International Journal of Sustainable Energy Planning and Management Vol. 34 2022 79–90

International Journal of
Sustainable Energy Planning and Management

District heating distribution grid costs: a comparison of two approaches

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ABSTRACT

Since the introduction of the effective width concept for the estimation of the linear heat density, it has been frequently used by researchers to calculate district heating distribution grid costs in pre-feasibility phases. Some researchers, however, still prefer using a detailed modelling approach to get reliable results. This paper aims to highlight the advantages, disadvantages, and challenges of using the effective width concept to calculate district heating distribution grid costs compared to a detailed, optimisation-based modelling approach such as DHMIN. The outcomes of this paper reveal that although there are differences in obtained indicators such as trench length or distribution gird costs, both approaches deliver very similar patterns in different areas with various heat demand densities and plot ratios. Furthermore, it was revealed that for getting reliable results for a given case study, the input parameters and cost components should always be tuned to that case study regardless of the approach used.

Keywords

Effective width;
District heating grid cost;
District heating potential;
Economic assessment;
GIS;

http://doi.org/10.54337/ijsepm.7013

1. Introduction

The linear heat density is a decisive parameter in the economic viability of implementing a district heating (DH) system. The concept of effective width was first introduced by Urban Persson and Sven Werner [1] in order to estimate the linear heat densities based on demographic data. Effective width refers to the ratio of a given land area to the length of the DH trench within that area. In contrast to the previous empirical approaches, where the calculation of the trench length and linear heat density was only possible after implementing the DH pipelines, the effective width concept allows for the estimation of future linear heat densities in areas where no DH network exists.

The main advantages of the approach are ease of use and low data intensity. The required data by the approach are heat demand densities and plot ratio (*e*), both of which are today publicly available, especially for EU countries; e.g. from the Hotmaps project for EU 27 countries [2] or from heat atlases on a national level such as Danish Heat Atlas [3] or Austrian Heat Map [4]. Furthermore, municipalities across the EU are gradually getting motivated to make a self-commitment to take climate protection steps. As a result, heating and cooling planning is practised more frequently across the EU on a municipal level, in many cases leading to further data availability.

The heating and cooling planning practice is also supported strongly in the recent European Commission's proposal for a revised Energy Efficiency Directive, encouraging municipalities to elaborate heating and cooling plans [5]. Considering the fact that district heating and cooling (DHC) is one of the main infrastructures allowing decarbonisation of the heating sector, there is no surprise that the concept of the effective width is

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being applied extensively for the economic assessment of DH network investments in pre-feasibility stages.

Nielsen and Möller used the effective width concept for estimating DH distribution grid costs in Denmark. The DH distribution grid costs were used together with heat production and transmission costs to obtain future DH potentials in Denmark [6]. In a similar work, Spirito et al. applied the effective width concept to estimate the DH distribution grid cost, which later on was used to calculate the potential diffusion of renewables-based DH for the case study of Milan. To identify most suitable DH areas, they used DBSCAN clustering algorithm [7].

Fallahnejad et al. proposed an approach based on the effective width concept for the identification of the potential DH areas [8]. In their GIS-based approach, areas with low heat demand densities were excluded. Then, coherent areas with average DH distribution grid costs that fall below a pre-defined level were considered potential DH areas. The distance of potential DH areas from the main heat source and imposed costs of heat transmission used as criteria for selecting the economical DH areas.

Heat distribution costs obtained from the effective width concept were further used in the Heat Roadmap Europe project – A Horizon 2020 Research and Innovation project [9]. In a paper published by the project, economic suitability for the DH is expressed as annualised network investment cost per unit of delivered heat. Accordingly, the concept of effective width and the definition of economic suitability was used to study DH distribution grid costs in EU countries [10]. Dénarié et al. introduced a relation between the effective width and the number of buildings in an area and used it to estimate the network length and heat distribution costs. The methodology was validated with existing DH grid data from the city of Milan [11].

Since the introduction of the effective width concept in 2010, the approach has been updated a few times. While the first version of the approach was based on 100 observations in Sweden, it was broadened to 1703 districts in 83 cities within Germany, France, Belgium and the Netherlands in the next elaboration of the approach in 2011 [12]. Furthermore, separate cost components for the inner-city areas, outer city areas and park areas were proposed. In 2019, the cost components were merged into one average function covering all three areas and pipe dimensions used in them. Additionally, it was revealed that plot ratio has the highest impact on effective width in sparsely built areas ($e \leq 0.4$). In contrast to low plot ratio areas, a constant effective width value of 60 m was considered for areas with higher plot ratios.

The efforts in improving the approach and achieving more accurate results for EU countries have been followed further in other studies and projects. The Horizon 2020 project sEEnergies [13], in one of its recent reports, suggested a formula for the calculation of the effective width of service pipes [14]. Furthermore, the formula of effective width for the DH distribution grid was updated. Besides the building data, DH data were obtained from Fjernvarme Fyn (Denmark's 3rd largest DH company) for the city of Odense. The report also pays specific attention to the areas with low plot ratios as well as country-specific construction cost components. The overall approach was elaborated in detail in a research paper as well [15].

With regards to the DH networks and parallel to the effective width approach, another research stream deals with the detailed planning of DH networks using techno-economic optimisation models. Here, the researchers focus on detailed network dimensions, routes, costs and connection of heat sources to the consumers. The temperature is often assumed to be at a steady state, and fluid hydraulics are modelled in a simplified manner as these aspects are rather topics of simulation models. Detailed modelling approaches often focus on the impact of certain parameters, such as choice of supply technology, use of storage systems or supply temperature, on the network length, dimension and costs.

Dorfner and Hamacher developed a graph-based optimisation model to determine the structure and size of a large scale district heating network and applied it to the case study of Munich [16]. The results of the optimisation are presented in GIS layers. This model was used as a basis for developing the open-source model DHMIN [17].

Thermos – a Horizon 2020 project – developed an online, open-source software where distribution network and supply technologies are selected in a mixed-integer linear programming (MILP) model [18,19]. The tool is user-friendly and well-suited for local and district level studies at building level resolution. Although the application in larger areas is possible, it is bound to higher data processing and calculation time due to its online nature.

