Heat Pump Use in Rural District Heating Networks in Estonia

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Abstract – District heating has proven to be an efficient way of providing space heating and domestic hot water in populated areas. It has also proven to be an excellent way to integrate various renewable energy sources (RES) into the energy system. In Estonia, biomass covers most of the heat demand, but carbon-intensive fuels are still used to cover peaks and lows. Heat pumps can be a good solution for rural areas, as there is usually plenty of land available for heat pump facilities. In addition, heat pumps require low-grade heat sources such as ambient air, groundwater, lakes, rivers, sea, sewage water, and industrial waste heat. One of the downsides of heat pumps is the need for large investments compared to boilers fired by natural gas and biomass, and electric boilers. This study examines the impact of heat pump use on consumer prices for district heating in rural district heating networks in Estonia.

Keywords – Consumer prices; district heating; heat pumps; low-temperature heat sources; rural areas

Nomenclature

<i>AHD</i>	annual heat demand	MWh
<i>AP</i>	allowable profit	EUR
<i>CC</i>	capital costs	EUR
<i>CHP</i>	combined heat and power plant	–
<i>COP</i>	coefficient of performance	–
<i>DH</i>	district heating	–
<i>hl</i>	heat loss	%
<i>HP</i>	heat pump	–
<i>OM</i>	operation and maintenance costs	EUR
<i>Pr_{max}</i>	maximum heat price	EUR/MWh
<i>RES</i>	renewable energy sources	–
<i>WACC</i>	weighted average cost of capital	EUR
<i>VC</i>	variable costs	EUR

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1. INTRODUCTION

There has been a growing interest in the utilisation of electrical solutions in the heating sector in recent years. The wide range of low-grade heat sources available along with advanced and highly efficient heat pump (HP) technology has generated widespread interest in the use of large-scale heat pumps in district heating systems. District heating (DH) has proven to be an efficient way of providing space heating and domestic hot water in populated areas [1]. It has also proven to be an excellent way to integrate various renewable energy sources (RES) into the energy system [2]–[4]. However, viability and feasibility are often critical issues for rural district heating networks because consumption density tends to be low and consumption often dwindles due to declining rural populations [5], improved energy efficiency in buildings [5], and warming climate conditions [6]–[8].

Recent research on power-to-heat technologies [9] has focused on the effects of wind energy penetration into electricity markets on the optimal power-to-heat capacity in local district heating systems. The effects of power-to-heat technologies on Germany's energy system were explored in [10], and it was discovered that the interaction between the heating and electricity sectors will make both sectors flexible when dealing with short-term fluctuations in wind and solar energy production. When biomass is limited, utilising power-to-heat solutions in systems with an ever-increasing share of renewable energy will also help to incorporate even more RES into the heating sector, according to [10]. A comparison between different methods for the best design of distributed power systems was made in [11], where heat pumps were considered as a power-to-heat solution. A risk assessment for integrated heat and electricity systems was conducted in [12], which determined that the use of power-to-heat solutions (electric boilers and heat pumps) leads to reduced risks when a greater proportion of renewable energy sources is incorporated into the system [13].

As per the European Commission's EU Energy System Integration Strategy, sector coupling will massively boost electricity consumption, increasing generation of renewable energy, and propagating RES technologies [14]. According to [15], heat pumps (as power-to-heat solutions) play a significant part in the coupling of RES and the heating sector, and the amount of heat obtained from RES is highly dependent on the type of strategy; the largest number of RES can be incorporated into a system using a wind energy generation-based strategy. It is mentioned in [16], that when the heating and electricity sectors are interconnected, residential heating load has considerable potential to maximise the utilisation of wind power while minimising carbon emissions.

DH is very important for Estonia [17]. In [18], Estonian DH regions are discussed, and five different scenarios for all types of Estonian DH regions are investigated. In [18], it is concluded that it is necessary to consider all possible changes in the DH network when planning a DH region. Therefore, we propose an algorithm based on 146 Estonian DH networks of different sizes, lengths, capacities and primary energy structures to help predict possible changes in DH networks.

This study was designed to assess the impact of heat pump use in rural DH networks in Estonia on DH consumer prices. Heat pumps can be a good solution for rural areas, as there is usually plenty of land available for heat pump facilities. In addition, heat pumps require low-grade heat sources such as ambient air, groundwater, lakes, rivers, sea, sewage water, and industrial waste heat [19], [20]. One of the downsides of heat pumps is the need for large investments compared to boilers fired by natural gas and biomass, and electric boilers [21].

