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Integrating Low-temperature Waste Heat in District Heating Systems. Legal Framework and Pricing

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***Abstract* – Decarbonisation of the heating sector is a key challenge for the European Union to achieve its ambitious goal of becoming the first climate-neutral continent in 2050. Decarbonising the heating sector is about reducing fossil fuel consumption, finding new scenarios based on renewables and restructuring the operation of the district heating (DH) system. Recovering and integrating waste heat into the DH system has an enormous potential to meet the heating needs of buildings through non – combustion technologies while reducing carbon emissions. The waste heat from urban sources is advantageous because they are located near DH networks and areas with high heat demand. However, there is still no legal or regulatory framework for using of waste heat in the Baltic States. This paper has two main objectives: firstly, to consider a mathematical model for the pricing of waste heat. The waste heat integration strategies are tested in the Case study of a DH system in Salaspils, Latvia. A simplified model of a waste heat recovery system that recovers heat energy from a wastewater treatment plant through heat pump integration is developed. Secondly, to consider different pricing and cost determination scenarios when the waste heat is integrated into the district heating system. The heat tariff calculation model is based on the approved Latvian heat tariff calculation methodology.**

***Keywords* – District heating; heat tariff; low temperature waste heat; modelling; waste heat; waste heat modelling prices.**

Nomenclature

CHP	Combined heat and power
DH	District heating
EU	European Union
GHG	Greenhouse gas
FC	Fixed costs
RES	Renewable energy source
VC	Variable costs

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1. Introduction

The use of fossil fuels has negative environmental impacts, it causes air pollution and climate change and has become controversial for geopolitical reasons. The Russian invasion of Ukraine in 2022 has had a major impact on European energy security, which was soon followed by the European Commission`s REPowerEU plan [1] aimed at reducing Europe`s dependence on Russian fossil fuels.

With the European Climate Act and the Green Deal, The European Union (EU) has set an ambitious target for Europe to become the first climate-neutral continent by 2050 and an interim target of a 55 % reduction in greenhouse gas (GHG) emissions by 2030 compared to 1991. The "Fit for 55" [2], adopted in July 2021, increases the renewable energy target from 32 % to 40 % and the EU energy efficiency target from 32.5 % to 39 %. A single European framework requires Member States to include in their national plans policies and measures covering the five key dimensions: decarbonisation, energy efficiency, energy security, internal energy markets, research, innovation, and competitiveness. Decarbonisation of the heating and cooling sector will be a key challenge and contribution to achieving climate neutrality: heating and cooling currently account for half of the EU`s final energy consumption and depend mainly on fossil fuels [3].

In recent decades, most European energy policies have focused on renewable electricity and have been implemented mainly at the EU and national levels. As most European countries have not addressed the decarbonisation of heating and cooling. The domestic market for heating and cooling has led to a significant lack of data on its characteristics. It has prevented the development of effective and efficient policies to decarbonise heating and cooling – the development of such policies has now become an EU priority [3].

Decarbonisation of the heating sector is also increasingly important in the context of the energy crisis, as it reduces dependence on fossil fuels. DH plays an important role in the decarbonisation of the heating sector, as it allows the use of renewable energy sources (RES) and the integration of low-temperature waste heat from urban sources [4].

Buffa [5] mentioned the importance of addressing environmental and energy issues for existing and future urban centres. The main objective of the strategy to address these challenges is the efficient use of energy and the use of local energy sources. Local energy sources can also include waste heat from urban areas such as data centres, supermarkets, and wastewater treatment plants. However, the use of indigenous energy sources also involves sophisticated energy system design, integration (RES), as well as the introduction of circular economy models in the energy sector.

Waste heat is considered as all forms of heat (latent as well as sensible) that is emitted from the system to ambient air and not used further. For instance, heat from combined heat and power plants is not considered as waste heat if it is used for heating purposes. Sources of waste heat in industries can be single machines or whole systems that release waste heat into the environment. These sources include wastewater from washing, drying or cooling processes and refrigeration systems or exhaust air from production halls. Waste heat can be released either diffusively as radiation or convection at a surface or through a heat carrier medium like exhaust gas, cooling fluids or steam [6]. Most common waste heat sources are industrial objects which is divided into three sections based on its temperature – low, medium and high temperature. Other low temperature waste heat sources occur in wastewater treatment plants, and data centres, commercial buildings. Waste heat was officially recognized by the EU as a RES of energy, by the directive published in December 2018 [7]. Therefore, this source of energy can become a new constituent of sustainable energy supplies, contributing to a more efficient resource use, and reducing pressure from other RES that are needed to achieve the energy transition. Neugebauer *et al*. [8] have calculated, that in Austria wastewater treatment plants might contribute 40 % of the installed heat power in DH grids without combined heat and power cycles additionally to the energy supply. Using sewage water heat in DH with the help of large – scale heat pumps are an often - used practice, as sewage water has high enough temperature for heat pump integration [9].

