Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 7 (2021) 401–409
www.elsevier.com/locate/egyr

The 17th International Symposium on District Heating and Cooling, Nottingham Trent University, 17th DHC Symposium, 6–9 September 2021, Nottingham, UK

Estimating energy efficiency increase in national district heating network

Ieva Pakare[a,*], Armands Gravelsins[a], Dace Lauka[a], Dagnija Blumberga[a]

[a] *Institute of Energy Systems and Environment, Riga Technical University, Azenes street 12/1, Riga, Latvia*

Received 26 July 2021; accepted 7 August 2021

Abstract

A comprehensive methodology has been developed to assess the efficiency potential of national heating networks. Considering the available information on heating networks in Latvia, three different heating system models have been identified depending on the district heating (DH) system scale. To determine the total length of heating networks in populated areas, a regression analysis method is used by analysing the correlation between the inhabitants and the length of heating networks. Authors define different alternatives for heat loss reduction, including the renovation of existing heat pipes and lowering heat carrier temperature. An engineering model is prepared for each alternative based on mathematical calculations to evaluate the economic, environmental, and climate impacts. Estimated costs and savings are used to determine the key economic indicator — net present value (NPV).

The results show that the potential reduction in national heat losses from heating network renovation is estimated at 569 GWh. It would reduce the national heat loss rate from around 12% to 6% from the produced heat. Lowering the heating network temperature saves an additional 57 GWh. However, the main benefit of lowering heat carrier temperature is the possibility to use low-cost plastic pipes, which increases the overall economic benefit of the heating network renovation.

Peer-review under responsibility of the scientific committee of the 17th International Symposium on District Heating and Cooling, Nottingham Trent University, 17th DHC Symposium, 2021.

Keywords: District heating; Low temperature heat supply; Cost-benefit analyses; Energy efficiency

1. Introduction

The assessment of national heat supply is complex as it consists of many local district heating (DH) systems and individual heat supply solutions. There are different methods for energy system modelling at the district level, including various technical simulations and decision-making tools [1]. However, the lack of specific data related to the technological solutions of heat production plants, heating network parameters, and consumers is a problem when developing such heat supply assessments on a national scale. For the heat consumer analyses, Calikus et al. [2] have offered a method for estimating consumer heat load by clustering customer profiles into different groups and

* Corresponding author.
E-mail address: ieva.pakere@rtu.lv (I. Pakare).

https://doi.org/10.1016/j.egyr.2021.08.088

Peer-review under responsibility of the scientific committee of the 17th International Symposium on District Heating and Cooling, Nottingham Trent University, 17th DHC Symposium, 2021.

identifying representative patterns. The method has been applied for different customer categories connected to two DH networks in the south of Sweden. Narula et al. have used data of 54 different DH systems in Switzerland for the national evaluation [3]. The authors have evaluated the minimal, maximal, and median values of several parameters — sold heat, connected load, network length, linear heat density, and capacity utilization factor for the evaluated data set. Unfortunately, not all countries have such detailed databases of DH systems.

Mapping is a possible method of identifying different energy sources available and estimating the national heat density and future DH development potential [4]. However, the precise length of heating network pipelines is usually not included in such an evaluation. Chambers et al. [5] have offered to use the Minimum Spanning Tree (MST) method to estimate potential heating networks by calculating the shortest set of connections between buildings. However, this method can only be used with the national scale thermal atlas and determine the potential DH network, not the actual system length.

To overcome the existing data gap related to national heating network analyses, the authors present a comprehensive methodology for both the data acquisition and the economic analysis of the national district heating system. The methodology has been applied for the heat supply system of Latvia by generalizing the survey data of different local DH systems. As a result, the energy efficiency potential in the DH network from modernization of heat pipes and introduction of the 4th generation DH concept [6] with lower heating carrier temperature has been determined.

2. Methodology

In the analysed case study – the heat supply system in Latvia – there are around 70 different small and large-scale DH systems. However, for now, there is no comprehensive database containing the main DH system parameters. The lack of information regarding local DH systems is often the bottleneck of the overall national heat supply analyses, which is also in line with the other studies [4,5]. The overall algorithm of the proposed methodology to determine the missing information and estimate the potential for national energy efficiency improvements of heat supply is showed in Fig. 1.