First and foremost, various aspects must be taken into account when considering the possibilities of using heat pumps in DH networks. In order to maintain balance in the electricity grid, it is important to assess how the addition of a large number of electricity

consumers, such as heat pumps, would affect the balance and the electricity market. Electricity market options for heat pumps in rural DH networks are described in [22] for the integration of heat pumps into rural DH networks in Austria. Since heat pumps can play an important role in balancing the electricity market, [22] shows how heat pumps can be used as regulators in the electricity market.

Oil shale is the primary energy source in Estonia, as well as an essential source of fuel and the major component in the energy mix. On the one hand, using oil shale as the main source of fuel guarantees a significant degree of energy security. However, it is an extremely carbon-intensive fuel. Consequently, the production of energy from oil shale results in a significant amount of greenhouse gases that affect the climate. Because of this, the Estonian economy has twice the amount of carbon dioxide (CO₂) than is usual in the EU. This is rapidly changing as the Estonian government continues to dismantle old energy plants and the number of innovations aimed at reducing CO₂ emissions and their negative impact is increasing. The amount of power generated in Estonia is more than its consumption, so the state trades electricity.

The total power generated in Estonia in 2019 was 7.615 TWh, while the demand for it was 8.257 TWh. In 2020, the amounts were 4.398 TWh and 7.954 TWh, respectively. More than half of the electricity was generated using oil shale (56 %), as well as biomass (17 %), wind (9 %), and sustainable waste (1 %) power plants. Latvia (76 %) and Finland (24 %) received 2.704 TWh of the electricity generated [23].

All three Baltic states are attempting to separate from the Russian power grid and join the Western European grid, which is due to be completed by 2025. Another important goal – climate neutrality – must be achieved by 2050. To achieve this goal, the Baltic countries must increase their renewable energy source (RES) capacities [23].

The largest RES in Estonia is the 48 MW wind power plant in Aulepa, the largest of its kind in the Baltics. Wind power plants (303 MW in total) are located inland in the north-east, north-west and west of Estonia. There are currently no offshore wind parks in Estonia. The largest combined heat and power plants (CHP) are Tartu CHP and Tallinn CHP with a capacity of 25 MW each. Biofuel plants are CHPs and therefore have to be spread throughout Estonia, close to urban settlements that use heat. It is known that 102 MW of biomass-powered, 17 MW of waste-powered, and 11 MW of biogas-powered plants are connected to the network [24].

There are three small DH systems in Estonia that use HPs as innovative heat generation technologies. They are located in Palamuse, Kaarepere, and Kiikla. Palamuse has two small, isolated DH systems where the demand for heat is supplied by ground source HPs. The DH network consists of the Palamuse School and its auxiliary buildings. The other network supplies DH to private structures (7 buildings). These HPs were commissioned in 2013. The annual DH consumption of the Palamuse School is 830 MWh and the private building network's annual consumption is 750 MWh. The annual *COP* of the HPs averages 2.6 [25]. Similarly, HPs are used in the DH network in Kaarepere, near Palamuse. As in the previous case, Kaarepere also uses ground source HPs. The consumers of the network are 6 private buildings and a kindergarten. Their annual heat consumption is 730 MWh. The annual *COP* of the pumps is usually 2.3. HPs were introduced in 2013, same as in Palamuse [25]. The heat demand is covered by a 400 Kw HP in the DH network of Kiikla village. It uses water from a nearby mine as a heat source. The HP was introduced in 2012, and according to its manufacturer, its *COP* should be 4.1 (on average). The annual heat consumption of the Kiikla DH network is 530 MWh [26].

Three seawater HPs are used for heating and cooling of the Seaplane Harbour historic centre in Tallinn. The introduced heating capacity of the facility is 395 kW, the cooling capacity is 250 kW, and the power capacity is 180 kW [27].

The use of heat pumps in DH also has a positive effect on air quality since heat pumps do not require combustion to generate heat and therefore no fine particles or acid-oxides (NO_x and SO_x) are emitted. Biomass boilers are widely used because they are considered CO_2 -neutral and because biomass is widely available in Estonia. However, the downside to using biomass is that it can be a source of air pollution. The impact of biomass boilers on the atmosphere has been studied in [27]–[29]. Emissions from biomass boilers depend on combustion methods. It is stated in [30], that NO_x and SO_x emissions are lower than the environmentally harmful amounts, and CO_2 emissions do not exceed the amount consumed by plant growth. This makes biomass an environmentally friendly fuel. On the other hand, it was found in [28] that fine particle emissions from biomass combustion can be harmful to health if flue gas cleaning equipment is not used.

