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SMART DISTRICT HEATING NETWORKS IN THE ERA OF ENERGY TRANSFORMATION

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Abstract: District heating, which accounts for half of the EU's energy consumption, still relies heavily on fossil fuels. This causes emissions of dust and greenhouse gases and into the atmosphere and leads to negative climate changes. For this reason, European Union countries have been implementing a climate and energy policy for many years, which in the area of heating is aimed at making it more efficient and sustainable. This requires the introduction of low-carbon technologies and the reduction of fossil fuel consumption by increasing the share of renewable energy sources. Modern, efficient and smart heating systems should guarantee reliable heat supply while reducing the environmental impact. The article discusses the direction of change and development of district heating systems through the introduction of innovative technologies. The new generations of 4GDH and 5 GDH district heating systems are described and the benefits of their use are indicated. The concept of smart district heating networks, their structure and the advantages of their implementation are discussed. The possibilities of creating smart energy systems using renewable energy sources and heat storage technologies were also indicated. The activities of Polish district heating companies in the introduction of smart heat networks are presented, based on research conducted.
Keywords: district heating; smart heating networks, renewable energy sources, intelligent control

1. INTRODUCTION

In recent years, the issues of energy security, energy saving and energy efficiency improvement, as well as the development and implementation of new energy technologies, have been increasingly taken into account in the global economy. Although the energy sector, including district heating, determines the socio-economic development of countries, it simultaneously has a negative impact on the environment, air quality and causes climate change on a global scale through dust and greenhouse gas emissions. In order to counteract these unfavourable processes, the European Union, including Poland, has been pursuing a stringent climate and

energy policy for a number of years as part of its sustainable development strategy. The essential elements of this strategy in the area of district heating are efficient energy use, an increase in the share of renewable energy sources (RES), the development of cogeneration, the reduction of greenhouse gas emissions and the implementation of energy-efficient technologies in buildings (European Commission, 2016; Ministry of Climate and Environment, 2021). This involves the transformation of the energy sector, including district heating, through the spread of low-carbon technologies and the reduction of fossil fuel consumption in favour of renewable energy sources. Of great importance in this process is the implementation of smart heating and electricity networks and their integration into sustainable smart energy systems (European Commission, 2011; Lund et al., 2014; Lund et al., 2016; Gao et al., 2017; Bloess et al., 2018; Kavvadias et al., 2019).

2. DIRECTIONS OF CHANGES AND DEVELOPMENT OF DISTRICT HEATING

The complexity of the factors currently influencing the development and directions of changes in enterprises in the heating sector is shown in Figure 1 (Wrzalik, 2021).

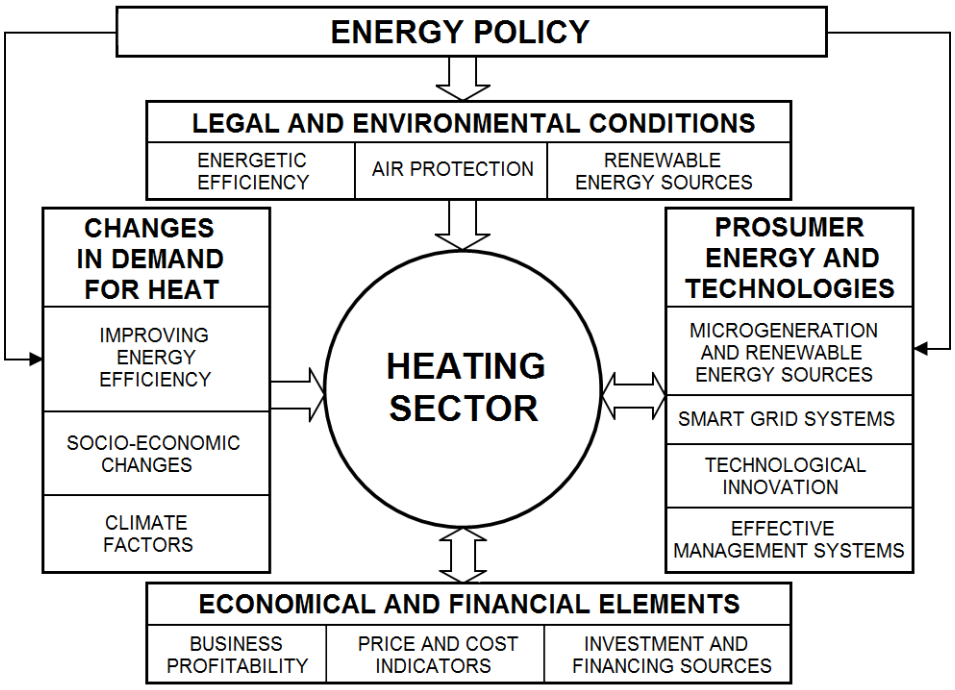

Fig. 1. Factors influencing the directions of changes in the heating sector
Source: own study

