30th NENE 2021
September 6 - 9
BLED-SLOVENIA
International Conference Nuclear Energy for New Europe

Evaluating the TEPLATOR Concept as a Nuclear Heating Solution Compared with other Alternatives in the Czech Republic

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ABSTRACT

The heating sector accounts for about 56% of the total final energy consumption in the Czech Republic. District Heating Systems (DHSs) supply nearly 40% of the residential heating demand where the heat sources are mainly coal-based heat-only or CHP plants, causing significant emissions of CO2. For limiting CO2 emissions, the termination of coal combusting in the Czech Republic is expected to be in 2038. Consequently, the energy policymakers and the companies are intensively looking for alternatives to fossil fuel-based plants for serving the heating needs. The other options are categorized into electric-based and non-electric-based DHSs, where different kinds of primary energy sources contribute to electricity generation or to only-heat generation. In both approaches, nuclear energy can be one of the primary energy sources. On the other side, a nuclear heat-only concept, namely TEPLATOR, is under development to be a carbon-free solution for the heating sector. In this study TEPLATOR concept is introduced, the heating sector and the available energy sources in the Czech Republic are discussed. Moreover, the advantages and disadvantages of the TEPLATOR heating concept compared with the other alternative options such as coal, natural gas, biomass, and electric-based heating technologies, are presented. Carbon emissions reduction, lower heat generation cost, economizing the expansion of DHSs in the lower heat demand density areas are some of the important advantages evaluated in this study. Finally, the benefits of this approach are formulated and calculated for a typical case study in the Czech Republic, which confirms the superiority of this nuclear heat-only concept in district heating applications.

1 INTRODUCTION

About 60% of total final energy consumption in the Czech Republic is for heating applications, as presented in Fig. 1 [1]. The residential sector in the Czech Republic is responsible for nearly 30% of the annual energy demand, as shown in Fig. 1, where space and water heating purposes share for about 80% of the total residential energy consumption, as represented in Fig. 2.

Currently, nearly 70% of the residential heating is supplied by fossil fuels [2], contributing almost 40% of the total EU CO_2 emissions [3]. Consequently, the attempts to cover this considerable share of the heating energy sector with higher efficiency technologies and clean energy sources can effectively decrease CO_2 emissions and supply the heating demand economically with a lower cost.

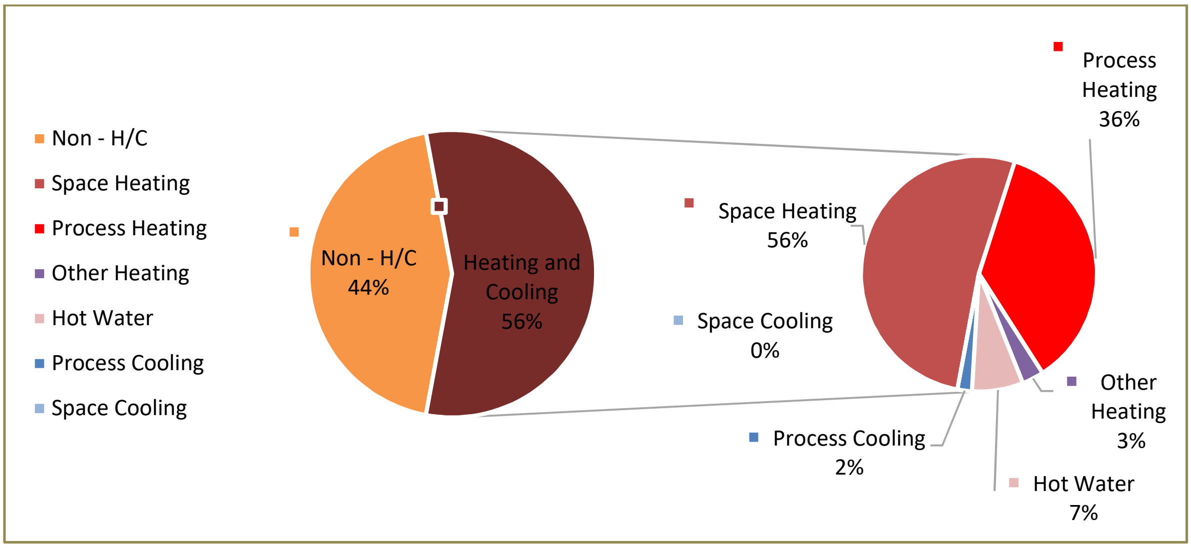

Figure 1: Heating energy consumption in the Czech Republic [1]