Marquant et al. introduced an approach for studying DH potential on a large-scale [20]. The approach divides a given case study into multiple districts according to the result of a density-based clustering algorithm. The potential DH areas are determined in an optimisation model. Although the GIS aspects are included in the approach, the DH network is modelled and illustrated in Euclidean distances with estimated heat transfer capacity.

Roeder et al. studied the DH network size and dimension in the presence of thermal storages [21]. The strength of the study is the introduction of a well-structured open-source tool. Their study of 129 DH connected households showed that by using thermal storage systems, the heat losses and piping costs could be reduced up to 10% and 14%, respectively. However, the conclusion cannot be generalised as it is project-specific. The authors mentioned that the CPU time for the optimisation was ca. 1 hour. Given the low number of buildings in the case study, the CPU time may drastically increase if the model is applied to a larger case study.

Designing a DH network and supplying heat with industrial waste heat as a supply source is the focus of the study done by Lumbreras et al. in their recent publication [22]. The approach provides a preliminary economic assessment (private business point of view) of supplying existing buildings with low-temperature heat, in which network dimensions and routes are determined. The authors confirm the need for a backup system for the low-temperature heat supply and suggest using existing decentral heating systems in the buildings for this purpose. However, this aspect was not assessed from an economical point of view or the end-user perspective.

Both research streams on effective width and detailed network modelling have their own benefits and limitations. Despite all efforts made to improve the effective width approach, it is sometimes referred to as a generic approach obtained from a region with certain construction economics and without additional details relevant to other areas [23]. These types of arguments are, however, not supported with adequate analyses. In other words, the validation of the approaches is often done based on existing DH networks in case studies, which in general is a creditable approach for the validation, but not sufficient for comparing the results of an approach with another one. Therefore, it is unclear to which extent DH related indicators obtained by a detailed modelling approach differ from the effective width concept results.

This paper aims to fill this gap and highlight the advantages, disadvantages, and challenges of using the effective width approach to identify grid costs and lengths compared to a detailed modelling approach. Thus, the research questions of this paper are: (1) For a specific case study, to which extent do the results of the generic DH grid modelling approach based on the effective width concept comply with the results obtained from a detailed, optimisation-based model? (2) What are the advantages and disadvantages of both concepts?

This paper uses the DHMIN model as a detailed modelling approach [17]. Both approaches are applied to the case study of Brasov in Romania. The paper is organised as follows: in the next section, both approaches and the methodology used for their comparison are elaborated. Section three presents the case study and the input parameters used in each approach, followed by the presentation and comparison of results in section four. The paper is concluded in the conclusion section.

2. Method

This section explains the steps that should be taken to compare the two approaches. Firstly, potential DH areas are identified. These areas are relevant for the comparison of the two approaches. Results of both approaches depend directly or indirectly on heat demand densities and plot ratios. To understand the differences of results under various heat densities and plot ratios, the identified DH areas are broken into smaller sub-areas. Finally, the DHMIN model is run on all sub-areas.

2.1. Identification of potential district heating areas

The effective width concept is a generic approach. In other words, it can be applied to any region for calculating DH metrics such as linear heat density and distribution grid costs. This is true even for regions that are not suitable for implementing DH, e.g., due to very low heat demand densities. Therefore, for comparison of obtained results via the effective width concept with results obtained from the DHMIN model, it is essential to look at suitable areas for DH. In this paper, suitable areas for implementing DH are referred to as “potential DH areas” or “coherent areas”.

Here, a similar approach as proposed by Fallahnejad et al. [8] is followed to identify potential DH areas. They used a heat demand density map and a heated gross floor area density map (for obtaining plot ratios), both with one-hectare resolution as input data. The annual expansion of DH grids was modelled as an evolving market share over the investment period. Additionally, reductions in future heat demands, e.g., due to the thermal retrofitting of buildings, were modelled as an expected accumulated energy saving.

The procedure of calculating DH distribution grid costs in each hectare element of heat demand and heated gross floor area density maps are extracted from reference papers [8,10] and formulated in equations 1 to 10. It is assumed that DH market share and accumulated energy saving evolve uniformly in all hectare elements. Plot ratios are not changed through the study horizon. To estimate the effective width and subsequently distribution gird costs, however, we adapted the method to the modifications made by Persson et al. in 2019 [10]. Accordingly, the DH distribution grid costs are obtained for each hectare element of the input maps. Regarding Eq. 5, a pipe diameter of 0.02 m is applied uniformly for all hectare grid cells with linear heat densities of above zero and below 1.5 GJ/m [10].

For the identification of potential DH areas, two conditions should be fulfilled:

- The average distribution grid costs within a potential DH area should be below a pre-defined cost ceiling;

  The average distribution grid cost within a region is obtained by summing the absolute annualised distribution grid costs in Euro divided by the sum of heat demand covered by DH over the lifetime of the grid. A constant market share and heat supply is considered for the years after the end of the investment period until the end of the grid depreciation time.
- The annual heat demand within a potential DH area should be above a given threshold.

  This condition is relevant for identifying the minimum size of DH grid system.

$$w = A_L / L = \begin{cases} 137.5 \cdot \mathrm{e} + 5 \ [m] & 0 < e \le 0.4 \\ 60 \ [m] & e > 0.4 \end{cases} \qquad \text{(Eq. 1)}$$

$$\mathit{Linear\ Heat\ Density} = Q_T / L = e \cdot q \cdot w = q_T \cdot w \quad [GJ/m] \qquad \text{(Eq. 2)}$$

$$q = Q_T / GFA \quad [GJ/(m^2)] \qquad \text{(Eq. 3)}$$

$$q_T = Q_T / A_L \quad [GJ/(m^2)] \qquad \text{(Eq. 4)}$$

$$d_a = 0.0486 \cdot \ln\left(Q_T / L\right) + 0.0007 \quad [m] \qquad \text{(Eq. 5)}$$

$$D_{T+t} = D_T \cdot \sqrt[m]{\left(1 - S\right)^t} \quad [GJ] \qquad \text{(Eq. 6)}$$

$$0 \le S \le 1;\ t \in \{0, 1, 2, \ldots, m\} \qquad \text{(Eq. 7)}$$

$$Q_{T+t} = D_{T+t} \cdot \left[MS_0 + t \cdot \frac{MS_m - MS_0}{m} \right] \quad \left[GJ\right] \qquad \text{(Eq. 8)}$$