Effective transformation and decarbonisation of the heating industry, improvement of safety and energy efficiency, as well as ecological indicators of heat supply require comprehensive modernisation and implementation of innovative technological solutions by heating companies. Innovations in heat engineering concern two areas: technical infrastructure (heat sources and district heating networks) and management of the heat generation and transmission process (Wrzalik, 2019).

The future of heat supply systems are 4GDH and 5GDH - low-temperature district heating networks integrated into sustainable energy systems using renewable energy

sources and heat storages (Lund et al., 2016; Bloess et al., 2018; Kavvadias et al., 2019; Allen et al., 2020; Millar et al., 2021). 4GDH and 5GDH systems enable the efficient supply of heat and cold to low-energy buildings from district heating systems with low network losses. Their important feature is the use of low-temperature renewable heat sources integrated with the operation of smart energy systems. Smart energy systems may be defined as "an approach in which smart electricity, thermal and gas grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system" (Lund et al., 2016). The latest generation district heating systems, conceptually shown in Figure 2, indicate the directions of development and possible pathways for decarbonising the heating sector.

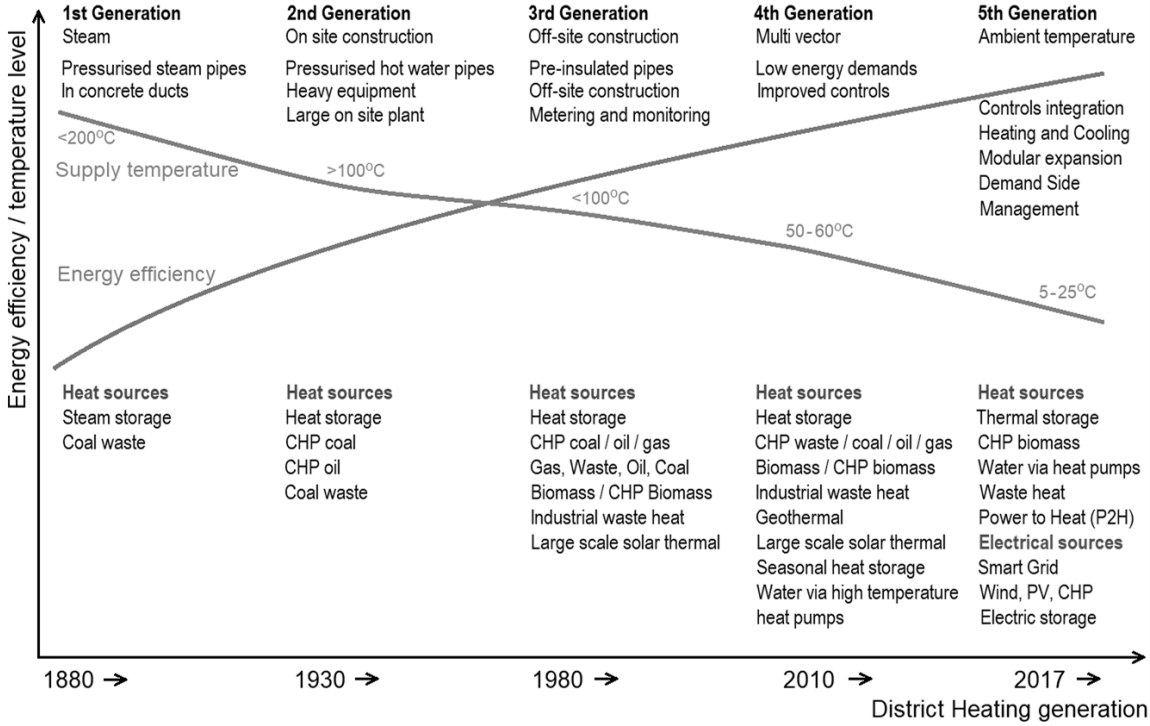

Fig. 2. Heat network trends to lower distribution temperatures and higher efficiency
Source: according to https://www.icax.co.uk/image_Fifth_Generation_Heat_Networks.html and Lund et al., 2021

Advantages of low-temperature district heating (LTDH) systems include reduced heat losses in the network (efficiency), reduced greenhouse gas emissions, flexibility to use multiple renewable heat sources (including consumers), increased use of heat storage units, improved power-to-heat ratios in CHP systems and economic benefits (Bach et al, 2016; Olsthoorn, et al, 2016; Imran et al, 2017; Mathiesen et al., 2019; Wiśniewski et al., 2019; Bamisile et al, 2020; Lund et al, 2021).

