Kristina Schumacher
Nordjylland
Mobil +49 176 34648339
ks@planenergi.dk

Magda Komoszynska (Kowalska)
Nordjylland
Mobil +45 2266 9219
mk@planenergi.dk

Identification and analysis of possible sustainable heating solutions in Pljevlja in Montenegro for CEE Bankwatch

FINAL REPORT

July-August 2021

NORDJYLLAND
Jyllandsgade 1
9520 Skørping

MIDTJYLLAND
Vestergade 48 H, 3. sal
8000 Aarhus C

SJÆLLAND
A.C. Meyers Vænge 15
2450 København SV

Tlf. +45 9682 0400
Fax +45 9839 2498

www.planenergi.dk
planenergi@planenergi.dk

CVR: 7403 8212

1 Executive summary

This study was conducted for the CEE Bankwatch Network working extensively on phasing out fossil fuels in several countries, including the highly fossil fuel dependant town of Pljevlja in Montenegro. The goal of the analysis was to identify and assess the most favourable sustainable solutions which could be implemented as environmentally and economically sustainable alternatives for heating, viable for the medium- to long term.

The process of decarbonisation of the heating supply systems begins with the reduction of heating demand (see chapter 4), both at the consumer side and in the heat transmission infrastructure. This then follows with the implementation of efficient, renewable heat generation technologies. The optimal solution for a community can dramatically vary from case to case, as it is subject to the local needs and objectives for the town. The strategy in determining feasible energy development solutions and heating alternatives in the Pljevlja town was based on a few key objectives: an affordable heat price for the consumer, reduction of carbon emissions and decreasing dependence on biomass and fossil fuels given the current energy mix entirely relying on wood fuel and lignite.

Existing consumers in Pljevlja are supplied by means of combustion of biomass and lignite either burned in small individual heating boilers (consumer group A.) or in large boiler rooms which supply 31% of the inhabitants who are connected in "microgrids" (consumer group B.). Given this variety of consumer types, a few crucial actions had to be proposed to achieve diametrical technological improvement to the heating system. Firstly, energy efficiency measures are necessary to allow the transition to renewable heating technologies and a certain share of building retrofits is presupposed in this study. The source data has already accounted for some level of building thermal improvements, and this analysis takes further retrofitting into account (see consumer group 3.2) which is necessary to implement renewable technologies operating at low heating temperatures.

To improve the energy transmission and reduce fuel consumption as well as incorporate alternative heating solutions with high spatial requirements which are feasible only outside of the condensed living area, also the implementation of a district heating network (consumer group C) is considered. This last group of consumers is created for this study by either connection of the microgrid users into larger DH networks or the connection of individually heated properties to a new heating pipeline.

Several identified technology options and combinations for each of the distinguished consumer groups were assessed using an Integrated Risk Matrix (IRM) approach. This methodology is used to summarise the merits and risks associated with each of the technology scenarios against weighted criteria. This facilitates an appraisal of diversified energy generation options and helps to identify a shortlist for further consideration.

The IRM has been conducted for four main DH expansion scenarios (I. – IV.) where the most suitable sizing of a possible DH grid is sought. Within each scenario, all groups of consumers are assessed separately for the most suitable form of renewable heating technology option which would satisfy their heating needs at the lowest cost and higher environmental improvement. There are also other technical, strategic, and planning criteria impacting the final score of each solution which are expanded in later chapters.

The final results of this study show that if no subsidies for renewable energy technologies are assumed, the overall investment costs indicate that no DH network should be set up and the current heat distribution based on individuals and microgrids should remain in place (Scenario I.). When incentives at 80% of total investment in heat pumps and solar thermal with seasonal storage are included, the development of a DH in the wider centre of the town is most promising (Scenario III.).

Small biomass boilers are overall the best way to replace old individual furnaces (A). Air-to-water heat pumps provide the most efficient energy supply for microgrids (B) while open-space solar thermal in combination with seasonal storage (Annex 9) is optimal to provide energy for DH (C).

A summary of the findings is presented in Table 1. The lower the overall score is, the higher the solution appears in the rank of the hierarchy among the investigated technology options. The best results are already demonstrated by the technologies in the table which scored highest in each of their consumer group.

A transition to renewable heating and complete elimination of coal use in Pljevlja is possible at moderate cost for customers. However, a significant reduction of biomass utilisation is only realistic if subsidies for the investment costs in heating plants are provided. The highest CO_2 reduction of circa 46 kt CO_2 is achievable according to scenario III. The difference between overall CO_2 emission reduction between scenarios I and III is insignificant even though the new wood-fueled biomass boiler should be around half as carbon-intensive as the heat pump which would be fed by almost 50% fossil fuel-based electricity. This disadvantage of heat pumps will diminish after Montenegro closes its coal plant as the emission factor of the used electricity improves. In general, the additional CO2 emissions from fuels in both scenarios are negligible compared to the total carbon savings achieved by ceasing operation of the current highly carbon-intensive mixture of coal/wood fuel.

Table 1: Summary of IRM results for the most recommended scenarios

Scenario	Consumer group	Technology	Heat contribution in MWh/yr.	CO2 reduction in t CO_2/yr.	Simple payback in yr.	Indicative heat price in €/MWh	Indicative NPV in €	Score
I.	A	New biomass boiler small	136.000	36.000	7,8	25	17.900.000	**14,7**
	B	Air-to-water heat pumps medium	36.000	8.000	7,9	19	7.400.000	**10,0**
III. with subsidies	A	New biomass boiler small	99.000	26.000	7,8	25	13.100.000	**14,7**
	B	Subsidized: Air-to-water heat pumps medium	20.000	4.000	1,5	9	7.200.000	**9,0**
	C	Subsidized: Open space solar thermal + storage	52.000	15.000	8,4	24	18.100.000	**13,1**

A sensitivity analysis implies that as soon as at least 22% of the investment cost for solar thermal technologies and heat pumps are subsidized, the option to establish a DH grid in the central zones 3, 6 and 7 while keeping the distribution system in the remaining zones unchanged (scenario III.), is rated better than scenario I.

Table of Content

2 Introduction

PlanEnergi was commissioned by CEE Bankwatch to develop a masterplan heating study for the town of Pljevlja, Montenegro. Currently, the heating supply of the town is based on wood and lignite. The heat distribution relies on individual furnaces and on boiler rooms which supply several houses connected in microgrids. The outdated stoves with poor filtering systems contribute to the large pollution problem in the region. In 2018, 680 premature deaths in Montenegro were registered due to air pollution (European Environment Agency, 2020).

To change this deficiency, the 2030 Energy Strategy of Montenegro envisages the development of district heating systems based on biomass (Energy Community Secretariat, 2020). However, a refurbishment of the old coal power plant (TPP) is also planned. This plant is then planned to provide the town with heat via a newly implemented district heating network (Dencon d.o.o. Podgorica, 2020).

This new heat supply would increase the air quality as the small distributed and highly polluting furnaces in the town could be eliminated and be replaced by one large plant with better filtering systems. Additionally, due to the more efficient centralized heat production and supply through DH, the fuel consumption could be reduced. However, this would not decarbonize the heating system in Pljevlja, as the generation plant would still be fossil-fuel based for some time. The Montenegrin government recently announced that it would phase out coal by 2035, rendering it questionable whether it is worth investing in a network for a plant that will operate for a maximum of 14 more years (and most likely much less in reality). Additionally, a large transmission line from the power plant to the town would be needed and the payment assessment for the pipeline by the owner EPCG has not been undertaken yet. This caused the plans for district heating networks in Pljevlja to be postponed until an undetermined future and therefore making the realization of the project uncertain.

2.1 Scope of the study

As a counterproposal to ongoing activities in Pljevlja and objectives indicated in the 2030 Energy Strategy of Montenegro, this study provides an overview of alternative options to transition the existing heating system to an renewable and energy-efficient solution based on renewable technologies. For this purpose, the reference heating system in Pljevlja is analysed first and a demand profile is created to account for possible future demand changes due to applying the energy efficiency measures.

This is followed by an evaluation of suitable renewable energy sources for the region and an Integrated Risk Matrix Assessment which is to determine the most promising implementation scenario of DH as well as the most economically viable and feasible supply option. The study concludes with the suggestion regarding the most cost-effective and fossil-free heating concept described in detail.

2.2 Source information about the heating system and demand

General information about the current heating system and the heat demand is extracted from the recent study on heat consumption in Pljevlja by Dencon (Dencon d.o.o. Podgorica, 2020).
The heating period is assumed to be 217 days long and the average outdoor temperature during the heating period is 3,2°C (Dencon d.o.o. Podgorica, 2020).

As typical in Montenegro, most households rely on individual heating. 83% of them use the private combustion stoves fed with a mix of coal and wood, 9% of the inhabitants apply modern pellet stoves, while only 2% rely on electricity for heating (NGO Green Home, 2020). About a third of the total heating demand is covered by larger boilers located in the more centralized DH systems (called ‘microgrid’) serving apartment complexes or a few connected houses. These boilers are also based on the combustion of lignite and wood (Dencon d.o.o. Podgorica, 2020).

So far, the domestic hot water (DHW) needs of the town are not supplied from the DH microgrids, and neither historical measured data nor estimates on DHW consumption are available (Ivanović, Vušanović, & Savićević, 2015).

The thermal isolation of most buildings is very poor, about 50% of households have not any kind of thermal insulation (NGO Green Home, 2020).
The program “environmental protection projects” concluded between the municipality and the public works administration is aiming to change that. By subsidizing 850.000€ for projects for pollution reduction and environmental protection and 490.000€ for the implementation of energy efficiency measures, the overall heat demand shall be reduced in the following years. This energy consumption improvement is taken into account in the current analysis and will be explained further in the later chapters.

3 Analysis of potential for alternative heating solutions

This chapter summarises the key assumptions for the study and the analysed heating system in Pljevlja.

3.1 General assumptions

The general assumptions include environmental and economic factors such as carbon intensity of different fuels and electricity, fuel prices and commercial indicators needed for the assessment of the economic viability of the proposed renewable investments.

Due to a lack of reasonable data on emission factors for fuels in Montenegro (Dragojević, Elezović, Tadić , Mrdak, & Zarubica, 2019), default EU values are implied instead (KEA-BW Die Landesenergieagentur, 2020). The emission factor for electricity is derived from the known share of renewables in electricity production (59% in 2018) (IRENA, 2019) and the fact that the remaining electricity is generated by coal combustion (Vlada Crne Gore, 2020). The commercial assumptions are based on customer prices in Pljevlja (NGO Green Home, 2020) (Mittelstand Global Exportinitiative Energie, 2021).

Fuel properties:
The most reasonable environmental and commercial fuel parameters identified as most reasonable are shown in Table 2.

Table 2: Environmental and economical fuel properties

Fuel	Emission factor in t CO_2/MWh	Consumer price in €/MWh
Lignite	0,36	23,5
Wood	0,02[1]	8,1
Lignite-wood-mix	0,19	15,8
Electricity	0,17	10,3
Wood pellets	0,03	21,6

[1] No Montenegrin emission factor for wood is available and no uniform factor exists in the EU. Generally, wood releases only as many emissions as it had absorbed during its lifetime and is therefore considered climate neutral by many countries, e.g., Denmark (Energistyrelsen, 2020). However, some emissions during the processing and transport process occur which is why in this study a more pessimistic estimate of 0,02 kg/kWh (German default value) is applied (KEA-BW Die Landesenergieagentur, 2020). Despite the low emission factor, biomass combustion

Commercial assumptions:
The economic assessment uses a contingency factor of 10% accounting for the investment expenses and a 3,5% discount rate (PlanEnergi's benchmarks).

Montenegro provides interest-free loans for the installation of new solar thermal systems and new boiler technologies (Direktorat za energetsku efikasnost, 2021). Since the character of a Master study does not include a detailed financial analysis of loan cost and the time value of money, the incentive has not been contemplated yet. For a more detailed examination later, this incentive needs to be considered. Equally, it could be assumed that this incentive might be expanded to other renewable thermal supply sources, too. So far, there are no other financial encouragements for renewable heating technologies in Montenegro. The CO_2 price is introduced as an input parameter and set to 0 €/t CO_2 to represent a "worst-case" scenario to reflect the actual investment case profitability in Business-as-usual conditions. Under the circumstances that Montenegro enters the EU-ETS scheme in the European market and becomes impacted with carbon emission charges, this could dramatically improve the economic viability of the renewable technologies and DH expansion in city of Pljevlja. Therefore, a sensitivity analysis is performed in chapter 5.3 to assess the impact of a CO_2 charge at different price levels on all fossil fuel consumers. In the master planning stage and given the uncertainty of the future EU-ETS rules applied in Montenegro, it was assumed that all CO_2 emission replaced by renewable technologies would benefit cost savings. A detailed evaluation of which type of producers, which year and price would incur a CO_2 expense could be a part of a detailed feasibility study as a next stage of the project.

3.2 Characteristics of demand side

Due to the mostly very poor thermal insulation and high age of the building stock, the average specific heat load is 150 W/m² (Dencon d.o.o. Podgorica, 2020). This is clearly higher than the average specific heat load in Western Europe of 50 to 70 W/m² (Ivanović, Vušanović, & Savićević, 2015). This high specific heat load in combination with the long heating period already indicates high thermal demand.

Given that all houses connected in microgrids will undergo building insulation improvements and replacement of radiators, the peak heat load of buildings in microgrids has been further adjusted with an overall 40% reduction. This assumption is made considering that the municipality already improved its own buildings, and a new investment plan will contribute 560.000€ for the retrofit of buildings currently connected to the main microgrid in the town centre. By this, more realistic calculations are enabled as most renewable energy technologies can only be applied on buildings with low flow temperatures (and therefore only modernized buildings).

The original specific heat consumptions per building type and town zone distinguished for thermally insulated and non-insulated houses are sourced from the heat consumption study (Dencon d.o.o. Podgorica, 2020) and are summarised in Annex 1.

The peak thermal demand has been further increased by accounting for 10% demand for domestic hot water supply which is foreseen as part of the Pljevlja development strategy.

Table 3 provides an overview of the adjusted peak heat load for each share of housing type.

---

has increased a lot during the past years while the planting and growing of trees is not happening accordingly. Therefore, over a short run more emissions are released which conflicts with climate goals. To account for this limited eco-friendliness, in a later assessment of the study biomass combustion is rated poorly in the qualitative criterion of "renewable energy contribution".

Table 3: Adjusted heat load for different zones and sectors

Zone	Heat load residential DH in kW	Heat load residential decentral in kW	Heat load business & public DH in kW	Heat load business & public decentral in kW	Heat load industry in kW
1	150	1.650	160	620	1.030
2	470	4.700	490	670	-
3	3.820	11.450	2.170	970	-
4	310	5.410	720	150	-
5	340	3.240	80	20	-
6	1.160	5.660	0	60	-
7	130	1.490	1.120	160	-
8	680	5.110	0	50	-
9	2.100	4.490	180	30	-
10	1.760	1.200	480	200	-
11	620	6.000	0	360	-
12	530	5.000	0	850	-
13	920	8.720	830	180	-
Other	-	-	-	-	4.000
Total	12.990	64.120	6.240	4.310	5.030

To assess alternative heating supply potential, a demand profile of the town needs to be established.

By applying default consumption profiles for different building types, the overall yearly demand and corresponding heat load curve could be found. The used default demand profiles for the different building types are presented in Annex 2. The calculations are not only distinguished between different building types (residential, public & business, and industrial) but also by different spatial zones and by the form of current supply (individual or microgrid).

The share of load connected to microgrids varies strongly between the zones, especially zones 3, 7, 9 and 10 are with a share of over 30% of DH networks well interconnected already.
After applying the peak demand data to the load profiles, a total yearly demand of 172.000 MWh for the whole town can be calculated.