$$I / L = C_1 + C_2 \cdot d_a \quad [€ / m] \qquad \text{(Eq. 9)}$$

$$C_{d,T} = \frac{C_{1,T} + C_{2,T} \cdot d_a}{\left(\sum_{t=0}^{m} \frac{Q_{T+t}}{\left(1+r\right)^t} + Q_{T+m} \cdot \sum_{t=m+1}^{n} \frac{1}{\left(1+r\right)^t} \right) / L} \quad \left[€ / GJ\right] \qquad \text{(Eq. 10)}$$

w	Effective width [m]
A_L	Land area [m^2]
GFA	Gross floor area [m^2]
q	District heating demand per unit of heated floor area in year T [GJ/m^2]
q_T	District heating demand per unit of heated land area in year T [GJ/m^2]
Q_T	District heating demand in year T [GJ]
D_T	Annual heat demand in year T [GJ]
S	Expected accumulated energy saving over the investment period [%]
m	Number of investment years [-]
n	Depreciation time [year]
d_a	Average pipe diameter [m]
MS_t	DH Market share within DH areas in t^{th} year of investment [m]
I	Heat distribution investments [€]
L	Total trench length [m]
Q_T / L	Linear heat density [GJ/m]
C_1	Construction costs constant [€/m], here 212 €/m
C_2	Construction costs coefficient [€/m^2], here 4464 €/m2
C_d	Annualized distribution grid cost per unit of delivered heat [€/GJ]
r	Interest rate

The input GIS layers, namely the heat demand density map and a heated gross floor area density map, have a resolution of 1 hectare. As a result, a potential DH area could be as small as one hectare. There is, however, no upper limit for the size of a coherent area. The above two conditions for identifying potential DH areas do not lead to uniform characteristics in terms of heat demand densities and plot ratios within cells of a coherent area. Therefore, to better understand the strengths, weaknesses, and differences of results of this approach with outputs of the DHMIN model, it is necessary to break coherent areas into smaller sub-areas.

2.2. Breaking coherent areas into sub-areas

A minimum peak load heat demand within each sub-area is set as a criterion to break coherent areas into sub-areas. This criterion assures that heat demands in sub-areas are not too low and also are compliant with the existing substation capacities in the market. In this work, a minimum peak load heat demand of 3.5 MW was set for each sub-area. For the determination of sub-areas, an optimisation-based clustering approach is used. The optimisation model is formulated so that no upper bound for the peak load heat demand is required.

A number of initial seeds within coherent areas are defined. For the calculations in the next step, seeds must be located on a street segment. Therefore, they may lay slightly outside coherent areas in some cases. The seeds represent substations, and their initial number should be large enough to fulfil the 3.5 MW criterion on minimum peak load heat demand. Furthermore, the initial seeds should be distributed across coherent areas (e.g., uniformly with a 200m radius) so that each cell within a coherent area could be allocated to one and only one seed. This is also important for maintaining the cohesion of sub-areas.

The objective function of the optimisation model is to minimise the distance of cells in a sub-area from their allocated seed, as shown in Eq. 11. To minimise the objective function, the model only maintains the most suitable seeds and allocates cells to a limited number of seeds. The mathematical formulation of the optimisation model is as follows:

$$\min c,s \sum_{c=1}^{C} \sum_{s=1}^{S} d_{cs} \cdot b_{cs} \qquad \text{(Eq. 11)}$$

Where:

$c \in \{1,2,\ldots,C\}$ set of cells in a coherent area

$s \in \{1,2,\ldots,S\}$ set of initial seeds

Two parameters are defined: d_{cs} shows the distance of cell c from seed s; P_c shows the peak demand in the cell c.

Two variables are defined: b_{cs} which is a Boolean that allocates each cell to only one seed; *seed_b*$_s$ which is a Boolean showing if the seed should be kept or should be omitted.

The constraints are as follows: one constraint to assure allocation of each cell to only one seed (Eq. 12); one constraint to keep seeds that have at least one allocation (Eq. 13); one constraint to maintain the minimum heat load demand of 3.5 MW in each cluster (Eq. 14).

$$\sum_{s=1}^{S} b_{cs} = 1 \qquad \text{(Eq. 12)}$$

$$\sum_{c=1}^{C} b_{cs} \geq seed\_b_s \qquad \text{(Eq. 13)}$$

$$\sum_{s=1}^{S} b_{cs} \cdot P_c \geq 3.5MW \qquad \text{(Eq. 14)}$$

Once the sub-areas are obtained, the heat demand, DH potential, trench length and specific distribution within sub-areas are calculated.

2.3. The DHMIN model

DHMIN is a mixed-integer linear programming model, which finds the maximum revenue trade-off for the extension and size of the DH network [17]. The main features of DHMIN are, among all, the capability to model peak loads (short duration) and typical loads (long duration), heat source availability (redundancy study), existing DH pipelines and to oblige pipe construction on a certain route, to find pipe dimensions and their corresponding heat losses.

In order to use DHMIN, it is necessary to have heat demand data on the building level. Building heat demands are allocated to their closest street segment. To comply with the obtained results from effective width approach, a connection rate as well as heat saving level are applied to the building heat demands across all street segments. Since the DHMIN model does not support an evolving market share for calculating levelized cost, the highest connection rate through the investment period is taken from the approach based on the effective width and used as an input to the DHMIN model. This implies higher heat delivery through the lifetime of the pipelines compared to the effective width approach.

The aggregated peak load demands on street edges are also fed into the model. It is assumed that the substation can supply the required heat in the sub-area. In contrast to the effective width approach, which solely was based on the demand side, the DHMIN model requires data on the supply side (e.g., heat sale price) as well to calculate the revenue. Fig. 1 depicts the input/output flow of the DHMIN model [17].