3. THE CONCEPT AND ADVANTAGES OF SMART HEATING NETWORKS

The concept of smart heat grids can be considered similar to that of smart electricity grids, which focuses on the integration and efficient use of renewable energy resources and the operation of grid infrastructure to enable distributed generation,

which can include interaction with consumers (Lund et al., 2014; Ancona et al., 2015; Gao et al., 2017). The European Commission indicates that the smart grid should be (European Commission, 2011):

- flexible i.e. meeting consumer needs in response to future changes and requirements;
- available for renewable energy sources and highly efficient local generators with zero or low carbon emissions;
- reliable, meaning that the network is secure and ensures the quality of the energy supplied;
- economical, i.e. high efficiency is achieved through innovation, efficiency and energy management.

The operation of smart heat networks is based on the real-time optimization of the use of available forms and sources of energy, including local ones, through the application of telemetry and IT techniques for the online collection and processing of data from energy systems, as well as residential, industrial and public buildings (Kuczyński and Ziembicki, 2012; Gao et al., 2017). The capabilities of smart district heating systems come from being equipped with an intelligent metering infrastructure, automation equipment and IT systems and specialized software for online control and optimal management of network operations (Kuczyński and Ziembicki, 2012; Rak, 2016; Gao et al., 2017; Wrzalik, 2019).

A schematic diagram of the structure of a smart district heating system using on-line supervision and management software is shown in Figure 3 (Wrzalik, 2019).

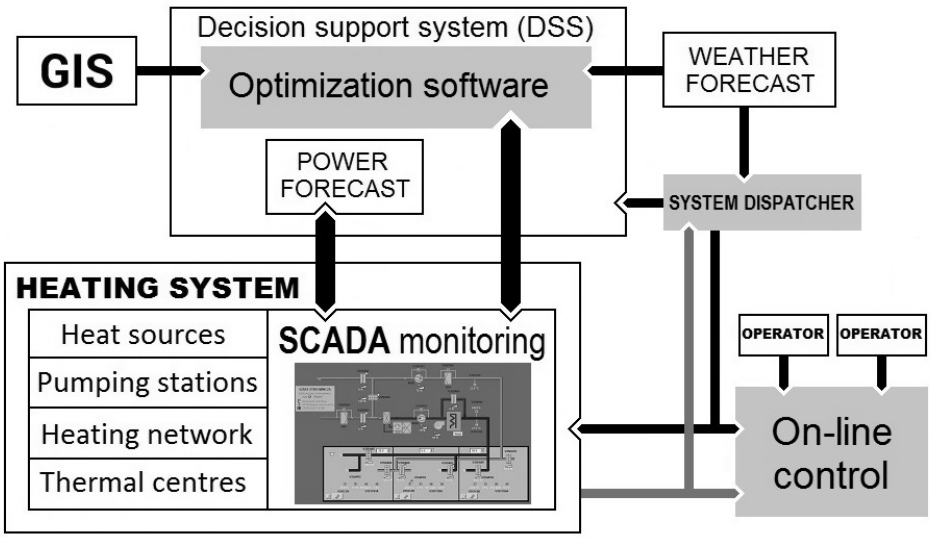

Fig. 3. Diagram of an intelligent district heating system with monitoring and management software, Source: own study

Based on an smart district heating system, intelligent heat load forecasting taking into account weather conditions, efficient heat quantity regulation, intelligent optimisation of network planning and real-time fault diagnosis can be realised (Gao et al., 2017).

The application of smart grids in district heating brings the following benefits (Lund et al., 2014; Ludynia, 2014; Imran et al, 2017; Mathiesen et al., 2019; Allen et al., 2020):

- increased efficiency and security of heat supply;
- possibility to monitor and manage the operation of the district heating system;
- better use of the potential of distributed generation and RES sources;
- reduction of costs of district heating operations.

