COMPREHENSIVE ASSESSMENT OF THE POTENTIAL FOR THE APPLICATION OF HIGH-EFFICIENCY COGENERATION AND EFFICIENT DISTRICT HEATING AND COOLING IN THE REPUBLIC OF SERBIA

Transposition of Article 14 of Energy Efficiency Directive, Call-Off 2022.006317

Ministry of Mining and Energy

Republic of Serbia

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Abbreviations

Abbreviation	Meaning
APV	Autonomous Province of Vojvodina
BE	Beogradske Elektrane (Belgrade district heating company)
BOT	Build-Operate-Transfer
CA	Comprehensive assessment
CBA	Cost-benefit analysis
CCGT	Combined cycle gas turbine
CCPP	Combined cycle power plant
CHP	Combined heat and power
CPC	Compound parabolic collector
CPV	Commercial PV
DE	District Energy
DH	District heating
DHC	District heating company
DHW	Domestic hot water
EBRD	European Bank for Reconstruction
ECHP	Electricity from a CHP plant
EDHC	Efficient district heating and cooling
EED	Energy Efficiency Directive
EHI	European Heating Index
EMP	Number of employees
Enon-CHP	Electricity generated by a CHP unit at times when the CHP unit doesn't generate useful heat
EPS	Elektroprivreda Srbije (Electric Power Industry of Serbia)
ETS	Emissions trading system
EU	European Union
FED	Final Energy Demand
FCHP	Fuel consumed in a CHP unit for CHP products (CHP heat and CHP electricity)
Fnon-CHP	Fuel used for generation of non-CHP-electricity in a CHP unit
FPC	Flat plate collector
FSH	Fraction of solar heat
GDP	Gross Domestic Product
GHG	Greenhouse gas
GT	Gas turbine
HCHP	Heat from a CHP plant
HE	High efficiency
HECHP	High efficiency cogeneration
HoB	Heat only boiler
HP	Heat pump
HRSG	Heat recovery steam generator
ICE	Internal combustion engine
KC	Clinical Centre
kgoe	Kilogram of oil equivalent
ktoe	Kiloton of oil equivalent
LCOE	Levelized cost of energy
LSG	Local self-government
LULUCF	Land Use, Land Use Change and Forestry
NIS	Naftna Industrija Srbije (Oil Industry of Serbia)
O&M	Operation and maintenance
PE	Public enterprise
PHR	Power-to-heat ratio
PPP	Purchasing Power Parity

Abbreviation	Meaning
PV	Photovoltaic
ReDE	Renewable District Energy
ReDEWeB	Renewable District Energy in Western Balkans
RES	Renewable energy source
RGE	Reciprocating Gas Engine
RIWH	Recovery of industrial waste heat
RS	Republic of Serbia
SDH	Solar district heating
SE	Solar energy
SEC	Specific energy consumption
SECO	Swiss State Secretariat For Economic Affairs
SHW	Sanitary hot water
SS	Steam for sterilization
TE-TO	CHP plant (in Serbian: Termoelektrana-toplana)
toe	Ton of oil equivalent
TOPS	Association of DHCs of Serbia
TPES	Total primary energy supply
TPP	Thermal power plant
USPV	Utility-scale PV
WWTP	Waste water treatment plant
WWHP	Waste water heat pump

1. Executive Summary

As per EU Acquis for transposition of Article 14 of Directive 2012/27/EU (the "Energy Efficiency Directive" or "EED") and as Contracting Party of the Energy Community, Serbia was required to carry out a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling.

This document is a methodology and tool for preparation of the Comprehensive Assessment (CA) and Cost-Benefit Analysis (CBA) and is carried out in compliance with Article 14 of the Energy Efficiency Directive (EED).

Purpose is to generate a process, necessary scope and content, and recommendations and best practices that need to be considered and implemented in the identification of potential for increasing of the energy efficiency. This identification process basically includes potential of high efficiency Combined Heat and Power (CHP or cogeneration) plants, efficient district heating and cooling (EDHC) and the recovery of industrial waste heat (RIWH).

Among other measures to accelerate energy efficiency improvements, the EED, through its Article 14, requires identifying of the potential for HECHP, EDHC as well as RIWH, and to analyse the costs and benefits of the possible opportunities, where requires a comprehensive assessment (CA) of the technology's application potential.

1.1 Objectives and Scope of Works

Preparing a comprehensive assessment according to content prescribed by Annex VIII of the EED to meet the requirements of Article 14 of the EED, and the requirements of the Commission Recommendation (EU) 2019/1659 of 25 September 2019. The content of the comprehensive assessment of the potential for efficient heating and cooling is defined in Article 14 of Directive 2012/27/EU, and Annexes 1 to 7 C(2019) 6625 of 25/09/2019 final; and

Preparing an Action Plan covering the period 2022-2030 and integration into other strategic documents in particular the Integrated National Energy and Climate Plan (INECP).

- **Review of Article 14 requirements on comprehensive assessment and gap analysis:**

  i) Review of latest requirements of EED Article 14 and Serbian requirements as contracting party to the Energy Community and EU candidate country;
  ii) Research and review of EU best-practice assessments e.g. Heat Roadmap EU;
  iii) Preparing of a draft work plan for the comprehensive assessment to meet all requirements of EED Article 1. The year 2021 was considered as a starting and reference year; and
  iv) Preparation of an Action Plan covering the period 2022-2030.

- **Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling**

The Comprehensive assessment according to EED Article 14, includes the following:

i) Adjusting the structure of the document to align with Annex VIII of updated EED directive 2012/27/EU and corresponding recommendations of Commission of 2019;

ii) Overview of heating and cooling sector in Serbia:
   - Updating latest data of energy and heat sector (supply, demand, energy prices, etc.) in residential, service and industrial sectors;
   - Updating of future demand forecasts;

iii) Strategies and policy measures:

- Reviewing of the latest EU and Serbian legislations and updating associated sections with new information;

iv) Analysis of the economic potential for efficiency in heating and cooling:
   - Developed comprehensive financial models;

v) Estimation of the potential of new strategies and policy measures:

- **Preparation of an Action Plan for the period 2022-2030**

i) A draft of the Action Plan (AP) for the period 2022-2030 has been prepared, taking into account the progress made on the recommendations based on the comprehensive assessment;
ii) There were considered ad-hoc technical inputs to integrate the main actions into other strategic documents for approval, in particular the National Energy and Climate Plan (NECP);
iii) A draft of the Management and Monitoring Plan for easier implementation of the AP was prepared.

1.2 Results

The approach for applying the requirements of Article 14 elaborates the following:

- Establish the heat and cooling demand of the country,
- Prepare a forecast of how this demand will evolve in the next decade,
- Prepare a heating and cooling map of the national territory,
- Establish the maximum or technical potential,
- Carry out the cost-benefit analysis,
- Define strategies, policies, and measures towards 2030,
- Determine the project's viability,
- Prepare the Action Plan, and
- Define priorities order and evaluate probability.

All these listed energy technologies - the high efficiency CHP (HECHP), high efficiency DHC and recovery of industrial waste heat (RIWH), certainly can highly contribute to increasing of energy efficiency at national level, and reducing of primary energy consumption, reduction of pollution, and increase the overall efficiency of the energy system. Also, it is necessary to keep in mind that the main benefits from cogeneration are:

- savings from reduced energy cost,
- an enhanced energy security situation, and
- lower pollutant and Greenhouse Gas (GHG) emissions.

The structure of the applied approach, i.e. methodology of the analysis includes eight steps that are ordered in a logical stepped structure. Each step is in a way self-explanatory. However, some notes important for the scope of the steps, their connecting and integration, will be given later.

A part of the results of the analysis of energy consumption are briefly presented below in diagrams in Figure 1.1.

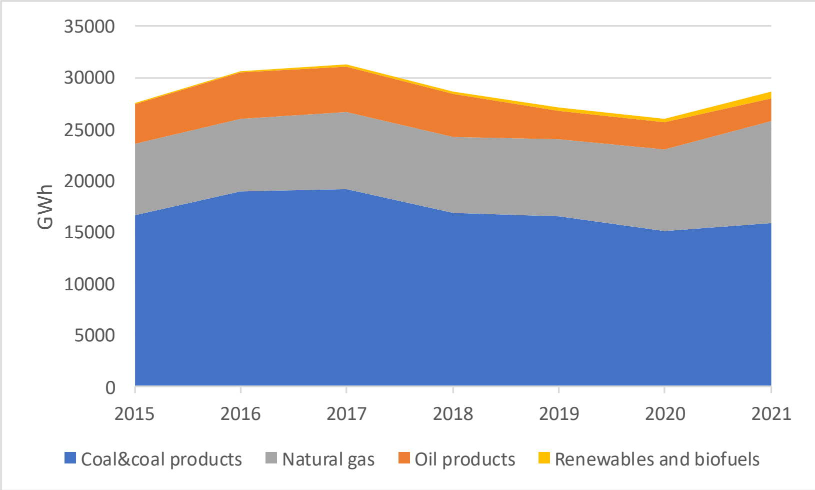

Figure 1.1 Energy sources used for heat production in the Republic of Serbia, 2015-2021

Heat energy is mostly generated from fossil fuels. Small quantity of heat energy was generated from RES. The distribution of final energy consumption per sectors is presented in Figure 1.2.