When considering HPs as a source for space heating, it should be borne in mind that the use of heat pumps to generate heat instead of combustion boilers has an overall positive effect on the atmosphere only if the electricity used for HPs is also produced in accordance with the clean production principles and from renewable energy sources. Fine particle and acid oxide emissions in the event of combustion can be reduced by using air treatment equipment such as flue gas condensers, electric precipitators and various kinds of filters. Such equipment can be expensive and not all boiler houses have it installed. According to Directive 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants, the maximum amount of fine particles (dust, fly ash) for medium-sized biomass boilers is 20 mg/Nm^3 [31]. Emissions of fine particles are also regulated by Directive 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain air pollutants, which established an emission reduction strategy [32].

There are about 230 district heating networks in Estonia, and 95 % of them use woodchips as their primary fuel, while shale oil or natural gas is used to cover peak loads. In other DH networks, the main fuel is natural gas or shale oil. Most biomass boilers were installed after 2014 with the support of the European Cohesion Fund [33]. As the European Union's goal is to become climate neutral by 2050 [34], all fossil fuel-fired boilers must be replaced with RES, which means that it is necessary to find a sustainable solution to cover peak loads. Replacing old biomass boilers with HPs is a solution that should be discussed.

Price is the most important factor for consumers. The Estonian DH market is regulated by the District Heating Act and the Competition Act, and the Competition Authority approves the maximum prices charged in the network regions. At the beginning of 2020, the weighted average of the maximum DH prices was EUR 60/MWh; the lowest price was EUR 35/MWh (excluding VAT 20 %) and the highest price was EUR 86/MWh [35]. Typically, the actual selling price is very close to the maximum price indicated. In rural areas, where heat demand density is usually quite low, the costs of boiler house and network operations and maintenance are relatively high. This results in a high DH consumer price. When DH is produced using heat pumps, the price of heat is directly related to the price of electricity. This study provides a thorough analysis of how the use of HPs in rural DH networks will affect the consumer price of DH and, as a result, it will determine the areas where the use of HPs for DH can be cost-effective and have a positive impact on the DH consumer price. At the same time, suitable HP capacities are estimated for DH networks of different sizes, resulting in two types of solutions: those that use HPs for covering only peaks and troughs and fully HP-based solutions.

2. METHODOLOGY

Since this study is focused on rural areas, only DH networks with an annual consumption of less than 16 GWh are considered. There are about 140 DH networks in Estonia that meet this criterion. This limit was chosen because all DH regions with an annual heat consumption below it can be considered a rural area in Estonia. The average population in these areas is anywhere from 165 to 5000 residents, and the number of DH consumers ranges from 3 to 70. In this study, all these networks are divided into seven groups according to annual consumption. The criterion for division was to maintain minimum fluctuations in annual heat consumption within a group. It was significant to include all groups, but special focus was on small district heating networks, because heat pump integration is especially important in the case of small DH networks. That is why there are 3 groups for district heating networks below 5000 MWh. The main characteristics of these groups are presented in Table 1. Annual consumption figures are given for a ‘normalised’ year. The input data in Table 1 are taken from the heat management and development plans of the DH networks considered. In most cases, DH is also used for domestic hot water.

TABLE 1. MAIN CHARACTERISTICS OF DH GROUPS

Group no.	Average annual heat consumption, MWh/year	Average number of consumers in the DH network	Average DH price, EUR/MWh	Average DH supply temperature, °C	Number of such DH networks in Estonia
1	681	3	70.3	80	23
2	1914	6	67.4	80	58
3	3956	15	64.5	80	24
4	6235	25	61.7	85	8
5	7812	37	56.7	90	8
6	10 393	52	64.4	100	9
7	14 192	70	57.1	110	5

For all network groups, annual heat demand profiles have been generated using *EnergyPro* software, based on the annual heat demand, DH network temperatures and ambient temperatures. Base and peak loads that are important for estimating the required HP thermal capacity were determined using the generated heat demand profiles. Since the average ambient temperature for continental Estonia has been chosen (islands are excluded due to the milder climate), the shape of the heat demand profile is thus the same for all groups, and the groups with higher annual consumption lead to higher base and peak loads. Heat demand profiles for all groups are shown in Fig. 1.