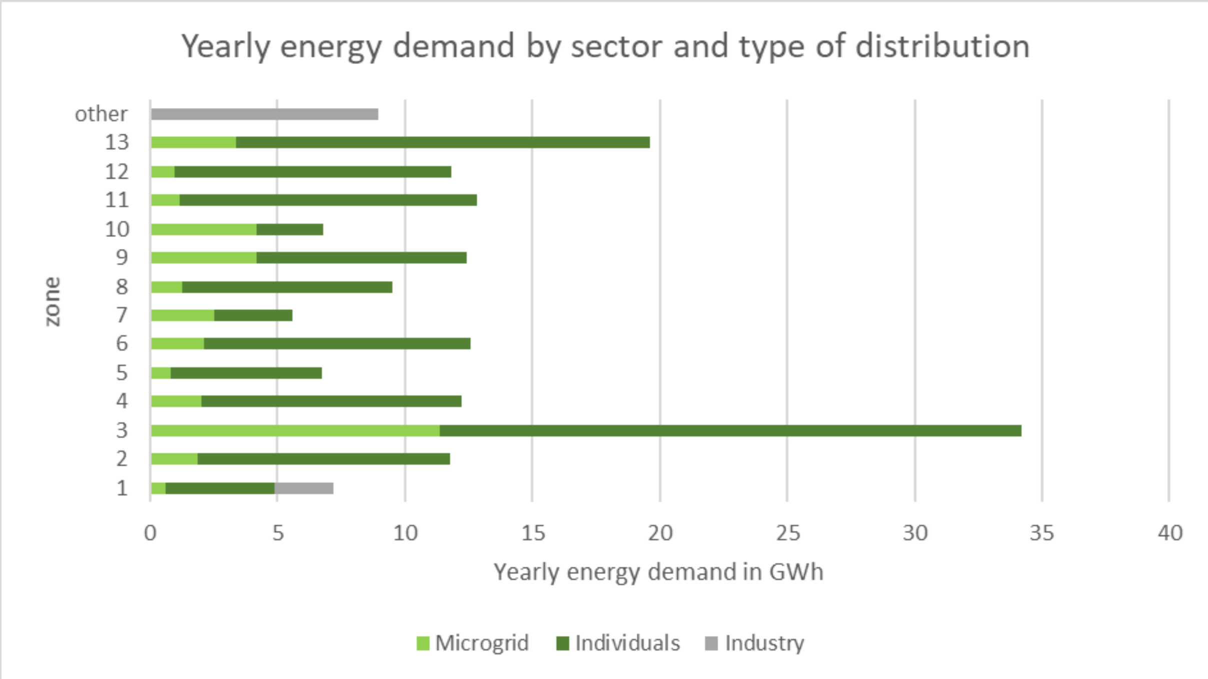

Figure 1: Yearly energy demand by sector and distribution type

Figure 1 shows the overall annual heat demand for the different zones. It becomes clear that also due to the assumed retrofit for houses currently supplied in microgrids, the energy demand for microgrids in comparison to decentral supplied houses in most zones is small. The retrofit causes a decline of the share of energy demand of microgrids from 31 to 22% of the total.
The heat load curve differs between the district building types. Overall, the total maximum heat load is 88,53 MW in December while the base load which is the minimum overall load accounts for only 2,16 MW. A major difference in demand between the seasons can be found. This is related to the structure of the building stock of the town. The share of residential dwellings is very large. Consequently, the strongly changing heat demand of residential buildings over time affects the overall demand curve greatly. The differences between various months and daytimes are visualized in Figure 2.

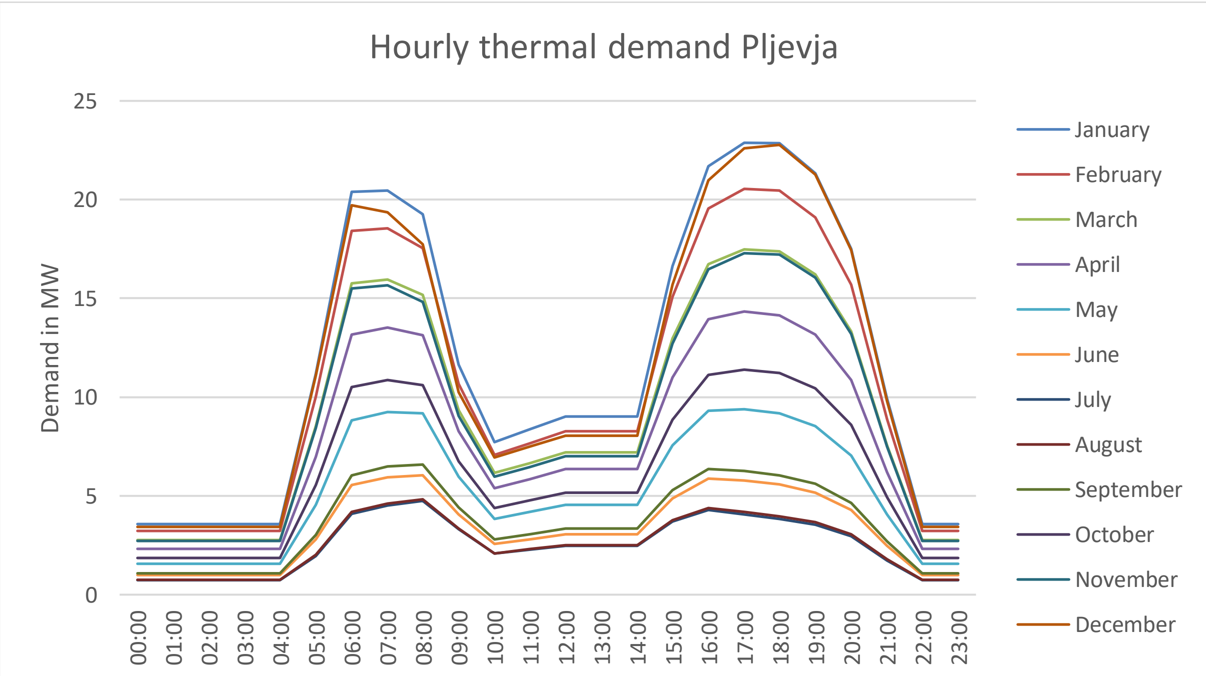

Figure 2: Total hourly heat demand Pljevlja without any efficiency measures

3.3 Characteristics of supply side

Counterfactual case:
Before analysing possible new thermal supply options, a “business as usual scenario (BAU)” is modelled. The BAU scenario reflects a future in which the current system is not changed, and current ways of heating stay in place. The following assumptions for the counterfactual case are made on basis of experimental data gained from a pollution study that examined exemplary boilers (Ivanović, Vušanović, & Savićević, 2015):

- Boiler efficiency small: 65%
- Boiler efficiency large: 69%
- Fuel use: 50% wood and 50% lignite

Maintenance costs are retrieved by multiplying the specific maintenance cost for new biomass boilers with the ratio of the efficiency of new boilers to the efficiency of old boilers. By doing so, the maintenance cost reflects the higher maintenance demand of older boilers due to outdated technology and less efficiency.
Technologies:
This study tries to model a heat supply that is completely based on renewable energy. Therefore, only renewable energy technologies are considered in this study. Due to a lack of knowledge about the geological properties of the area of Pljevlja the use of deep geothermal energy is not considered. Instead, biomass boilers, solar heating and heat pumps are examined.

All technical properties as well as costs for renewable technologies are based on European benchmark data, presented in the “Technology data” reports by the Danish Energy Agency (Danish Energy Agency and Energinet, 2017) (Danish Energy Agency and Energinet, 2020). The local costs of technologies and construction wages were not available at the time of performing the study, hence for this assessment stage only European data is applied.
Investment costs comprise of equipment costs (for components and machinery) and installation costs (engineering, civil works, buildings, grid connection, installation, and commissioning).
The fixed Operation and Maintenance costs include costs for administration, operational staff, payments for O&M service agreements, network changes, property tax, insurance, reinvestments to keep the plant operating during its lifetime and auxiliary electricity consumption. Variable O&M constitute out of the cost for consumption of auxiliary materials, treatment and disposal of residuals, spare parts and output related to repair and maintenance.

For biomass boilers, three different unit types can be distinguished.

Table 4: Properties of biomass boilers

Type of stocking	Manual	Automatic	Automatic
Unit capacity in kW	30	400	6.800
Efficiency in %	82%	85%	114%
Fuel type	Wood	Wood pellets	Wood chips
Capex in €/kW	227	220	101
O&M in €/kW	15,2	4,3	32,5

Different types of heat sources can be exploited for heat pumps. The potential for waste heat of industrial processes was examined but the contacted companies already have concepts to use excess heat so that the remaining potential would not be sufficient for the operation of a heat pump. Therefore, air-to-water heat pumps are considered as ambient air is always available. The efficiency of heat pumps relies greatly on the temperature level of the heat source as well as the heat sink. The heat source flow for air-to-water heat pumps is set to 3,2°C, the average temperature during the heating period in Pljevlja (Dencon d.o.o. Podgorica, 2020). Due to missing data, the average ground temperature for ground-to-water heat pumps in winter is set to 5°C.

The heat sink temperature depends on the size and type of the supplied building. For small heat pumps placed in retrofitted individual houses a flow temperature of 75°C and return temperature of 45°C is assumed. For medium-sized and large heat pumps, used in larger supply grids, the temperature level of 90 / 60°C is set. Based on these temperatures the Lorentz efficiency of heat pumps could be found by applying the following formula

$$COP_L = \frac{T_{lmH}}{T_{lmH} - T_{lmL}} \qquad (1)$$

Whereas the mean thermodynamic temperatures can be calculated as followed

$$T_{lm} = \frac{T_{max} - T_{min}}{\ln\left(\frac{T_{max}}{T_{min}}\right)} \qquad (2)$$

Together with commercial information of the Danish Energy Agency (Danish Energy Agency and Energinet, 2017) the latter qualities are used as an input for the IRM calculations.

Table 5: Properties of heat pumps

Unit type	Air-to-water small	Air-to-water medium	Air-to-water large	Ground-to-water medium
Unit capacity in kW	10	400	3000	400
Lorentz-Efficiency in %	50%	50%	50%	50%
COP	2,8	2,4	2,4	2,4
Fuel type	Electricity	Electricity	Electricity	Electricity
Capex in €/kW	940	353	950	623
O&M in €/kW	27,8	4,1	2,0	4,1
O&M variable in €/MWh	0	0,5	2,2	0,5

For solar thermal heating, the total yearly irradiation is identified for the given location as 1284 kWh/m²/yr. (PVGIS (c) European Union, 2021). Due to the assumption that the supply of domestic heat water will create a constant heat demand and seasonal storage will be installed in combination with large rooftop and open space installations, it is assumed that the complete irradiation may be utilized for these technologies. Whereas, for small solar thermal heating systems a utilization factor of 60% of the total irradiation is introduced.

For further calculations, the assumption is made that 40% of the available rooftop area can be used for panels and 50% of the identified open space is utilizable. The identified area for open space solar in the proximity of the town is only based on an initial assessment of the map of the area. Possible suitable areas are marked in Annex 8. For a more detailed determination of advisable solar fields, a further geological assessment in a feasibility study would need to be carried out.

Additionally, the area to capacity ratio is set to 1,43 m²/kW and the land required per m² of collector is specified as 2 m²/m² (Danish Energy Agency and Energinet, 2017). The specific storage price in this size range is 40,95 €/m³ and the size of the storage can be approximated by quadrupling the gross collector area and adding 20% to account for heat losses (Danish Energy Agency and Energinet, 2020).

For details on seasonal storages see Annex 9.

Based on the irradiation, our own benchmarks, and data of the Danish Energy Agency the following table represents the qualities of solar thermal technology.

Table 6: Properties of solar thermal heating

Unit type	Small rooftop	Medium rooftop	Open space
Unit capacity in kW	4	140	9.100
Average efficiency	50%	45%	45%
Capex in €/kW	810	579	267
O&M in €/kW	16,2	2,8	0,02
O&M variable in €/MWh	0	0	0,3

Infrastructure for district heating

The cost for a possible district heating network is based on data used for the cost estimation of the planned district heating grid in combination with the thermal power plant (Dencon d.o.o. Podgorica, 2020). The specific prices for different pipe types as well as the price assumptions for other works and materials out of the study are related to the total grid length planned in the study. This results in length specific prices for other materials and works which can be added to the pipe price as a first estimate of the total length specific price for each pipe type. An overview of the cost can be seen in Table 15 in Annex 3.

To calculate the overall cost for a new district heating grid internal benchmark calculations are used. By applying the peak load of the proposed area and overall length of the planned grid the flow rate and needed length of each pipe type can be found. With this information, the economic assumptions of Table 15 can be applied to find the overall price for a certain district heating grid.

Due to the early stage of examination in the study, the overall length of the newly planned grid is not based on exact measurements or a first route proposal. To generalize, the needed pipe length is determined by multiplying the diameter of the affected zone by 3 (benchmark procedure) and by the share of individually supplied houses in this zone (to reduce the needed pipeline by the already existing infrastructure of microgrids). The resulting cost following this calculation approach is presented in Table 16: Cost for different DH expansions in Annex 3.

3.4 Determination of most promising district heat distribution

To determine which alternative supply technologies might be suitable for the town of Pljevlja the heat consumers need to be further divided by the type of the heating supply method. This includes three main categories which are highlighted in the heating maps in Annex 4.

A. The demand for residential and public buildings is currently individually supplied (= "A. individuals")
B. All dwellings that are currently supplied by large boiler rooms (= "B. microgrids").
C. The individual heating consumers can to some extend become converted to DH supply. At the same time, the existing microgrids can get linked to create larger interconnected networks (= "C. Converted DH")

These three demand consumer groups need to be analysed separately since not all heating technologies and capacity ranges are applicable for individual houses and centralised DH plants and boiler rooms.

Each consumer group refers to a specific heat load. Section A. and B. always 'co-exist' as there will always be houses individually heated and houses commonly heated. However, by introducing consumer group C. the demand of individuals in the other consumer groups will analogically reduce by the demand now covered by district heating. Similarly, the more single microgrids are connected into combined systems, the more the heat capacity of microgrids will decrease.

Given the feasible opportunities for transforming the heating system in Pljevlja indicated in the earlier studies and internal discussions with the local authorities and representatives of Bankwatch, a few plausible scenarios have been proposed and analysed. These include:

0. In the **"Business as usual"** scenario, the existing heating system in Pljevlja is reflected, therefore there is neither a change in the heat supply methods nor the proportion of individually heated or microgrids.
1. The **"I. Refurbishment of technologies, no DH"** scenario reflects an unchanged distribution of individually heated and connected to the microgrids buildings as in the "Business as usual" case. At this stage no more district heat is considered. The key analysed improvement is a replacement of old heating technologies in the houses and boiler rooms just without any changes to the DH infrastructure or heating distribution systems in the houses.
2. The second scenario **"II. Connecting microgrids in the centre to DH (zone 3)"** examines a replacement of old boilers and additionally an improvement of the microgrids in the town centre. The existing microgrids in zone 3 are connected so that one larger DH grid is created which can be supplied by one larger heating unit.
3. **"III. Complete coverage of DH in zones 3,6 and 7 (wider centre)"** describes an even further expansion of the existing microgrids in the town centre. Not only existing microgrids are connected but also individually heated dwellings are converted to district heating. Although, the distribution of heat in the other zones remains unchanged, all supply technologies are exchanged.
4. The last scenario **"IV. Complete coverage of DH in zones 3, 4, 6, 7, 8 and 9 (largest suburbs)"** investigates a larger expansion of the DH grid so that all buildings in the named zones, irrespective of their former supply, are now connected and supplied centrally by DH.

The scenario definitions are also presented in Table 7 to facilitate the understanding of differences in the considered heat supply strategies.

