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System dynamics model analysis of pathway to 4th generation district heating in Latvia

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A B S T R A C T

In the article, a possibility to introduce the 4th generation district heating (4GDH) in Latvia is analyzed with the system dynamic modeling. Three policy instruments were included into the system dynamic model: subsidies, instrument for risk reduction and instrument for efficiency increase, and their impact on the system operation was analyzed. Six development scenarios are examined in the article, two of which are supplemented with the transition of heat network to the low-temperature regime at a different share of the renewable energy (60%, 80%, 95%).

The heat tariff was used as the main indicator determining the pace and structure of the technology change. In the model the existing natural gas technology was included and three technologies of the renewable energy – biomass combustion equipment, solar collectors with the accumulation and heat pumps.

Results of the modeling shows that scenario, at which no policy instruments are used, reduce CO_2 emissions for 58.6% until 2030; but it is possible to achieve a zero emission level, in case political instruments are used.

1. Introduction

The beginning of the district heating (DH) system dates back to the end of the 19th century and beginning of the 20th century, when industrialization processes rapidly developed in Europe and North America, and the number of urban inhabitants grew very fast [1]. In order to improve the life quality of urban inhabitants, it was commenced to build DH and power systems. Over a period of time DH developed due to innovative technical solutions, and retains its topicality also nowadays. Most part of the European Union (EU) inhabitants live in cities, therefore the district heating and cooling supply is well developed [2]. At 3373 cities of EU there is a DH system [3], and the installed heat energy capacity in Germany reaches 49,931 MW_{th}, in Finland – 22,940 MW_{th}, in Poland – 58,300 MW_{th} [4]. Owing to the technical progress, the DH has transformed over the time, as a result of which the efficiency of the system was increased [1].

The aim of the DH is to provide inhabitants, as well as commercial and industrial consumers with the required amount of the heat energy by using modern and sustainable heat supply technologies, their competitiveness, security and qualitative level of services to the consumers [5]. Sustainability, competitiveness and heat supply security are three criteria, which simultaneously compete among themselves and supplement each other. Harmonized interaction of these criteria should provide DH with the advantages, if compared to the individual and decentralized heat supply [5]. In case one of the criteria obtains a dominant position in the DH, the advantages are compromised, and situation arises, when consumers choose the decentralized heat supply [6]. Historically, DH was formed by using progressive technologies of that time, and also nowadays at several systems innovative solutions are being implemented, which mainly are related to the integration into DH of the renewable energy [7].

The DH consists of three elements: heat source, heat transportation system and heat consumers [8]. Each element of the heat supply can be characterized with several independent variables, which jointly form a system. This system has an important role into the reduction of CO_2 emissions, which is set a priority by all EU states [9].

The 4th generation DH (4GDH) conception embraces all innovations, which have been approbated and introduced into the DH over the last years. Important emphasis is put on the integration

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into the common system of the renewable energy [10], which is characterized by the integration into the DH system of solar collectors with the accumulation [11]; integration into the common system of heat pumps [12]; reduction of the consumed heat energy [13]. This system includes network with a low temperature (LT) and low consumption buildings. The DH is included into the common smart energy supply system, and protected from the legal point of view [1].

Several researches are devoted to the question – how big will be the share of the renewable energy achieved at the DH both in the short term [14], and long term perspective [15]. Different tools are used for the modeling: a tool for modeling of energy systems -EnergyPLAN [14], a model of linear optimization – Balmorel model [7] and other. With an aim to create a successful energy management program, also a multi criteria analysis is used to optimize different parameters [16], and decomposition analysis [17], and the net of artificial neurons [18]. In order to determine the boundaries of DH efficiency, the Data Envelopment Analysis is used in other researches [19]. Irrespective of the fact that in several researches development strategies of separate DH parts of the 4GDH are examined, the system is still being insufficiently analyzed in its entirety. Therefore the aim of this research is to explore the possibility to introduce in Latvia the 4GDH by using the method of system dynamic (SD) modeling and by considering conditions of the 4GDH conception: transition to the renewable energy, introduction of low temperature regime, reduction of consumption by the end user. Into the model, policy instruments are integrated and different scenarios are formed with an aim to determine the most efficient development scenario for the transition to the renewable energy by simultaneously improving the energy efficiency and by advancing towards the zero emission level.