Flexibly coupling the electricity and heat sectors in smart energy systems can contribute to both renewable energy integration and decarbonisation (Lund et al., 2016; Bloess et al., 2018; Kavvadias et al., 2019; Mathiesen et al., 2019). There are different ways to convert electricity into heat. The most important options for the residential heating sector are shown in Figure 4.

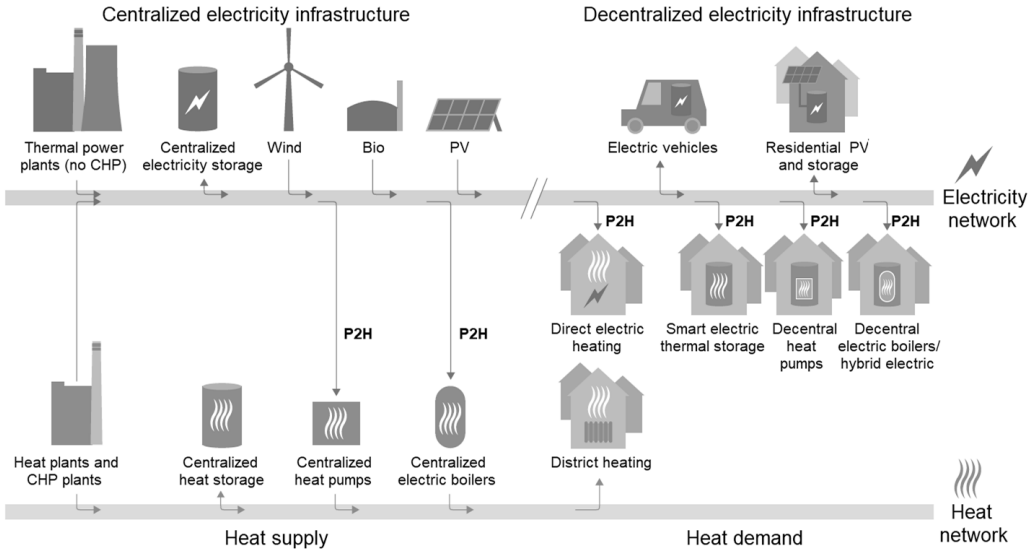

Fig. 4. Interconnections of power-to-heat options with electricity and district heating networks
Source: Bloess et al., 2018

The potential of RES in district heating and their efficiency is growing rapidly with the development of heat storage technologies. Seasonal storage facilities make it possible to store surplus energy from renewables and CHP units during the summer season.

4. INTELLIGENT HEATING SYSTEMS IN POLAND

Polish energy companies are increasingly creating smart district heating networks using IT tools and teletransmission systems in the following areas (Komosa and Kiedrowski, 2013; Rak, 2016; Wojdyga and Chorzelski, 2017):

- using telemetry to monitor and control the operation of the heating network,
- forecasting changes in heat demand and adjusting the operation of sources and pumping stations to this, taking into account weather conditions,
- widespread automation of the operation of district heating nodes,
- introduction of intelligent supervisory and control systems with visualization of processes,
- implementation of specialized software for managing heat production and transmission based on market models of heat supply regulation.

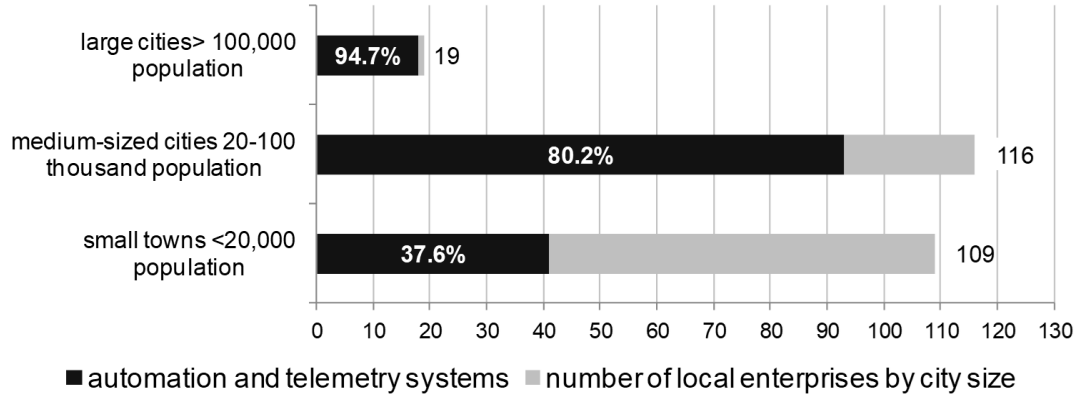

Fig. 5. The degree of use of automation and telemetry systems in local heating enterprises
Source: own study