Table 7: Definitions of different supply scenarios

	Individual (Individually heated buildings)	Microgrids (Buildings connected to existing microgrids)	Converted DH (Individually heated buildings converted to DH and microgrid linked with a common transmission line)
"Business as usual"	Supplied with existing boilers (all zones 1-13)	Supplied with existing boiler rooms (all zones 1-13)	N/A
"I. Refurbishment of technologies, no DH"	Replacement of the existing boilers with new technologies (all zones 1-13)	Replacing existing boilers in boiler rooms with new technologies (all zones 1-13)	N/A
"II. Connecting microgrids in the centre to DH (zone 3)"	Replacement of the existing boilers with new technologies (all zones 1-13)	Replacing existing boilers in boiler rooms with new technologies in all microgrids apart from the town centre (zone 1-2 and 4-13)	Implementing larger centralised heat production plants to supply an aggregated DH system (made of few microgrids) in the town centre (zone 3)
"III. Complete coverage of DH in zones 3,6 and 7 (wider centre)"	Replacement of the existing boilers with new technologies in all individually heated properties, excluding these that have been converted to DH in zones 3, 6, and 7	Replacing existing boilers in boiler rooms with new technologies in all microgrids apart from the town centre and two neighbouring large zones (zone 1-2, 4-5, 8-13)	Implementing larger centralised heat production plants to supply aggregated DH system (made of few microgrids and through connecting all individually heated customers to DH) in the town centre and two neighbouring large zones (3, 6 and 7)
"IV. Complete coverage of DH in zones 3, 4, 6, 7, 8 and 9 (largest suburbs)"	Replacement of the existing boilers with new technologies in all individually heated properties, excluding these that have been converted to DH in zones 3, 4, 6, 7, 8 and 9	Replacing existing boilers in boiler rooms with new technologies in all microgrids apart from the town centre and several neighbouring zones (1-2, 5, 10-13)	Implementing larger centralised heat production plants to supply aggregated DH system (made of few microgrids and through connecting all individually heated customers to DH) in the town centre and several neighbouring zones (3, 4, 6, 7, 8 and 9)

The heat load of each consumer group within the considered scenarios has been determined and is shown in Table 8.

Table 8: Considered expansion scenarios for district heat

Name of expansion scenario	Type of customer group	Affected capacity in MW
0. BAU	A. Individual	69,5
	B. Microgrids	19,2
I. Refurbishment of technologies, no DH	A. Individual	69,5
	B. Microgrids	19,2
II. Connecting microgrids in the centre to DH	A. Individual	69,5
	B. Microgrids	13,3
	C. Converted DH	6,0
III. Complete coverage of DH in zones 3, 6 and 7 (main centre)	A. Individual	50,8
	B. Microgrids	9,7
	C. Converted DH	28,2
IV. Complete coverage of DH in zones 3, 4, 6, 7, 8 and 9 (wider centre)	A. Individual	34,4
	B. Microgrids	6,9
	C. Converted DH	47,4

The demand of the different consumer groups A, B and C varies between the different scenarios of expansion 0 to IV. Figure 12 to Figure 14 visualizes on a spatial level the distinction between the different consumer groups for scenarios I to III. Nonetheless, the map is only qualitative. There is no information about the microgrids in the different zones. It is unclear whether a share of 13% of microgrids in a zone means that there is just one microgrid with one boiler or several ones spread over the zone. The colours only help to reflect which share of microgrids, individual heating and larger connected heating there is.

For simplification in this stage of the investigation, the most promising distribution scenarios shall be identified first. Therefore, for each consumer group within each scenario, only one technology is applied and examined for comparison.

For individual buildings, new biomass boilers are seemingly the most suitable technology since it is assumed that only houses in microgrids will undergo a retrofit. With old radiators, the needed flow temperatures remain high and biomass boilers can cover these temperatures with the best efficiency.

For microgrids, the use of medium air-to-water pumps is assessed since this is a mature technology that does not require any specific spatial conditions. For the same reason, large air-to-water heat pumps are considered for converted DH demand.

Based on the respective heat loads shown in Table 8 and the technology specificities summarized in "Table 4: Properties of biomass boilers" and "Table 5: Properties of heat pumps", for each consumer group within each scenario the most important economic indicators could be found.
After determining the cost savings, simple payback period, indicative heat price and indicative NPV for each consumer group separately, the results of A, B and C are added up together within the scenarios to show the overall outputs for each scenario.

This first estimation demonstrates that scenarios I., II. and III. show similar results for economic and environmental aspects. Since the BAU case provides no environmental improvement and the IV scenario of the largest DH expansion has a very poor economic performance; the further calculation only focuses on the remaining three scenarios.

4 Proposal for energy reduction measures

Although the focus of th study is choosing choosing a renewable heat supply technology, the first step towards a climate-neutral system should always be a reduction of energy demand. The lower the heat demand, the easier and cheaper it can be covered by alternative supply technologies. Lower energy demand can be achieved by an energy-optimized retrofit of the building.

The levels of refurbishment reach from minor works as remodelling works, over the replacement of facades to full building refurbishment internally and externally. A retrofitted building profits from lower running costs and has an increased property value. For this heat study only measures to lower the heating demand, not the electricity demand, are analysed. To reduce the heat demand, potential reasons for heat losses need to be identified first.

Detection of heat loss sources
The main reason for heat dissipation is the heat transfer through the building's envelope due to conduction (U.S. Environmental Protection Agency, 2007). To classify areas where the heat losses are the greatest, thermographic infrared imaging of the façade in winter can be performed (U.S. Environmental Protection Agency, 2007). On the imaging, the areas with the highest temperatures can be identified. These indicate that the thermal resistance of the building's envelope is very low and heat from the inside is conducted to the outside.

Additionally to conduction, infiltration of houses causes heat losses due to convection (Cheshire, 2012). By positive and negative pressure testing the spots with the greatest infiltration can be found and the magnitude of the leakage can be determined. Problem areas are for example window sealings, cracks and seams in exterior panels as well as existing holes for wiring (Cheshire, 2012).

Improvement of building fabric
Overall, energy losses can be reduced by implementing materials with low u-values for the house's envelope. The u-value describes the level of conductivity and is accordingly the inverse of the heat resistance. Decreasing of u-values can either be done by exchanging existing building parts or adding up insulation layers. All parts of the envelope, the walls, roof, doors, glazing and ground bearing slab need to be considered individually.

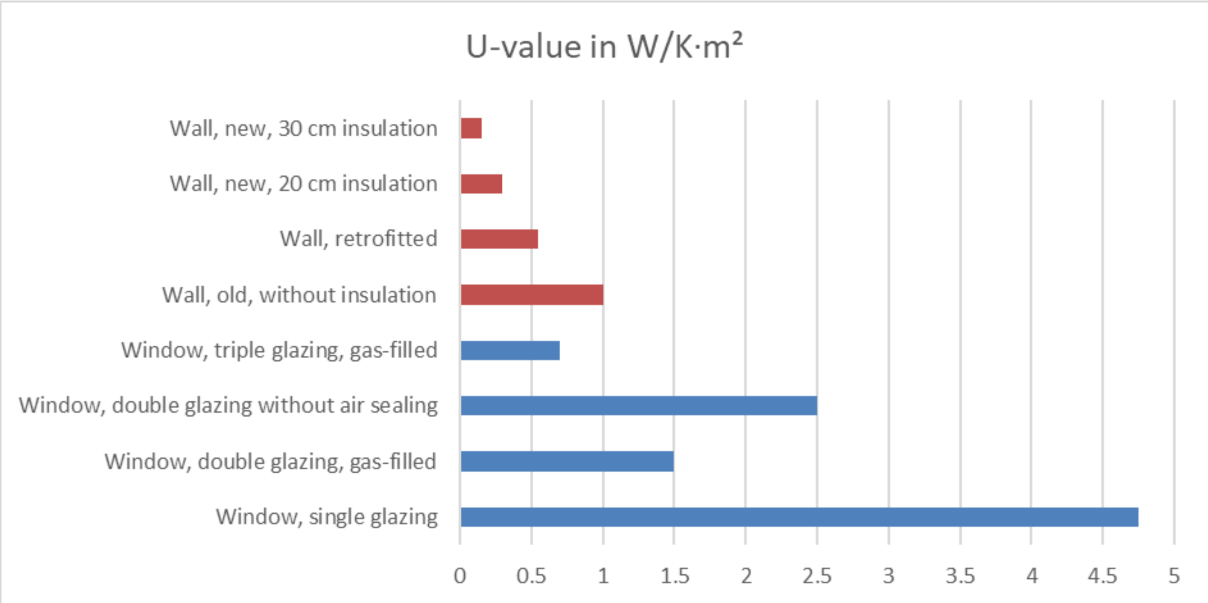

Figure 3: U-values for different window and wall types (Volta, 2018)

Roofs can also either be replaced completely or subsequently retrofitted.
When replacing the roof, new rigid insulation directly beneath the new covering can be included. When the old roof shall remain in place, a fibre-glass blanket or blowing insulation (such as spray-on urethane, fibreglass foam, blown-in loose cellulose or fibreglass) can be added to the attic floor or the inside of the roof's surface (U.S. Environmental Protection Agency, 2007).

Insulating within the roof cavity is very cost-effective but creates a "cold roof". For flat roofs, the risk of condensation arises (Cheshire, 2012). "Warm roofs" (with insulation directly behind the roof tiles) do not have this problem, but moisture penetration needs to be avoided. Moreover, it should be assured that the structural members of the roof, especially those out of metal, are insulated carefully (Cheshire, 2012). Especially in pitched roof spaces, the thickness of the insulation should be checked to avoid problem spots.

During an energetic refurbishment, windows can be exchanged. New windows should have frame materials with low u-values and multi-layered glazing. There are different suitable window types such as windows with spectrally selective glasses or double-glazed, gas-filled or electrochromic windows. Alternatively, window films can be applied (U.S. Environmental Protection Agency, 2007). They reflect indoor radiant back into the room in winter and reduce solar radiation in summer. Window coatings can harm daylight levels, though (U.S. Environmental Protection Agency, 2007).

For doors is draught-proofing against infiltration is most crucial. Therefore, additional lobbies for entrances, weather stripping on doors or automatic door-closers could be implemented (Cheshire, 2012).

To reduce the heat transmission to the ground, the ceiling of the basement should be insulated, too. Internal floor covering can also avoid draught.

Due to heat loss through uninsulated walls up to 30% of the provided thermal heat can be misspent. Thus, the insulation of the façade is crucial in the process of reducing the energy demand. Walls can be insulated either internally or externally. The external insulation shows no risk for thermal bridges and the thickness of the insulation is unlimited (Cheshire, 2012). However, outer insulation has a visual impact and is expensive. Internal insulation can be very disruptive and there is a risk of condensation in the outer skin of the external wall. If available, cavity wall insulation is the best option since it is most cost-effective and less disruptive (Cheshire, 2012).

Improvement of heating system
After reducing the building's energy demand, the optimization of the supply and distribution system itself can lead to further energy reduction.

The DHW operation can be improved by using flow taps with PIR control, well-insulated vessels, and pipes (Cheshire, 2012). No-return valves prevent backflows, and a new variable flow control system can increase the efficiency of the DHW and heating system.

The physical status and age of the heating system should be regularly checked to assure the right calibration (U.S. Environmental Protection Agency, 2007). Radiators can work wrongly and inefficient, for example, might some radiators heat up unequally which leads to energy losses and difficult temperature control. If this should be the case, hydraulic balancing should be carried out (Cheshire, 2012).

After an analysis of the existing radiators, boilers, and the demand of the building, the valves, pumps, and pipes can be adjusted correctly so that they match each other and the demand of the specific room again. This approach can only be pursued if the heating system shows sufficient properties. A two-pipe-system, pre-adjustable thermostatic valves or lock shield valves need to be in place or must be implemented first so that the flow control becomes possible (Cheshire, 2012).

In general, an exchange of pumps, valves and pipes helps to optimize the flow control.

Flow control is crucial since the heat demand can be limited strongly if the heat and hot water are only supplied when needed and are not always held in the system. To achieve fewer running hours and avoid unnecessary overheating, additional control systems can be considered (Cheshire, 2012).
By implementing a time control, the heating can be regulated beforehand based on known daily patterns of the occupants.

Furthermore, temperature control can help to regulate system optimisation. Important for a functioning temperature control are sensors with an appropriate range and location (Cheshire, 2012). Apart from the room temperature, the outside temperature might be considered, too to account for the varying perceived heat demand of the occupants based on the weather. Automatic control gains importance with increasing building sizes (Cheshire, 2012).

Apart from an optimisation of the heat distribution system, a replacement of heating elements should be examined. An exchange of the type of radiator can lead to better performance and an improved alignment with the needs of the building and occupants.

Warm air systems are not examined here as they would need to be indirectly fitted with water. This causes a decrease in performance compared to systems based on direct gas or fuel use. Since not the hot water or steam is conducted directly to the rooms but the air which was heated up before in a heat exchanger that operates with water or steam, more energy losses occur. Moreover, warm air systems require complex and long ductworks that have high installation costs and increase the energy consumption for the fan operation (Cheshire, 2012).

Conventional radiators and natural convectors are comparably cheap and can be easily controlled. However, the heat transfer is mainly due to convection which leads to strong air circulation and an overall high air temperature. Thus, they should only be implemented in well-insulated rooms with a low air exchange rate to avoid heat losses (Cheshire, 2012).

Radiant panels transfer heat with a radiation share of more than 90%. The energy can be supplied with hot water, steam, or electricity. Systems based on electricity (infrared systems) are not presented here as the direct use of electricity to generate heat has a very poor efficiency (IBS Ingenieurbüro Schreiner, 2011).

When supplied with hot water the heating pipes can be integrated into the floor (underfloor heating), the walls or the ceiling. Alternatively, panels can also be put up in front of walls or below the ceiling (IBS Ingenieurbüro Schreiner, 2011).

Underfloor heating operates at very low temperatures of 30 to 35°C. Due to the small differences between the floor and air temperature, the self-regulation of the temperature reacts quickly to changes. Installation in or on walls and ceilings show temperatures in a spectrum of 50 to 90°C (IBS Ingenieurbüro Schreiner, 2011). Here, the lower the supplied temperatures are the larger the panel area needs to be.

Since radiant energy is only absorbed by bodies and not the air, comfort levels for humans can be achieved at lower ambient air temperatures and air circulation is avoided (Cheshire, 2012). Lower heat losses especially for buildings with high ceilings and high infiltration are the consequence. A temperature reduction of 1°C reduces the heat demand already by 5%.

In general, radiant heating systems show ambient temperatures 1 to 2 °C below convective systems (IBS Ingenieurbüro Schreiner, 2011). The heat distribution is uniform throughout the whole room which creates together with the absent air circulation a pleasant room climate. Even if maintenance cost is low and the overall energy demand can be reduced, the investment during a retrofit is quite costly (IBS Ingenieurbüro Schreiner, 2011).

Considering that some renewable heating supply technologies can only operate at lower flow temperatures a change to radiant panels is inevitable, though.

After the implementation of the several described steps, the exchange of the boiler technology is the last energy efficiency measure. The assessment of the technologies with the best performance, sustainability and suitability was the subject of this study.

Nonetheless, it is important to follow the proposed order of measures presented in this consumer group: first, the identification of the largest heat losses, followed by the improvement of building fabric and then the heating system (IBS Ingenieurbüro Schreiner, 2011). The heating supply should be exchanged lastly so that the sizing of the supply unit can be designed for the reduced demand.

5 Recommendations of preferred solutions

Based on the described assumptions and characteristics of the heating system in Pljevlja the most suitable heating solution will be determined and examined further.

5.1 Findings of the Integrated Risk Matrix Assessment

To find the optimal renewable supply option, a list of the most suitable technologies is created first. At this stage, the separation into different consumer groups shows its relevance. Not all technologies are suitable for every demand form. For instance, small new biomass boilers are only applicable in consumer group A as for microgrids or DH the supply units need to have larger capacities each to be able to supply the larger consumer group. Inversely, open space solar thermal can only be utilized in consumer group C for DH. The energy is produced outside of the town and hence a DH network is needed to transmit and distribute the heat to the buildings. An overview of the technologies which are convenient for the different consumer groups and the different scenarios is given in Table 9.