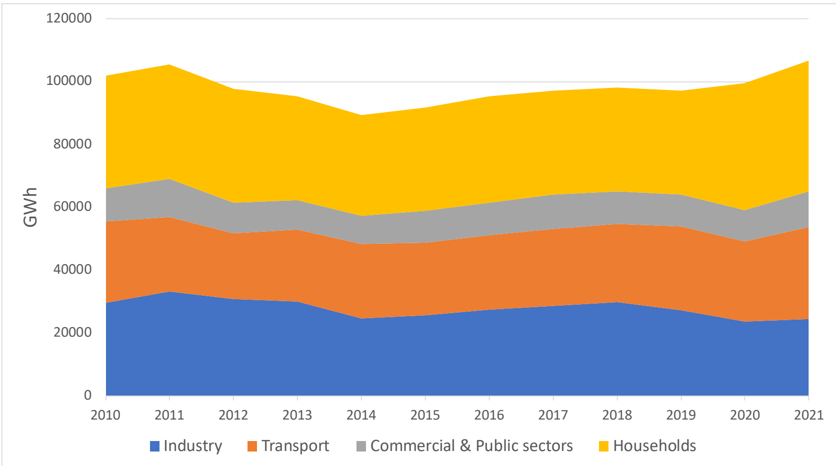

Figure 1.2 Final energy consumption, by sectors of consumption, 2010-2021

The household sector is consuming the largest part of final energy in the Republic of Serbia. Also, energy efficiency indicators of the Republic of Serbia indicate relatively high energy consumption per unit of gross domestic product.

Analysis of consumption of energy for heating and cooling included thermal power plants and plants for combined power and heat production, district heating plants within the district heating systems, auto producers (industrial CHPs and industrial heating plants), and individual boiler rooms that are not included in the energy balance.

The total energy input in these facilities amounted to 28,583 GWh in 2021. Most of this energy was used in TPP&CHP (54.3%) and district heating plants (24.9%). The total share of auto producers was 20.8%. The share of consumed energy in industrial CHP was 14.7%, and in industrial heating plants it was 6.1%. The coal was the dominant fuel (55.6%), followed by natural gas (34.6%). The share of oil products (7.7%) and RESs (2.1%) was significantly lower.

Energy consumption in industry sub-sectors is presented in Table 1.1.

Table 1.1. Heat consumption in industry by sub-sector (2021) in ktoe and GWh

Sub-sector	Heat	
	In ktoe	In GWh
Iron and steel	55.94	651
Chemical and petrochemical	59.71	694
Non-ferrous metals	7.02	82
Non-metallic minerals	1.19	14
Transport equipment	0.89	10
Machinery	0.50	6
Mining and quarrying	0.00	0
Food, beverages, and tobacco	26.71	311
Paper. pulp and printing	17.11	199
Wood and wood products	0.02	0.2
Construction	0.00	0
Textiles and leather	1.12	13
Not elsewhere specified (Industry)	22.23	259

The analyses presented in this study have resulted in the possible contribution of new, or enhanced high-efficiency district heating systems and HE CHPs to the goals of Serbian energy policy until 2030.

Table 1.2. Technical potential of high efficiency district heating system until 2030

Implemented measure/technology	Potential (GWh)
Expanding of consumption on the existing network	215
Efficient DH using natural gas in CHP facilities	150
Efficient DH by waste incineration	297
Efficient DH by biomass	369.7
Efficient DH using heat pumps	113.1
Efficient DH using thermal solar	432.4
Waste heat from industry	198

Table 1.3. Technical potential of HE CHP until 2030

Sector	Analysed case/Branch	Heat potential	Electricity potential
Residential	Buildings with 1 dwelling	15,797 kWh/building/year	5,840 kWh/building/year
	Buildings with 2 dwellings	28,820 kWh/building/year	11,680 kWh/building/year
	Buildings with 3 and more dwellings (8 dwellings)	69,076 kWh/building/year	43,800 kWh/building/year
Services	Health centres	2 GWh	1.2 GWh
	Hospitals	51.6 GWh	43.4 GWh
	Clinical centres	3.8 GWh	3.2 GWh
	Small hotels	6.5 GWh	4.3 GWh
	Large hotels	31,2 GWh	20.1 GWh
	Swimming pool	24.7 GWh	17.7 GWh
Industry	Iron and steel	21.5 GWh	17.5 GWh
	Chemical and petrochemical	122.0 GWh	100.6 GWh
	Non-ferrous metals	8.8 GWh	12.4 GWh
	Non-metallic minerals	31.6 GWh	40.8 GWh
	Food, beverages and tobacco	153.4 GWh	137.4 GWh
	Paper, pulp and printing	39.7 GWh	28.6 GWh

	Wood and wood products	0.9 GWh	1.0 GWh

There are vast differences in investments and NPV results, but it singles out main characteristics:

1. If we calculate NPV considering the EU price of CO_2, all described projects have positive NPV.
2. The size of the project plays a major role – the bigger the better. It should be added here that projects with more working hours are more favorable.
3. CHP is using more gas than previously, and it should be counterbalanced by additional electricity production. This can be achieved only with large machines.

The relation between the investment and the NPV is presented in Figure 1.3.

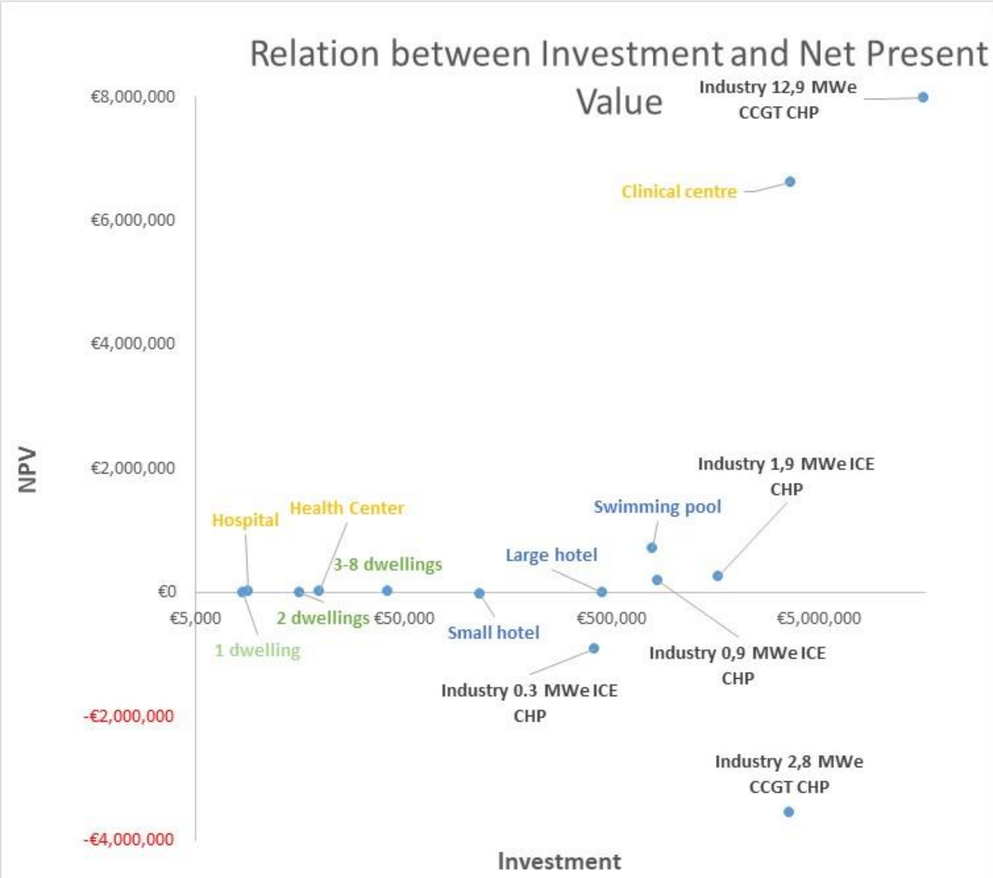

Figure 1.3 Relation between the investment and NPV

Attention needs to be paid to the residential sector and the possibility of connecting to the DHS network, because of the big number of them and an enormous influence on the overall CO_2 footprint. Calculation of CO_2 using the g EU price gives us a positive NPV. The conclusions are:

1. Fuel oil and electricity: These two energy sources should be replaced as soon as possible by connection to the DHS network, where possible. Considering the positive NPV, it should be done in the short term and for the benefit of everyone (household, DH, and society as a whole).
2. Wood pellet and TA stove + 2 hours of high tariff: The profitability of connecting to the DHS network is not direct, and could be provided through additional incentives (donations through the reduction of investment costs, various financial incentives).
3. Wood and coal: The largest number of households use these energy sources and their impact on the CO_2 footprint is the greatest. However, for their DH connection to be economically profitable, greater incentives are needed (compared to option 2).