The main starting point of the methodology is collecting available historical data of technological parameters and the operation of particular DH systems. The general data from statistical databases, surveys, and analysis of available literature, including previous DH studies, is the primary input for the definition of reference DH systems covering the total national heat supply. Taking into account the available information on heating networks in Latvia, three different transmission system models have been defined regarding the analysed system scale:

- Model 1 – Large-scale system (more than 100 thousand inhabitants);
- Model 2 – Average-scale system (25 to 100 thousand inhabitants);
- Model 3 – Small-scale system (less than 25 thousand inhabitants).

The main evaluation criterion is the number of total inhabitants in the particular populated area where the DH system exists. The main purpose of the models is to create reference DH systems that can be generalized. Those are further applied to regions for which detailed information on DH networks (including pipe lengths and diameters) is unavailable. There is only one city in Latvia with more than 100 000 inhabitants represented by Model 1. However, it accounts for more than 50% of total heat generation in Latvia. Therefore, this DH system has been evaluated separately. Model 2 includes the eight largest DH systems of main cities, but in Model 3, 49 DH systems of smaller towns and parishes are included.

2.1. Case study

In Latvia, heat is produced in boiler houses and cogeneration plants by simultaneously producing electricity. The main fuel in the energy sector is natural gas (accounts for 57.8% of consumed primary resources), but 41.8% or 6736 GWh is produced from wood biomass. Most of the heat is produced in cogeneration plants, which has increased in recent years. Cogeneration plants use natural gas, biogas, and wood chips as the primary fuels. Boiler houses generate about 24% of the total heat produced. Since 2008, the number of natural gas boiler houses has decreased by 14%, but the number of wood biomass boiler houses has increased rapidly.

The total length of heating networks in Latvia is about 2000 km. Most (approximately 56%) of the heating pipelines were built more than 25 years ago, but 60 km of heating networks will be restored by 2020 [7]. The

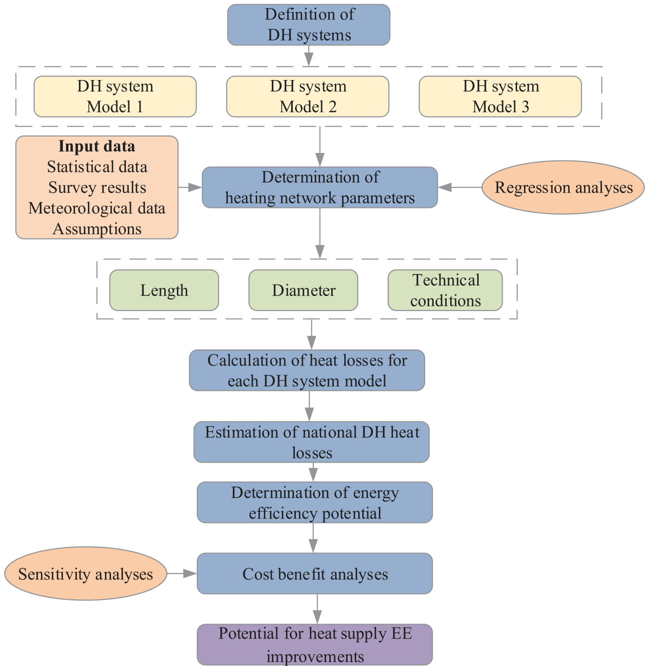

Fig. 1. Overall flow chart of the proposed methodology.

share of heat losses in Latvian DH systems varies from 10% to more than 30% of the amount of heat supplied. Heat losses have been on a declining trend since 2009, mainly due to increasing the energy efficiency of heating networks and optimizing the heating network length. The average heat loss ratio to the produced heat in 2017 was 12%.