Table 9: Technology overview

Section		Technology	Scenario I.	Scenario II.	Scenario III.
A. Individuals	1	Old biomass boiler	☑	☑	☑
	2	Heat pumps small	☑	☑	☑
	3	New biomass boiler small	☑	☑	☑
B. Microgrids	4	Solar thermal rooftop & Old biomass boiler	☑	☑	☑
	5	Solar thermal rooftop for DHW & New biomass boiler medium	☑	☑	☑
	6	Solar thermal rooftop & New biomass boiler medium	☑	☑	☑
	7	New biomass boilers medium	☑	☑	☑
	8	Air-to-water heat pumps medium	☑	☑	☑
	9	Air-to-water heat pumps small & New biomass boiler medium	☑	☑	☑
C. Converted DH	10	New biomass boiler large		☑	☑
	11	Solar thermal rooftop & Seasonal storage		☑	
	12	Solar thermal rooftop & Seasonal storage & New biomass boilers medium			☑
	13	Open space solar thermal & Seasonal storage		☑	☑
	14	Air-to-water heat pumps large		☑	☑
	15	Ground-to-water heat pump		☑	☑

It becomes clear that for every scenario in each consumer group nearly the same technologies can be considered. However, for consumer group C a difference must be made between solar thermal rooftop supply for scenario II. and III. The demand in the large DH grid in scenario III. cannot solely be covered by a solar storage system as the available rooftop area is not sufficient for the high demand. New medium-sized biomass boilers are included to cover the remaining demand.

For solar thermal panels in consumer group B, only buffer storage is included. This means that it cannot be assured that the installed capacity can be fully used nor that during demand times the capacity can be effectively utilized to cover the full demand (due to unpredictable weather conditions). Therefore, biomass technologies are needed to ensure a stable supply, independent of weather conditions.
The combination of small air-to-water heat pumps and biomass boiler is based on a 60% to 40% share of heat contribution.

The study follows the approach of an IRM assessment. By this, the most important economic factors such as the simple payback period, the initial NPV and the indicative heat price are calculated and analysed. Furthermore, environmental, technical, and strategic criteria are assessed. The IRM analysis is carried out for the three expansion scenarios individually.

The results for the different categories are rated on a scale from 1 to 5, where 1 is the best rating. For the qualitative analysis, the criteria summarized in Table 17 in Annex 5 are applied. For the quantitative assessment, the range for a certain score is determined based on the respective data. Annex 6 shows as an example for scenario I. which ratings could be achieved by the different technologies. The resulting score for each scenario is derived as a weighted sum using a specific weighting for each criterion which is established based on the understanding of the business priorities of CEE Bankwatch and the town of Pljevlja. As the economic feasibility is crucial for the actual improvement of the heating situation in Pljevlja, the financial criteria account together for 50 % of the weighting. Environmental criteria are weighted as 16 % totally, while the development risk is the third most important category with 11 % of total weighting.

This approach finds the most suitable technology for each consumer group. Both, the weighting and the example final technology ranking of the IRM for scenario I. is provided in Annex 7.

The IRM assessment is done for all three expansion scenarios. Each of the consumer groups (A., B., and C.) which occupy separate town zones in Pljevlja is treated independently and consequently has developed its own most optimal heating supply solution. A summary of the optimal cases for the different scenarios is given in Table 10. The lower the overall score is, the higher the solution appears in the rank of the hierarchy among the investigated technology options.

Table 10: Key IRM findings per consumer group

Scenario	Consumer group	Technology	Heat contribution in MWh/yr.	CO2 reduction in t CO_2/yr.	Simple payback in yr.	Indicative heat price in €/MWh	Indicative NPV in €	Score
I.	A	New biomass boiler small	136.000	36.000	7,8	25	17.900.000	**13,7**
	B	Air-to-water heat pumps medium	36.000	8.000	7,9	19	7.400.000	**10,0**
II.	A	New biomass boiler small	136.000	36.000	7,8	25	17.900.000	**13,7**
	B	Air-to-water heat pumps medium	25.000	5.000	7,9	20	5.100.000	**11,0**
	C	Open space solar thermal + storage	11.000	3.000	16,5	47	-200.000	**15,1**
III.	A	New biomass boiler small	99.000	26.000	7,8	25	13.100.000	**13,7**
	B	Air-to-water heat pumps medium	20.000	4.000	7,3	18	4.300.000	**10,0**
	C	Open space solar thermal + storage	52.000	15.000	14,41	42	3.900.000	**14,1**

The highest scorings are reached for consumer group A for all scenarios with the new biomass boiler technology. Due to the small range of options for individual heating, new biomass boilers are the most suitable option even if the scoring is in comparison to other consumer groups quite poor.
Medium air-to-heat water heat pumps reach the lowest (the best) rating in each scenario for consumer group B. Other technologies perform poorly in comparison. Especially, all different types of solar thermal heat supply only achieve ratings >18. Since the installed capacity for solar thermal needs to be very high

to supply a large proportion of the heat demand and as another technology is needed additionally to provide a back-up for bad weather situations at peak demand times, the investment costs for these scenarios are very high. Solar thermal in combination with biomass shows a low renewable energy contribution so that not only the quantitative but also the qualitative scoring is poor.

For consumer group C open space solar is identified as the most suitable technology for houses in DH grids in scenario II. and scenario III.
However, the rating of solar thermal in scenario III is better than the rating for it in scenario II. as a result of the economics of scale for scenario III.
After combining the most promising outputs of the consumer groups A+B+C proportionally to the heat consumption for each of the three consumer groups, a comparison between the different extension scenarios is possible as demonstrated in Table 11.

Table 11: Scenario results comparison IRM

Scenario	CO2 reduction in t CO_2/yr.	Simple payback in yr.	Indicative heat price in €/MWh	Indicative NPV in €	Overall score
I.	43.700	7,8	24,1 €	25.300.000 €	**12,9**
II.	44.600	9,1	25,90 €	22.800.000 €	**13,3**
III.	45.900	11,3	29,31 €	21.300.000 €	**13,4**

This comparison visualizes that overall, expansion scenario I. has the best rating. This indicates that no real DH grid should be set up. Instead, the boilers in the individual buildings would be replaced by modern small biomass boilers. For the larger boiler rooms in the communal micrSogrids, medium-sized air-to-water heat pumps would be implemented. Even if the environmental benefits are the lowest for this configuration, this is offset by the strong economic advantages, the low spatial requirements, the low disruption, and high technological suitability.

5.2 Additional assessment under consideration of varying assumptions

The IRM assessment found that based on the chosen criteria and weighting, a combination of small new biomass boilers and air-to-water heat pumps is recommended. However, this scenario would require 166.000 MWh of wood which equals about 40.000 tonnes of wood per year. It is unclear how this large amount of biomass could be provided sustainably. Moreover, scenario I. shows in comparison the smallest benefits for the environment (see Figure 4).

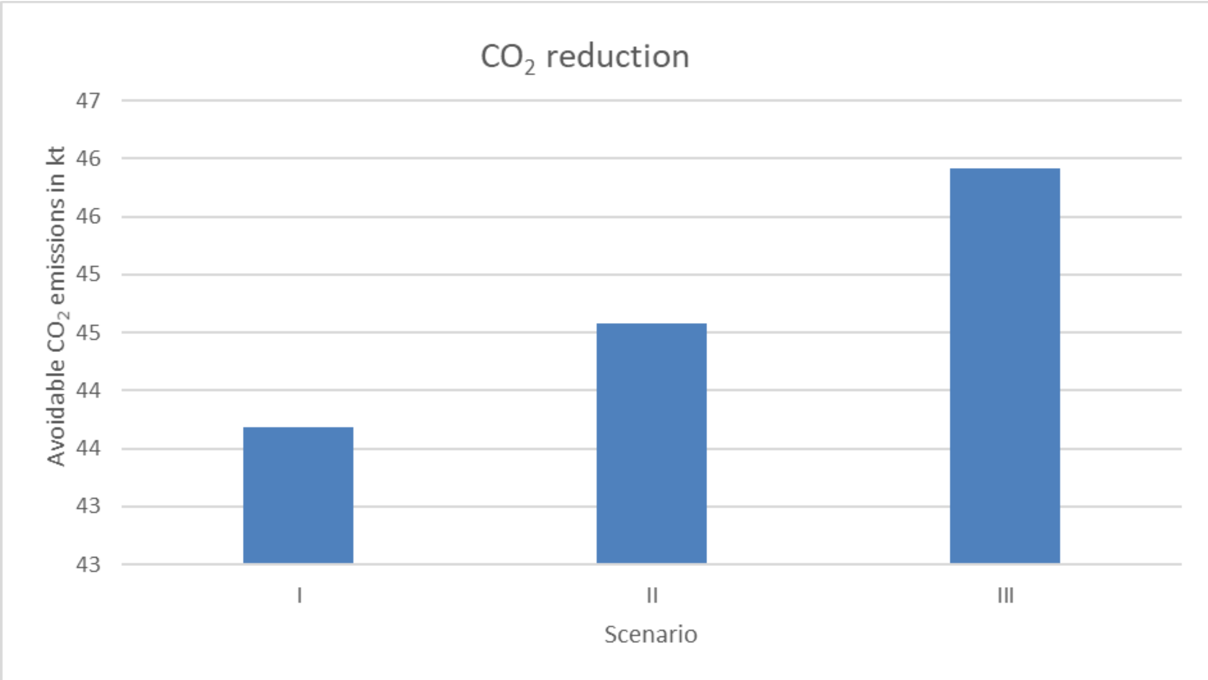

Figure 4: CO_2 reduction in different expansion scenarios

Therefore, a second approach for the IRM assessment is carried out. Alternative technologies to biomass such as heat pumps and solar thermal panels were previously ranked badly mostly because they were economically uncompetitive. However, since these technologies offer more environmental advantages and are more future-orientated (no fuel procurement or storage, high efficiency, fully sustainable), possible subsidies for the initial investment by potential lenders are realistic.

Hence, the IRM is performed again to determine how subsidies for certain technologies would affect the overall outcomes and the feasibility of a less biomass-based scenario. A founding of 80% of investment cost is assumed for the most environmentally friendly supply options of the previous analysis (III. scenario: small biomass (A), medium air-to-water heat pumps (B) and large open-space solar thermal (C)).

In addition, a 4th expansion scenario is examined more in detail. The largest share of DH allows with this scenario achieve the greatest reduction of biomass. The chosen technologies for the different consumer groups in scenario IV. are based on the findings from chapter 4. Small biomass boilers are considered for the remaining individuals (A), medium air-to-water heat pumps for microgrids (B) and open space solar with seasonal storage for the new DH network (C).

As the demand for heat in consumer group C is in this scenario with 47,43 MW very high, an area of 150.000m² for a fully solar thermal-based supply would be necessary. However, around Pljevlja an area of this size is not available so that about a quarter of the needed demand will be covered by large air-to-water heat pumps instead.

Since only scenarios III. and IV. demonstrate a crucial change in heating supply and a significant decrease in biomass use, the subsidies for heat pumps and solar thermal collectors are only applied in these scenarios. Table 12 provides an overview of the outcomes of the IRM assessment when a share of incentivised investment costs of 80% for heat pumps and solar collectors is assumed.

Table 12: Scenario result comparison incentivised technologies

Scenario	Technologies	CO2 reduction in t CO_2/yr.	Simple payback in yr.	Indicative heat price in €/MWh	Indicative NPV in €	Overall score
I.	New biomass + air-to-water-heat-pumps medium	43.700	7,8	24,1 €	25.300.000 €	**13,7**
II.	New biomass + air-to-water-heat-pumps medium + open space solar + storage	44.600	9,1	25,9 €	22.800.000 €	**14,0**
III.	New biomass + Subsidized: air-to-water-heat-pumps medium + Subsidized: open space solar + storage	45.900	7,4	23,1 €	38.500.000 €	**13,5**
IV.	New biomass + Subsidized: air-to-water-heat-pumps medium & large + Subsidized: open space solar + storage + heat pumps	45.900	8,5	24,4 €	37.500.00 €	**13,7**

It becomes clear that scenario I. is no longer the most beneficial, instead scenario III. is rated lowest/ best.

The economic improvement due to the reduced investment cost causes a large improvement in the quantitative rating. Nevertheless, the expenses for the new DH grid and transmission line from the solar thermal field are not covered in the assumed subsidies. Especially for scenario IV. about 10,6 Mil. € for the distribution and transmission infrastructure needs to be accounted for. Scenario III. provides the best compromise between a large share of DH (32% of demand covered by DH, 11% by microgrids) and economic feasibility (total remaining investment cost of 34 Mil. €).

In comparison to scenario I, the wood demand for scenario III. could be reduced by 27 % and 5,1% more GHG emissions could be prevented. The maintenance cost could be reduced by 27 % since the new technologies are less maintenance and operation intensive than biomass. However, the investment cost is despite the cost reduction still 25% higher than for the scenario without DH.

5.3 Sensitivity analysis of the highest-ranked heating supply options

The additional assessment in chapter 5.2 shows that a change of input parameters can largely impact the findings of the analysis. To determine the influence of varying underlying assumptions, a sensitivity analysis for the three most uncertain factors is carried out. For each scenario, the highest-ranked technology combination described in Table 10 is analysed.

As a first assumption, the interest rate is set to 3,5 %. The consequences of the variation of this assumption by +/- 80 % are shown in Figure 5. For all scenarios, a contrary correlation between interest rate and NPV can be found. Worth mentioning is that with the rising investment volume in later scenarios, the interest rate gains increased influence on the NPV. While a 50 % increase of the interest rate causes a 38 % decrease of the NPV in the first scenario, the NPV of scenario IV. declines by 116 %.

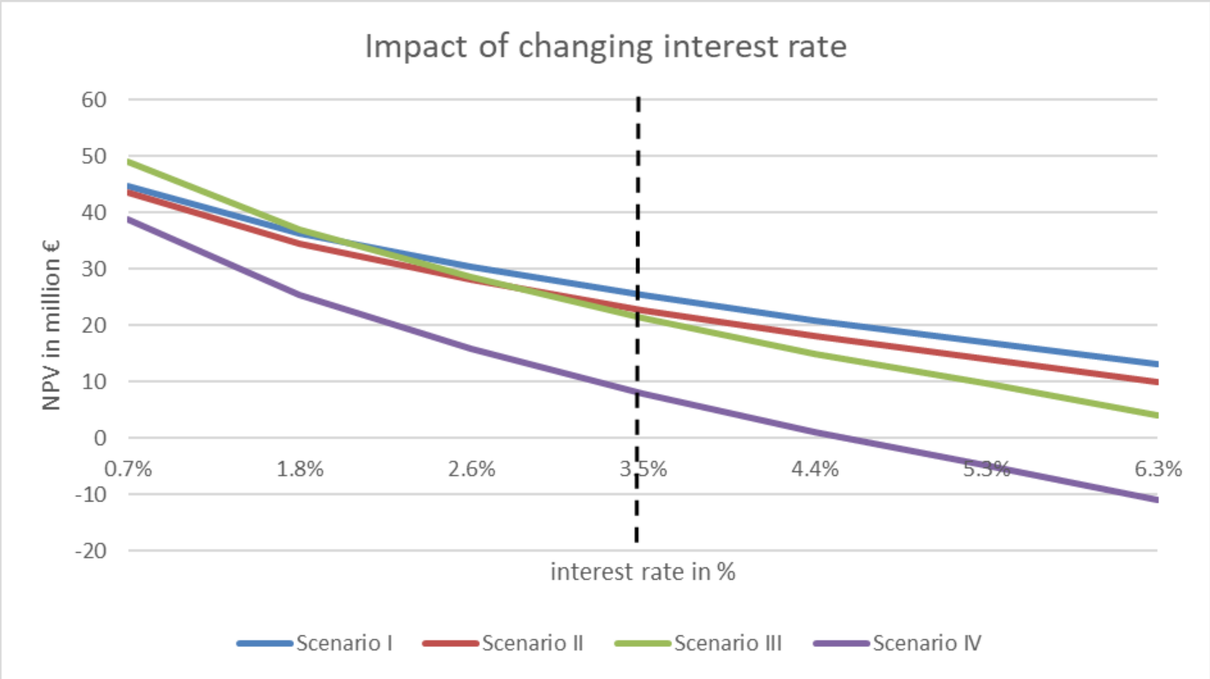

Figure 5: Sensitivity analysis: Interest rate

The study in the base analysis does not factor in any CO_2 cost. However, especially due to Montenegro's plans to become part of the European Union, it is to be expected that the EU-ETS or a similar CO_2 pricing system will be applied in Montenegro in the coming years and at least after 2030. This means that at least large emitters of CO_2 such as power plant operators need to buy certificates that allow them to emit CO_2. A decreasing share of CO_2 allowances (expected to cease by 2030) is allocated to the companies which involves a higher number of CO_2 certificates to be purchased at a trading market.
The price for the certificates varies but since the cap of total existing certificates is reduced successively, a ton CO_2 is expected to cost up to 90€ by the end of the decade. The influence of this additional cost is described in Figure 5.