Depending on the heat demand profile, different options were proposed for each group. This study presents two different options. The first option is to use a biomass boiler for base load and HP for summer loads and partly during the heating season. The criterion for selecting the base load boiler is to obtain the maximum amount of heat from the base load boiler. It is also assumed that the minimum load for the boiler is 50 % of its nominal capacity and the maximum load is 110 % of its nominal capacity. The second option is that all demand is covered by HPs.

When selecting HPs, it is important to know which heat sources are located nearby, as the temperature level of the heat source determines the coefficient of performance (*COP*) of the HP.

Fig. 1. Heat demand profiles for each group.

In this study, the *COP* for each possible heat source is estimated considering the temperature levels of possible local low-temperature heat sources and the temperature levels in rural DH networks. Possible heat sources discussed in this study are ground, seawater, lakes and rivers, and sewage water. This study obtained the necessary heat source temperatures for every hour using data from the Estonian National Weather Service [36]. For sewage water, the data given in [20] are used.

To estimate the *COP* of HPs, the Carnot equation for heat pump efficiency was used (Eq. (1)) with efficiency coefficient $\varepsilon = 1$:

$$COP = \varepsilon \frac{T_{\text{supply}}}{T_{\text{supply}} - T_{\text{source}}}, \quad (1)$$

where T_{supply} (K) is the DH supply temperature and T_{source} (K) is the heat source temperature.

The average *COP*s of all mentioned HP heat sources for each hour, considering heat source temperatures, are shown in Fig. 2. *COP* estimation also takes the DH supply temperature for each group into account.

To estimate the necessary electric capacity of HPs for each group for both options, the minimum *COP* value is used. This ensures the necessary electric capacity under all conditions. The higher the ambient temperature, the higher the *COP*.

The required electric capacities for option 1 (HP and biomass boiler) and option 2 (HP only) for each group and for different heat sources are shown in Table 2.

The proposed options and the existing solution are compared by the DH consumer price calculated using the Estonian Competition Authority's Method for DH maximum price [37]. In order to calculate the prices, the required investments, annual fuel costs, and operations and maintenance costs were estimated.

Fig. 2. Average *COP* for ground source, hydrothermal and sewage water HPs.

TABLE 2. HP ELECTRIC CAPACITIES FOR BOTH OPTIONS

Group no.	Option 1 – HP electric capacity, MW _{el}			Option 2 – HP electric capacity, MW _{el}		
	Ground source	Surface water	Sewage water	Ground source	Surface water	Sewage water
1	0.033	0.033	0.031	0.088	0.093	0.084
2	0.081	0.085	0.077	0.247	0.26	0.234
3	0.164	0.164	0.155	0.509	0.509	0.482
4	0.273	0.287	0.259	0.845	0.888	0.803
5	0.357	0.375	0.319	1.11	1.164	0.992
6	0.511	0.534	0.490	1.608	1.608	1.541
7	0.755	0.784	0.726	2.366	2.459	2.277

According to the Estonian Competition Authority's heat price calculation method, the maximum heat price depends on the allowable profit and sales capacity since the annual sales capacity of a heat producer is equal to the annual heat demand plus heat losses. The method of the Estonian Competition Authority has also set a limit for the allowable heat loss, which is 15 %. The maximum heat price Pr_{max} (EUR/MWh) according to the method of the Estonian Competition Authority can be calculated using Eq. (2):

$$Pr_{max} = \frac{AP}{AHD \cdot (1 + hl)}, \quad (2)$$

where AP (EUR) is the allowable profit, AHD (MWh) is the annual heat demand and hl (%) is the heat loss. Allowable profit consists of several other components: variable costs, operating costs, capital costs, and weighted average cost of capital ($WACC$). The $WACC$ is determined by the Estonian Competition Authority and for heat producers the $WACC$ is 5.76 %. To determine the possible heat price for both proposed solutions, it is necessary to estimate the variable costs, operating costs and capital costs, since the allowable profit is calculated as follows: (Eq. (3)).