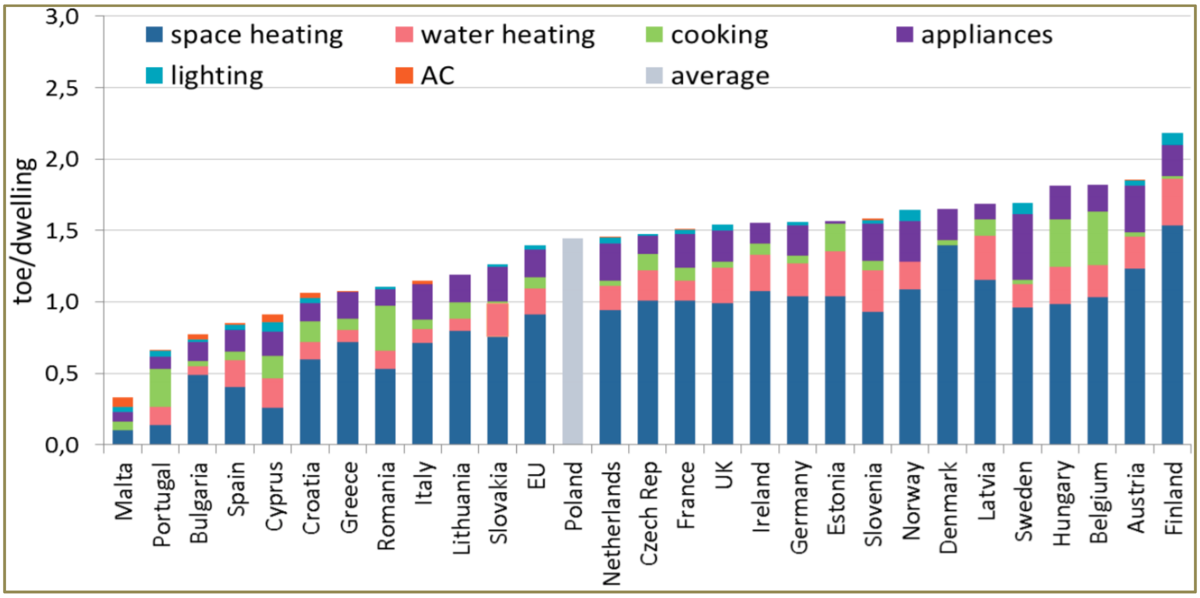

Figure 2: Breakdown of residential energy consumption in EU [4].

One recently investigated concept for district heating applications is a heat-only nuclear reactor, namely TEPLATOR. “The TEPLATOR is a critical assembly derived by the state-of-the-art computational tools using better moderation, more optimal fuel lattice pitch, lower fuel temperature, lower coolant pressure for producing commercial heat, using either used BWR, PWR or VVER irradiated fuel assemblies (FAs) or also can be operated with fresh fuel” [5]. Each unit of the TEPLATOR reactor can be operated within 50-150 thermal MW output producing hot water with a temperature of 98 °C appropriate for district heating applications. A schematic view of the reactor is shown in Fig. 3, and the plant layout is presented in Fig. 4. More details and comprehensive information about this technology are accessible in the previous studies [6] – [9].

This concept is developed to be implemented to expand the district heating networks or replace the out-dated fossil fuel-based heating plants considering that the Czech Republic aims to stop using coal combusting in 2038 where nearly 50% of the heating energy is used is currently produced by coal-based plants.

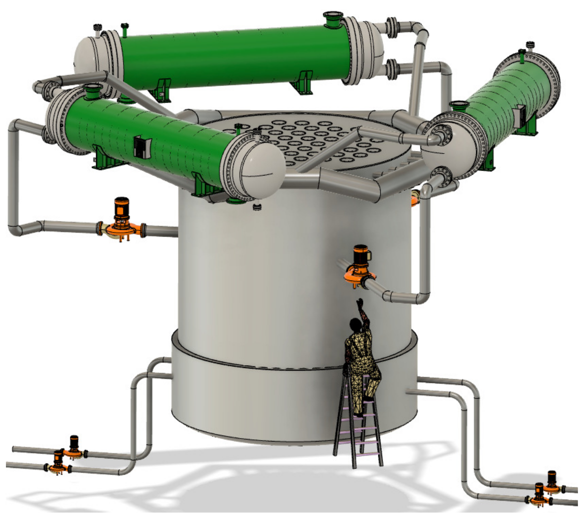

Figure 3: Schematic view of TEPLATOR and the primary heating cycle [5]