Even if in the EU CO_2-cost are currently only paid by large emitters, it was assumed for this analysis that all emissions which can be avoided by new technologies equal a cost saving of €/t CO_2, not only those avoided by large emitters. For a more detailed analysis and determination of the influence of a changing CO_2 price over time, a feasibility study needs to be performed before the tendering stage of the project.

A nearly linear relationship between the CO_2 price and the NPV can be noted. The larger the share of avoided emissions, the larger the impact of the CO_2 price. Accordingly, scenarios III. and IV. benefit the most from a rising CO_2 price since they avoid the largest number of emissions. For a rising CO_2 price, the cost advantage of scenario I. declines. For a CO_2 price of 100 €/t CO_2 the NPV of scenario III. is only 500 thousand € smaller than the NPV of the first. Overall, this sensitivity analysis stresses the rising attractiveness of all renewable technologies in comparison to the fuel-based counterfactual case.

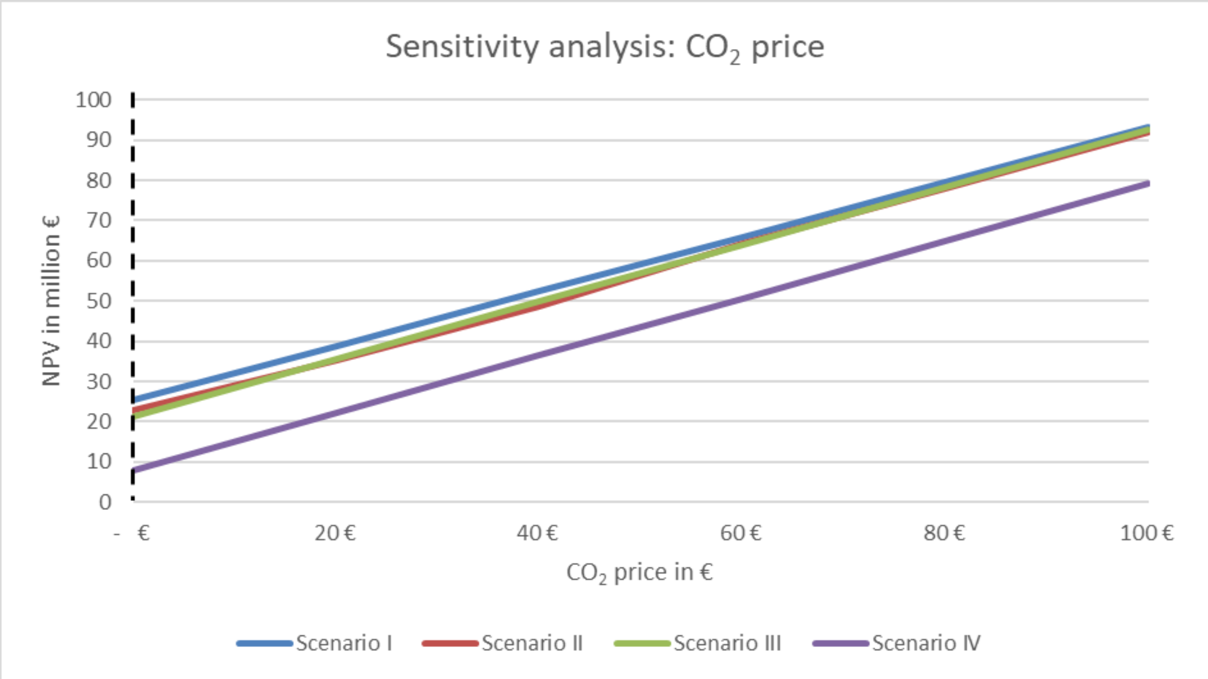

Figure 6: Sensitivity analysis: CO_2 price

Finally, the analysis of the impact of the subsidy share in Figure 7 highlights that the subsidies determine the profitability of scenario IV. strongly.

A 50 % increase in funding causes a 33 % increase in NPV. Additionally, it is worth noticing that if more than 85 % of the investment cost is subsidized, the 4th scenario is more profitable than scenario III. Predictably, scenario I. and II. do not vary due to a change of subsidies since it is assumed that only the latter two scenarios would have a realistic chance for funding because of the smaller biomass share. Despite this, the graph in Figure 7 indicates that the conclusion of chapter 5.1 - that scenario I is the most cost-competitive - is only true if scenario III. is not subsidized at more than 19 %.

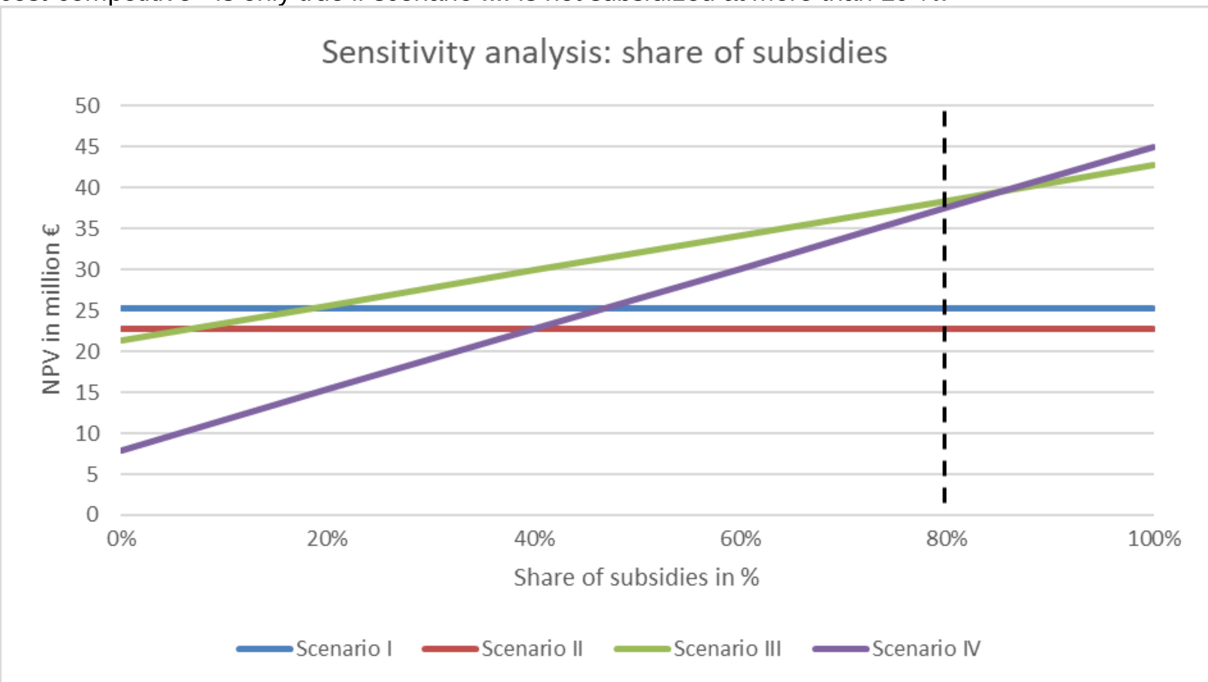

Figure 7: Sensitivity analysis: Share of subsidies

In general, it needs to be considered that due to the “Masterplan” character of this study all factors are subject to a high degree of uncertainty. Especially since the underlying information on the heat demand was not provided but approximately calculated and the prices were mostly only based on average European data, the scale of the found results may change significantly when more accurate data for Montenegro is provided.

However, the ratio of the findings between the possible heating technologies and scenarios is likely to remain similar and provides, therefore, provides a decent basis for a further decision-making process.

5.4 Possible construction phasing

Should it be possible to obtain subsidies for the investment cost, scenario III. would be the most recommended supply option. This scenario includes the implementation of a DH grid and transmission line to supply customers in zones 3, 6 and 7 with renewable energy from a new solar thermal collector field with seasonal storage.

In the previous calculation, it was assumed that all investment costs for the DH grid, the transmission line, the seasonal storage, and solar thermal collectors would arise in the first year of the considered time horizon. In the upcoming years, the full economic benefits or cost savings compared to the counterfactual case could be seen.

This approach is sufficient for the first rough cost estimation. Nonetheless, it should be pointed out here that the implementation of a new district heating grid and large renewable energy source cannot be completed within a year and that the actual cash flows may vary strongly.

Before constructing the renewable supply source, a certain share of the distribution network should already be implemented so that the generated energy can be transferred to the customers. Additionally, it needs to be considered that energy efficiency measures need to be carried out first so that the DH grid and the heat source may be designed for the correct temperature levels and adjusted maximum heat load.

Implying the underlying time-consuming process of refurbishments and the slow construction of pipe-network and distribution stations itself, it can be assumed that the implementation of the grid and transmission line takes 8 years until it is fully completed. The construction progress and referring cost for the development can be spread equally by 12,5% each over the years.

Since the infrastructure on the demand side is built up gradually, the supply side should accordingly be constructed successively as well.

Solar thermal collectors can be added separately to increase the overall capacity of the plant. However, the planned large scale thermal water storage cannot be increased slowly but must be built in the needed size immediately. Therefore, one possible phasing approach could be the implementation of half of the needed solar thermal capacity and one seasonal storage with half of the overall needed volume in the 4th year. Considering that in the 5th year half of the customers have a connection to the DH grid, the new renewable energy source would be designed appropriately, and the demand and supply sides would match each other. Consequently, the heating in the first four years would remain biomass and fossil fuel-based even if some houses show a connection to DH already. No cost or CO_2 savings compared to the counterfactual case could be noticed.

In the upcoming years, the remaining houses in the three zones would be integrated into the grid. Nevertheless, the supply of the newly connected houses would remain based on the old boiler technologies first as the supply side could not provide enough energy for all buildings.

After the DH network is completed in the 8th year, the second half of the solar thermal area and the second seasonal storage could be built. By this, it is guaranteed that the renewable technology is never oversized, and its output may be used in the town.

Building two individual seasonal storages may also be beneficial as the heat could be distributed better geographically and the in- and outlets could be coordinated individually for different parts of the town.

After the 4th year, half of the maximum cost and emission savings can be achieved and after the 8th year, the full potential is exploitable.

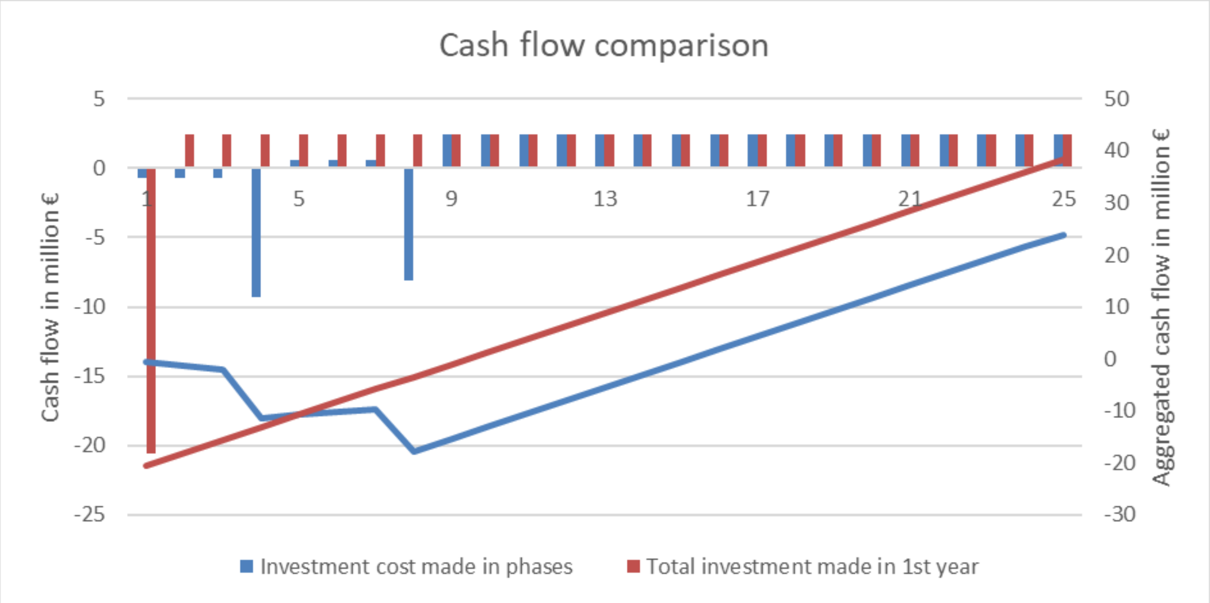

Figure 8: Cash flow comparison between the first estimation of full investment in the first year and phasing of construction and investment for scenario III. inclusive subsidies

Figure 8 shows how the phasing of construction affects the estimated cash flows in comparison to the previous full initial investment assumption.
Due to the fact the old boiler technologies need to be operated longer, the sum of the avoided cost in the first 8 years is smaller than in the first assumption. The indicative NPV decreases from the first assumed 18,1 million € to 8,8 million €.

This phasing approach is very general still. A detailed feasibility study would need to be performed to describe how and when the different building types should be connected and how the supply infrastructure would need to be built up. Therefore, more detailed information about the specific demand, temperature level and maximum load for each dwelling would be required as well as more information about the current supply infrastructure in the microgrids.

5.5 Resulting benefits for citizens of Pljevlja

The most recommended renewable heating solutions in scenarios I. and III. would provide economic advantages for customers who currently rely on individual heating based on a coal and biomass mix. With an average heat price of 25 €/MWh for new biomass boiler technologies in individually heated dwellings, the costumers would have to pay 9€/MWh less than the current 34 €/MWh for heat. This improvement is due to a reduced fuel demand (higher boiler efficiency), the elimination of coal purchases and lower maintenance costs.

Customers in microgrids are currently supplied very cheaply for less than 10 €/MWh (Ivanović, Vušanović, & Savićević, 2015). The new microgrids and DH network cannot compete with these heat prices. However, many other benefits compared to the counterfactual system can be found.

The need for energy efficiency measures in houses supplied by renewable heat, results in a decreased energy demand for the individual buildings, the overall cost for heating declines. Moreover, retrofitted buildings provide a more pleasant living atmosphere with a balanced ambient temperature, floor heating and without draught problems.

In buildings that are further on individually heated, the new biomass boilers not only offer commercial advantages. Since the filtering systems of modern boilers are improved and the operation can be optimized, the level of pollution can be reduced strongly compared to the old boilers.

Air-to-water heat pumps in microgrids avoid pollution completely. The environmental benefit compared to the old combustion technology depends on the origin of the electricity needed to run the heat pump. With an increased share of renewables in the power mix of Montenegro, even more, GHG emissions can be prevented.

The DH system in the second most recommend scenario “III: Complete coverage of DH in zones 3,6 and 7 (wider centre)” with subsidies provides even further benefits resulting in an additional share of houses commonly supplied. Customers in DH networks can profit from a very secure energy supply, fewer obligations regarding maintenance and fuel purchase, additional space gain (no boiler rooms needed), very steady heat prices independent from fuel prices and an increasing building value. Furthermore, DH grid operators may provide working places for citizens of Pljevlja.

The combustion of biomass emits similar pollutants as the combustion of fossil fuels such as particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO) and other hazardous air pollutants (HAPs) (Williams, Jones, & Pourkashanian, 2012). Consequently, biomass can cause similar health problems, for example breathing difficulties or lung cancer.
All described scenarios reduce the share of combustion for heat generation. Since the heat contribution of biomass to the overall supply is reduced by 25% in the 3rd compared to scenario I. though, the pollution problem of Pljevlja could be tackled by implementing the technologies of scenario III. especially.