There is no detailed database regarding the main technical parameters of different DH systems, such as heating network length and conditions and heat source capacities. A detailed survey on characteristics of DH systems conduced in 2015. However, 36% of DH operators did not provide the necessary data, and there have been changes in the operational conditions since 2015. Therefore, it is hard to develop detailed heat supply system assessments without a more accurate data set.

2.2. Technical analyses

A regression analysis method was used to determine the more precise length of heating networks, analysing the correlation between the total population in particular cities and smaller towns and the length of heating networks (see Fig. 2). The regression analyses are used to analyse those DH systems included within Model 2 and Model 3, but not for the capital city Riga, which is included in Model 1, representing a single DH system. Fig. 2 shows that the goodness of fit is high in both cases. Therefore, the obtained empirical equations can determine the heating network length using the population of particular towns and cities and the data from a previously conducted survey on heating network lengths [7]. The total determined heating network length for cities included in Model 2 is 460 km, but the total length in other districts and county centres of Model 3 is 593 km. The DH system's total heating network length in Riga (Model 1) is 756 km [8].

The heat losses vary significantly depending on the diameter of the heat pipes. Figs. 3 and 4 show the distribution of pipelines by diameter for old and new heating lines in different reference models. Most of the heating pipelines have an internal diameter of 65 to 200 mm. The internal diameter of the main pipelines reaches up to 1200 mm. The distribution is determined by the previous studies [7]. As illustrated, the main pipelines in the smallest DH systems (Model 3) have an internal diameter of 70 or 80 mm, but in Model 2 - with an internal diameter of 110, 200, and 250 mm.

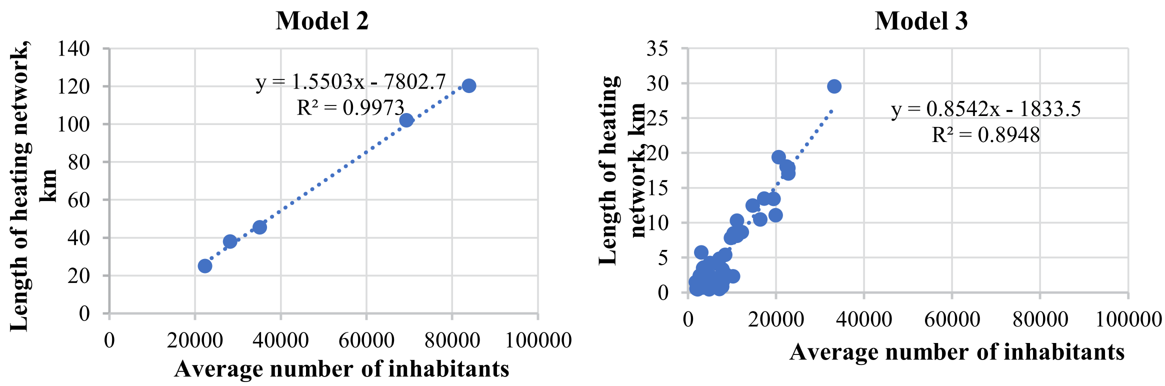

Fig. 2. Regression analysis models for determination of heating network lengths.

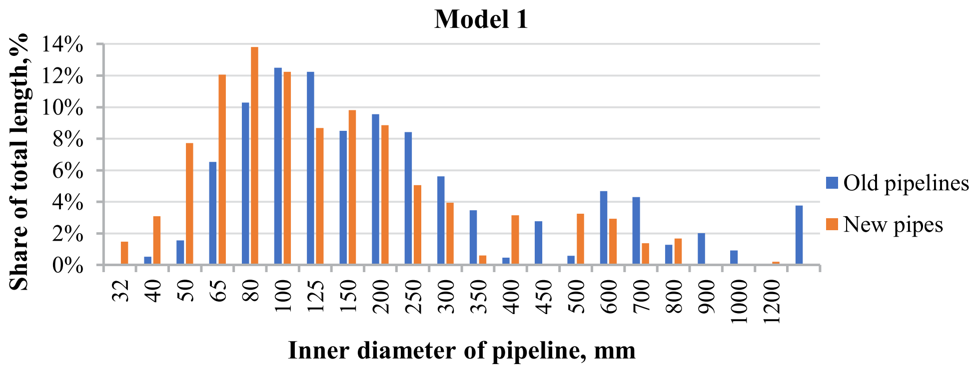

Fig. 3. Distribution of heating pipes according to inner pipe diameter in Model 1.