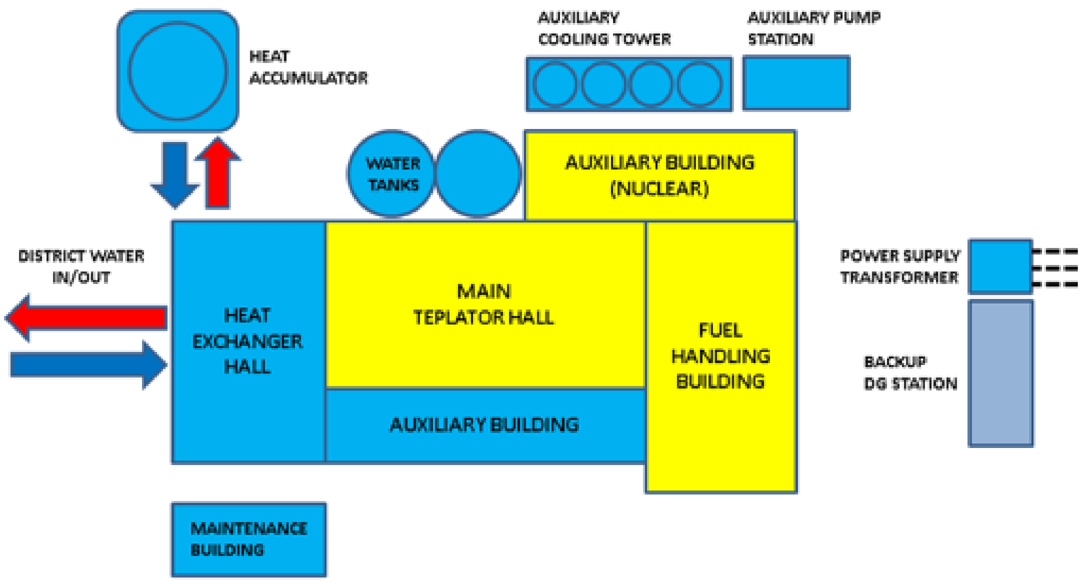

Figure 4: TEPLATOR plant layout [5]

Compared with conventional heating technologies such as natural gas, coal, and electric-based heating plants, TEPLATOR is a carbon-free heat source. Thanks to the reusing the spent nuclear fuel (SNF), no more spent nuclear fuel is produced. The local resources of the SNF available from Dukovany NPP (2,306 FAs) and in the neighboring countries are enough for fuelling this technology for many decades with nearly zero fuel cost. This nuclear technology has a life cycle of 60 years, while the conventional technologies are expected to operate for 25-40 years efficiently. The generated heat by this technology is estimated to be 4 EUR/GJ, and this low cost may encourage the heat supplying companies to extend the district heating networks covering even the areas with a low heat demand density. These advantages are evaluated in this study.

2 PROBLEM STATEMENT AND FORMULATIONS

District heating systems mainly consist of heat sources, heat storage, transmission, and distribution networks supplying the consumers, as shown in Fig. 5. The heat storages are necessary for balancing the energy demand variations. The essential role of the peak shaving decreases the required heating capacity leading to a significant reduction in investment cost [10]. Widely different heat-storing technologies can be used while the phase-change material-based technologies such as molten salt are promising concepts [11].

On the demand side, the consumers have two options for their heating needs: buying the heat from the district heating companies or using their individual boilers, depending mainly on the final cost of the received heat. Therefore, the DH companies aim to extend their networks to improve their profit need to evaluate the final district or local heating energy cost at the end-user side.