The structure of the DH sector in Europe is very heterogeneous. Northern and Eastern Europe have the highest number of people receiving DH, while Southern Europe has a rather low number of DH clients, probably due to climatic conditions and missing historical infrastructure [4]. In the EU, The Scandinavian and Baltic countries have the highest share of DH (Sweden – 50 %, Denmark – 46 %, Lithuania – 40 %, Estonia – 39 %), while in the several EU Member States the market share of DH is less than 1 % (Belgium, Ireland, Spain). The EU – 27 mainly produces heat in Combined heat and power (CHP) plants (63 %). Two-thirds of this heat is produced using fossil fuels (mainly natural gas), while biofuels and biomass, the main low CO_2 emitting fuels, account for 27 %. The Scandinavian and Baltic countries with high shares of DH also have high shares of low – carbon fuels and are currently the best performers in the EU in terms of decarbonisation, with RES accounting for more than 45 % [10].

DH is a natural monopoly and therefore is subject to some form of regulation in most countries. Unlike electricity and natural gas networks, DH is often a vertically integrated service, with generation, network and distribution vertically managed by a single company [3]. In some countries, a combination of public and private ownership is common, with large heating networks owned and operated by large energy companies, while smaller networks are usually owned by municipalities [11]. This creates institutional rules and regulations to ensure market transparency and protect consumers from abuse. This creates institutional rules and regulations to ensure market transparency and protect consumers from abuse. DH consumers are therefore protected from monopoly by regulations. Such rules are put in place to ensure market transparency, protect consumer`s rights create confidence in DH and ensure that citizens are willing to use DH [10]. However, different European countries have different approaches to regulating DH. This ranges from stricter, more obligation – or rule–based requirements, to prescriptive regulation with fewer rules and obligations. Regulation varies across EU Member States, ranging from stricter, rules-based requirements, as in Denmark, to regulation with simpler or less stringent rules, such as competition–based regulation, as in Finland [3], [11].

Billerbeck *et al*. have studied DH and concluded that in most countries DH requires some form of authorisation, such as a licence. Depending on the country, this type of licence is then linked to the size of the DH network or the ownership structure. This is the case in Norway, where, according to the Norwegian Energy Act, a licence is required for DH with a total capacity of more than 10 MW. The licensing process is also different: in Denmark, operators of new DH networks can submit a project proposal to the municipality, and approval of these proposals takes place under the Danish Heat Supply Act. In France, a tendering procedure must be organised by the local authority and the selected operator receives the contractual right to operate the DH network. In several European countries, such as Hungary, Lithuania, Estonia and Poland, all DH networks require an operating licence or permit, which is usually granted following a standardised procedure. In some countries, such as Germany, they only need to be registered with the German Commercial Register. However, there are also countries where no registration or licence is required, such as Finland [11].

DH regulation should be considered from both a company and societal perspective. From a company perspective, DH regulation should address the high upfront capital costs that are necessary given the long-term investment perspective of DH and the associated risks. From a societal perspective, regulation should ensure that thermal energy is affordable for consumers and protect high prices, as well as long-term planning to meet climate targets. There can be some very important aspects of consumer attitudes towards DH as they directly affect consumers. For instance, the rules that make it compulsory for a customer to be connected to DH and not be able to opt out of it, and therefore the price that is charged for the heat, cannot be influenced by the customer. Billerbeck *et al*. [12] consider that by analysing the interplay between DH regulation and market power, it is possible to ascertain to what extent different DH regulations contribute to positive consumer attitudes towards DH. If the EU aims to increase the take-up of DH in line with decarbonisation objectives, it is important to understand consumer perceptions of DH and the role of its regulation. By analysing the regulation of DH, it is possible to understand not only the interplay, but also to identify opportunities for the development of DH and barriers to the transition from third-generation DH to fourth-generation DH, which are in line with the history of the development of the DH system provided by Lund [13] and Revesz [14].

A waste heat recovery system consists of 3 essential elements: the source of waste heat, recovery technology and the use of the waste heat [15]. In a system of recovery and integration of waste heat, there are several parties involved, whose relationship is established by means of a contract. Of particular importance is the fact that the source and the receiver of the waste heat are usually two different stakeholders, each with its own objectives and interests. Moreover, it's not only these two parties that may be involved, since the final consumer, who is the one who pays for the heat supplied and has an interest in receiving the heat at the lowest price, receives the heat from the DH company. Therefore, the process of recovering and integrating waste heat into DH can be time-consuming and complex.