Fig. 2 illustrates the model input/outputs by an example. In this figure, the street segments are shown in turquoise. In the left figure, the heat loads are shown in red. Higher heat loads are depicted with thicker red lines. The substation is presented by a yellow triangle. The right-hand-side figure shows the optimal heat flow and

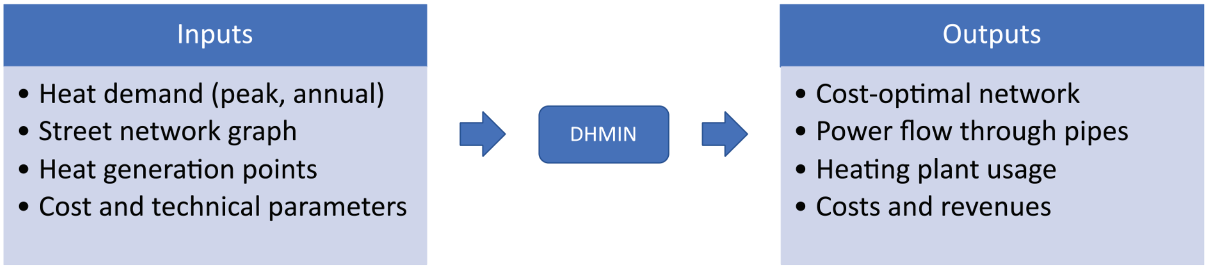

Fig. 1 Input/output flow chart of model DHMIN (source: Dorfner)

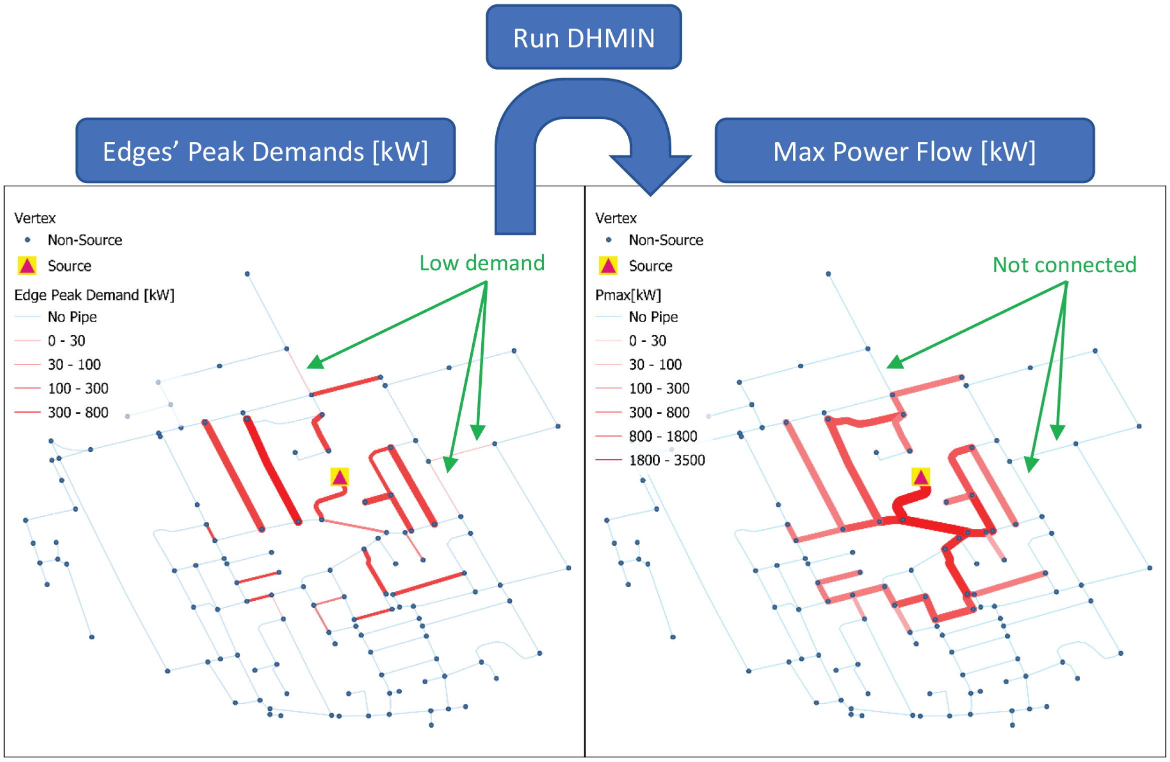

Fig. 2 example of input data sets (left) and obtained results (right)

the extension of distribution grids. Based on the heat flow, suitable pipe dimensions and their associated costs can be calculated. More details on the DHMIN model are provided in the reference [17].

3. Case study

The district heating system in the city of Brasov initially was designed to supply steam to the industrial consumers and hot water to residential consumers. With the shutdown of industrial consumers in 1990, the DH system got away from its primary purpose and became ineffective due to oversized pipelines and high heat losses in the grid. The lack of coherent policy in reviving the DH system as well as the loss of customers, further deteriorated the situation for the DH system in Brasov. However, in recent years, the Local Council has established new actions toward increasing DH efficiency and, consequently, increasing welfare in Brasov.

This paper uses the policy recommendations for Brasov's DH system provided by the progRESsHEAT project – a Horizon 2020 project for supporting the market uptake of existing and emerging renewable technologies [24]. The policy recommendations aim to increase the DH system's competitiveness in Brasov, given the local barriers and drivers for this technology. To compare the results obtained in this paper with the existing DH grid topology in Brasov [25], the boundary conditions defined in policy recommendations [26] should be considered. In this paper, however, we focus on comparing the results of two approaches, which were introduced in section 2.

Table 1 and Table 2 show the input parameters for each model, which are obtained from progRESsHEAT project. As it can be seen from the tables, each model requires a different set of input parameters. In the case of the DHMIN model, certain parameters can be provided by the user or can be calculated by the built-in functions in the model. In this paper, where possible, the built-in function is used. In addition to the input parameters, the input data used by each model are different as well. While the first approach requires only heat demand density map and plot ratio map, the DHMIN model requires shapefile of street segments (obtained from Open Street maps), heat load on each street segment (calculated based on building heat demand from prgRESsHEAT and peak load factor in Table 2), max pipeline capacity on each street segment (optional), location of heat source (was set according to the Section 2.2), etc.