Conclusion is that heat energy generation in the Republic of Serbia is predominantly based on fossil fuel combustion.

The relation between then investment needed to connect to DH and the NPV is presented in in Figure 1.4.

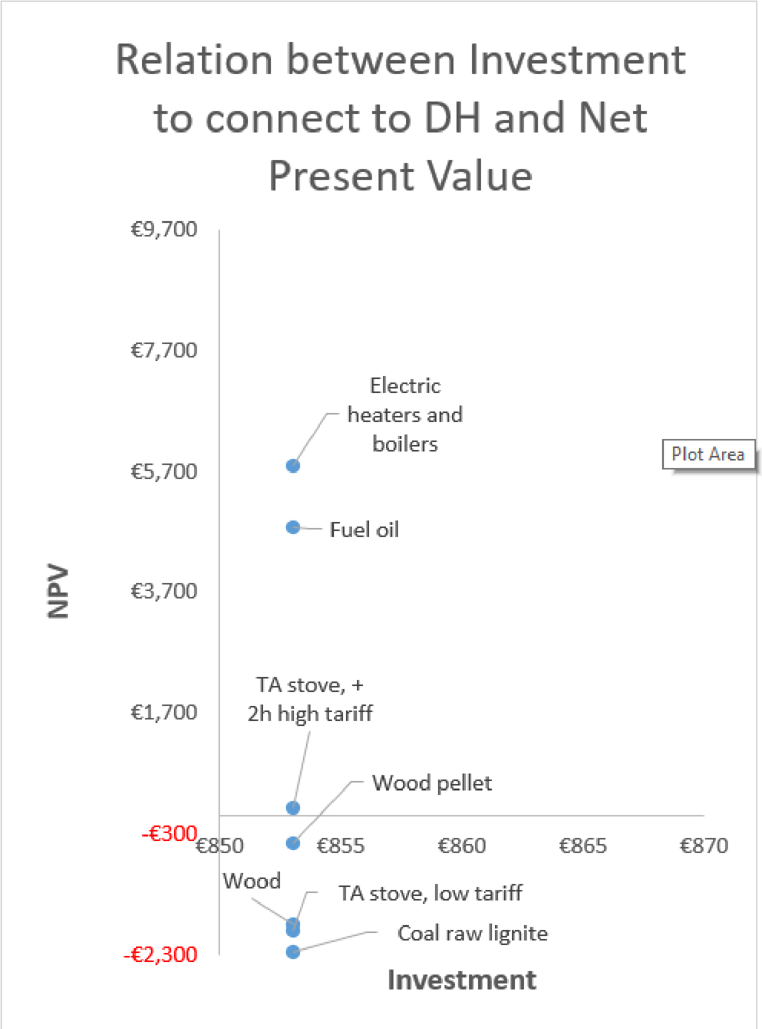

Figure 1.4. Relation between the investment needed to connect to the DHS and the NPV

2. Introduction

This document is a methodology and tool for preparation of the Comprehensive Assessment (CA) and Cost-Benefit Analysis (CBA) that is following Article 14 of the Energy Efficiency Directive (EED).

Its purpose is to generate a process, necessary scope and content, and recommendations and best practices that need to be considered and implemented in the identification of potential for increasing of the energy efficiency.

This identification process includes potential of high efficiency Combined Heat and Power (CHP or cogeneration) plants, efficient district heating and cooling (EDHC) and the recovery of industrial waste heat (RIWH). All these listed technologies can highly contribute to increasing of energy efficiency at regional and national level, and reducing of primary energy consumption, reduction of pollution, and increase the overall efficiency of the energy system.

It is necessary to keep in mind that the main benefits from cogeneration are:

- savings from reduced energy cost,
- an enhanced energy security situation, and
- lower pollutant and Greenhouse Gas (GHG) emissions.

CHP plant and especially HECHP plants are faced with lots of challenges due to lack of policies and incentives that would favor their use.

CHP unit would consume more fuel, has higher operating costs, and requires extra investment costs compared with the available alternatives like a HoB boiler or only electricity generating power plant. CHP plants require more management care for fitting into the energy system and for proper (profitable) operating, because they are generating two different outputs – heat and power – and because of higher investment cost, higher fuel consumption and because their operation requires additional skills and knowledge.

For applying the requirements of Article 14 elaborates the following:

- Establish the heat and cooling demand of the country,
- Prepare a forecast of how this demand will evolve in the next decade,
- Prepare a heating and cooling map of the national territory,
- Establish the maximum or technical potential,
- Carry out the cost-benefit analysis,
- Define strategies, policies, and measures towards 2030,
- Determine the project's viability,
- Define priorities order and evaluate probability.

Among other measures to accelerate energy efficiency improvements, the EED, through its Article 14, requires identifying of the potential for HECHP, EDHC as well as RIWH, and to analyse the costs and benefits of the possible opportunities.

METHODOLOGY

In the Energy Efficiency Directive (EED), Article 14 requires an analysis of heating and cooling at country level using an integrated approach.

It was necessary to assess both heat demand and the potential for HECHP as well as EDHC and RIWH to meet the demand cost-effectively. CA and CBA were applied at the whole country`s territory taking into account all influencing factors set out in Annex VIII: climate conditions, economic feasibility, and technical suitability, that are all set out in Annex VIII. The practical result of the analysis are splitted and analysis of the requirements and provisions of Annex 14 into nine “smaller” parts that would allow simpler analysis.

The structure of the applied approach, i.e. methodology of the analysis, is presented in Figure 2.1.

The methodology includes eight steps that are ordered in a logical stepped structure. Each step is in a way self-explanatory. However, some notes important for the scope of the steps, their connecting and integration, have been given later.

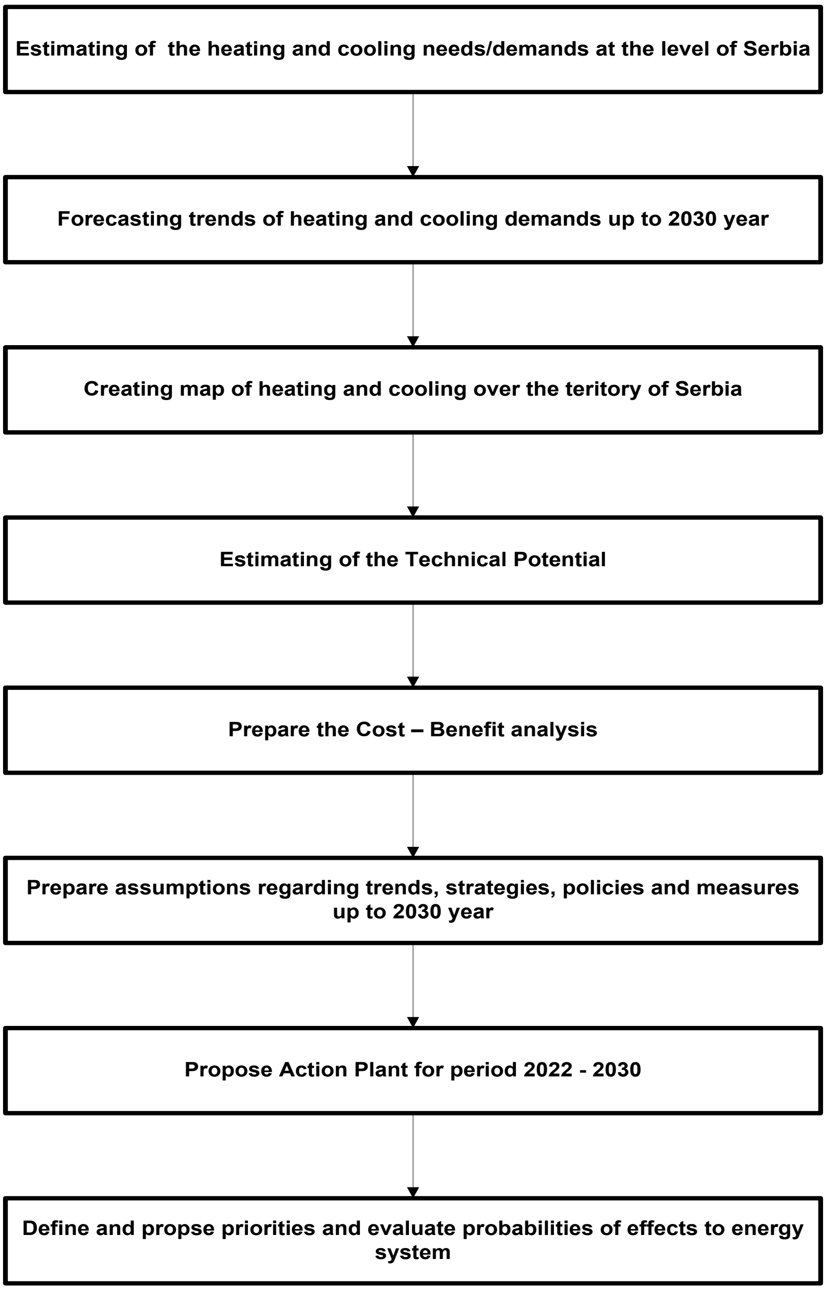

Figure 2.1. Structure of the applied methodology

3. The demand for heating and cooling

3.1 The national energy balance

The energy balance of the Republic of Serbia[1] contains the data on annual production, stocks, imports, exports, transformation and consumption of electricity, heat, blast furnace gas, coal, oil and oil derivatives, natural gas, solar PV, wind, hydro energy, geothermal energy, wood fuels, biogas, and industrial waste. The energy balance includes the data for the territory of the Republic of Serbia, without the AP Kosovo and Metohija.