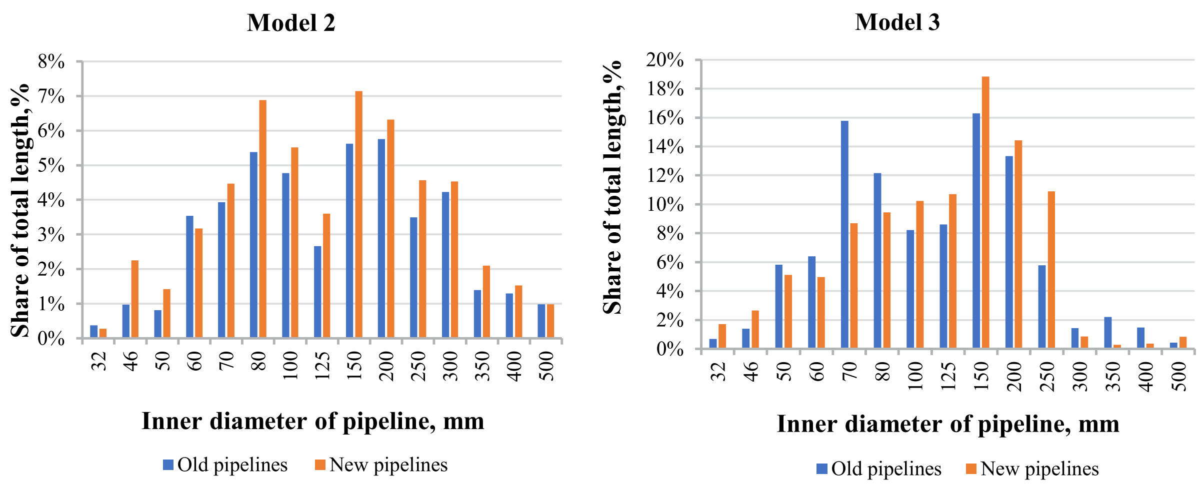

Fig. 4. Distribution of heating pipes according to inner pipe diameter in Models 2 and 3.

An important factor affecting the heat transfer losses is the technical condition of the heating networks pipes and the thermal insulation parameters. Those factors are different for new, industrially insulated pipelines and older heating lines. Therefore, the calculation of heat losses is done separately for old and new heating lines. The transmission loss models use both the available information on the age of the heat pipelines and assumptions about the distribution of old and new heat pipelines. [7].

According to Eq. (1) [1], a heat loss calculation was performed by considering the available information regarding the diameters, lengths, and condition of heat pipes.

$$\sum q_{i,n} = \frac{(t_{sup} + t_{ret} - 2t_{gr})}{R_{pipe\ i,n} + R_{insul\ i,n} + R_{shell\ i,n} + R_{ground\ i,n} + R_{inter\ i,n}} \tag{1}$$

where q is the linear density of the particular pipe size i and pipe type n; t_{sup}, t_{ret}- supply and return water temperatures; t_{gr}-average ground temperature; R_{pipe}, R_{insul}, R_{shell}, R_{ground}, R_{inter}- linear resistance of inner pipe, insulation, shell, ground, and pipes.

The linear resistance coefficients for different pipe types have been calculated according to the methodology described by Ziemele et al. [1]. Table 1 summarizes the main assumptions for the calculations that are based on the information provided by the heat pipe suppliers.

Table 1. Assumptions for the determination of the linear heat transfer coefficient [1].