Ziemele *et al*. [16] point out that the heat tariff methodology has only one efficiency indicator, the classical production efficiency, which does not incentivise the DH companies to improve the efficiency of the heat process. The heat tariff structure in Latvia is not a very effective instrument to reduce GHG emissions. The government can influence the DH companies by increasing the natural resource tax, but given that most DH companies are monopolies, these costs will still end up in the final tariff and be paid by heat consumer. It is therefore essential to introduce additional mechanisms that also track the efficiency level of the DH company and encourage the production of non-combustion heat.

Lygnerud *et al*. [17] from the successful waste heat integration into DH networks in Sweden concludes, that it is important to ensure trust between the collaborating partners, involve different stakeholders and establish joint goals. Another important aspect is the identification of a suitable business model. Therefore, several authors [18], [19] have investigated potential pricing mechanisms for waste heat integration through different methods. However, the research on suitable pricing mechanisms for waste heat integration under strict heat tariff regulation is missing. The novelty and objective of this research are to focus on the use of waste heat in DH by developing different mathematical models for the calculation of the heat tariff in which waste heat is integrated as additional heat energy. The goal of our paper is to show how it is possible to integrate waste heat from urban sources under different business models without changing the approved heat tariff calculation methodology based on legal conditions in Latvia.

The paper is structured as follows: Section 2 describes the regulatory framework for DH. Section 3 discusses the DH tariff applied in Latvia. Section 4 discusses potential business model scenarios, giving several examples of how waste heat can be integrated into DH and demonstrates a model for the pricing of waste heat based on the waste heat from wastewater treatment plants and considering involved stakeholders. Section 5 presents the results, while the conclusions are presented in Section 6.

2. BACKGROUND INFORMATION: DISTRICT HEATING SYSTEM AND REGULATION IN LATVIA

In Latvia, heating is provided through district or individual heating systems or individual heating. DH is carried out by a single vertically integrated DH operator, which produces, transmits, and distributes heat energy in an interconnected manner [20]. Municipalities may promote the development of DH within the planning of their administrative area by drawing up a detailed and local plan for the municipality, providing, where possible, for the planned location of DH utilities and, BY with the location and planning framework for DH elements, defining a DH zone, which is visually accessible on the website [21].

The heat tariff calculation methodology for DH companies has been approved by a decision of the Council of the Public Utilities Regulatory Commission of Latvia. It establishes the procedure for calculating tariffs for regulated heat supply services: heat production, heat transmission and distribution, and heat trading. The DH companies may choose a one-part or two-part tariff for heat costs. In the case of a one-part tariff, the variable and fixed costs of heat are allocated to the unit of heat sold to users and DH companies receive payment for the heat at the set one-part tariff. In the case of a two-part tariff, the variable costs of heat are allocated to the unit of heat sold to users in the energy charge and the fixed costs are allocated to the total heat capacity demanded by all users. DH companies shall receive the energy charge for the heat energy sold and the capacity charge for the heat capacity demanded by the users as a fixed charge irrespective of the amount of heat energy consumed by the users [22]. The heat tariff is calculated by applying the same heat tariff to all users. The heat tariff is calculated separately for each heat supply service – production, transmission and distribution of heat, and trading of heat. The production of heat is the most important heat supply service, while the costs of the sales service are the lowest. Each service is split into two parts: fixed costs and variable costs, which together make up the total costs. Fixed costs don't depend on the amount of heat produced, but include investment costs, loan payments, interest payments, depreciation costs, taxes, rent, operating costs, insurance, etc. staff salaries are also fixed costs [23].

3. METHODOLOGY

The goal of this study is to develop different scenarios for the calculation of heat tariffs in a case study, where low-temperature waste heat from urban sources is integrated into DH. The calculation of cooperation models is based on the approved Latvian heat calculation methodology discussed above. Tariff scenarios are calculated using an Excel tool. The calculated cooperation models may be submitted to the Regulator as annexes for the approval of the heat tariff. This document uses the heat tariff at fixed fuel costs and electricity prices. A sensitivity analysis is also applied to scenarios – the sensitivity analysis is based on fuel and electricity price changes.

3.1. Heat Tariff Calculation

There are two ways of calculating tariff for DH companies, most companies choose a one – part tariff, which is calculated according to the following formula (1) [22].

$$T = T_1 + T_2 + T_3, \tag{1}$$

where:

T	heat sales tariff, EUR/MWh;
T_1	heat production tariff, EUR/MWh;
T_2	heat transmission and distribution tariff, EUR/MWh;
T_3	heat trading tariff, EUR/MWh.