The primary energy production covers exploitation, i.e. the use of domestic resources of coal, crude oil, natural gas, non-renewable industrial waste and renewable energy sources (hydro, solar PV and wind energy, geothermal energy, wood fuels, biogas and renewable industrial waste). A total of 10,304 ktoe of primary energy was generated in Serbia in 2021. The structure of primary energy production is presented in Figure 3.1.

This production satisfies 62.2% of the total demand for primary energy.

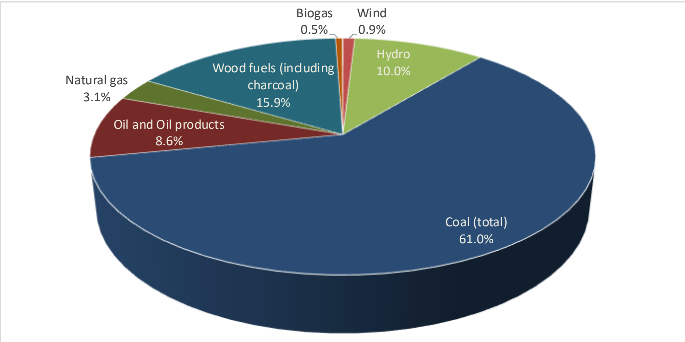

Figure 3.1. Structure of primary energy production in 2021

The import of primary energy (including electricity) in 2021 amounted to 7,463 ktoe. The necessary additional quantities of crude oil and oil derivatives, natural gas, and coal are provided by import. Crude oil and oil derivatives have the largest share in imports – 54.3%, followed by natural gas - 28%, coal - 9%, electricity - 8%, and wooden fuels 0.6%. The net import dependence of Serbia in 2021 amounted to 35.66%. Total primary energy supply (TPES) in 2021 amounted to 16,440 ktoe. The structure of different energy sources in TPES is presented in Figure 3.2.

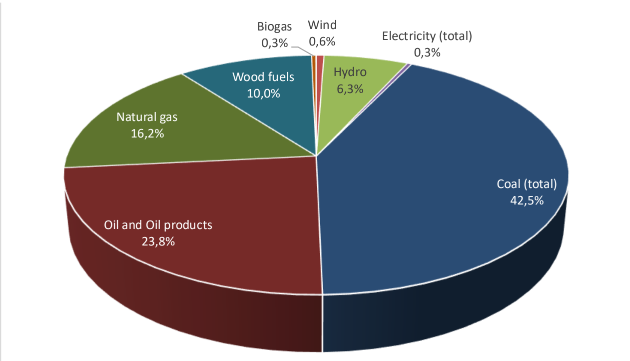

Figure 3.2. Structure of primary energy supply in 2021

The trend of changes in the TPES structure in the Republic of Serbia in the period 2010-2021 is presented in Figure 3.3. A slight decrease in the use of solid fossil fuels (coal) is noticeable. A more significant decrease in 2014 is the result of floods, while the drop in 2021 is the result of problems in coal production. The deficiency of coal in 2021 was the reason for an increase in oil and petroleum products, natural gas, and RES (hydropower) utilization, mostly for electricity production.

[1] https://www.stat.gov.rs/sr-latn/oblasti/energetika/tabele/

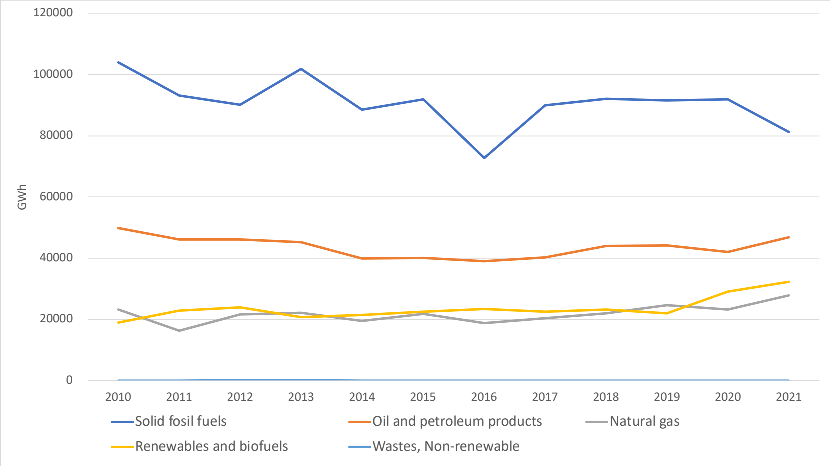

Figure 3.3. Total primary energy supply, 2010-2021

The Republic of Serbia is very dependent on fossil fuels. Coal is the most important domestic energy source, primarily in the production of electricity. The share of RES - 34.2% in electricity production in 2021 (dominantly hydro energy – 31.3%) is slightly lower than the EU average. In addition to hydropower, a significant renewable energy source in the Republic of Serbia is wood biomass, which is primarily used for heating purposes in households.

The total final energy consumption includes the consumption of energy derived from transformation, as well as a part of the total available primary energy which does not enter the transformation processes but is directly consumed by end users. The total final consumption in Serbia in 2021 amounted to 10,109 ktoe (117,568 GWh) of which 732 ktoe (8,513 GWh) was non-energy consumption, while the final energy consumption was 9,388 ktoe (109,182 GWh). In terms of sectors of consumption, the final energy was mostly consumed in the sector of households - 38.2%, then in transport - 26.8% and in the industry - 22.4%, while other sectors accounted for 12.7%. Due to the highest share in the transport sector, oil products are the most used energy sources in final consumption – 31.1%, followed by electricity – 26.7%, wood fuels – 17.3%, natural gas - 12.9%, and heat – 8.3%.

After decrease in consumption in the 2010-2019 period, significant increase in consumption is evident in the last two years due to new evaluation of biomass utilization in households[2]. The considered period is characterized by very small changes in the structure of used energy sources. There was a decline in the use of coal and its share in final consumption fell from 10.6% in 2010 to 3.2% in 2021. The change in the share of other energy sources in the considered period is less than 1%. The immutability of shares is also characteristic of the sectoral distribution of final consumption. The share of the household sector is the largest. In the entire considered period, it amounted to 34-39%, the share of industry is 22-31%, traffic 21-28%, and the public and commercial sector participates in final consumption with about 10-12%.

Energy efficiency indicators of the Republic of Serbia indicate relatively high energy consumption per unit of gross domestic product.

3.1.1 Consumption for heating and cooling[3]

The heat production capacities in the Republic of Serbia are installed in:

- Thermal power plants and plants for combined power and heat production (TPP&CHP),
- District heating plants within the district heating systems,
- Auto-producers (Industrial CHPs and Industrial heating plants), and
- Individual boiler rooms that are not included in the energy balance.

The total energy input in these facilities amounted to 2,457.7 ktoe (28,583 GWh) in 2021. The most of this

[2] Statistical Office of the Republic of Serbia, Energy Consumption in Households in the Republic of Serbia, 2020, Belgrade, 2021, ISBN 978-86-6161-207-7

[3] https://ec.europa.eu/eurostat/web/energy/data/energy-balances;

energy was used in TPP&CHP (54.3%) and district heating plants (24.9%). The total share of auto-producers was 20.8%. The share of consumed energy in industrial CHP was 14.7%, and in industrial heating plants it was 6.1%. The coal was the dominant fuel (55.6%), followed by natural gas (34.6%). The share of oil products (7.7%) and RESs (2.1%) was significantly lower.

Analysis of fuel consumption in the 2015-2021 period (Figure 3.4.) shows a negative trend in coal consumption (average decline 3.5% from 2016), and a steady increase in natural gas consumption (average 5.2% annually). Oil products have significant decline (44%) in the last six years, while RESs consumption increased 6,4 times in the same period.