Assumption	Value
Soil temperature	+8 °C
Coefficient of thermal conductivity of pipe wall	50 W/(m K)
Heat transfer coefficient of the pipe casing	0.43 W/(m K)
Thermal insulation heat transfer coefficient for new heating pipes	0.03 W/(m K)
Thermal insulation heat transfer coefficient for old heating pipes	0.45 W/(m K)
Depth of pipe-laying	1.5 m
Distance between supply and return pipes	0.15 m

The linear density of the heat flow is determined at different flow and return temperatures depending on the outdoor air temperature. The total heat loss Q (Wh) is calculated according (2).

$$Q = q_{i,n} \cdot L \cdot T \tag{2}$$

where L - total length of heat supply lines, m; T - number of heating hours, h.

The calculation assumes an average DH temperature regime of 95/75 (maximal supply temperature of 95 °C and a return temperature of 75 °C, adjusted to actual outdoor temperature) to determine the total heat losses. The average number of hours at various outdoor air temperatures is used [9]. The calculation assumes that thermal energy in Models 1 and 2 is used for heating and domestic hot water production. Therefore, the heat is delivered to consumers year-round (8760 h). Due to the smaller number of consumers in DH systems of Model 3, it is assumed that DH provides the heat mainly for space heating. Therefore, the operation period is shorter (around 8000 h).

The obtained total heat losses from transmission loss models are compared with the available official statistical data regarding the national DH heat losses (see Fig. 5.) [10]. Due to lack of data, the results from Model 2 and Model 3 are not compared separately. The main assumptions regarding the linear heat transfer coefficient of pipelines were adapted to align with the actual situation. Therefore, calculated and actual heat losses are negligible, and the developed heat loss models can be used to model energy efficiency scenarios.

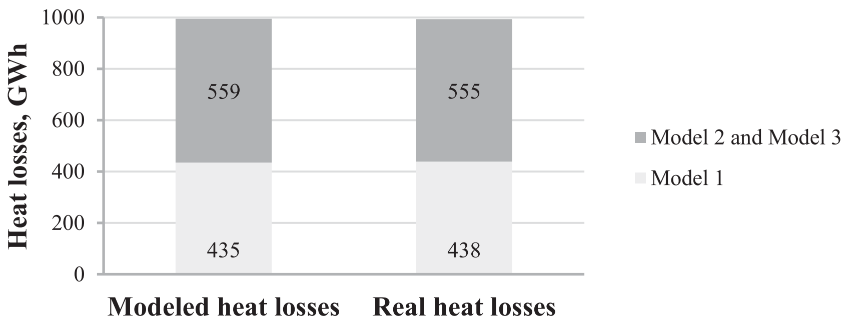

Fig. 5. Validation results of transmission heat loss models.

Two different energy efficiency scenarios have been analysed within the particular study by using mathematical estimations:

Scenario 1: Modernization of DH heating network, which assumes that all outdated pipes have been replaced;

Scenario 2: 4GDH scenario, which assumes both the modernization of heating network and lowering of heating network temepratures.

2.3. Cost-benefit analyses of analysed scenarios

The cost-benefit analyses have been performed to evaluate the economic and environmental benefits of the heating network's potential energy efficiency increase. The average heat tariff in Latvia was used to determine the economic savings from reducing heat losses. According to the Public Utilities Commission [11], it was 54.4 EUR/MWh in 2017. The calculation assumes that the heat tariff increases each year due to the growth of resource costs. The increase is modelled by using available national statistical data [10] on heat costs for the end-user. The empirical equation shown in Fig. 6 is used for the determination of the heating pipeline's specific costs.

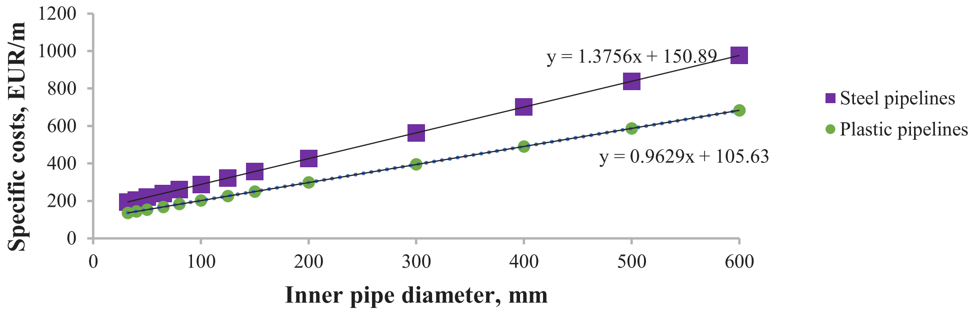

Fig. 6. Specific costs of steel and plastic pipelines [12].