Table 1 Input parameters for the first approach based on effective width concept (source: [26])

Parameter	Value	Unit	Description
Investment Horizon	16	years	Period in which money flows into the expansion of DH networks
DH market share - Start	16	%	Share of heat demand covered by DH in coherent areas at the start of the investment period
DH market share - End	62	%	Targeted share of heat demand covered by DH in coherent areas at the end of the investment period
Accumulated energy savings (expected)	17.5	%	Achievable heat saving level by following the policy recommendations at the end of the investment period compared to the start year
Minimum annual heat demand in a potential DH area	1	GWh	The threshold from which an area can be considered as a potential DH area
Grid cost ceiling	27	€/MWh	The average DH grid cost within a potential DH area may not exceed this value
Depreciation period	30	years	For the DH network
interest rate	6	%	-

Table 2 Input parameters for the second approach based on DHMIN model (source: [26])

Parameter	Value	Unit	Description
Investment Horizon	16	years	Period in which money flows into the expansion of DH networks
heat sale price	89.5	€/MWh	Wholesale heat sale price
Connect quota	62	%	Representing buildings connected to the grid. Here, is considered as a share of heat demand of buildings along a street segment, which is covered by DH
Pipe costs	built-in function of DHMIN	-	Identifies the cost of pipeline based on its length and dimension
Thermal losses	built-in function of DHMIN	-	Identifies the heat losses along each pipe segment
Peak load factor	0.000568	-	Used to size pipes
Source vertex capacity	equivalent to the demand in sub-area	-	Heat load that can be covered by heat source
Depreciation period	30	years	For the DH network
interest rate	6	%	-

While DH pipes are available in discrete nominal sizes, e.g., DN40 and DN50, DHMIN uses a simplified continuous function for the determination of pipe sizes and costs. DHMIN uses the piecewise linearization to keep the problem linear and solve the model with a Mixed-Integer Linear Programming approach.

4. Results

First of all, the potential DH areas were identified, as explained in section 2.1. The obtained coherent areas were divided into sub-areas following the steps in section 2.2. In total, 15 sub-areas were obtained. Fig. 3 shows the sub-areas and labels them based on the heat demand in each sub-area. The first three sub-areas belong to the city centre and have higher heat demands compared to the rest of the sub-areas.

The indicators for the first approach were calculated for each sub-area. The DHMIN model was run on each of the 15 sub-areas. Fig. 4 shows the distribution grid calculated by the DHMIN model in each sub-area. To compare obtained indicators from both approaches, three indicators are investigated.

Each sub-area is primarily characterised by its annual heat demand and DH potential. Based on the first approach, a DH potential in the magnitude of 62% of the total heat demand of the sub-area is achieved deterministically. However, DHMIN covers only the portion of 62% of the heat demand, for which the revenue is maximised. Fig. 5 shows the heat demand in each sub-area and the achievable DH share obtained from DHMIN. Except for sub-area 10, where only 51% market share was achieved, other sub-areas have market shares of close to 62%.

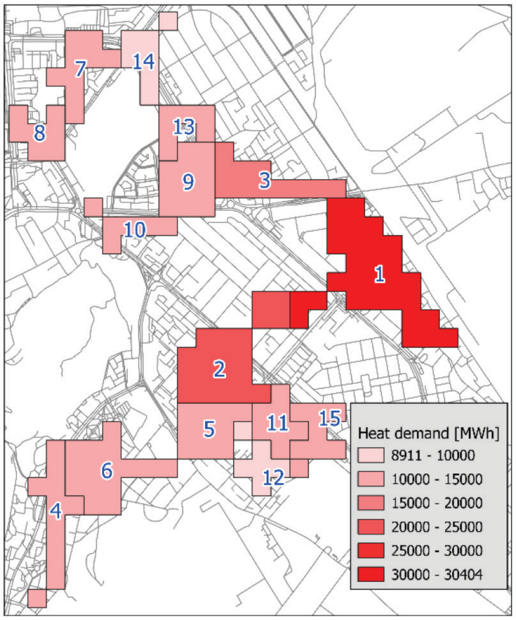

Fig. 3 District heating sub-areas and their rank based on the heat demand

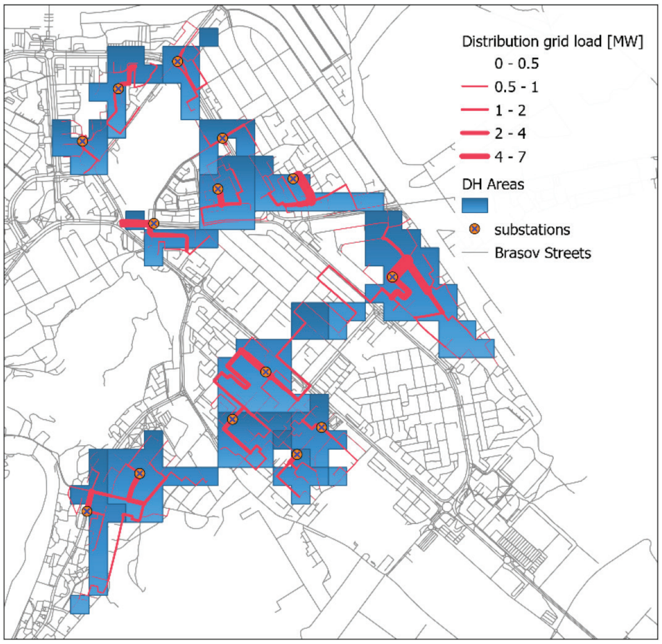

Fig. 4 Potential district heating areas and distribution grids in sub-areas

Trench length is an important parameter for the cost of distribution grids. Fig. 6 demonstrates the trench length obtained by both approaches and also shows their differences in percentage. In contrast to the DH potentials, there is a considerable difference between obtained values from both approaches. This difference is more significant in smaller sub-areas. One reason is that effective width is set to the constant value of 60m for areas with a plot ratio of greater than 0.4, which is basically an average number and might slightly deviate in reality. Another reason is that the DHMIN model uses street segments for estimating trench length, and they might be slightly longer than the required trench length in practice. Despite the differences, the key fact is that both approaches closely follow the same trench length pattern. In other words, both approaches demonstrate similar peaks and dips.

The third investigated indicator is the specific distribution grid cost in sub-areas. Comparing specific distribution grid costs is difficult as both approaches have different cost components and model inputs. Fig.