$$AP = VC + OM + CC + WACC \quad (3)$$

Variable costs VC (EUR) consist of fuel costs (both biomass and electricity), environmental fees and water and sewerage services. For an annual estimate of variable costs, biomass and electricity prices are needed. The 2020 NordPool prices for Estonia are used for both electricity and biomass prices. The biomass price has been quite stable in recent years and in 2020 the price was EUR 16.42/MWh, which was also used in this study. Since biomass combustion emits fine particles, all biomass boiler houses must also pay environmental fees for fine particle emissions. The fine particle emission fee for particles smaller than $2.5 \mu\text{m}$ is EUR 1000/t [38]. In the case of this study, it is assumed that flue gas treatment equipment is not used, because flue gas condensers are usually installed in bigger boiler houses with a base load of 7 MW and more. This is mainly due to the fact that investments in this type of equipment are quite high and it is more economical for smaller boiler houses to pay environmental fees for particle emissions than to install flue gas condensers.

Water and sewerage services are also considered variable costs. Water and sewerage services are necessary for DH as water preparation and water use from local water utilities is necessary. The cost of water and sewerage services is not related to the heat source and depend only on the heat demand. Based on information from various regional heat management development plans in Estonia, the cost of the service is approximately EUR 17.8/MWh. This provides the same result for both options.

Operations costs OM (EUR) are the costs for boiler and HP services that must also be considered. Capital costs CC (EUR) are the investments divided by the expected technical useful life of the equipment. It is expected that service life for both biomass boilers [39] and HPs [40] is 20 years. The operations and maintenance (OM) costs for a biomass boiler are assumed to be EUR 9.5/MWh, according to the data given in several Estonian regional heat management development plans. To estimate the costs of HP operation and maintenance, the data from [41] were used (EUR 14/kWh). The value is the same for ground source, surface water and sewage HPs.

The main assumptions used in this study are listed below:

- The base load boiler was selected based on the maximum number of hours of use at full load;
- HP COP was estimated using the Carnot equation for HP efficiency;
- To estimate HP COP , the annual heat source temperature graphs and DH supply temperature were used;
- The minimum COP value was used for the required HP electric capacity;
- For DH consumer prices, the Estonian Competition Authorities Method was used;
- To estimate fuel costs, 2020 prices (electricity and woodchips) were used;
- Flue gas treatment equipment was not considered;
- Water and sewerage services are the same for both options.

3. RESULTS

Estimates of DH heat source capacity based on the heat demand profiles and previously described assumptions are shown in Fig. 3.

Fig. 3. Existing boiler capacities and capacity estimates for each group.

The results also showed that the maximum share of the total heat that can be delivered by base load boilers is 78 %, and peak boilers or HPs can cover the rest, i.e., 22 %. In addition, the existing base load boiler capacities are significantly higher than those proposed in this study. For smaller DH networks (groups 1, 2 and 3), this may be associated with high losses in the network caused by the low heat demand density.

Since HPs are also electricity consumers, when they are used for heat production in DH, they can significantly increase the demand for electricity in the power grid. Therefore, it is necessary to estimate the annual HP power consumption to determine the total extra power consumption that is caused by DH HPs.

The total number of electricity consumers to be added to the electricity grid for both options is shown in Table 3.

TABLE 3. ADDITIONAL ELECTRICITY CONSUMERS FOR BOTH OPTIONS

Group no.	Option 1 – HP electric capacity, MW _{el}			Option 2 – HP electric capacity, MW _{el}		
	Ground source	Surface water	Sewage water	Ground source	Surface water	Sewage water
1	0.76	0.76	0.71	2.02	2.14	1.93
2	1.86	1.96	1.77	5.68	5.98	5.38
3	3.77	3.77	3.57	11.71	11.71	11.09
4	6.28	6.60	5.96	19.44	20.42	18.50
5	8.21	8.63	7.34	25.53	26.77	22.82
6	11.75	12.28	11.27	36.98	36.98	35.44
7	17.37	18.03	16.70	54.42	56.56	52.37
Total	50.00	52.03	47.31	155.78	160.56	147.50

Table 3 shows that applying Option 1 to all rural DH networks will result in an additional consumption of around 50 MW in the electric grid. If all considered rural DH networks choose

to cover the heat demand using HPs, the additional consumption will amount to 160 MW. The peak consumption in the Estonian electric grid is usually around 1500–1600 MW, therefore, the consumption of HPs in rural areas will amount to a maximum of about 10 % extra consumption.

Annual electricity consumption is also necessary to estimate annual fuel costs since electricity is considered a fuel for HPs.

Fig. 4 shows the annual fuel costs for Option 1 and Option 2 in the case of ground source, surface water and sewage water HPs.