Each part consists of fixed costs (FC) and variable costs (VC) Eq. (2) [22]:

$$T = \frac{VC + FC}{Q_{\text{prod}}}, \tag{2}$$

The variable costs of the tariff (VCR, EUR/yr) are determined by Eq. (3) [22]:

$$VC = \frac{Q_{\text{prod}}}{\eta}\left(C_{\text{fuel}} + C_{\text{tax}} + C_{\text{el}} + C_{\text{oth}}\right), \tag{3}$$

where:

Q_{prod}	produced amount of heat, MWh/yr;
η	heat generation efficiency;
C_{fuel}	fuel price, EUR/MWh;
C_{tax}	taxes, EUR/MWh;
C_{el}	electricity price, EUR/MWh;
C_{oth}	other costs, EUR/MWh.

The fixed costs of the tariff are determined to the following formula (4):

$$FC = C_{\text{wage}} + C_{\text{rep}} + C_{\text{dep}} + C_{\text{ins}} + C_{\text{ptc}} + C_{\text{oth}} + C_{\text{pro}}, \tag{4}$$

where:

C_{wage}	wages, EUR/MWh;
C_{rep}	equipment repair and maintenance costs, EUR/MWh;
C_{dep}	depreciation of fixed assets, EUR/MWh;
C_{ins}	insurance, EUR/MWh;
C_{ptc}	interest payments, EUR/MWh;
C_{oth}	other costs, EUR/MWh;
C_{pro}	property tax, EUR/MWh.

To assess the impact of fuels on the overall tariff T (EUR/MWh), a fuel component is determined by Eq. (5) [22].

$$A_{\text{fuel}} = \frac{Q_{\text{Prod}} \cdot C_{\text{fuel}}}{\eta \cdot Q_{\text{Con}}} \tag{5}$$

The allocation of FCR and VCR is also maintained for transmission and sales tariffs, but unlike in Eq. (2), the costs are not divided by the total heat produced Q_{prod}, but by the heat transferred to consumers Q_{nod} excluding losses in the heat networks Q_{los}. Fixed costs (F_{CK}, EUR/yr) shall be calculated in the same way for all parts of the tariff, according to the following formula (6) [24].

$$F_{\mathrm{CK}} = Q_{\mathrm{Prod}} \cdot C_{\mathrm{O\&M}} + C_{\mathrm{S}} + C_{\mathrm{k}} + C_{\mathrm{ins}} + C_{\mathrm{prof}} + C_{\mathrm{oth}}\,, \tag{6}$$

where:

F_{CK} fixed costs, EUR/MWh;
$C_{\mathrm{O\&M}}$ operation and maintenance costs for selected part EUR/MWh;
C_{S} salary with social taxes, EUR/MWh;
C_{k} depreciation and loan payments, EUR/yr;
C_{ins} insurance payment, EUR/yr;
C_{prof} DH company profit, EUR/yr;
Q_{con} heat received by the customer, MWh/yr.

The largest part of the heat tariff is the production tariff, which is highly dependent on fuel costs [25].

3.2. Case Study Description and Waste Heat Integration Potential

The town of Salaspils is selected for the case study, which has 18 011 inhabitants and 85 % of its heat supply is provided by DH. The total annual heat demand is about 60 TWh, and the maximum heat load of the consumers is 27 MW. Most of the heat (about 60 %) is produced by two wood chip boilers (7 MW and 3 MW), while the peak load is about 13 % covered by natural gas; natural gas boiler 23 MW. The heating company also uses RES for heat production – a solar collector park with 1720 collectors has been installed. The heat is stored in a storage tank of 8000 m^3. The input data for the heat production rates and fuel mix are taken from the publicly available summary of the heat supply company's draft heat tariff for 2023.

In future development scenarios, it is assumed that the part of DH produced by natural gas will be replaced by waste heat. The potential for waste heat is derived from a previous study [26], which analysed the potential for waste heat from a wastewater treatment plant. The most important parameters for the heat recovery of treated wastewater are the temperature level and the flow rate, and these parameters determine the potential amount of waste heat that can be recovered and integrated into DH. The heat potential from wastewater treatment plants is non-uniform over time, so the part of the heat produced from wood chips can also be partly replaced by waste heat. It is not possible to integrate all the amount of waste heat that could be recovered from the wastewater treatment plant into the DH of the case study. The potential of the waste heat is highest in summer when the heat is already generated by RES – solar collectors.

Table 1 shows the total heat production based on fuels. Scenarios 2 and 3 show the amount of waste heat that is integrated into the district heating system.