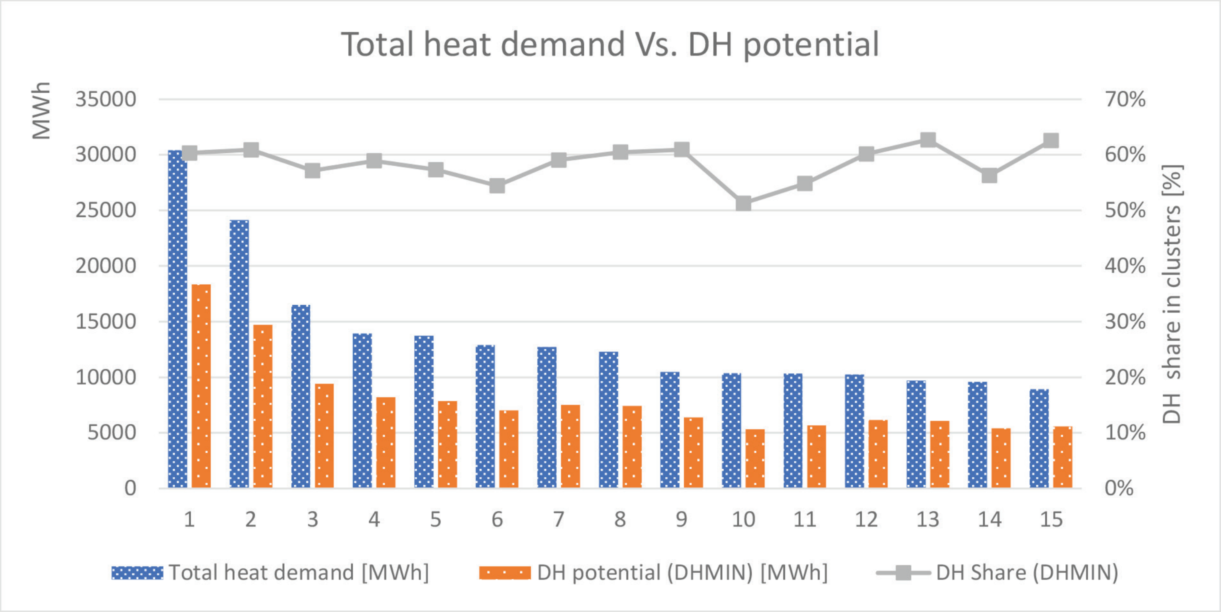

Fig. 5 Total heat demand Vs. DH potential obtained by DHMIN

7 demonstrates the obtained specific distribution grid costs from both approaches. Here, the differences in absolute values (Fig. 7, left figure) are significant. In all sub-areas, the DHMIN model returns lower distribution grid costs. This is due to the fact that the DHMIN model assumes a constant heat delivery in the magnitude of approximately 62% of the heat demand in sub-areas over the lifetime of the distribution grid, while the approach based on the effective width considers evolving DH market share starting at 16% of the heat demand in sub-areas.

To facilitate the comparison, the result of each approach is normalised to its average value (Fig. 7, right figure). As it can be seen, both approaches are closely following the same pattern. It can be inferred that the characteristics influencing the specific distribution grid in sub-areas are reflected and followed in both models.