The present value (NPV) of the project is identified as the primary indicator for assessing the financial results of scenarios. The assumptions used in the calculation to determine the discount rate are summarized in Table 2. It is assumed that the available co-financing for the replacement of the heating pipelines will be increased, which means that the own contribution of the heating companies will be 20% of the total costs.

Table 2. Assumptions for economic analyses [13].

Assumption	Value
A lifetime of heat pipelines	25 years
The proportion of own contribution, %	20%
Fixed profit margin, %	10%
Borrowing rate	8%
Leverage ratio	80%
Inflation	5%
Weighted cost of capital or discount rate	9.5%

The potential environmental benefit when reducing heat transfer losses is determined by multiplying the saved amount of energy by the particular CO_2 emission factor. The main energy sources used for heat production are natural gas, wood biomass, and biogas (see Section 2.1.). According to the Ministry of Environmental Protection and Regional Development, the average CO_2 emission factor for DH is 0.1114 tCO_2/MWh [14].

3. Results

This section presents the technical and economic results of two different energy efficiency scenarios applied for the developed national DH system models.

3.1. Scenario 1- Modernization of DH heating network

Scenario 1 assumes replacing old heat pipes in all analysed regions described by Models 1–3. The estimated total length of the outdated pipelines is 862 km. Energy efficiency improvement costs are related to the replacement of heating network pipelines — material costs, digging and backfilling of heating lines, restoration of pavement, etc. The total cost of replacing all outdated pipelines (installed before the year 2000) is around 371 million EUR.

The total energy savings from the replacement of heating pipelines have been determined using the developed transmission loss models. The heat transfer coefficient of the thermal insulation of the heating pipeline decreases from 0.45 to 0.03 W/(m °C) due to the installation of new heating pipes. Replacement of the heating lines reduces the total amount of heat loss by 51% or 512 GWh per year. A further economic assessment assumes that the heat loss savings reduce by 0.5% each year due to the aging of replaced heat pipes. The estimated CO_2 saving is 58 038 tCO_2 per year.

The total savings from the decrease of heat losses at the corresponding heat tariff is 27 million EUR. According to assumptions, the NPV value of the project reaches — 117 thousand EUR, reflecting high investments and insufficient financial savings. The obtained economic results are shown in Fig. 7.

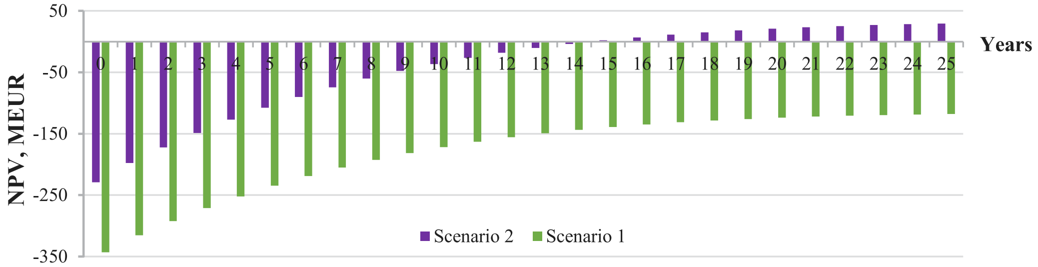

Fig. 7. NPV values for Scenario 1 and Scenario 2.

3.2. Scenario 2- 4GDH scenario

In addition to the energy efficiency scenario analysed above, the transition to 4GDH is considered. Further evaluation analyses that the flow temperature is reduced by 20 °C during the peak load period, but it is only slightly reduced at outdoor air temperatures above 0 °C (see Fig. 8). Further economic evaluation analyses the heat carrier temperature above 60 °C to prevent the formation of dangerous Legionella bacteria without modification of hot water preparation systems [15].