Equivalently, it can be noticed that the reduction of CO_2 emissions improves the climate balance of Pljevlja for all renewable scenarios. However, by implementing large solar thermal collector fields and reducing biomass use further, the environmental improvement is greater for scenario III.

6 Conclusions

The heating transition study for the town of Pljevlja in Montenegro proved to be a challenging assignment. The access to the data regarding the overall heat demand and details about the current heat distribution, e.g., the location and size of microgrids, was very limited. Moreover, the sensitivity analysis indicates that the NPV reacts sensitively to a variety of input parameters. All findings of the study are therefore provisional but indicate overall trends and recommendations.

Due to missing information on geological and hydrological conditions, not all potential different heat sources and hence all renewable technologies could be adequately analysed.

The IRM has been conducted for four main DH expansion scenarios (I. – IV.) where the most suitable sizing of a possible DH grid is sought. Within each scenario, all groups of consumers are assessed separately for the most suitable form of renewable heating technology option which would satisfy their heating needs at the lowest cost and higher environmental improvement. There are also other technical, strategic and planning criteria impacting the final score of each solution, however, the economic criteria are weighted more heavily as practical feasibility or the environment to exclude commercially unfeasible solutions. The chosen rating approach has accordingly a great impact on the highest-ranked technology, but this was set up in accordance with the client's key objectives: the affordable heat price for the consumer, reduction of carbon emissions and increasing independence on biomass and other fossil fuels.

The performed IRM shows the same technology recommendations for the same demand consumer groups in each respective scenario.

For individually heated houses biomass boilers are the most realistic supply option. The needed amount of biomass for the supply reaches from 89.000 MWh in scenario IV. to 166.000 MWh of wood in scenario I. The use of biomass boilers cannot be avoided completely as the temperature levels in old, not retrofitted, buildings do not match the requirements of most renewable energy technologies to operate efficiently.
This shows the general importance of the made assumption regarding the implementation of energy efficiency measures. Refurbishments should always be approached first to lower the overall heat demand and temperature levels.

Medium-sized air-to-water heat pumps demonstrate the best rating overall and are very well suited for microgrids despite the poor COP due to cold ambient temperatures. Their benefits could even grow in the future when the share of renewable energy in the electricity grid increases and even more GHG emissions may be avoided.
For a possible larger DH grid, solar thermal collectors erected on an area outside of the town in combination with a large thermal seasonal storage are the most suitable supply source. Especially the independence from any fuels, complete CO_2-neutrality and low operation intensity are benefits of the technology.

The better ratings achieved for technologies applied in microgrids and DH display that economic advantages can be attained through larger unit scales.

In comparison to the counterfactual case, all examined scenarios have a positive NPV and payback time below 10 years. The transition towards a sustainable heating supply is in principle feasible.
Overall, the most favourable option for the transition of the heating system in Pljevlja when no funding is included is to refurbish supply technologies without implementing a new DH grid (scenario I). This is with the economic factors as NPV and heat cost for the customer treated with a priority over the carbon emission goal.

Scenario I. profits from a low development risk, hardly any disruptive influence and high cost-effectiveness without subsidies. However, due to the high remaining share of biomass, pollution cannot be avoided completely, and it is unclear how the wood supply could be carried out sustainably if the assessment criteria important for the town need to be met.

The option to establish a DH grid in the central zones 3, 6 and 7 while keeping the distribution system in the remaining zones unchanged (scenario III.) is rated better than scenario I as soon as at least 22% of the investment cost for solar thermal technologies and heat pumps are subsidized. Advantages are the stronger

CO_2 reduction, low operation intensity and short simple payback period. The financial support to the investments allows finding a balance between the acceptable heat tariff, emission abatement and reduction of the town's dependence on biomass fuel.

Especially scenario III. is recommended for further examination in a more detailed feasibility study stage. This would allow a thorough assessment of the construction phasing, supply share of solar energy and placing of the technologies and DH expansion in respect to the local geological and planning conditions.

7 List of abbreviations

Abbreviation	Definition
DH	District Heating
IRM	Integrated Risk Matrix
TPP	Thermal Power Plant
DHW	Domestic Hot Water
BAU	Business as usual
O&M	Operation and Maintenance
COP	Coefficient of performance
NPV	Net present value
EU-ETS	European Union Emission Trading System
PTES	Pit Thermal Energy Storage

8 Bibliography

Cheshire, D. (2012). *Energy efficiency in buildings CIBSE Guide F.* London: The Chartered Institution of Building Services Engineers.

Danish Energy Agency and Energinet. (2017). *Technology Data Heating Installations.* Copenhagen: Danish Energy Agency and Energinet.

Danish Energy Agency and Energinet. (2020). *Technology Data Generation of Electricity and District Heating.* Copenhagen: Danish Energy Agency and Energinet.

Dencon d.o.o. Podgorica. (2020). *TOPLOTNI KONZUM TOPLIFIKACIJE GRADA PLJEVLJA.* Pljevlja: Opština Pljevlja – Direkcija za izgradnju i investicije.

Direktorat za energetsku efikasnost. (2021, May 31.). *Energetska efikasnost u crnoj gori*. Retrieved from Projects: http://energetska-efikasnost.me/en/projects/

Dragojević, S., Elezović, S., Tadić , I., Mrdak, D., & Zarubica, R. (2019). *Montenegro Second biennial update report on climate change.* Podgorica: Ministry of Sustainable Development and Tourism. Retrieved from https://unfccc.int/sites/default/files/resource/SECOND%20BIENNIAL%20UPDATE%20REPORT%20ON%20CLIMATE%20CHANGE_Montenegro.pdf

Dronninglund District Heating, N. (2020). *Long Term storage and solar district heating .* Dronninglund: PlanEnergi.

Energistyrelsen. (2020). *Standardenergipriser og CO2-emissionsfaktor.* Copenhagen: Energistyrelsen.

Energy Community Secretariat. (2020). *Montenegro - Annual Implementation Report.* Podgorcia: Energy Community Secretariat.

European Environment Agency. (2020). *Air quality in Europe - 2020 report.* Copenhagen: European Environment Agency.

IBS Ingenieurbüro Schreiner. (2011, May 13.). *Flächen- & Strahlungsheizung*. Retrieved 06. 29., 2021, from Flächen- & Strahlungsheizung: http://energieberatung.ibs-hlk.de/grundl_wasys_fl%26strahlhzg.htm

IRENA. (2019). *Energy Profile Montenegro.* Abu Dhabi: IRENA. Retrieved from https://www.irena.org/IRENADocuments/Statistical_Profiles/Europe/Montenegro_Europe_RE_SP.pdf

Ivanović, V., Vušanović, I., & Savićević, S. (2015). *ELABORAT ZA RJEŠAVANJE PROBLEMA ZAGAĐENOSTI U PLJEVLJIMA.* Podgorica: Univerzitet Crne Gore Masinski Fakultet Podgorica.

KEA-BW Die Landesenergieagentur. (2020). *CO2-Bilanzierung mit BICO2BW*. Retrieved 06. 07., 2021, from https://www.kea-bw.de/kommunaler-klimaschutz/angebote/co2-bilanzierung

Mittelstand Global Exportinitiative Energie. (2021). *Factsheet Montenegro.* Belgrad: Deutsch-Serbische Wirtschaftskammer. Retrieved from https://www.german-energy-solutions.de/GES/Redaktion/DE/Publikationen/Kurzinformationen/Standardfactsheets/2021/fs-montenegro-2021.pdf?__blob=publicationFile&v=3

NGO Green Home. (2020). *Houshold air pollution.* Podgorica: NGO Green Home.

PVGIS (c) European Union. (2021, May 05). *PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM*. Retrieved from https://re.jrc.ec.europa.eu/pvg_tools/en/#MR

Sterner, M., & Stadler, I. (2017). *Energiespeicher - Bedarf, Technologien, Integration.* Regensburg: Springer Vieweg.

Sveinbjörnsson, D., Laurberg Jensen, L., Trier, D., Hassine, I., & Jobard, X. (2017). *D2.3 - Large Storage Systems for DHC Networks.* Skorping: PlanEnergi.

U.S. Environmental Protection Agency. (2007). *Energy Star - 7. Reducing Supplemental Loads.* Washington D.C.: U.S. Environmental Protection Agency.

Vlada Crne Gore. (2020). *Predlog odluke o Energetskom bilansu Crne Gore za 2021. godinu.* Podgorcia: Vlada Crne Gore.

Vlada Crne Gore. (2020). *UREDBU O AKTIVNOSTIMA ODNOSNO DJELATNOSTIMA KOJE EMITUJU GASOVE SA EFEKTOM STAKLENE BAŠTE ZA KOJE SE IZDAJE DOZVOLA ZA EMISIJU GASOVA SA EFEKTOM STAKLENE BAŠTE.* Podgorcia: Government of Montenegro.

Volta, D. (2018). *Thermische Energietechnik.* Flensburg: Hochschule Flensburg.

Williams, A., Jones, J., & Pourkashanian, M. (2012, April 01.). Pollutants from the combustion of solid biomass fuels. *Progress in Energy and Combustion Sciene*, pp. 113-137.

Annex 1

The underlying report for the determination of the heat load is the heat consumption study by Dencon (Dencon d.o.o. Podgorica, 2020). In the absence of more accurate data, the building stock was divided into different categories first:

- Individual buildings (additionally separated for different storeys)
- Collective buildings (additionally separated for different storeys)
- Public
- Business
- Industrial (Dencon d.o.o. Podgorica, 2020)

Afterwards, the corresponding heated area per category and zone was identified. For each category, the specific heat load was calculated separately for houses with and without energy efficient façade joinery. After including the share of houses with energy efficiency measures for each category, a mean specific heat load for each building type was determined (see Table A1).

Table 13: Specific heat load for different building types (Dencon d.o.o. Podgorica, 2020)

Building category	Number of storeys	Specific heat load (buildings without insolation) in W/m²	Share of buildings without efficiency measures	Specific heat load (buildings with insolation) in W/m²	Average specific load for insulated and non-insulated buildings in W/m²
Individual	1	205	75%	103	179
Individual	2	190	75%	95	166
Individual	3	160	75%	80	140
Individual	4	145	75%	73	127
Collective	2	170	94%	85	165
Collective	4	145	94%	73	141
Collective	7	135	94%	68	131
Collective	8	120	93%	60	116
Business		160	80%	80	154
Public		160	70%	80	136
Industry		150	0%	75	150

The peak heat load was then found by multiplying the specific loads with the referring areas.

The study also distinguished the loads between the zones and way of supply, either individual or via microgrids. A summary of the heat load data provides Table 14:

Table 14: Specific heat consumption per zone in kW (Dencon d.o.o. Podgorica, 2020)

Zone	Residential microgrids	Residential decentral	Business and public microgrids	Business and public decentral	Total
1	230	1.500	240	560	2.540
2	710	4.270	740	610	6.320
3	5.790	10.410	3.290	880	20.370
4	480	4.920	1.090	140	6.620
5	510	2.940	130	20	3.600
6	1.760	5.150	0	50	6.960
7	190	1.360	1.700	140	3.400
8	1.040	4.650	0	40	5.730
9	3.180	4.080	270	30	7.560
10	2.660	1.090	730	180	4.660
11	950	5.460	0	330	6.730
12	800	4.550	0	770	6.120
13	1.400	7.920	1.270	160	10.750

