply system. This study presents a methodology to describe this balance for a specific case and its application for the case of Denmark.

The methodology presented consists of a techno-economic analysis in two steps. In the first step, a DH grid model is used to assess the reduction in grid losses by implementing different pipe insulation standards. In the second step, the specific grid losses found in the first step are analysed in an integrated energy systems model where all main energy sectors and their interrelations are included. The outcome of the study can provide decision support when planning investments in DH systems today and in the future. The results from the case of Denmark shows that pipes with higher insulation standard (series 3) is generally preferable, but the highest insulation standard available today (series 4) might be preferable in the future if fuel prices or increase or investment costs decrease.

1. Introduction

Heat loss from district heating (DH) networks is a problem, but this is also inevitable. Reducing heat losses will reduce the primary energy demand and thereby fuel consumption and the need for infrastructure investments [1]. On the other hand, reducing heat losses is also associated with an additional economic cost and this makes a balance between heat losses, costs and fuel consumption [2]. This balance is important to assess when planning for DH networks because investments in DH network and infrastructure are long-term investments that may last more than 40 years.

Reducing heat demands in DH systems in general have been shown in several studies to be important in the future because of limited resources when fossil fuels are no longer available [3,4]. It has also been shown that DH systems in the future will have an important role even with substantial heat savings in Denmark [5,6] as well as the EU [7]. The heat losses from the pipe networks are an important figure in this connection because this accounts for a relatively large share of heat production.

Dalla Rosa et al. [8] divide the variables affecting heat losses into four categories: Operational data, thermal conductivity, geometry of pipes and pipe arrangement such as single pipe, twin pipe etc. Several different strategies have been suggested to reduce heat losses;

Abbreviations: RE, Renewable Energy; DH, District Heating; CHP, Combined Heat and Power; DHN, District Heating Network; CEESA, Coherent Energy and Environmental System Analysis; 4DH, 4th generation District Heating; DN, Nominal Diameter.

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reduction of network temperature level [9], design of pipe network layout [10,11], choice of pipe types [12], operation and management [13] and changing the insulation thickness or material of the pipes [14,15]. General for the studies suggesting these strategies is that they have applied analyses of isolated energy systems and only considering the heat flows and not the rest of the energy system, such as electricity, fuel production or industry.

This study suggests and demonstrates a methodology to assess the balance between reductions in heat losses and socioeconomic costs considering all energy sectors. The methodology is combining two analyses where the first is a detailed heat loss analysis of different alternative pipe systems and their heat losses considering the variables described in [8].

The second part is an integrated energy systems analysis taking all substantial sectors within energy and the dynamics between them into account. The savings in fuel and costs do not decrease as a linear function with the heat losses, but depends on the changes in system dynamics with lower heat losses, and the combined analysis is therefore important and can provide valuable information when planning for short and long-term investments in DH systems.

The paper is organised as follows. Section 2 presents the theoretical concept Smart Energy Systems and how 4th generation DH is an important part of future integrated energy systems. In section 3 the methodology of the two-part analysis is presented in details. In sections 4 and 5, a case study is presented and elaborated. Lastly, in section 6 the suggested method is discussed and a conclusion given.

2. Smart energy systems and 4th generation district heating

Smart energy systems is a concept that highlights the importance of integrating energy sectors concurrently with the introduction of RE production [2]. The electricity, heating, fuel, industry and transport sectors need to be more integrated to be able to accommodate higher shares of e.g. wind or solar power. Lund has defined smart energy systems in Reference [16] as the combination of 1) Smart electricity grids, 2) Smart thermal grids and 3) Smart gas grids. The imbalance between the supply from renewables and the demand must be coped with by dynamic interaction between the components in the energy system. Examples are short-term flexible CHP plants [17], large heat pumps for DH and cooling [18], electrolysers and large-scale fuel production for transportation [19] or energy storage systems [20].