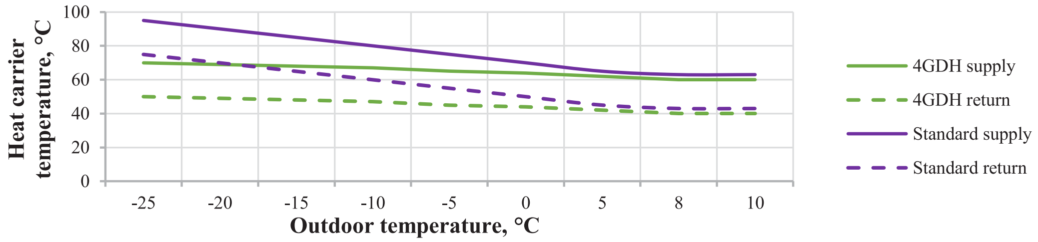

Fig. 8. Temperature regimes for the analysed scenarios.

Lowering the temperature of the heating networks involves the provision of appropriate conditions and parameters (appropriate heat distribution systems in buildings, customized heat exchangers, etc.). The amount of investment required to implement these measures is related to the specific DH system's specific parameters — the proportion of energy-efficient buildings, the number of heating units to be reconstructed, etc. In most cases, lowering the temperature of the networks requires no additional investment, only careful monitoring of various transmission errors and long-term planning for the creation of low-temperature housing estates.

The potential reduction of heat losses in Scenario 2 due to heat pipe reconstruction and temperature reduction is estimated at 569 GWh or 57%. Lowering the grid temperature saves 57 GWh compared to Scenario 1. The estimated CO_2 savings is 64 513 tCO_2 per year.

When switching to a lower temperature regime, it is possible to use cheaper plastic pipes. Consequently, the calculation assumes that the specific costs of heat pipelines would decrease (see Fig. 6). As a result, the NPV value obtained in Scenario 2 reaches 29 568 thousand EUR (see Fig. 8.). Therefore, the main financial savings in this scenario occur due to cost-effective plastic pipelines.

4. Conclusions

The development of a comprehensive national heat supply assessment requires a quantity of technical and operational data from numerous local DH systems, which usually is not compiled. To overcome the lack of specific data, the authors present a comprehensive methodology for national DH assessment and division in three main system models depending on the total number of inhabitants in the populated area.

The methodology has been applied to analyse the national heat supply system of Latvia. The article presents the cost-benefit analyses for the energy efficiency increase in the heat distribution system. In addition, regression analysis is used to determine the total length of DH pipelines. Evaluation includes two different scenarios — modernization of old heating networks and additional heat carrier temperature lowering according to the 4GDH concept.

The modelled total length of the outdated pipelines is 862 km. The total cost for replacing all outdated and inefficient pipelines is 371 million EUR. After the energy efficiency measures, the national heat losses are reduced by 51%. The total savings from the reduction of losses at the corresponding heat tariff is 27 million EUR. The estimated CO_2 savings are 58 038 tCO_2 per year. According to the assumptions, the NPV value in Scenario 1 is negative due to high investments and insufficient financial savings.

When analysing the heating network modernization with additional heat flow temperature reduction by 20 °C, the potential reduction of heat losses is 569 GWh or 57%. Lowering the heat transmission temperature saves 57 GWh. The estimated CO_2 savings in Scenario 2 is 64 513 tCO_2 per year. The main benefit from lower heat supply temperatures is the possibility of using cheaper plastic pipes and the NPV value obtained in Scenario 2 reaching 29 568 thousand EUR.

The proposed methodology for estimating main heating network parameters can be applied in more complex modelling tools. It can be used to analyse DH heating network modernization in other countries and estimate the energy efficiency potential through thermal insulation improvements and heating network temperature lowering. The identified regression analyses could be adjusted and used for DH network length determination by using the population of the urban areas as the primary input parameters. Other necessary input data are related to the shares of new and old pipelines, differences in the diameters of the pipes, operational time, and district heating network temperatures.