TABLE 1. HEAT PRODUCTION BASED ON FUELS

	Scenario 1	**Scenario 2**	**Scenario 3**
Natural gas, GWh	8.46	6.53	6.53
Wood chips, GWh	38.63	36.19	36.19
Solar collectors, GWh	9.08	9.08	9.08
Flue gas condenser (for wood chips boilers), GWh	7.94	7.94	7.94
Waste heat, GWh	0.00	4.37	4.37
Total	**64.11**	**64.11**	**64.11**

The DH operator has so far generated the heat demand in the biomass and natural gas boiler house, but for this study, scenarios have been developed in which waste heat is integrated into the DH – the source of the waste heat is in an urban area but is not connected to the DH network, so investments are needed to allow the waste heat to be transferred.

4. Scenarios And Waste Heat Tariff Model

As noted in the previous section, the source of the waste heat is not connected to the DH network, which means that the recovering waste heat requires the construction of infrastructure – DH pipeline. This study compares two pricing scenarios with a reference scenario. The pricing scenarios reflect different pricing schemes for waste heat.

An overview of the scenarios is given in the Table 2.

TABLE 2. AN OVERVIEW ON THE SCENARIOS

	Pricing scheme description	**Price for waste heat is included**	**Price for the waste heat**
Scenario 1	No waste heat recovery	–	–
Scenario 2	Purchased as additional heat	Under the section Heat production tariff – cost of purchased heat	65.45 per MWh
Scenario 3	Payments for capital investments	In the production tariff under fixed costs	Annual interest payment thousand EUR 197.34

The first scenario is a reference scenario, in the second scenario, the costs for waste heat are included in the heat tariff as additional heat energy, which is purchased, while in the third scenario, infrastructure is built to integrate waste heat, and the costs are included in the tariff, but no as additional heat energy, but as included in the tariff as an interest payment, because DH company invests in the waste heat infrastructure.

Scenario 1. The waste heat is not recovered and integrated into district heating, but this scenario serves as a reference scenario for comparison with other scenarios. First scenario is based on the existing situation of the analysed Case study. Almost 60 % of the heat production is produced with wood chips, natural gas is used to cover the peak load, about 13 %, the rest is provided by recovery from the flue gas condenser, and the heat is produced with solar collectors.

The first scenario is based on the existing situation of analysed Case study. Almost 60 % of the heat production is produced with wood chips, natural gas is used to cover the peak load, about 13 %, the rest is provided by recovery from the flue gas condenser, and the heat is produced with solar collectors.

Scenario 2. The second scenario assumes that the heat from the wastewater treatment plant is purchased as additional heat. The price at which to purchase the heat is determined by the investment required to integrate the heat into the DH. The cost of purchased heat is reflected in the tariff under the section Heat production tariff – the cost of purchased heat.

The cost of purchased heat is determined by the following formula:

$$NVP = \frac{Cap.costs - Profit}{\left(1 + WACC\right)^{n}}, \tag{7}$$

where:

NVP	Net Present Value;
Cap.costs	capital costs;
WACC	weighted average cost of capital;
n	years.

$$Profit = H_{\text{tariff}} \cdot WH - E_{\text{HP}}, \tag{8}$$

where:

H_{tarif} heat tariff for waste heat;
WH waste heat amount;
E_{HP} electricity for heat pump.

To integrate the waste heat into the DH system, it is necessary to build a heat pipe from the source of the waste heat to the DH network. The waste heat is located at 2000m.

Capital costs is calculated by the following formula (9).

$$Cap.costs = HP + \left(h_{\text{p}} \cdot h_{\text{Pl}}\right), \tag{9}$$

where:

Cap.costs capital costs, EUR;
HP heat pump costs, EUR;
h_{p} heat pipe costs, EUR/m;
h_{pl} heat pipe length, m.

To calculate the capital costs, it is assumed that the heat pipe cost is 400 EUR/m. A heat pump is also needed to integrate the low-temperature waste heat source into the DH. The capital costs of the heat pump are calculated based on the amount of waste heat and operating hours, as well as the cost of the heat pump. To make the capital investment economically feasible, a payback period of 15 years is assumed, so the minimum price per MWh of waste heat is set at 65.45 EUR/MWh. Assuming a waste heat tariff of 65.45 EUR/MWh, the cost of waste heat purchased in the production tariff is 285.81 thousand EUR.

The construction of a new heat pipe increases the electricity consumption and the heat losses, which are included in the production costs.

Scenario 3. In this case, heat is produced using wood chips, natural gas, solar collectors and heat is recovered from the flue gas condenser. As in the Scenario 2, the heat produced from natural gas and wood chips is replaced by the heat recovered from the wastewater treatment plant. In Scenario 3 heat is not purchased, but the DH operator has invested in the infrastructure to recover waste heat and then uses it free of charge.