Annex 2

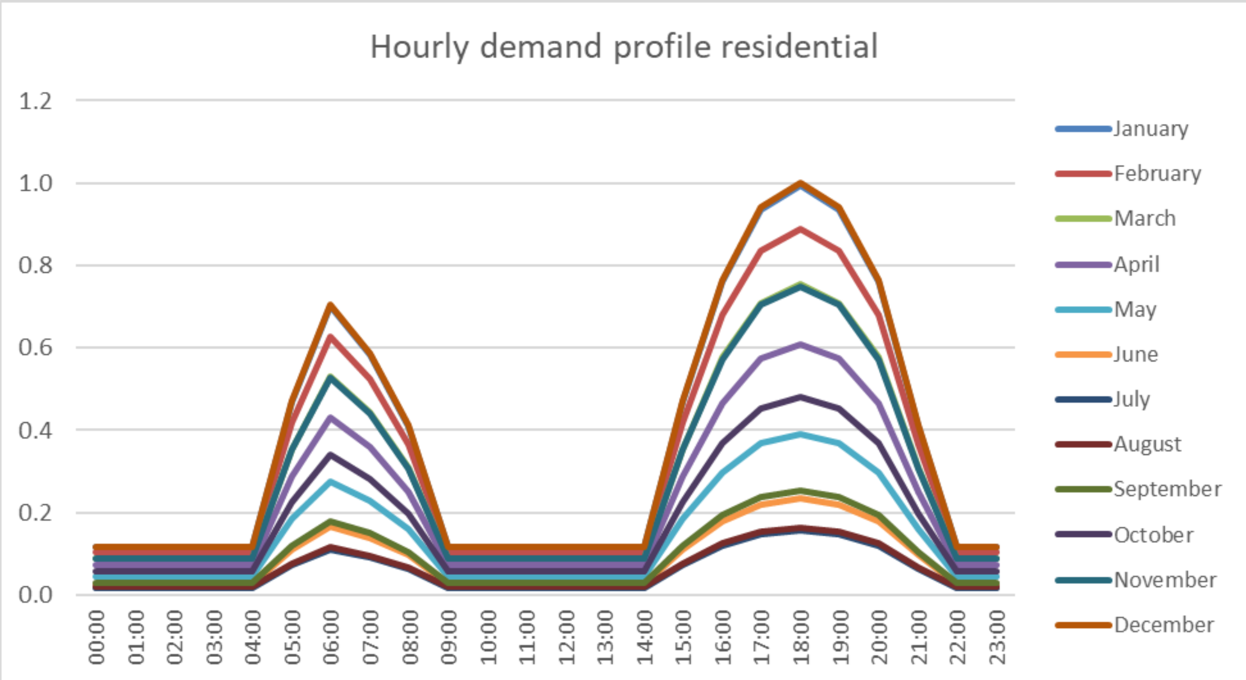

Figure 9: Demand profile for residential buildings

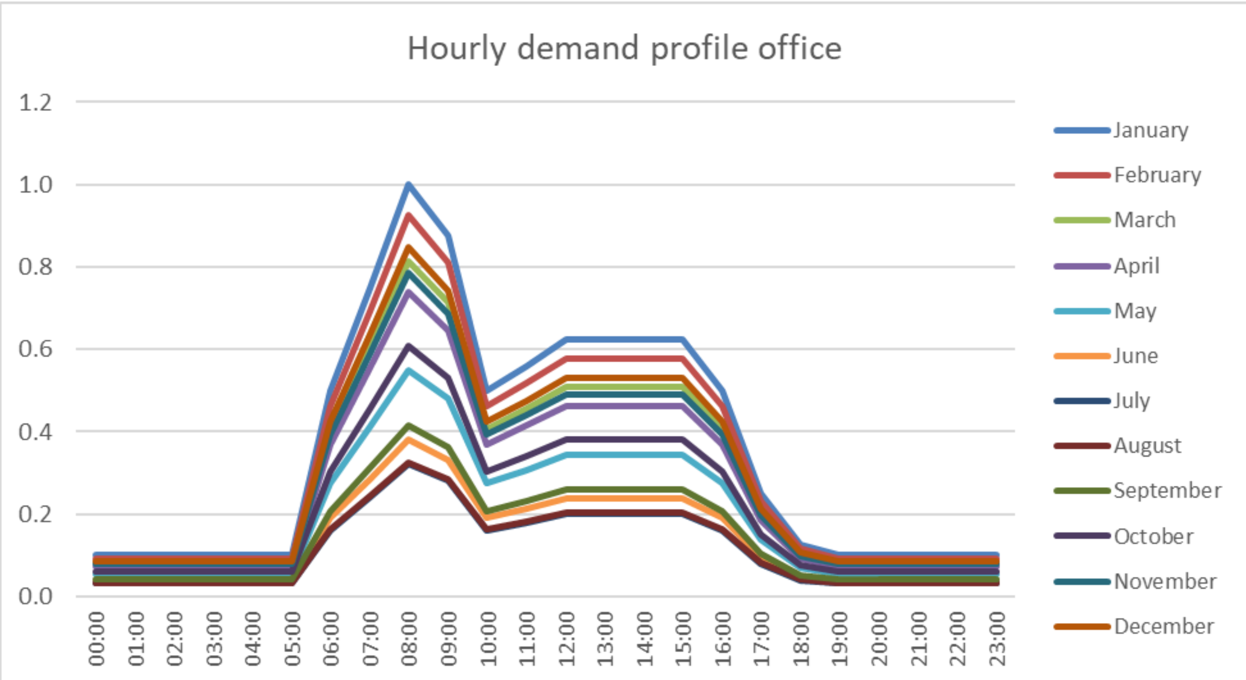

Figure 10: Demand profile for offices and public buildings

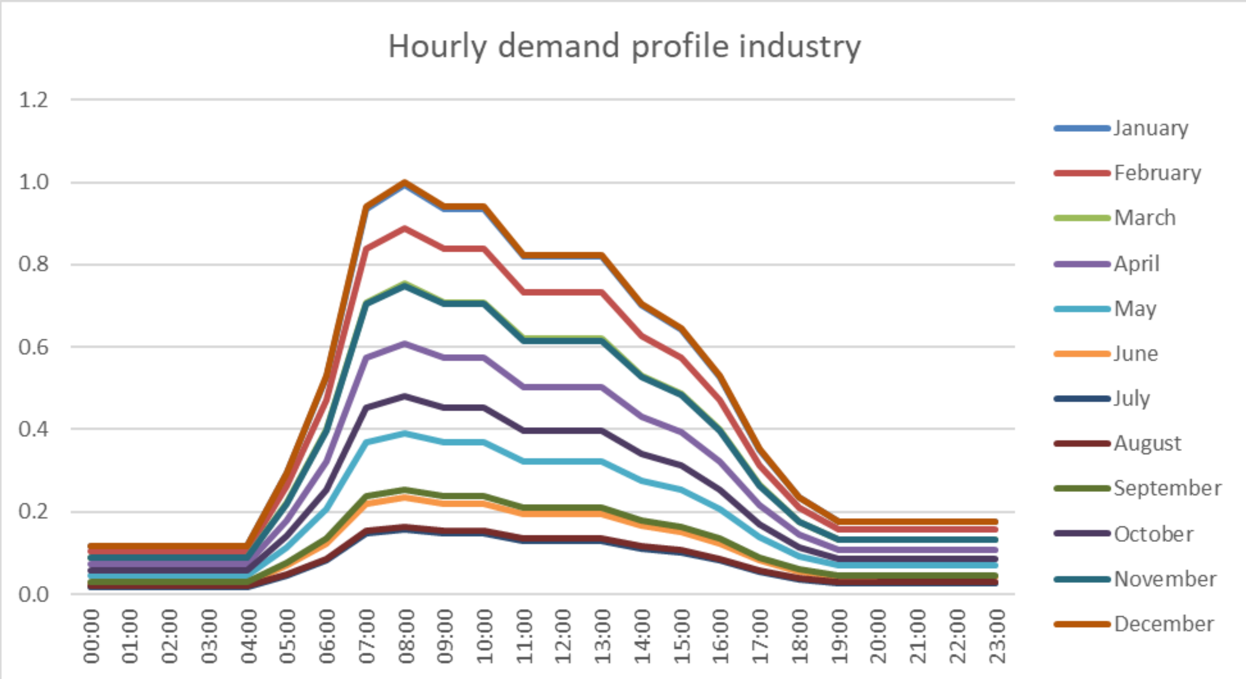

Figure 11: Demand profile for industry

Annex 3

Table 15: Commercial assumptions DH pipes

Pipe type	Diameter in mm	Pipe in €/m	Price materials in €/m	Price other work in €/m	Price total in €/m
DN32	42	35	140	160	340
DN40	48	35	280	160	480
DN50	60	40	160	160	360
DN65	76	45	1.340	160	1.550
DN80	89	50	1.610	160	1.820
DN100	114	75	1.880	160	2.120
DN125	140	85	2.250	160	2.500
DN150	168	108	2.220	160	2.490
DN200	219	150	6.720	160	7.030
DN250	273	184	9.610	160	9.950
DN300	324	215	12.340	160	12.720
DN350	356	235	14.040	160	14.440
DN400	406	310	17.910	160	18.380
DN450	457	365	28.320	160	28.850

Table 16: Cost for different DH expansions

	Load in MW	Length in m	Cost in €
Expansion II centre	6	200	100.00€
Expansion III 3,6,7	28	2.070	2.200.000 €
Expansion IV 3,4,6,7,8,9	47	4.300	9.100.000€
Connection open space solar II	6	1.100	600.000€
Connection open space solar III	28	1.100	1.200.000€
Connection open space solar IV	36	1.100	1.500.000 €

Annex 4

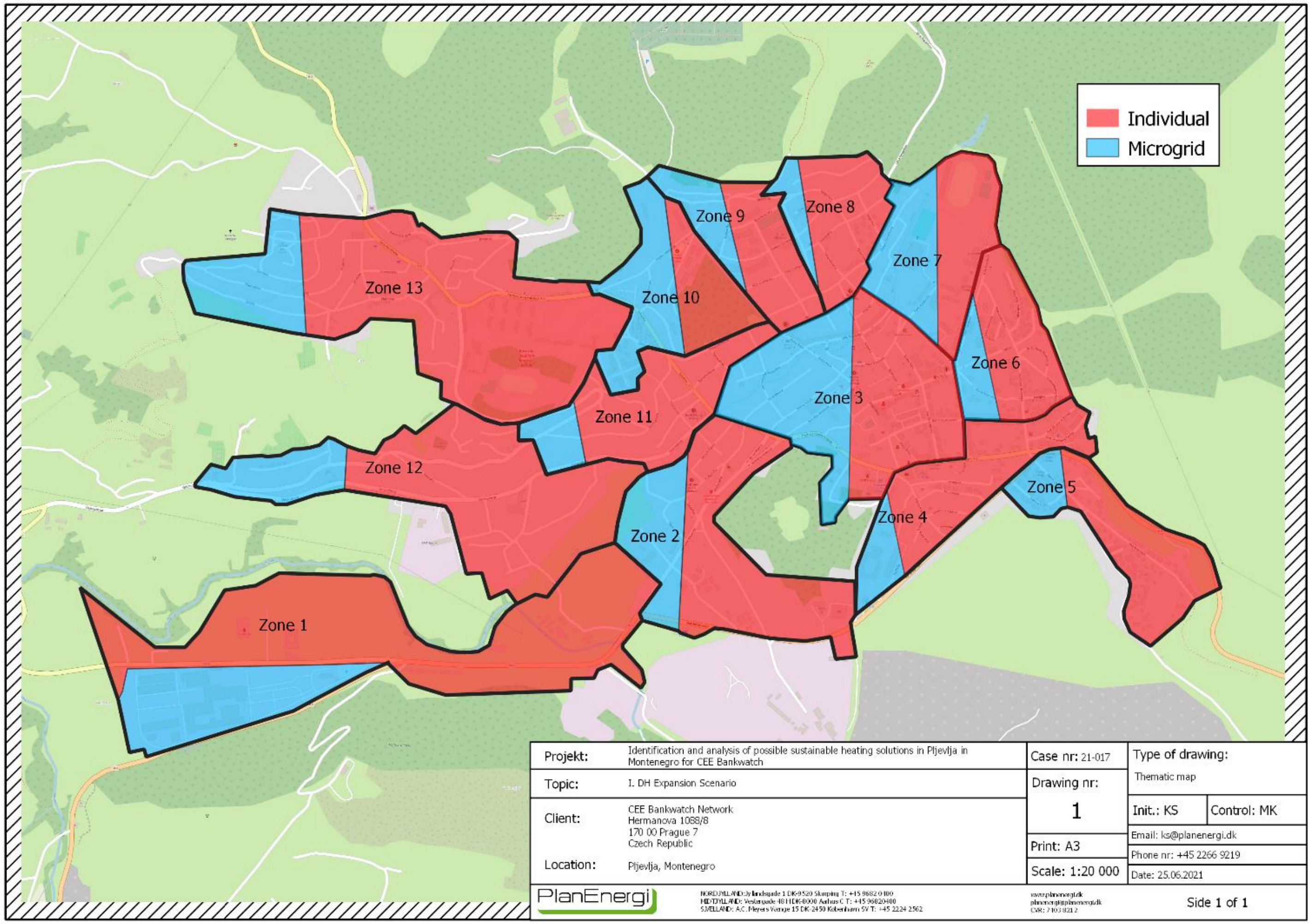

Figure 12: Spatial drawing of expansion scenario I.

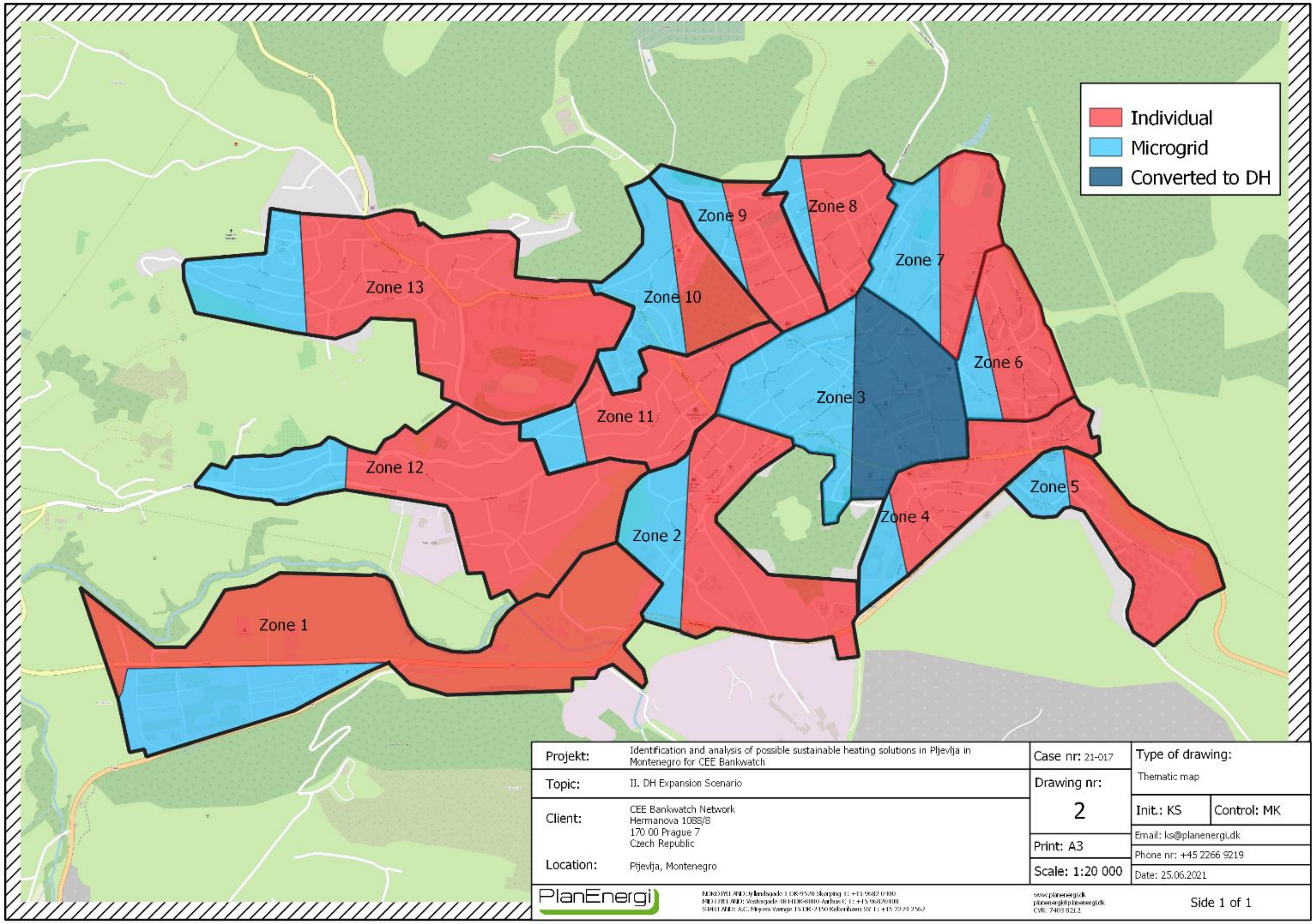

Figure 13: Spatial drawing of expansion scenario II.

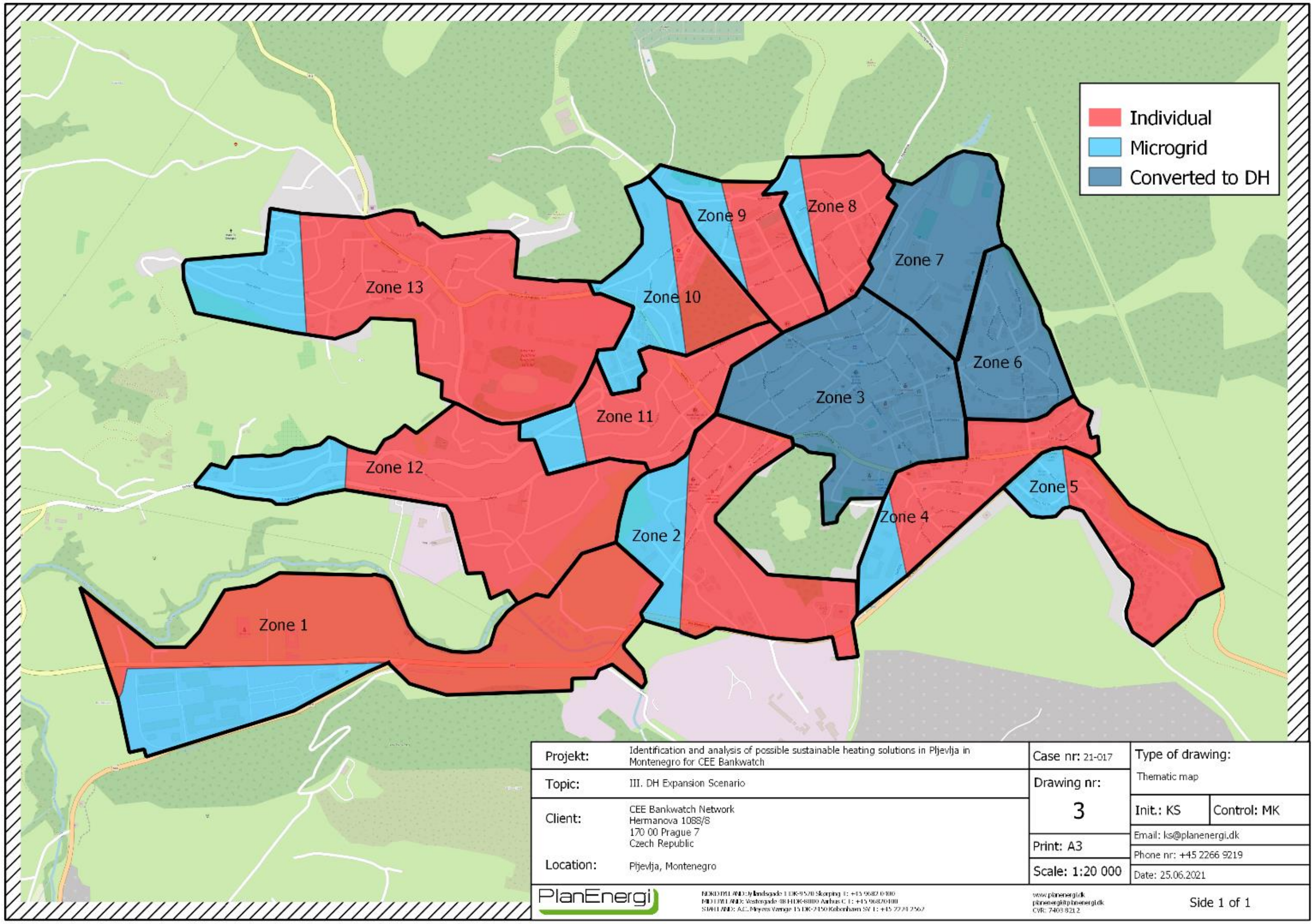

Figure 14: Spatial drawing of expansion scenario III.