Further analyses related to the energy efficiency improvements of the heating network could analyse different policy support measures and more specific technical solutions and estimations regarding the possibility of reducing heating network temperature.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The research is funded by the Ministry of Economics of the Republic of Latvia, project “Development of heat supply and cooling systems in Latvia” (project No. VPP-EM-EE-2018/1-0002).

References

[1] Ziemele J, Pakere I, Talcis N, Blumberga D. Multi-criteria analysis of district heating systems in Baltic states. Energy Procedia 2014;61:2172–5;
Calikus E, Nowaczyk S, Sant'Anna A, Gadd H, Werner S. A data-driven approach for discovering heat load patterns in district heating. Appl Energy 2019;252(January). http://dx.doi.org/10.1016/j.apenergy.2019.113409.

[2] Calikus E, Nowaczyk S, Sant'Anna A, Gadd H, Werner S. A data-driven approach for discovering heat load patterns in district heating. Appl Energy 2019;252:113409.

[3] Narula K, Chambers J, Streicher KN, Patel MK. Strategies for decarbonising the Swiss heating system. Energy 2019;169:1119–31. http://dx.doi.org/10.1016/j.energy.2018.12.082.

[4] Lund R, Persson U. Mapping of potential heat sources for heat pumps for district heating in Denmark. Energy 2016;110:129–38. http://dx.doi.org/10.1016/j.energy.2015.12.127.

[5] Chambers J, Narula K, Sulzer M, Patel MK. Mapping district heating potential under evolving thermal demand scenarios and technologies: A case study for Switzerland. Energy 2019;176:682–92. http://dx.doi.org/10.1016/j.energy.2019.04.044.

[6] Pakere I, Gravelsins A, Lauka D, Bazbauers G, Blumberga D. Linking energy efficiency policies toward 4th generation district heating system. Energy 2021;234:121245.

[7] Ekodoma. Collection and analysis of data needed for heat supply planning. In: Long-term trends of district heating until 2030 (in Latvian). Ltd Ekodoma; 2015, http://petijumi.mk.gov.lv/sites/default/files/file/pielikums_petijums_EM_2015_par_siltumapgades_datu_ieguvi_anal_un_rokasgramat_sagat_pasval_energoplan.pdf (accessed Jan. 31, 2020).

[8] Rigas Siltums. Annual report. Ltd Rigas Siltums; 2018, http://www.rs.lv/sites/default/files/page_file/rs_gada_parskats_2018.pdf (accessed Jan. 31, 2020).
[9] LVGMC. Meteorological database. Latvian Center for Environment, Geology and Meteorology; 2020, https://www.meteo.lv/en/ (accessed Jan. 31, 2020).
[10] CSB. National energy statistics. Central Statistical Bureau of Latvia; 2020, http://data1.csb.gov.lv/pxweb/lv/vide/vide__energetika__ikgad/ENG190.px/ (accessed Jan. 31, 2020).
[11] PUC. Historical information of heat tariffs. Public Utilities Commission; 2020, https://www.sprk.gov.lv/content/tarifi-4 (accessed Jan. 31, 2020)..
[12] Nielsen S, Möller B. GIS based analysis of future district heating potential in Denmark. Energy 2013;57:458–68. http://dx.doi.org/10.1016/j.energy.2013.05.041.
[13] Pakere I, Lauka D, Blumberga D. Does the Balance exist between cost efficiency of different energy efficiency measures? DH systems case. Energies 2020;13:5151.
[14] VARAM. Methodology for the calculation of greenhouse gas emissions. The Ministry of Environmental Protection and Regional Development; 2020, http://www.varam.gov.lv/lat/darbibas_veidi/Klimata_parmainas/?doc=26279 (accessed Jan. 31, 2020).
[15] Yang X, Li H, Svendsen S. Energy, economy and exergy evaluations of the solutions for supplying domestic hot water from low-temperature district heating in Denmark. Energy Convers Manage 2016;122:142–52. http://dx.doi.org/10.1016/j.enconman.2016.05.057.