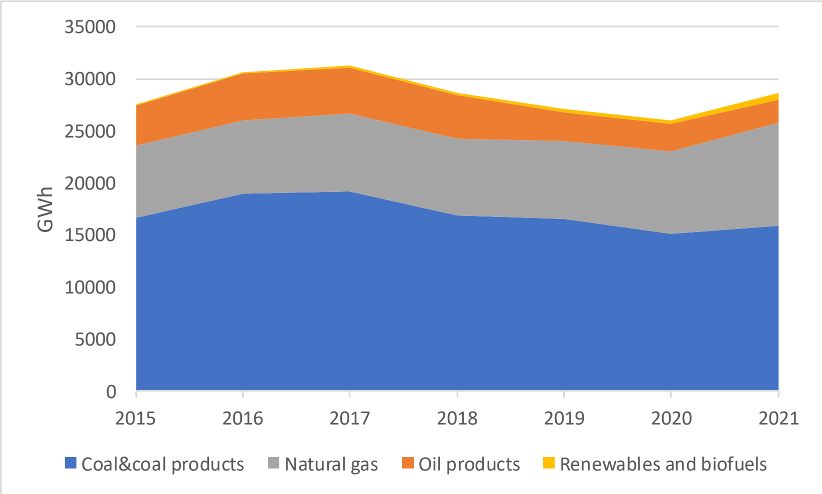

Figure 3.4. Energy sources used for heat production in the Republic of Serbia, 2015-2021

The consumption of energy sources in these facilities is presented in Figure 3.5. It is evident that coal is the dominant fuel. The share of natural gas use was between 5 and 10% until 2020. However, in 2021, due to problems with the coal supply to TPP, the share of natural gas reached 16.2%. The share of RES (solid biofuels and from 2020 biogas) was around 0.8%, while the oil products were not used in the last five years.

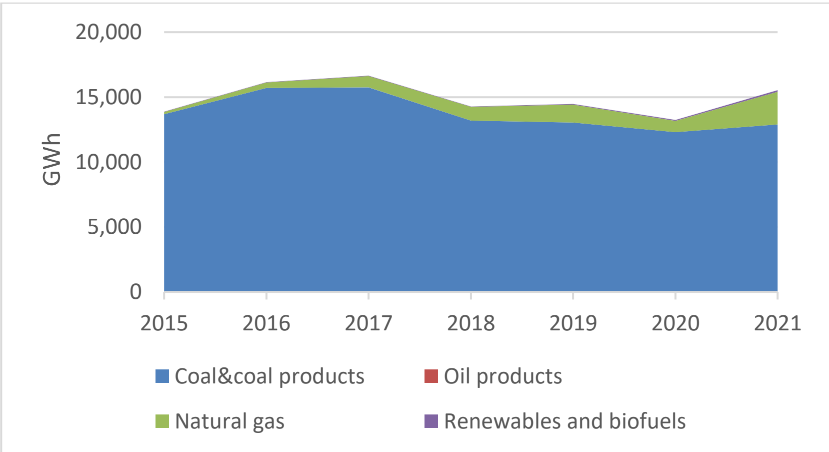

Figure 3.5. Energy sources used for heat production in TPP and CHP, 2015-2021

District heating systems exist in 60 towns in Serbia, with a total installed heat capacity of boilers of 6,587 MW (2021). These systems are based on fossil fuels, mostly natural gas (Figure 3.6.) In the 2010-2021 period, the share of natural gas increased from 68% in 2015 to 77.6% in 2021. Natural gas mostly substituted oil products and the share of oil products reduced to 16.4% in 2021 (from 26% in 2015). The share of coal is around 5%, while the share of RESs is less than 0.5%. As the district heating systems are mostly operated for space heating, the decrease in total energy used for heat production can be explained by implemented energy efficiency measures (more efficient boilers, reduction of heat losses in distribution, better insulation of buildings, etc.) and less heat demand in the winter seasons (higher average outdoor temperature).

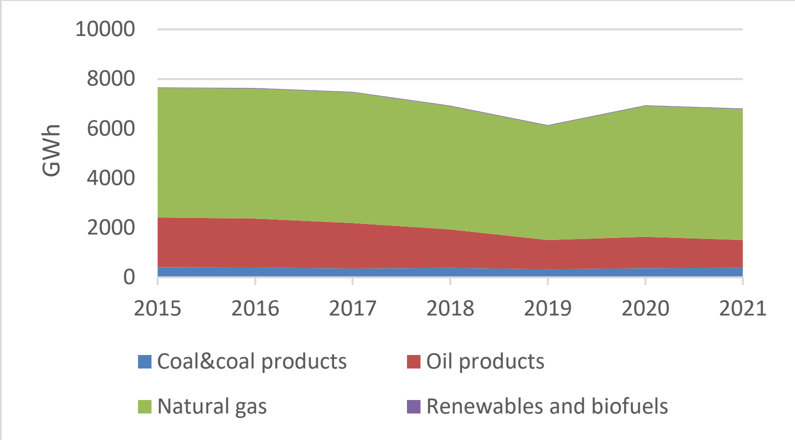

Figure 3.6. Energy sources used for heat production in district heating systems, 2015-2021

Auto-producers in the Republic of Serbia include industrial facilities for combined heat and power production (Industrial CHPs), and industrial facilities for heat production only (Industrial heating systems). Total capacity of industrial CHPs in the Republic of Serbia is 111.24 MWe. In addition, there are heat sources in the industry with heat power of 711.52 MWth. These sources are mostly used to produce heat for production processes and for heating the working space in industrial enterprises.

For the industrial CHPs there is evidently an increase in natural gas and RESs utilization and a significant decline in oil products and coal use. The shares of fuels for heat production in industrial heat plants are relatively constant. Oil products are the mainly used energy source in industrial heat plants, while the RESs use is negligible.

Cooling capacities in Serbia include installation in public and commercial buildings, households, and industrial facilities. These systems use mainly electricity as an energy source, but the amount of energy used for cooling is not separately presented in the national energy balance.

3.1.2 Derived heat

The amount of balanced, produced heat in the Republic of Serbia amounted to 10,336 GWh in 2021. Out of this amount, 61.4% of heat was produced in district heating plants, 17.0% in industrial CHPs, 13.1% in TPP&CHPs, and 8.5% in industrial heating plants. This distribution of production is similar in the whole considered 2015-2021 period, with the small variability in productions from district heating and industrial plants mostly caused by different conditions in winter (heating) seasons. In addition, heat production from TPP&CHPs had the highest value in the whole considered period.

The total output of electricity production from thermal power plants and CHPs that operate in PE EPS was 5,175 GWh in 2021, while the output from industrial CHPs in the same year, amounted to 527 GWh. Electricity production from these facilities reached a maximum value in the whole considered period.

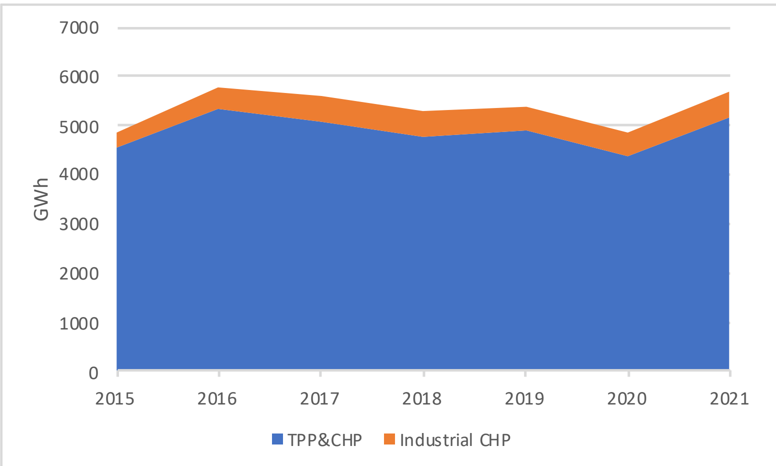

Figure 3.7. Electricity from the CHPs in the Republic of Serbia, 2015-2021

3.1.3 Variability of consumption[4]

The variability of heat consumption in final energy consumption for the period 2015-2021 is presented in Figure 3.8. and, distribution losses are presented in the same figure.

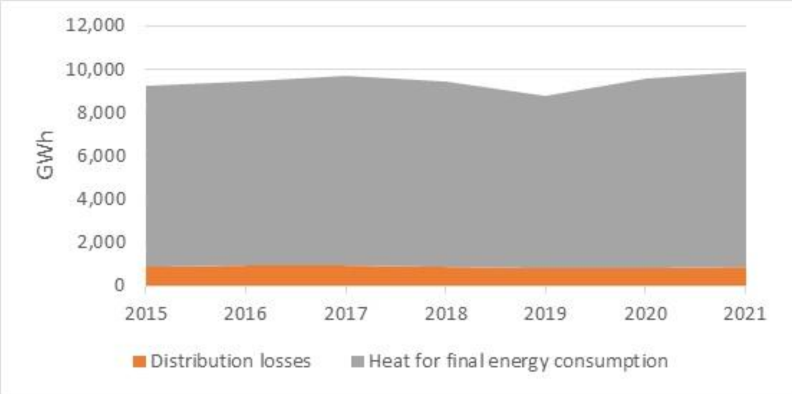

Figure 3.8. Heat in final energy consumption in the Republic of Serbia, 2015-2021

The average annual heat consumption in the considered period was 8,552 GWh. Maximal consumption was in 2021 and amounted to 9,032 GWh (5.6% over average), while the minimal consumption was in 2019 (7,973 GWh, -6.8% from average). The distribution losses varied in the analysed period.