Annex 5

Table 17: Rating for qualitative criteria

Rating	*Environmental*	*Technical*		*Strategic*		*Planning*
Score	Environmental impact	Spatial requirements	Technology suitability	Operation intensity	Disruption	Development risk
1	The technology only provides carbon neutral heat and has a very positive impact on the environment.	Very low footprint per unit of installed capacity required to house plant and store fuel and store fuel.	The technology is very well suited to the requirements of the site. This includes high capability of meeting loads, sophistication of technology and easy fuel access generators.	The operation of this technology is low in maintenance, uncomplicated and no specially educated stuff is needed.	Very low disruptiveness of the chosen solution to local operations and/or its impact on the character of the local area.	The program from planning to installation and commissioning of the option is very short and simple. Easy planning application process and system integration.
2	The technology provides heat with a very low carbon intensity.	Low footprint per unit of installed capacity required to house plant and store fuel.	The technology is well suited to the requirements of the site. This includes capability of meeting loads, maturity of technology and easy fuel access	The operation of this technology is quite low in maintenance, mostly uncomplicated and no specially educated stuff is constantly needed.	Minor disruptiveness of the chosen solution to local operations and/or its impact on the character of the local area.	The program from planning to installation and commissioning of the option is short and simple. Easy planning application process and system integration.
3	The technology provides low carbon heat. Depending on the production technique and transportation length of the fuel there can be an environmental impact.	Moderate footprint per unit of installed capacity required to house plant and store fuel.	The technology is reasonably well suited to the requirements of the site. This includes capability of meeting loads, reasonable maturity of technology and reasonably easy fuel access.	The operation of this technology needs regular maintenance, has quite complex processes and specially educated stuff is regularly needed to supervise it.	Limited disruptiveness of the chosen solution to local operations and/or its impact on the character of the local area.	The program from planning to installation and commissioning of the option is of moderate time length and complexity. Relatively easy planning application process and system integration.
4	The technology provides an improvement for the environment. However, the fuel is not carbon neutral.	Large footprint per unit of installed capacity require to house plant.	The technology is poorly suited to the requirements of the site. This includes questionable capability of meeting loads, immaturity of technology and limited fuel access.	The operation of this technology needs maintenance often, has complex processes and specially educated stuff is often needed to supervise it.	Significant disruptiveness of the chosen solution to local operations and/or its impact on the character of the local area.	The program from planning to installation and commissioning of the option is long and difficult. Complex planning application process and system integration.
5	The technology provides no improvement for the environment.	Very large footprint per unit of installed capacity required to house plant and store fuel.	The technology is very poorly suited to the requirements of the site. This includes poor capability of meeting loads, immaturity of technology and limited fuel access.	The operation of this technology needs maintenance very often, has very complex processes and specially educated stuff is always needed to supervise it.	High disruptiveness of the chosen solution to local operations and/or its impact on the character of the local area.	The program from planning to installation and commissioning of the option is very long and difficult. Very complex planning application process and system integration.

Annex 6

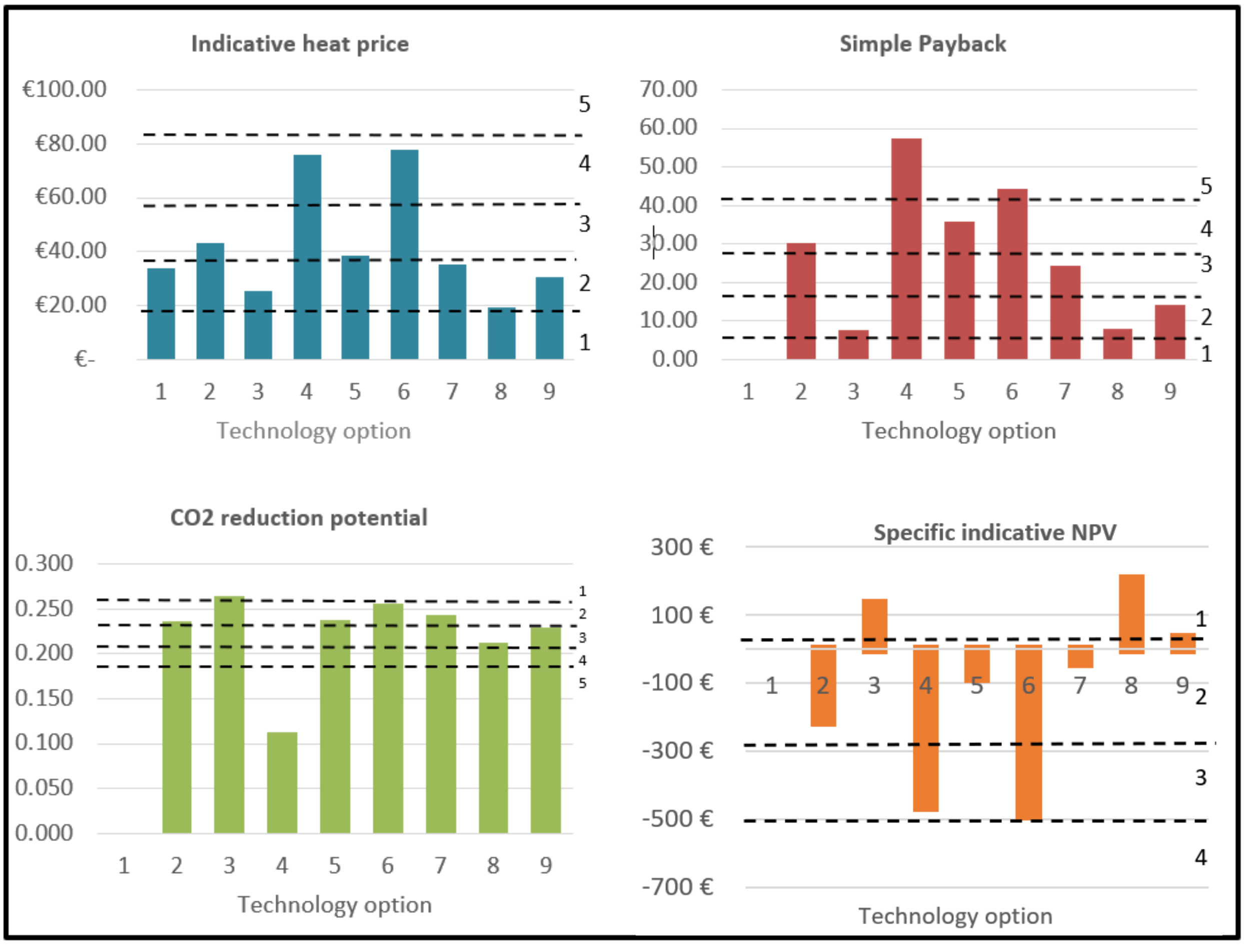

Figure 15: Rating range quantitative criteria scenario I.

Annex 7

Scenario I

Group	Ref	Technology Option	Financial: Simple payback	Financial: Indicicative heat price	Financial: Indicative NPV	Environmental: CO2 reduction	Environmental: Renewable energy contribution	Technical: Spatial requirements	Technical: Technology suitability	Strategic: Operation intensity	Strategic: Disruption	Planning: Development risk	Score	Rank	Rank per section
		Weighting	100%	100%	100%	50%	50%	40%	40%	60%	20%	70%			
		Weighting proportion	16%	16%	16%	8%	8%	6%	6%	10%	3%	11%			
A. Individuals	1	Old biomass boiler	1	2	2	5	5	4	3	5	2	1	16.9	5	3
A. Individuals	2	Heat pumps small	4	3	3	2	2	2	2	1	3	2	16.2	4	2
A. Individuals	3	New biomass boiler small	2	2	1	1	4	3	2	4	2	2	13.7	2	1
B. Microgrids	4	Solar thermal rooftop + Old biomass boiler	5	4	4	5	4	4	4	3	3	3	25.2	9	6
B. Microgrids	5	Solar thermal rooftop DHW + New biomass boiler medium	4	3	2	2	4	4	2	4	3	3	19.5	7	4
B. Microgrids	6	Solar thermal rooftop + New biomass boiler medium	5	4	4	2	3	4	2	3	4	4	23.3	8	5
B. Microgrids	7	New biomass boilers medium	3	2	2	2	4	4	3	4	4	2	17.4	6	3
B. Microgrids	8	Air-to-water heat pumps medium	2	2	1	3	2	2	2	1	3	1	11	1	1
B. Microgrids	9	Air-to-water heat pumps small + New biomass boiler medium	2	2	2	3	3	3	2	2	3	2	14.2	3	2

Figure 16: IRM results for scenario

Annex 8

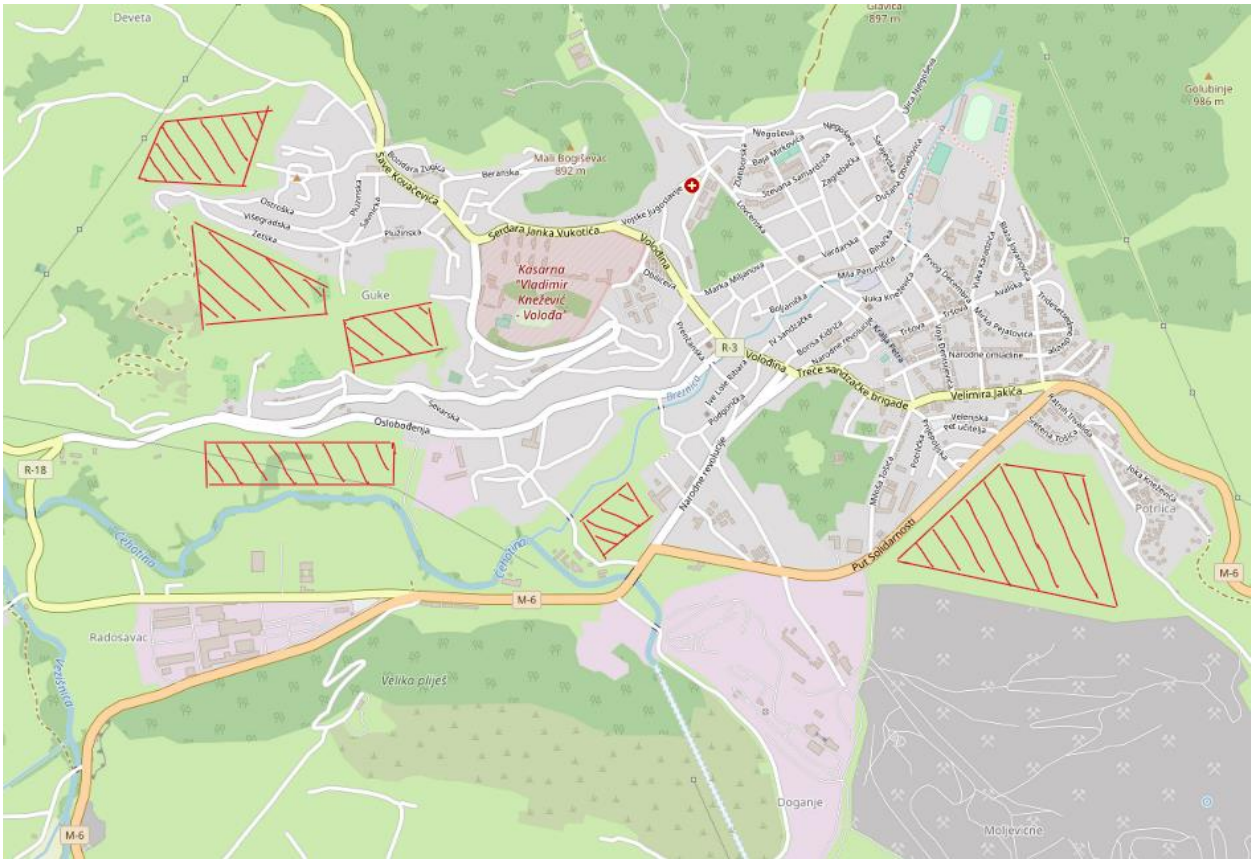

Figure 17: Sketching of potential areas for solar open space

Annex 9

Information on Solar Seasonal Storages:

To balance out the discrepancy between heat demand in winter and renewable heat production by solar thermal collectors in summer, seasonal storages can be used. Since the production profile of solar energy cannot be influenced, a storing of heat becomes necessary to decouple demand and supply side (Sterner & Stadler, 2017).

Heat storages can be based on a sensible, latent, chemical or sorption storing principle, whereas sensible storages are by far the most common and best-known technologies. Sensible storage can be implemented in form of large steel, metal, or plastic tank or as pit storage (PTES) which is covered with a membrane and insulation lit on the top. Sensible thermal storages do not require any special geological requirements and are therefore suitable for nearly every side (Sveinbjörnsson, Laurberg Jensen, Trier, Hassine, & Jobard, 2017).

Sensible thermal storages store heat by increasing the temperature of a medium. The most favourable medium in many cases is water as it is non-toxic, cheap and has a high specific heat capacity. When warm water is filled, a stratification of water layers with different temperature levels occurs. In- and outlets at different heights are necessary to conduct the water at the right temperature level and remain the stratification. The overall heat capacity can be increased by expanding the size (the volume) of the storage and the temperature difference between the top and bottom water layer. A storage capacity from 60 to 80 kWh/m^3 can be reached. Typical storage sizes range between 1.000 and 1 million m^3 (Sveinbjörnsson, Laurberg Jensen, Trier, Hassine, & Jobard, 2017).

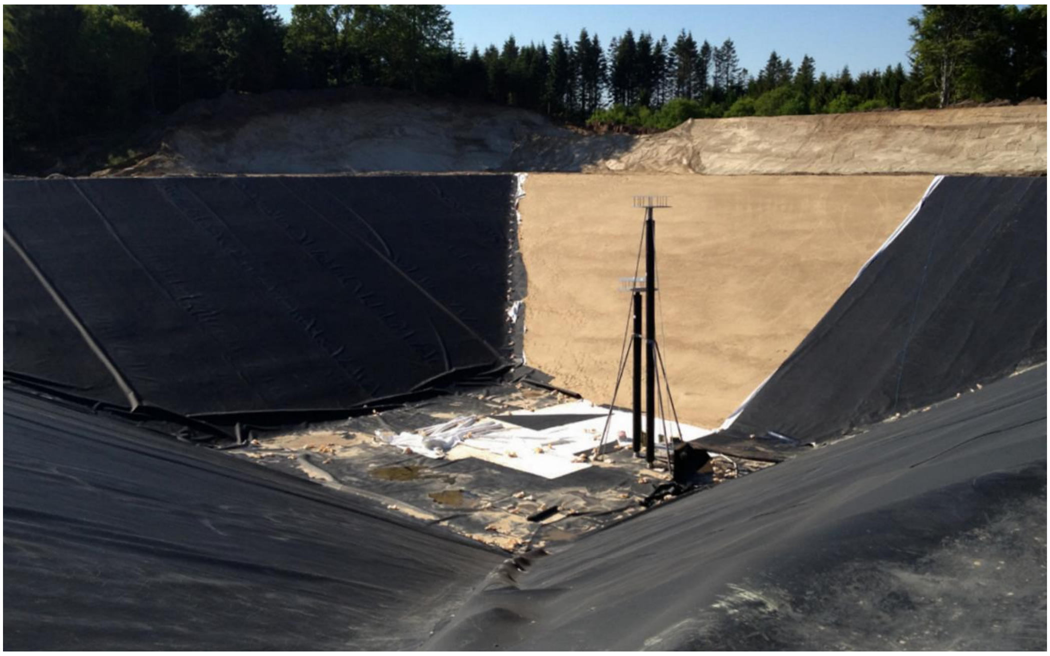

Figure 18: Picture of the building process of PTES in Dronninglund, Denmark (Dronninglund District Heating, 2020)