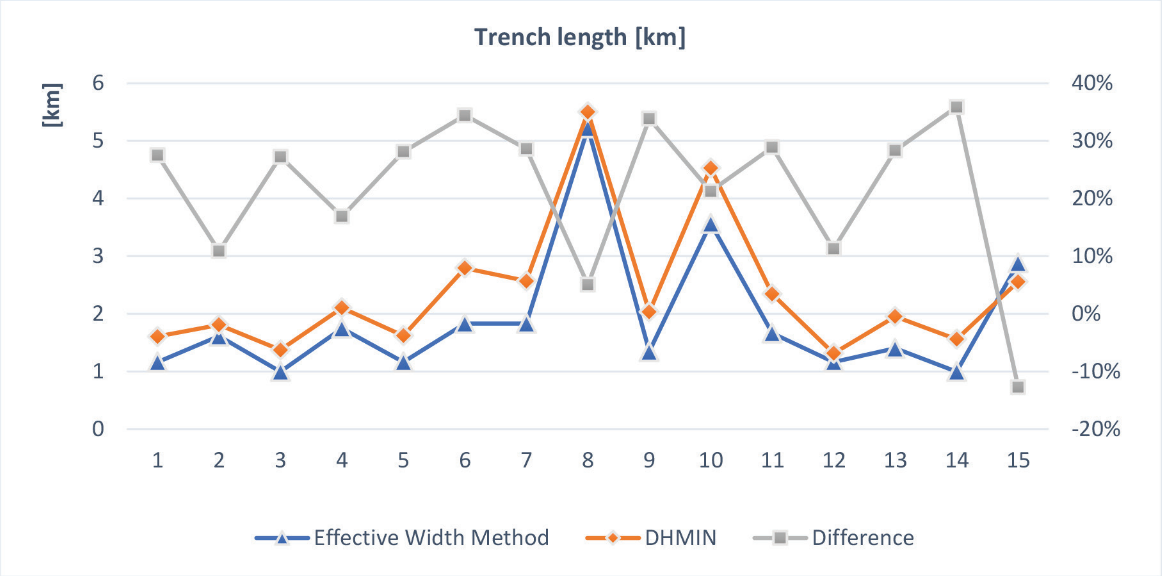

Fig. 6 Comparison of trench length

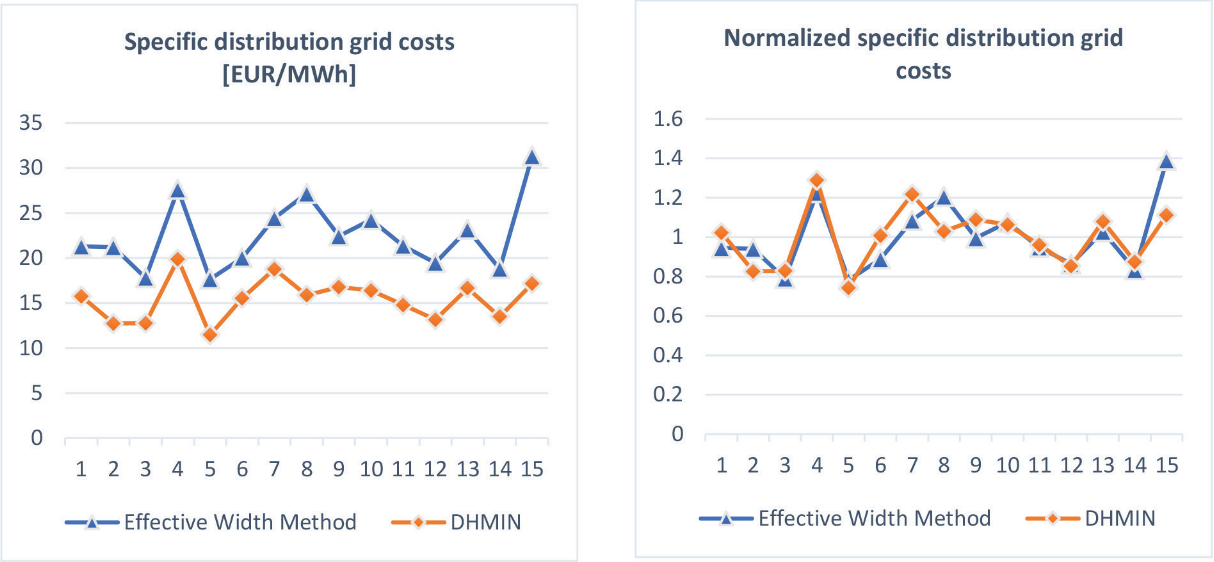

Fig. 7 Comparison of specific distribution grid costs

5. Limitations and discussion of results

The limitations of each approach have been mentioned in their reference papers [10,17] and will be discussed further here. The formula of the effective width has been obtained through interpolation on the empirical data of the existing DH system [1]. The mixture of the DH generation available in the empirical dataset may lead to better modelling of DH grid costs for a certain DH generation compared to other ones. Moreover, the DH system supply temperature is not addressed directly by the approach, as it is encapsulated in the empirical data sets.

The interpolation on the empirical data set gives effective width values that can lead to overestimating the DH distribution grid costs in certain cases, while others might be underestimated. This aspect has been addressed in the revised approach [14] by putting the effective width line below the values obtained for each sample DH network. Although the obtained costs in this manner lead to a conservative estimation, it can be argued that the obtained potential DH areas based on overestimated costs are highly reliable.

Despite the limitations, the approach has great benefits. First of all, the methodology is transparent and replicable. It is, therefore, possible to calculate a new formulation of the effective width with another set of DH network data and plot ratios. Once the formulation of effective width is available, no further data on the DH grid is required. Additionally, for the calculation of the DH distribution grid, only two data sets are required: The heat demand density map and the plot ratio map, both of which can be found from open-source data sources. Finally, the low computation time required by the approach can be highlighted as one of its main advantages.

Compared to the effective approach, DHMIN models the DH grid with more details. The additional level of details is accompanied by the need for additional data, assumptions and simplifications. DHMIN does not model fluid dynamics. Thermal losses are modelled in a simplified manner. The relation between pipe dimensions and pipe properties like thermal losses, transfer capacity and specific costs are provided in a generic manner within built-in functions. However, if generic functions do not fit a certain case study, the user should revise them.

DHMIN considers one supply temperature for the whole DH system. The supply-side and temporal aspects are modelled weakly. Although it is possible to do redundancy studies with it, the model is not suitable for unit commitment calculations. Furthermore, inter-temporal optimisation for investment decisions is not supported by DHMIN, as it provides the optimal solution for target system configurations. Furthermore, identifying the ideal technology investment pathways to reach the optimal target configurations is not covered [17]. Due to the optimisation nature of the model, solving large scale problems (>20,000 street segments) requires long CPU time and commercial solvers.

Despite the limitations, DHMIN has great advantages. The model is written in Python and has an open-source license (GNU GPLv3) permitting redistribution and modification. Spatial aspects are modelled with great detail, which was also relevant for the comparison purposes followed in this paper. The libraries used in the model allow the integration of various open-source and commercial optimisation solvers. The numerous components of the model and built-in functions give the possibility to improve the model where additional data is available. Furthermore, DHMIN allows modelling of existing DH pipelines or imposing pipe construction at certain routes.

Regardless of the approach, the input parameters and cost components should be tuned anyway to get reliable results on DH potential and costs for a given case study. The evolution of the gross floor areas should also be a focus of future studies. The identification of potential DH areas can be done with low CPU time using the effective width concept as well as constraints named in section 2.1. This could be very useful for large-scale case studies. DHMIN, on the other hand, provides higher spatial details and additional outputs at the cost of higher CPU time. Besides the CPU time, the availability of input data could be decisive. The approach based on the effective width concept is less data-intensive and might be preferred in case of data availability. The data preparation and model setup for running the DHMIN model requires more effort.

Depending on the use case and required level of details, one approach might be preferred to the other one. It is also possible to combine both approaches, where the potential DH areas are obtained based on the suggested approach in section 2.1, and detailed spatial analyses within coherent areas are done using DHMIN. In this case, more data is required, and preparatory steps are bound with more effort than applying only one approach.

Considering the limitations, it should be noted that both approaches are suitable for the pre-feasibility studies. To compare the behaviour of approaches, it was necessary to look at different heat demand levels and the size of coherent areas. This was done by comparing results in the sub-areas. Both approaches follow similar patterns in the case of DH potential and trench length. With regards to the differences of both methods, it can be concluded that both methods confirm the results of each other with an acceptable approximation.

6. Conclusions

In this paper, two approaches for calculating DH distribution grid costs were compared with each other. The first approach was based on the effective width concept. The second approach, on the other hand, was based on a detailed optimisation model. It should be emphasised that the goal of comparisons was not to identify the better approach; but rather to understand the challenges of using each of the two approaches, their strengths and weaknesses. For the comparison, three indicators were investigated: achieved DH potential, trench length and specific distribution grid costs.

Although both approaches provide different values for studied indicators in absolute terms, the comparisons revealed that they demonstrate and follow similar patterns in different sub-areas. Regardless of the approach, to get reliable results for a given case study, the input parameters and cost components should be tuned anyway to that case study.