The cost of heat recovery is determined using the following formula:

$$Invest = \frac{Cap.costs(1 + pct)^n}{15}, \tag{10}$$

where:

Cap.costs capital costs, EUR;
pct percent (0.05);
n years (15).

The third scenario assumes that the DH company invests in the waste heat recovery infrastructure itself, so that capital costs are determined for both the construction of the heat pipe and the installation of the heat pump. The capital investments are subject to compound interests and have a payback period 15 years, so the annual interest payment is set at EUR 197.34 thousand, which is included in the production tariff under fixed costs. In this case, the production tariff increases the electricity costs and the heat losses.

5. RESULTS

The heat produced part of the tariff is the largest part of the heat tariff – this section depends on fuel costs, variable costs, and fixed costs. The largest part is direct fuel costs. As mentioned above, in the first scenario no additional heat is purchased but all is produced by the DH itself, while in the second and third scenarios heat from the waste heat source is integrated. The fuel costs for heat are shown in Fig. 1.

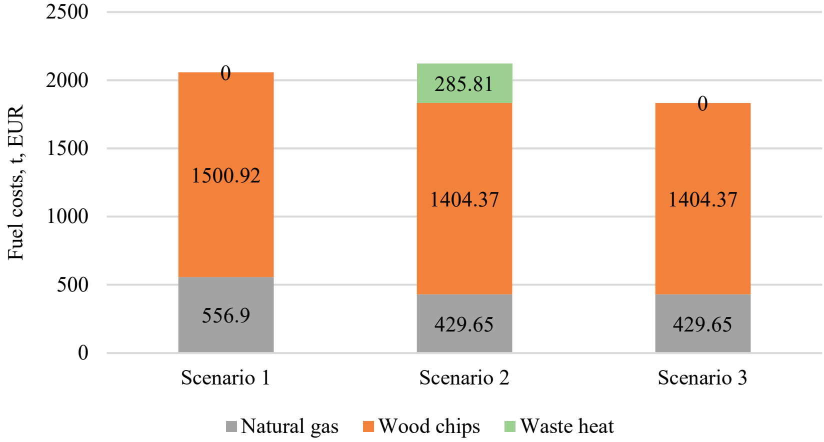

Fig. 1. Fuel costs.

In Scenarios 2 and 3, the fuel costs for natural gas and wood chips are the same, but in Scenario 2, DH purchases additional heat from a waste heat source that has invested in infrastructure to be able to transfer and integrate the heat into the heat supply network. Waste heat is purchased at 65.45 EUR/MWh, bringing the total cost to EUR 285.81 thousand.

The variable and fixed costs of the heat tariff are shown in Fig. 2.

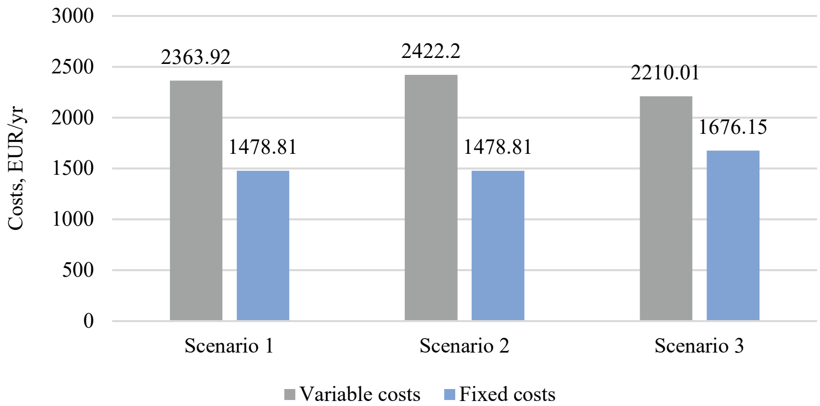

Fig. 2. The variable and fixed costs.

The variable cost of the heat tariff increases in the second scenario because the DH operator purchases heat from a waste heat source and therefore the cost of electricity to run the heat pump also increases. In the third scenario, on the other hand, variable costs decrease as fuel costs are lower compared to the other scenarios, while fixed costs increase as the DH operator invests in infrastructure for the recovery of waste heat.

On the other hand, the variable and fixed costs of the heat transmission and distribution tariff are higher in the second scenario due to higher heat loss costs as the production tariff is higher in the other scenarios. The variable and fixed costs of heat transmission and distribution tariff are shown in Fig. 3.