On the basis of the conducted research, it was found that automation and telemetry systems are implemented in 62.3% of local district heating companies in Poland, with the prevalence of their use being highest in large cities (94.7%) - Figure 5. The second important component enabling the creation of a smart district heating network is the implementation of innovative IT technologies for planning and managing the operation of the district heating system. The degree of uptake of IT systems in district heating companies depending on the population of the city, i.e. the complexity of the district heating system, is illustrated in Figure 6.

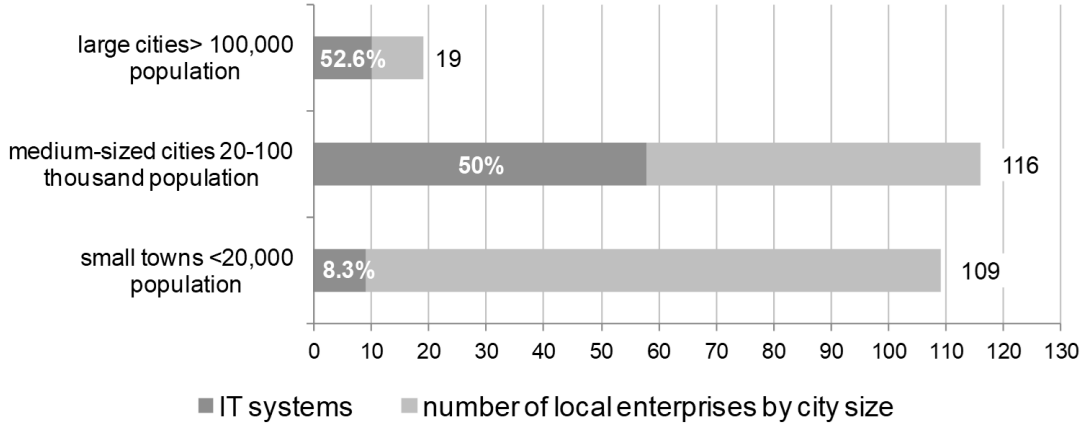

Fig. 6. The degree of dissemination of IT systems in local heating enterprises
Source: own study

Based on the analysis of data included in the annual reports of local heating companies and information from their websites, 20 companies were identified that declare that their heating networks are intelligent. Based on a detailed analysis of the data contained in the annual reports of 250 local district heating companies and information from their websites, 20 companies were identified that declare their district heating networks to be smart. These are mainly enterprises operating in the largest cities (e.g. Warszawa, Kraków, Łódź, Wrocław, Poznań, Szczecin, Lublin, Toruń, Rzeszów, Olsztyn), and of the remaining ones, those characterised by high efficiency

of technological innovation implementation (e.g. Siedlce, Ostrów Wielkopolski, Łomża and Przemyśl).

It should be noted that one of the directions of the Polish energy policy (PEP2040) is to increase the use of RES and waste in district heating, modernise and expand heat and cold distribution systems and popularise heat storage and smart grids (Ministry of Climate and Environment, 2021)

5. CONCLUSION

The concept of sustainable development, including the climate policy implemented in EU countries, supports the transformation of the heating sector through mechanisms that promote increased energy efficiency, the development of renewable energy sources, prosumer energy, digitalisation and the implementation of innovative technologies. The policy of decarbonisation and reduction of greenhouse gas emissions is forcing a shift away from fossil fuels to renewable energy sources. Therefore, over the next few years, district heating in many EU countries will be an area of accelerated technological change and transformation of district heating systems towards efficient and low-carbon systems with an increasing share of energy from renewable sources. Efficient 4GDH and 5GDH district heating systems can play a key role in this process. Switching to renewable energy sources for district heating can help meet the growing energy needs of cities, improve efficiency, reduce dust and gas emissions and provide cost-effective temperature control. Flexible integration of the power and heat sectors in smart energy systems should contribute to both renewable energy integration and energy decarbonisation. Smart district heating networks promise to reduce operating temperature, optimise the management of multiple energy sources, and provide increased flexibility to the grid and the end users.

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