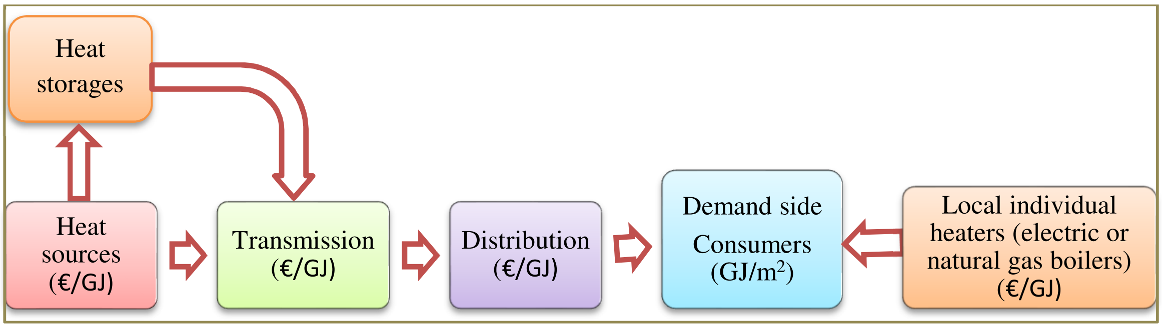

Figure 5: District or local heating options

On the heat generation side, the heat sources may be from different types of technologies categorized into electric-based and non-electric-based technologies (Fig. 6. Each technology generates heat with a different cost depending mainly on the fuel and investment costs. The heat transmission and distribution cost are higher in the fewer demand-density areas. Consequently, as we generate the heat at a lower cost, the final heat cost to the end-users can be competitive even at the lower heat demand density areas. Therefore, eliminating the heating consumption of fossil fuels in the outer cities or in the low population density areas may be economically possible. The Nuclear heat-only concept, namely TEPLATOR, which generates heat at low-cost thanks to reusing the SNF, makes the district heating feasible even in the low heat demand density areas. This study evaluates this vital superiority.

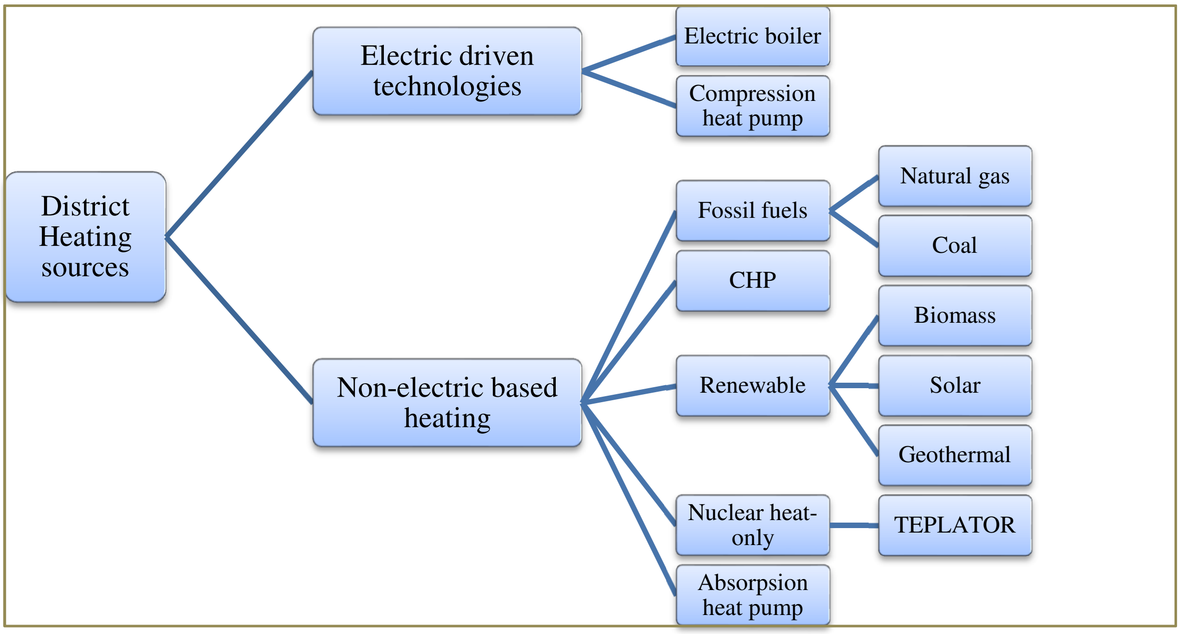

Figure 6: District heating technologies

To evaluate the average district heat energy cost delivered to the consumers here simplified formulations are used. The energy cost at the end-user (*DH^{eu}*) is formulated in (1), where we use the levelized costs for heat generation (*DH^{g}*) and distribution (*DH^{d}*) (including the transmission). The district heat distribution cost is formulated as a quadratic function of the heat density (*hd*) in (2), where the factors a, b and can be found using the available data and curve fitting method.