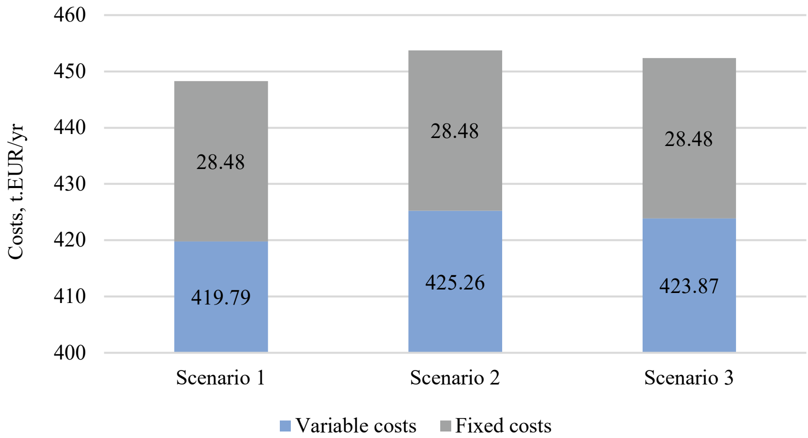

Fig. 3. The variable and fixed costs of heat transmission and distribution tariff.

As mentioned above, the final heat tariff is the sum of all three components – production tariff, transmission and distribution and trading of heat tariffs. Table 3 summarises the results for the three scenarios.

TABLE 3. FINAL RESULTS OF HEAT TARIFF COMPONENTS

	Scenario 1	**Scenario 2**	**Scenario 3**
Production tariff, EUR/MWh	69.15	70.06	69.83
Transmission and distribution of heat tariff, EUR/MWh	7.9	8	7.97
Trading of heat tariff, EUR/MWh	1.5	1.5	1.5
Heat tariff total, EUR/MWh	78.55	79.56	79.3

As shown in Table 3, the lowest heat tariff is in the first scenario, where heat is produced by DH without waste heat integration. The highest tariff is in the second scenario, where the heat from the waste heat source is purchased as additional heat.

For all three scenarios, a sensitivity analysis is carried out to test the robustness of the results under certain changes. Sensitivity analysis explores the relationship between the output and the input of the process [27]. In this case, sensitivity analysis is used to show changes in 3 factors; natural gas price, woodchip price and electricity price which impact the waste heat integration via heat pump operation costs.

The sensitivity analysis results for Scenario 1 are shown in Fig. 4.

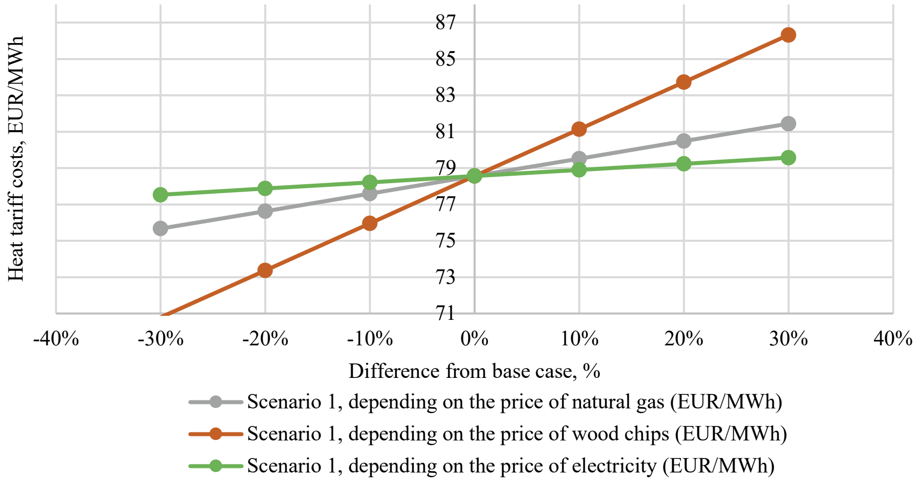

Fig. 4. Scenario 1 sensitivity analysis.

The sensitivity analysis shows that the price of wood chips has the largest impact on the final heat tariff. If the final tariff in the first scenario is 78.55 EUR per MWh, it increases to 86 EUR per MWh if the price of wood chips increases by 30 %. On the other hand, if the price of wood chips decreases by 30 %, the final tariff decreases to 71 EUR per MWh. The electricity price has the smallest impact.

The sensitivity analysis results for Scenario 2 are shown in Fig. 5.