Fig. 4. Annual fuel costs for each option.

TABLE 1. ANNUAL PARTICLE EMISSIONS AND ENVIRONMENTAL FEES FOR OPTION 1

Group no.	Particle emissions for Option 1 biomass boiler, t/year	Annual fee for fine particle emissions, EUR/year
1	0.350	350
2	0.977	977
3	2.013	2013
4	3.174	3174
5	3.976	3976
6	5.282	5282
7	7.216	7216

It can be seen that sewage water HPs have slightly lower annual fuel costs than other types of HPs, which can be explained by higher heat source temperatures. It can be also seen that the option where only HPs are used as the DH heat source has lower fuel costs, which can be explained by the fact that the average electricity price is lower than the price of woodchips.

Table 4 shows the average annual amount of emitted fine particles for each group and the corresponding fee that can be accounted for as part of the variable costs.

The results in Table 4 show that in any case, the environmental fees for fine particle emissions are not significant compared to other variable costs. Still, the results in Table 4 show how much fine particles would not be emitted when HPs are used instead of biomass boilers.

Operations and maintenance costs (*OM*) for both options are given in Table 5.

TABLE 5. ANNUAL OPERATIONS AND MAINTENANCE COSTS FOR BOTH OPTIONS

Group no.	Total annual operations and maintenance costs for Option 1, EUR/year	Total annual operations and maintenance costs for Option 2, EUR/year
1	8574	3 780
2	22 387	9 240
3	45 987	18 900
4	73 932	31 220
5	91 014	37 520
6	121 829	50 820
7	164 226	67 200

It can be seen in Table 5 that the *OM* costs are reduced by more than half in the case of Option 2, where only HPs are used. This is because Option 1 also includes two different types of heat sources that require maintenance, while Option 2 only requires one type of maintenance service. Option 1 has lower HP *OM* service costs, but there are additional *OM* costs for the biomass boiler, making the final *OM* cost higher than that of Option 2.

The necessary investments for each group in Option 1 (heat pump and biomass boiler) and Option 2 (HP only) are shown in Fig. 5. Information on average biomass boiler investments was obtained from public announcements of the Estonian Environmental Investments Centre [42]. For HP investments, the data from [43] were used.

The actual investment requirements depend on whether the existing base load boiler is new or needs to be replaced. If a new biomass boiler has been installed within the past 10 years, then it should not be replaced and probably only investment in a peak load boiler will be required. If the existing boiler is old or uses carbon-intensive fuels, larger investments are necessary to achieve climate policy goals.

Capital costs (*CC*) are estimated using investment data provided in Fig. 5 and previously stated technical lifetimes. Once all costs have been estimated, the *WACC* can be calculated and added to the costs. The final consumer price can be calculated using Eq. (2); it is shown divided by costs in Fig. 6. Fig. 6 shows the final DH consumer price for both solutions for average HP costs and for the existing DH consumer price.

Fig. 6 illustrates well that the DH consumer price can be reduced by using HPs as a heat source in rural DH networks, since for all DH groups except group 1, the estimated consumer price is lower than the existing DH price. It should also be noted that the existing price has already been reduced through investment support in many cases, but the calculated data in Fig. 6 does not include investment support, which means that the DH consumer price could be even lower. For group 1, the higher calculated price can be attributed to very low annual heat consumption, which results in lower annual profit, making the estimated consumer price higher.

Fig. 5. Required investments for each group for both options.

Fig. 6 also shows that, in all cases, Option 2 results in a lower consumer price than Option 1, the main reason for this is the higher *OM* costs in the case of Option 1.

There is also a remarkable relationship between annual consumption and annual DH network consumption, indicating a major problem for small rural DH networks. Since there are very few consumers in the network, the annual heat consumption is also very low, resulting in a small profit from heat sales. The relationship is also evident in this study and is presented in Fig. 7, which shows the relationship between annual heat consumption and the estimated consumer price of DH.

Fig. 7 illustrates this relationship well: the higher the annual heat consumption, the smaller the consumer price. However, it can be seen that the consumer price increases exponentially when heat consumption decreases. This leads to the conclusion that for very small DH networks such as groups 1 and 2, finding new consumers for the DH network is crucial to maintaining the viability and feasibility of the DH network.

DH consumer prices for both options for different HP types are also provided in Table 6.

Fig. 6. DH consumer price divided by costs for both solutions and existing consumer price.