$$DH^{eu}(€/GJ) = DH^{g} + DH^{d} \quad (1)$$

$$DH^{d}(€/GJ) = \mathrm{a} \times hd^{2} + \mathrm{b} \times hd + c \quad (2)$$

3 CASE STUDY AND RESULTS

To evaluate how the low-cost heat generated by the TEPLATOR concept can contribute to extending the district heating share, the levelized heat distribution cost presented in Fig. 7 is used. A quadratic curve modeling the heat distribution cost is extracted using the fitting method shown in Fig. 8.

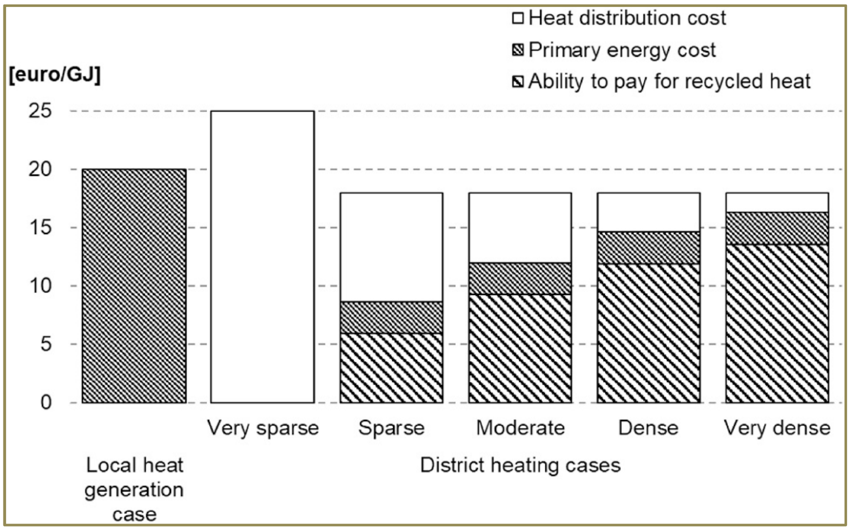

Figure 7: The levelized cost of heat distribution in different heat density demand areas [12].

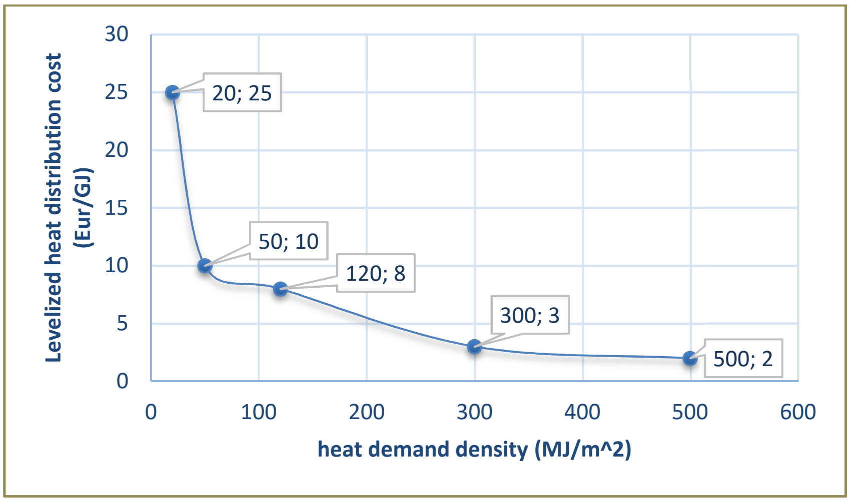

Figure 8: Levelized heat distribution cost as a function of heat demand density.

The levelized costs of the district and local heat generation by different technologies are illustrated in Table .1. These costs are evaluated in [13] for Germany, which are generally near to the costs in the Czech Republic.

District Heating generation cost (€/GJ)		Local heating cost (€/GJ)	
Gas boiler	8	Gas boiler	14.7
Biomass boiler	11.4	Electric Boiler	18
Teplator	4		

Fig. 9 represents the resulted levelized total cost of the district heating supplied by different technologies. Comparing with the local heating using natural gas, district heating system is the feasible and beneficial option even in the moderate heat demand density areas (hd>50 MJ/m^2) in case of using TEPLATOR technology, while the DH using the conventional heat sources (such as natural gas-based boilers) will be feasible only in the dense areas (hd>120 MJ/m^2). Biomass DH is not competitive in areas with a heat density of up to 250 MJ/m^2.