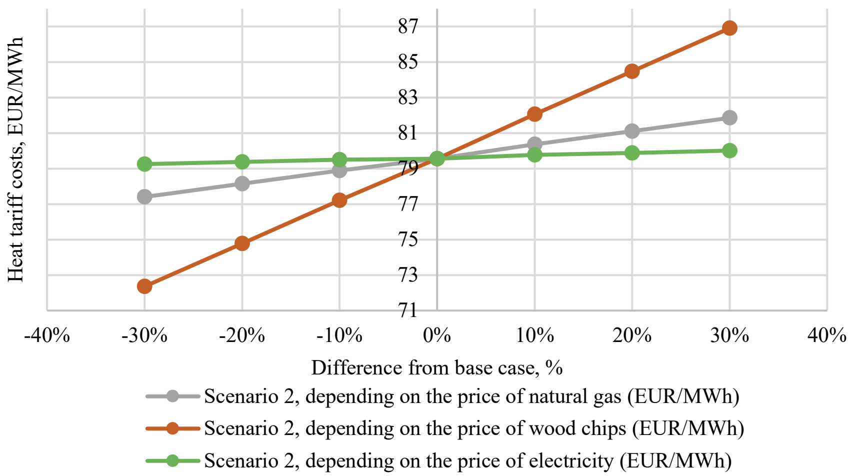

Fig. 5. Sensitivity analysis in Scenario 2.

The sensitivity analysis shows that similarly to the first, the second scenario has the largest tariff change due to changes in the price of wood chips. If the price of wood chips were to increase by 50 %, the second and third scenarios would be slightly more favourable than they are today. If the final tariff in the first scenario is 79.5 EUR per MWh, the final tariff increases to 86.9 EUR per MWh if the price of wood chips increases by 30 %. On the other hand, if the price of wood chips decreases by 30 %, the final tariff decreases to 72 EUR per MWh.

The sensitivity analysis results for Scenario 3 are shown in Fig. 6.

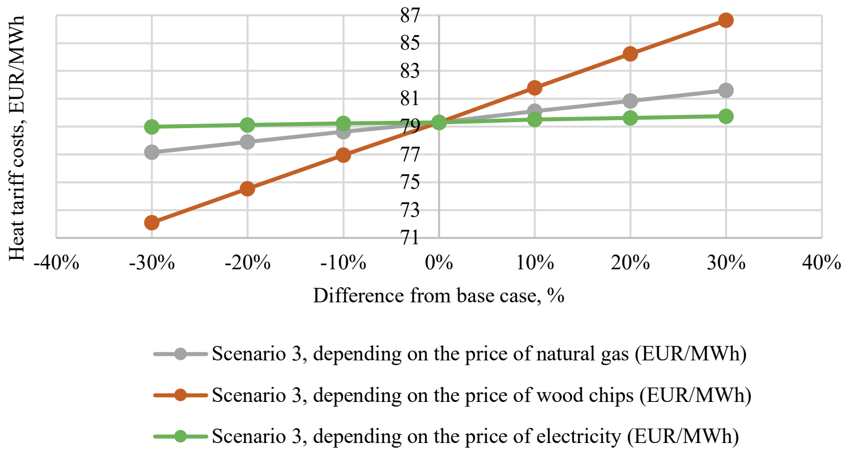

Fig. 6. Sensitivity analysis in scenario 3.

Also in the third scenario, the price of wood chips is the most affected, as wood chips are mainly used to produce heat. If the final tariff in the first scenario is 79 EUR per MWh, the final tariff increases to 86.6 EUR per MWh if the price of wood chips increases by 30 %.

6. CONCLUSION

Considering the results obtained for all three scenarios, the most favourable scenario now is if the heating company produces its own heat. The price of waste heat in the second scenario is higher than the price of natural gas, as the price of heat must be higher than EUR 65.45 per MWh for the company to recover its investments over 15 years. The price of natural gas on the market has now fallen compared to the period of the energy crisis in Europe. Therefore, if the natural gas price is below EUR 66 per MWh, it is unprofitable to integrate the waste heat into the DH of the case study, because an analysed case study is already very efficient, using both wood chips and solar collectors. Consequently, in this case, it is not profitable to recover the waste heat from an urban source, because integration of waste heat in DH requires a large investment and the source of the waste heat is far from the DH grid. Also, the amount of waste heat from wastewater treatment plants is not sufficient to fully replace the consumption of natural gas. The thermal energy in the waste heat source remains unused because it cannot all be integrated into the DH. The full potential of the waste heat from the waste heat source cannot be used because, during the summer, when the waste heat is generated, the DH company produces heat with solar collectors, so the waste heat is not needed – heat that cannot be used for DH could be stored in thermal storage tank. However, the amount of waste heat from wastewater treatment plants is not large, so it will not be economically viable.

To promote the decarbonisation of the energy sector, the government or the municipality can support the DH companies to promote the integration of the waste heat. One of the potential supports could partly cover the necessary investments for necessary infrastructure. Grants for capital cost reduction could significantly reduce waste heat costs and therefore increase the competitiveness with other heat sources, e.g., natural gas or solid biomass. The future studies could be dedicated to comparison of different policies and support measures for low temperature waste heat integration into DH systems.

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