Fig. 7. DH consumer price relationship to DH annual heat consumption.

TABLE 2. DH CONSUMER PRICES FOR BOTH SOLUTIONS FOR DIFFERENT TYPES OF HEAT SOURCES

Group no.	Consumer price for Option 1, EUR/MWh			Consumer price for Option 2, EUR/MWh		
	Ground source HP	Surface water HP	Sewage water HP	Ground source HP	Surface water HP	Sewage water HP
1	92.61	101.14	100.97	81.90	90.15	89.15
2	65.66	68.32	68.20	56.25	58.64	57.64
3	57.38	58.38	58.21	49.38	49.62	49.07
4	55.14	55.42	55.31	48.43	48.48	47.50
5	53.55	53.69	53.39	47.66	47.57	45.76
6	52.83	52.75	52.64	48.38	47.63	47.11
7	51.34	51.14	51.04	48.47	48.02	47.10

Investment costs can be significantly reduced through investment support. According to national plans, new renewable heating solutions are going to be installed, including heat pumps with a capacity of more than 20 MW [44]. When support mechanisms are used, this can reduce the capital costs by 50 % and lead to lower DH consumer prices. DH consumer prices with 50 % investment support are given in Table 7.

TABLE 3. DH CONSUMER PRICES WITH 50 % INVESTMENT SUPPORT

Group no.	Consumer price with 50 % investment support for Option 1, EUR/MWh			Consumer price with 50 % investment support for Option 2, EUR/MWh		
	Ground source HP	Surface water HP	Sewage water HP	Ground source HP	Surface water HP	Sewage water HP
1	67.77	72.04	71.87	57.85	62.20	61.20
2	53.87	55.16	55.05	44.70	46.11	45.11
3	49.69	50.19	50.01	41.24	41.36	40.81
4	48.76	48.87	48.75	41.20	41.45	40.47
5	47.94	47.98	47.68	41.05	41.23	39.42
6	47.76	47.69	47.58	42.09	41.71	41.19
7	47.08	46.96	46.85	42.66	42.64	41.72

Comparison of the results in Tables 6 and 7 shows that investment support has a greater impact on consumer prices in smaller DH networks (groups 1, 2 and 3). Through investment support, consumer prices can be reduced by up to 31 % (group 1, sewage HP); the reduction is the smallest in group 7 for Option 1 at only 8 %. With investment support, consumer prices will be lower than the existing DH prices in every single case.

4. DISCUSSION AND CONCLUSIONS

The main purpose of this study is to find solutions that will make DH feasible and lower consumer prices for rural DH networks in Estonia. In this study, two different options were considered and compared in terms of the estimated consumer price: biomass boiler plus HP and HP only. Various types of HPs were considered in order to determine which type of heat source is most feasible.

The results show that for smaller DH networks (groups 1, 2 and 3), ground source HPs will be more cost effective than hydrothermal HPs or sewage water HPs. For larger DH networks

(groups 4, 5, 6 and 7), the difference between HP types is not very significant. In any case, from a consumer price point of view, using HPs to cover total demand is the best solution. However, this is only applicable if existing boilers need to be replaced. DH consumer prices are lower for all heat sources when the total demand is covered by HPs. The average difference between the consumer price of Options 1 and 2 is 13 %, the difference is more significant for smaller DH networks (groups 1–5) and less for larger DH networks (groups 6 and 7).

The impact on power consumption was also assessed, leading to the fact that even when all rural DH networks use HPs as heat sources, power consumption in the Estonian electricity grid will increase by about 10 % (160 MW) in case of peak consumption.

The results also show the importance of investment support, which can significantly reduce the consumer price. For smaller DH networks the investment support can reduce the consumer price by up to 31 %, while for larger DH networks the effects of investment support are not so noticeable.

The situation for very small DH networks (groups 1, 2 and 3) is difficult anyway, as heat demand density is very low and DH is often not viable. One possible solution for these networks is to give up DH and use individual solutions. This will make it possible to save on heat distribution losses that tend to be high in these DH network groups. If these areas still want to continue using DH, the only possible solution is to increase the annual heat demand by adding new consumers to the network.

In conclusion, it should be noted that using HPs in rural DH networks is a solution that is worth considering. This solution can reduce the DH consumer price and is a good alternative to carbon-intensive peak boilers. It can also integrate RES into the heating sector and help to couple the heating and electricity sectors.

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