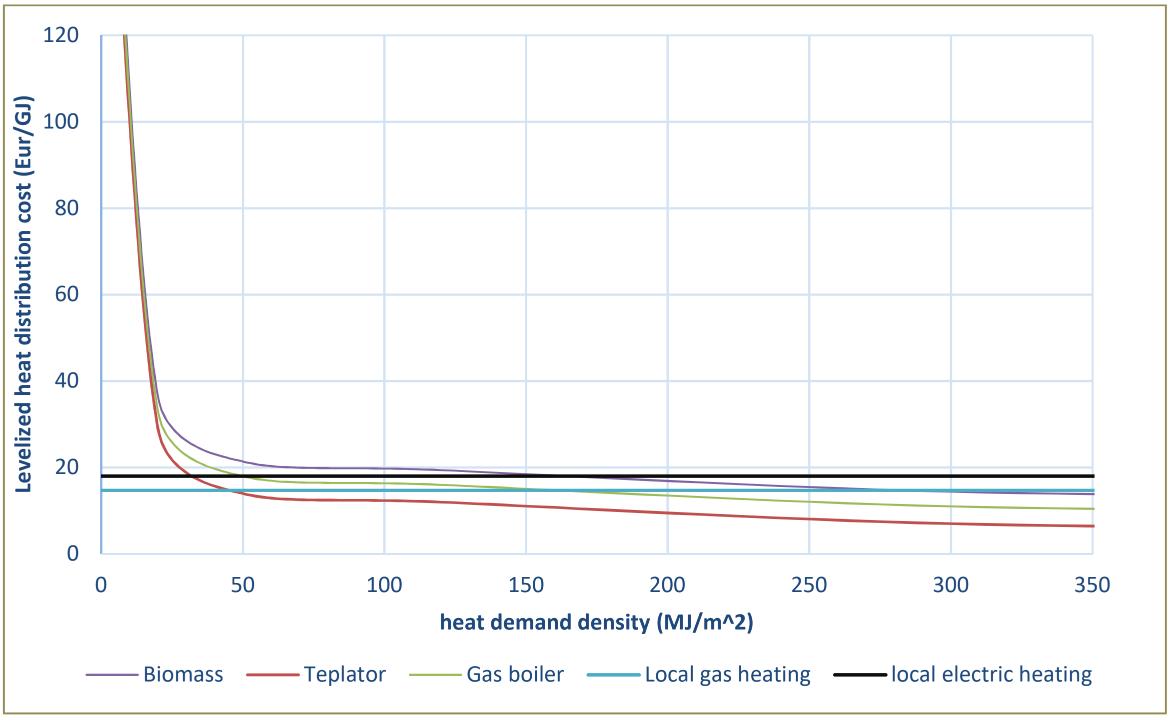

Figure 9: Heating costs using different technologies as a function of heat demand density

3.1 Conclusion

The low-density populated areas share a large part of most of the EU countries, and up today supplying their heating demand by extending district heating systems is nonbeneficial for the DH supplier companies. Therefore, the people use their local heating systems, mainly fossil fuel or electric-based technologies, contributing a considerable part of CO_2 emissions.

The district heating systems consist of two main parts, heat source and distribution network. However, the high cost of the heat distribution limits the expansion of these systems to the high-density populated regions. On the other side, decreasing the heat generation cost reduces the total heating cost. Therefore, this is an opportunity to economically expand DH systems in less population/heat demand density areas.

One of the recently introduced nuclear heat-only concepts (TEPLATOR) can produce heat at a considerably lower cost than conventional or even renewable heating technologies. This cheap energy is mainly raised from reusing the spent nuclear fuel and the low construction cost due to the operation under low pressure and temperature, reducing the required vessel thickness.

This study confirms the capability of low-cost heat generation as a vital advantage in encouraging the companies to develop their heating industry, covering even the outer city areas with DH systems economically. Consequently, a large part of CO_2 emissions will be eliminated where there is no feasible chance for the contribution of clean energies such as biomass or solar.

ACKNOWLEDGMENTS

This work was supported by the UWB university grant [SGS- 2021-018], and by the Czech technological agency grant [TK 03030109].

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