Depending on data availability, one may prefer one approach to the other one. The approach based on the effective width concept is more suitable for cases with limited data availability. It might be preferred for calculation on a large area as it does not need any optimisation or complex calculation. It is also possible to model an evolving market share through the investment period. To obtain reliable results from the approach based on the effective width concept, besides tuning the cost components for a case study, it is also important to perform some sort of filtration of the potential DH area. Where detailed data is available, the DHMIN model can provide relatively detailed results. The DHMIN model requires no filtration of areas. Running the DHMIN model for a large area, however, requires additional effort for data preparation and model setup. The CPU time for solving the optimisation problem could increase as the case study becomes larger.

Acknowledgements

A significant part of this paper was primarily presented at the 7th International Conference on Smart Energy Systems (SES) that took place on 21-22 September 2021 in Copenhagen and was organised by the Sustainable Energy Planning Group at Aalborg University together with the Energy Cluster Denmark. The paper was prepared for the International Journal of Sustainable Energy Planning and Management (IJSEPM) and is published in a special issue related to the SES Conference.

References

[1] Persson U, Werner S. Effective Width: The Relative Demand for District Heating Pipe Lengths in City Areas. 12th International Symposium on District Heating and Cooling; Tallinn, Estonia from September 5th to September 7th, 2010, Tallinn University of Technology; 2010, p. 128–31.

[2] Hotmaps. Hotmaps 2016. http://www.hotmaps-project.eu/ (accessed March 23, 2018).

[3] Aalborg University D of SEP. The Danish Heat Atlas. EnergyMaps 2021. https://energymaps.plan.aau.dk/?page_id=33 (accessed November 29, 2021).

[4] Interaktive Karte. Austrian Heat Map 2021. https://austrian-heatmap.gv.at/karte/ (accessed November 29, 2021).

[5] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency (recast). COM/2021/558 final. 2021/0203 (COD) 2021.

[6] Nielsen S, Möller B. GIS based analysis of future district heating potential in Denmark. Energy 2013;57:458–68. https://doi.org/10.1016/j.energy.2013.05.041.

[7] Spirito G, Dénarié A, Fattori F, Motta M, Macchi S, Persson U. Potential Diffusion of Renewables-Based DH Assessment through Clustering and Mapping: A Case Study in Milano. Energies 2021;14:2627. https://doi.org/10.3390/en14092627.

[8] Fallahnejad M, Hartner M, Kranzl L, Fritz S. Impact of distribution and transmission investment costs of district heating systems on district heating potential. Energy Procedia 2018;149:141–50. https://doi.org/10.1016/j.egypro.2018.08.178.

[9] Heat Roadmap Europe 2022. https://heatroadmap.eu/ (accessed April 28, 2022).

[10] Persson U, Wiechers E, Möller B, Werner S. Heat Roadmap Europe: Heat distribution costs. Energy 2019;176:604–22. https://doi.org/10.1016/j.energy.2019.03.189.

[11] Dénarié A, Macchi S, Fattori F, Spirito G, Motta M, Persson U. A validated method to assess the network length and the heat distribution costs of potential district heating systems in Italy. International Journal of Sustainable Energy Planning and Management 2021:59-78 Pages. https://doi.org/10.5278/IJSEPM.6322.

[12] Persson U, Werner S. Heat distribution and the future competitiveness of district heating. Applied Energy 2011;88:568–76. https://doi.org/10.1016/j.apenergy.2010.09.020.

[13] sEEnergies. SEEnergies 2022. https://www.seenergies.eu/ (accessed April 28, 2022).

[14] Persson, Urban, Möller, Bernd, Sánchez-García, Luis, Wiechers, Eva. District heating investment costs and allocation of local resources for EU28 in 2030 and 2050 2021. https://doi.org/10.5281/ZENODO.4892271.

[15] Sánchez-García L, Averfalk H, Persson U. Further investigations on the Effective Width for district heating systems. Energy Reports 2021;7:351–8. https://doi.org/10.1016/j.egyr.2021.08.096.

[16] Dorfner J, Hamacher T. Large-Scale District Heating Network Optimization. IEEE Transactions on Smart Grid 2014;5:1884–91. https://doi.org/10.1109/TSG.2013.2295856.

[17] Dorfner J. Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale. Doctoral thesis. Technische Univesität München, 2016.

[18] Thermos. THERMOS 2021. https://www.thermos-project.eu/home/ (accessed April 15, 2022).

[19] Kuriyan K, Shah N. A combined spatial and technological model for the planning of district energy systems. International Journal of Sustainable Energy Planning and Management 2019:Vol. 21 (2019). https://doi.org/10.5278/IJSEPM.2019.21.8.

[20] Marquant JF, Bollinger LA, Evins R, Carmeliet J. A new combined clustering method to Analyse the potential of district heating networks at large-scale. Energy 2018;156:73–83. https://doi.org/10.1016/j.energy.2018.05.027.

[21] Röder J, Meyer B, Krien U, Zimmermann J, Stührmann T, Zondervan E. Optimal Design of District Heating Networks with Distributed Thermal Energy Storages – Method and Case Study. International Journal of Sustainable Energy Planning and Management 2021:5-22 Pages. https://doi.org/10.5278/IJSEPM.6248.

[22] Lumbreras M, Diarce G, Martin-Escudero K, Campos-Celador A, Larrinaga P. Design of district heating networks in built environments using GIS: A case study in Vitoria-Gasteiz, Spain. Journal of Cleaner Production 2022;349:131491. https://doi.org/10.1016/j.jclepro.2022.131491.

[23] Letellier-Duchesne S, Nagpal S, Kummert M, Reinhart C. Balancing demand and supply: Linking neighborhood-level building load calculations with detailed district energy network analysis models. Energy 2018;150:913–25. https://doi.org/10.1016/j.energy.2018.02.138.

[24] progRESsHEAT - Fostering the use of renewable energies for heating & cooling 2017. http://www.progressheat.eu/ (accessed April 28, 2022).

[25] Büchele R. Factsheet of the status quo in Brasov. Vienna: TU Wien; 2016.

[26] Rață C, Tatu I, Büchele R, Wien T, Steinbach J. Local heating and cooling strategy recommendations for Brasov. Agentia Pentru Management ul Energiei si Protectia Mediului Brasov; 2017.