The heat produced in TPP&CHPs and district heating plants is distributed by district heating systems. Due to main use for space heating, the annual variation of heat consumption is significant. The heating season starts in October and lasts until April. During the rest of the year, there is no heat supply. The maximal heat consumption is during December, January, and February. In district heating systems, heat is usually supplied 16 hours per day, except during the "ice days" (maximal daily temperature lower than 0°C) when the heat energy is delivered 24 hours per day. Detailed data on the variability of heat consumption produced in industrial cogeneration and industrial heating plants are not available.

3.2 Residential sector

3.2.1 Breakdown of consumption by energy source and use

The total consumption recorded in the Republic of Serbia in the residential sector, between 2012 and 2021, is shown in the following table, by energy source.

Table 3.1. Consumption by the residential sector in the Republic of Serbia (data in ktoe, total also in GWh)

Fuel type / year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Solid fossil fuels	239.6	204.7	169.6	156.1	215.6	228.6	207.6	209.4	248.8	148.0
Lignite	152.1	108.1	114.9	103.3	95.4	92.9	67	79.6	122.6	48.2
Brown coal briquettes	87.5	96.6	54.7	52.9	120.3	135.7	140.6	129.8	126.2	99.8
Oil and petroleum products	92.3	74.2	43.7	61	65.5	47.6	37.7	47.4	26.1	30.6
Liquefied petroleum gases	52	70.1	39.6	61	65.5	47.6	37.7	47.4	26.1	30.6
Gas oil and diesel oil (excluding biofuel portion)	33.4	3.1	3.1	0	0	0	0	0	0	0.0
Fuel oil	6.9	1	1	0	0	0	0	0	0	0.0
Natural gas	194.5	174	142.5	151.1	167.8	191.1	194.3	203.2	241.3	295.9

[4] https://ec.europa.eu/eurostat/web/energy/data/energy-balances;

Renewables and biofuels	943.8	801	852.2	847.2	873.1	803.5	840.9	871.2	1356	1,428.1
Primary solid biofuels	943.8	801	851.5	847.2	873.1	803.5	840.9	871.2	1,356.0	1,428.1
Charcoal	0	0	0.7	0	0	0	0	0	0	0.0
Heat	404.1	376.6	358.1	401.6	404.3	394.9	404.4	376.5	436.3	459.7
Electricity	1,248.2	1,216.3	1,186.8	1,209.1	1,197.9	1,187.9	1,153.4	1,147.0	1,179.5	1,193.2
Total [ktoe]	**3,122.5**	**2,846.8**	**2,752.9**	**2,826.1**	**2,924.2**	**2,853.6**	**2,838.3**	**2,854.7**	**3,488.0**	**3,555.5**
Total [GWh]	**36,308.4**	**33,102.6**	**32,010.7**	**32,861.9**	**34,002.6**	**33,181.7**	**33,003.8**	**33,194.5**	**40,558.5**	**41,343.2**

In the period 2012-2021, the use of lignite was reduced by 68.30% and electricity by 4.41%, while the use of primary solid biofuels increased by 51.32% and the heat obtained by 13.75%. Starting from Eurostat data, the consumption of each source was defined for each use, to isolate the consumption for heating. This allocation was made by updating and comparing the results of the research[5] and the report of the Energy Agency of the Republic of Serbia[6]. In 2021, the total demand of Serbian households for heating and cooling exceeded 40,000 GWh, including almost 30,000 GWh for space heating and about 5,800 GWh for hot water production.

Table 3.2. Consumption in the residential sector in the Republic of Serbia (data in GWh) in 2021, broken down by use

	Oil products	Natural gas	Coal	Electricity	Derived heat	Renewable sources	Total
Heating and cooling	40.7	3,441.2	1,720.6	12,295.9	5,344.9	16,606.3	39,986.8
Winter heating	40.7	2,856.2	1,681.1	4,333.5	5,024.2	15,609.9	30,082.9
Summer cooling	0.0	0.0	0.0	166.5	0.0	0.0	166.5
Domestic hot water	0.0	378.5	22.1	4,883.8	320.7	166.1	5,771.2
Cooking uses	0.0	206.5	17.3	2,912.1	0.0	830.3	3,966.2
Other electrical uses	0.0	0.0	0.0	1,578.3	0.0	0.0	1,041.0
Other oil products	315.1	0.0	0.0	0.0	0.0	0.0	315.1
Total residential	**355.8**	**3,441.2**	**1,720.5**	**13,874.2**	**5,344.9**	**16,606.3**	**41,342.9**

3.2.2 Demand for heating: geographical distribution

According to the 2011 population census, the Republic of Serbia had a population of 7,186,862, and the number of households, which in this study were taken as units for thermal energy needs, was 2,423,208. As mentioned earlier, the largest part of energy consumption for heating and cooling in households is for winter heating (almost 74%), which largely depends on the characteristics of the building.

Table 3.3. Areas of dwellings inhabited by residents divided according to the period of construction and the number of residential units in the building

Building age and type	Occupied dwellings	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings	Other residential buildings	Non-residential buildings
Total	2,423,208	1,375,768	223,601	818,885	2,581	2,373
Usefool floor space, m²	179,703,282	116,914,529	16,217,834	46,255,543	156,641	158,735
before 1919	85,418	63,408	7,415	14,280	158	157
1919–1945	143,192	94,091	10,823	37,893	139	246
1946–1960	244,091	156,689	18,387	68,334	332	349
1961–1970	441,932	232,353	42,081	166,638	510	350
1971–1980	557,203	298,016	59,812	198,449	573	353
1981–1990	441,579	246,858	43,388	150,660	374	299

[5] Statistical Office of the Republic of Serbia, Energy Consumption in Households in the Republic of Serbia, 2020, Belgrade, 2021, ISBN 978-86-6161-207-7
[6] https://www.aers.rs/Files/Izvestaji/Godisnji/Eng/AERS%20Annual%20Report%202020.pdf

1991–2000	205,757	123,172	20,800	61,391	204	190
2001-2005	103,025	47,812	8,159	46,858	124	72
2006 or later	118,891	42,770	6,116	69,853	78	74
Occupied dwellings still not completed	4,892	3,888	720	238	21	25
Unknown year	77,228	66,711	5,900	4,291	68	258
%		56.77	9.23	33.79	0.11	0.10

Table 3.4. Consumption for winter heating of the residential sector (GWh) broken down by period of construction and number of dwellings in the building[7]

Building age and type	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings	Other residential buildings	Non-residential buildings
Before 1919	1,336.9	122.8	168.1	1.6	1.7
1919–1945	188.5	531.0	11.5	3.6	2.4
1946–1960	3,039.3	297.8	842.7	3.6	3.9
1961–1970	4,311.0	666.4	1,584.7	4.9	3.8
1971–1980	5,026.6	568.3	2,077.1	4.7	3.7
1981–1990	3,747.3	530.9	1,064.1	2.9	2.3
1991–2000	1,534.9	203.6	275.3	1.0	1.2
2001-2005	595.8	79.9	210.1	0.6	0.4
2006 or later	17.4	5.8	0.5	5.7	0.0
Occupied dwellings still not completed	48.4	7.0	1.1	0.1	0.2
Unknown year	323.6	57.8	19.2	0.3	1.6
Total	**20,169.6**	**3,071.2**	**6,254.5**	**29.0**	**21.3**

Table 3.5. Consumption (year 2021) for space heating and cooling and DHW production in the residential sector, by region

Region	Dwellings with residents (2011)	Winter heating consumption	Consumption for DHW	Total consumption
	No	GWh	GWh	GWh
Belgrade region	586,337	7,149.1	1,396.4	8,545.5
Urban	489,654	5,970.2	1,166.2	7,136.4
Other	96,683	1,178.8	230.3	1,409.1
Region of Vojvodina	677,559	8,261.3	1,613.7	9,875.0
Urban	412,768	5,032.8	983.1	6,015.8
Other	264,791	3,228.5	630.6	3,859.2
Region of Šumadija and Western Serbia	648,371	7,905.4	1,544.2	9,449.6
Urban	316,167	3,854.9	753.0	4,607.9
Other	332,204	4,050.5	791.2	4,841.7
Region of Southern and Eastern Serbia	510,941	6,229.8	1,216.9	7,446.7
Urban	271,393	3,309.0	646.4	3,955.4
Other	239,548	2,920.7	570.5	3,491.3
Republic of Serbia	2,423,208	29,545.6	5,771.2	35,316.8
Urban	1,489,982	18,167.0	3,548.6	21,715.6
Other	933,226	11,378.6	2,222.6	13,601.2

[7] Kadrić, Dž, Živković, B, Delalić, N, Delalić, B, Bešovič, I, „The residential building national typology in the Republic of Serbia and in Bosnia and Herzegovina in the function of determination of needed and delivered energy for the residential sector heating", BIBLID 0350–1426 (206), https://doi.org/10.24094/kghc.018.47.1.67.