Fig. 1 shows the difference between a conventional energy system (left) and a smart energy system (right) on a conceptual level. It shows that the smart energy system has higher penetration of wind power, is more integrated between the energy sectors and much less dependent on input of fuel.

DH is a central part of a smart energy system in the Danish context, where heat demands cover a large proportion of the primary energy demand. DH is important because it enables the utilisation of heat sources that would not be feasible to utilise with individual heating systems. The ability to make use of excess electricity production from e.g. wind turbines in heat pumps in combination with thermal storage for the heating supply is another important contribution to the development towards a RE system [1].

CHP plants, together with fuel boilers, are currently the main contributors to DH supply in Denmark, but in the future in a system based on 100% RE, the supply from these can be replaced with industrial waste heat, ambient heat sources harnessed by heat pumps, solar and geothermal heat among others. To integrate these new heat sources in a feasible way, however, the DH systems have to change compared to the system of today [1].

In general, the heating demand should be reduced to approximately 50% of its present level [21]. At the same time, DH will be expanded to cover areas that currently have their demand covered by natural gas boilers, oil boilers or electric heating [7,22]. This means that DH systems should be planned and designed to accommodate lower heat demand densities, but with an increasing number of consumers. One important point here is that heat losses from the pipes need to be significantly reduced, by lowering the temperature in the network and improving the pipes' insulation and network layout [23].

3. Methodology

In this section, the suggested method for assessing the feasibility of different types of DH pipe systems is presented.

3.1. Method structure

The purpose of this method is to assess different insulation standards to provide an input for decision support for a planning or policy process related to investments in DH pipe infrastructure. This method combines a detailed heat loss analysis of DH networks with an integrated energy systems analysis.

Fig. 2 illustrates the overall structure of the methodology proposed in this study, where three alternatives for the existing (reference) pipe networks are evaluated.

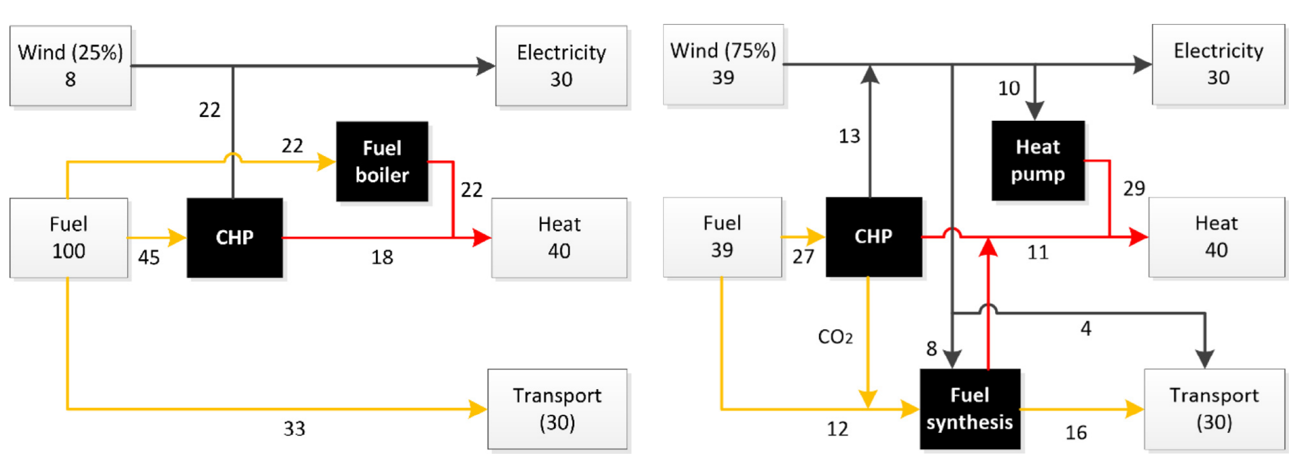

Fig. 1. Conceptual flow diagram of two energy systems. White boxes indicate supply (left) and demand (right) where black boxes indicate conversion technologies. Arrows indicate energy flows where black is electricity, red is heating and yellow is fuel. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)