2. Methodology

The SD theory is based on the complex system, that analyzes behavior, which changes over the time, by identifying and defining elements within it, and their mutual correlation [20]. There are three conceptions forming basis of the system dynamics, and if using them correctly, an adequate result can be obtained [21]:

1) stocks, flows and feed back;
2) precisely defined boundaries of the system;
3) causal relationships, not correlations.

SD method follows 5 steps, which starts with problem formulation, continues with creation of dynamic hypothesis and only in the 3rd step actual building of model structure starts (Fig. 1). Model building is based on the actual links between system variables. Data from statistical databases and scientific articles are taken as input parameters. When model structure is ready and accepted by the experts in the field, model testing and validation step follows. At this step historical data from actual DH company are put in to the model and tested. If result, generated by the model, is in the acceptable boundaries, work moves to the final step, which is policy making and simulation of different scenarios. If validation fails, it is necessary to overlook and modify model structure and then try to validate it again, until validation result is acceptable.

Within the article, a model is elaborated by using the SD, which allows researching the 4GDH by using different political instruments, and the most optimal scenario for transition to the 4GDH is determined by reducing the environmental impact simultaneously.

2.1. Background information

At the district heating of Latvia, the fossil fuel currently dominates. Historically it can be seen (Fig. 2) that in 1990 two types of fossil fuel dominated – natural gas and oil products [22]. There were practically no renewable energy in the DH of Latvia, as biomass constituted only 0.5% of the total energy resource consumption. Over the last years, the share of the renewable energy grows considerably, while fossil fuel consists only of the natural gas. The total energy consumption includes fuel used at the boiler houses and cogeneration stations, inter alia including also the energy resources consumed for power production at the cogeneration stations.

The renewable energy part has been insignificant (10%) from 1997 to 2011, however, over the last years the use of the renewable energy has grown rapidly (24%). This can be explained with the changes of natural gas price. During the period of time from the beginning of 2010 until the beginning of 2014, the natural gas price has changed from 163.3 EUR/thousand nm^3 to 284.57 EUR/thousand nm^3 [23], or for nearly 75%, which is a considerable increase and leaves significant impact on the heat tariff at those DH regions, at which natural gas is used. The growing heat tariff forces to look for the solutions to cut expenses, therefore the increase in the share of renewable energy is only logical. The model developed shows the dynamics that underline the system's behavior in order to introduce the 4GDH and to increase the share of the renewable energy.

2.2. Creation of dynamic hypotheses

The installed technology capacities are selected as the main stock of the model, because the share of the used resource depends on the changes in the installed capacity. The capacity of the natural

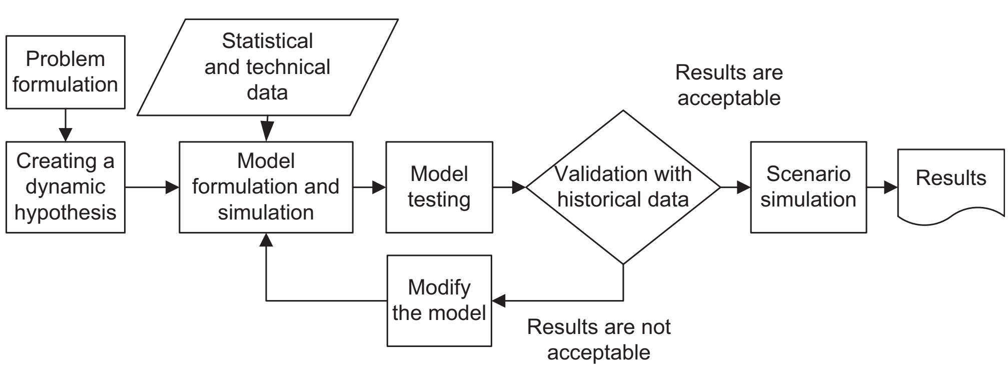

Fig. 1. Algorithm for model development and validation.

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