3.2.3 Map of municipalities and conurbations with a plot ratio of at least 0.3

Residential consumers or households are treated as distributed energy consumers and are included into the Comprehensive assessment of national heating and cooling potentials (CA) as parts of particular heat demand areas and not as individual points. An important parameter for heat demand areas is the plot ratio. The plot ratio, employed in Annex IX of EED, is a factor often used to identify the feasibility of installing district heating systems or efficiency of their layout. It is defined as the ratio of useful (heated) floor area of buildings to the land area where the buildings are situated:

$$Plot\ ratio = \frac{Useful\ floor\ area\ of\ buildings, m^2}{Land\ area\ of\ territory\ where\ buildings\ are\ situated, m^2}$$

Bearing in mind that in the Republic of Serbia there is no reliable data on the area of spatial units of all inhabited places, data from the CORINE Land Cover platform were used for plot ratio analysis. Most of the 126 urban areas of the Republic of Serbia do not meet the condition of Plot ratio >0.3, except in Belgrade, Majdanpek, Bor, Pećinci, Užice, Novi Sad and Niš. On the other hand, in addition to the mentioned urban areas where Plot ratio is > 0.3, in another 53 urban areas there are district heating systems that supply households with heat and hot water in buildings with more than 3 apartments and where the size of the territorial units used does not exceed 1.0 km² (for example, the Municipality of Vračar in Belgrade - Plot ratio = 0.54, Belgrade as a whole unit has a Plot ratio = 0.42; or the settlement of Benska Bara in Šabac - Plot ratio = 0.54, while if we look at the whole city of Šabac, the Plot ratio is 0.19). District heating systems exist in 60 city systems and all 60 district heating systems supply heat to the population, while only 5 supply hot water, namely DHS in Belgrade, Novi Sad, Pančevo, Niš and Bor.

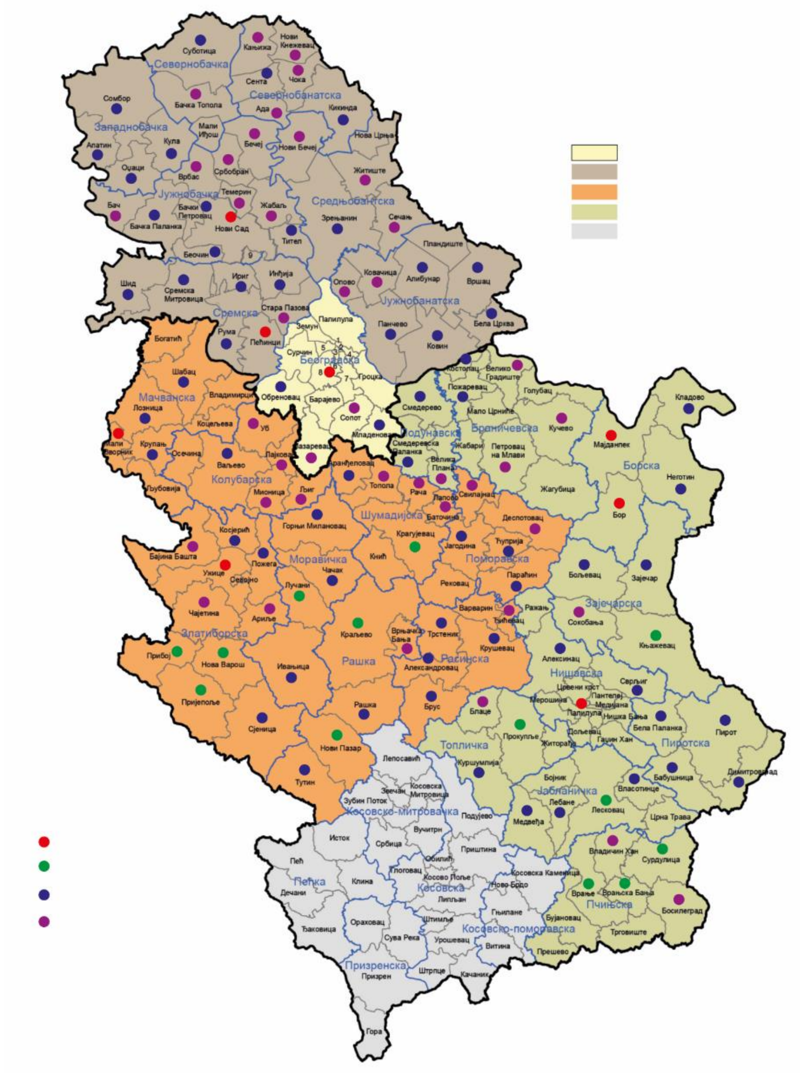

Figure 3.9. Map of the Plot ratio

3.3 Service sector

3.3.1 Breakdown of consumption by energy source and use

The total consumption recorded in the Republic of Serbia in the service sector, between the years 2012 and 2021, by energy source, is shown in the following tables.

Table 3.6. Consumption by the service sector in the Republic of Serbia (data in ktoe, total in ktoe and GWh)

Fuel type/year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Solid fossil fuels	123.5	91.4	48.0	64.8	67.4	44.0	31.4	36.5	54.8	22.6
Lignite	116.4	82.6	42.9	62.7	64.4	41.1	28.5	33.9	52.2	20.5
Brown coal briquettes	7.1	8.9	5.0	2.1	2.9	2.9	2.9	2.7	2.6	2.0
Oil and petroleum products	103.5	59.4	68.2	73.0	73.8	67.0	64.3	58.4	53.2	52.9
Liquefied petroleum gases	30.5	28.3	17.0	12.4	11.3	8.3	6.7	7.5	5.6	11.3
Gas oil and diesel oil (excluding biofuel portion)	37.6	10.4	17.8	17.4	17.4	18.3	17.8	15.4	13.7	16.2
Fuel oil	35.4	20.7	33.4	43.2	45.1	40.5	39.9	35.5	33.9	25.5
Natural gas	98.8	96.8	113.8	135.7	156.5	186.7	199.2	186.4	191.3	278.0
Renewables and biofuels	8.2	31.2	50.0	53.2	32.6	53.6	29.4	29.2	23.9	25.1
Geothermal	2.5	1.9	2.0	2.1	2.0	2.1	2.0	2.1	1.9	1.5
Primary solid biofuels	5.7	29.4	46.5	49.5	28.8	49.2	25.6	25.0	19.1	20.2
Charcoal	0.0	0.0	0.0	0.0	0.7	0.8	0.4	0.1	0.1	0.0
Biogases	0.0	0.0	1.5	1.5	1.1	1.4	1.4	2.1	2.8	3.4
Heat	78.1	103.6	99.8	124.9	125.7	142.2	121.5	109.8	115.8	124.5
Electricity	422.9	421.2	392.6	423.0	430.4	446.3	445.7	443.2	417.6	447.2
Total [ktoe]	**835.0**	**803.6**	**772.3**	**874.6**	**886.4**	**939.8**	**891.4**	**863.5**	**856.6**	**950.3**
Total [GWh]	**9,708.9**	**9,344.8**	**8,980.8**	**10,170.4**	**10,307.0**	**10,928.1**	**10,365.7**	**10,041.1**	**9,960.8**	**11,050.2**

Table 3.7. Consumption by the service sector in the Republic of Serbia (data in GWh) broken down by use (year 2021)

Use/energy source	Oil products	Natural gas	Coal	Electricity	Derived heat	Renewable sources	Total
Heating and cooling	615.2	3,232.5	262.4	5,199.8	1,448.0	292.3	**11,050.2**
Winter heating, DHW and other uses	615.2	3,232.5	262.4	3,899.8	1,448.0	292.3	**9,750.2**
Summer cooling	0.0	0.0	0.0	1,299.9	0.0	0.0	**1,299.9**
Total residential	**615.2**	**3,232.5**	**262.4**	**5,199.8**	**1,448.0**	**292.3**	**11,050.2**

Electric heating and cooling systems in the service sector can be complex and are already highly integrated, for the purposes of humidity control and controlled ventilation. It is believed that this requirement is currently not easily replaced by district heating or cogeneration systems. Consumption for heating and cooling is estimated at 5,850.4 GWh. For further analysis, it is justified to reduce the consumption in the amount of 1,448 GWh for derived heat and consider the consumption in the amount of 4,402.4 GWh

3.3.2 Demand for heating: sectoral and geographical distribution

The service sector is very diverse in terms of structure and consumption profile. Table 3.88. presents a reconstruction of consumption for each sub-sector, drawing on the extensive literature[8].
National energy consumption for heating is divided geographically by sub-sectors, based on “Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level” (2015) corrected for specific parameters of sub-sector consumption in the Republic of Serbia according to the data of the District heating business association "Toplane Srbije ” (DHBA Serbia - TOPS), in the following tables:

Table 3.8. Consumption for heating by the service sector in the RS, divided by sub-sectors (data in GWh)

Sub-sector	Consumption for heating	Area	Specific annual consumption
	GWh	m²	kWh/m²*a
Public administration	1,129.3	7,788,295.17	145
Health service	645.5	2,082,200.00	310
Leisure time activities	157.7	788,500.00	200
Education	959.7	4,735,090.00	203
Hotels	245.4	1,168,571.43	210
Sports facilities	550.0	5,000,000.00	110
Offices	1,553.0	10,353,333.33	150
Commerce – Supermarket chains	175.3	1,252,142.86	140
Other	434.5	2,803,225.81	155
Total	**5,850.4**	**35,971,358.60**	**163**

Table 3.9. Heating consumption in the service sector by region in the Republic of Serbia, divided by sub-sectors (data in GWh)

Region/sector	Public administration	Health service	Leisure time activities	Education	Hotels	Sports facilities	Offices	Commerce – Supermarket chains	Other
Belgrade region	451.7	173.0	44.2	320.8	68.8	220.0	621.2	70.1	145.2
Region of Vojvodina	254.1	149.4	30.0	246.3	46.7	123.8	349.4	39.4	111.5
Region of Šumadija and Western Serbia	242.8	182.5	46.0	225.6	71.6	118.3	333.9	37.7	102.1
Region of Southern and Eastern Serbia	180.7	140.6	37.5	167.1	58.3	88.0	248.5	28.1	75.6
Republic of Serbia	**1,129.3**	**645.5**	**157.7**	**959.7**	**245.4**	**550.0**	**1,553.0**	**175.3**	**434.5**

[8] https://ec.europa.eu/eurostat/web/energy/data/database
Regulation on the plan of the network of healthcare institutions (Official Gazette of RS , no. 5/2020, 11/2020, 52/2020, 88/2020, 62/2021, 69/2021, 74/2021 and 95/2021), Rulebook on closer conditions for the establishment, start of work and performance of primary school activities (Official Gazette of RS , no 88/17, 27/18 and 10/19)
Rulebook about the detailed conditions in regards to space, equipment and teaching materials for the implementation of the teaching and learning plan and program in a gymnasium (Official Gazette of RS , no 13/2019) , https://hoteli.cu.rs/

3.4 Industry

3.4.1 Breakdown of consumption by energy source and use

3.4.1.1 Final energy consumption in industry. Current state overview

Energy consumption in industry accounts about 22-25% of final energy consumption in Serbia. Historical data related to structure of consumption of the whole branch are presented in Table 3.1010. Annual consumption in industry in the analysed period (2010-2021) was in the range of 1,954 ktoe in the year 2014 up to 2,719 ktoe in 2011. Final energy consumption in industry shows the relation with GDP growth rate[9]. Electricity has the highest share in the energy mix (37.9%), followed by natural gas (24.8%), oil derivatives (12.2%), bioenergy[10] (9.1%) and heat (9%).

Table 3.10. Final energy consumption in industry by energy source, in ktoe[11]

Fuel	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Electricity	643.94	660.79	610.83	623.48	621.07	648.24	687.96	722.44	751.10	755.20	740.96	806.70
Natural Gas	610.58	591.23	605.52	710.64	388.61	435.06	438.01	541.96	615.18	495.42	374.78	526.71
Gasoline	17.12	25.68	14.98	29.96	11.77	2.14	1.07	1.39	1.13	1.10	1.44	2.20
Diesel	96.08	212.00	256.91	138.90	129.50	128.96	99.28	87.16	88.83	100.48	111.71	130.19
Residual Fuel Oil	121.98	104.27	165.26	69.84	86.57	80.47	93.23	74.24	70.70	60.49	41.50	45.06
LPG	36.16	32.77	22.60	39.55	28.25	27.12	30.51	19.70	12.36	10.57	10.68	13.17
Coal Bituminous	60.39	64.80	76.00	70.06	47.85	45.48	50.08	54.46	25.44	20.98	20.28	14.50
Coal Sub bituminous	48.42	78.36	33.14	15.31	31.37	51.14	60.15	23.98	89.33	6.40	4.80	36.01
Coal Anthracite	7.15	6.63	6.24	11.28	20.28	9.72	5.86	12.44	15.34	8.67	19.47	11.23
Coal Lignite	98.79	171.07	178.31	105.60	115.36	137.95	178.84	126.85	112.30	108.18	158.96	45.87
Metalurgical Coke	128.10	89.46	18.33	5.75	16.21	30.86	56.70	43.28	28.78	5.05	5.06	23.62
Wood	52.67	133.63	70.58	193.27	127.02	130.96	130.39	180.90	170.71	190.48	180.19	174.96
Charcoal	0.00	0.00	0.72	0.72	0.72	2.15	0.72	2.67	1.31	1.34	3.83	15.35
Biogas	0.00	0.00	0.00	0.31	0.12	0.45	0.65	2.07	1.43	2.19	3.40	3.45
Heat	345.68	373.94	247.32	237.46	162.89	189.76	199.65	214.14	212.55	199.30	197.62	192.44
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Petroleum Coke	82.82	83.29	110.46	108.65	119.37	110.80	129.12	145.02	177.63	195.35	56.41	54.58
Other oil products											20.88	15.29
Industrial waste non renewable											0.77	0.76
Coal Unspecified	1.63	0.00	1.58	1.02	0.59	4.26	0.59	0.25	1.64	0.16	0.00	
Blast furnace gas	74.19	91.60	29.43	33.01	46.65	5.42	8.79	10.06	19.08	19.09	13.69	15.41
Total	**2,425.70**	**2,719.52**	**2,448.22**	**2,394.80**	**1,954.19**	**2,040.95**	**2,171.58**	**2,263.00**	**2,394.82**	**2,180.45**	**1,966.41**	**2,127.51**

3.4.1.2 Final energy consumption in industry by sub-sectors

3.4.1.2.1 Iron and Steel

Data about historical consumption in Iron and Steel industry for the period 2010-2021, by energy source in ktoe, say that in 2021 the highest share of consumption was related to electricity (35.6%), followed by natural gas (35.1%) and heat (15.4%).

[9] https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2.21&locations=RS&start=2010
[10] Bioenergy refers to firewood, charcoal and biogas
[11] Eurostat

3.4.1.2.2 Non-metallic minerals

Data about historical consumption for the period 2010-2021, in the non-metallic minerals industry sub-sector, by energy source in ktoe, say that in 2021 the highest share of consumption was related to natural gas (26%), followed by electricity (24.9%) and petroleum coke (18.3%), while the share of heat in the energy mix was 0.4%.

3.4.1.2.3 Chemical and petrochemical

Consumption by energy source, in chemical and petrochemical industry, by energy source in ktoe, say that in 2021 the highest shares of consumption were those of electricity (28.2%), heat (25.6%) and natural gas (17.5%).

3.4.1.2.4 Non-ferrous metals

Consumption by energy source, in Non-ferrous industry, by energy source in ktoe, say that in 2021 the highest shares of consumption were those of electricity (41.2%), natural gas (32.4%), residual fuel oil (11.9%) and heat (9.7%).

3.4.1.2.5 Transport equipment

Historical consumption by energy source, in Transport equipment industry, by energy source in ktoe, say that in 2021 the highest share of consumption dominantly used energy source was electricity (74.1%), followed by natural gas (17.4%). The share of heat was 3.8%.

3.4.1.2.6 Machinery

Energy consumption in the Machinery sub-sector, by energy source in ktoe, is characterized by dominant share of electricity (60.4%) and natural gas (21.4%). Share of heat was 0.4% in 2021.

3.4.1.2.7 Mining and quarrying

Energy consumption in the mining and quarrying industry, by energy source in ktoe is characterized by high shares of diesel (52.5%) and electricity (45.1%) in energy mix. Consumption of other energy sources is significantly lower. There was no consumption of derived heat in 2021..

3.4.1.2.8 Food, beverages and tobacco

Historical consumption by energy source, in ktoe, in the food, beverages and tobacco sub-sector, say that the highest shares of consumption were related to electricity (32.1%), followed by firewood (25.8%) and natural gas (24.5%). The share of heat was 6.4%.

3.4.1.2.9 Paper, pulp and printing

Energy consumption in ktoe, in the Paper, pulp and printing industry is characterized by high shares of electricity (41.4%), natural gas (24.5%) and heat (20.4%) in energy mix. Consumption of other energy sources is significantly lower in 2021.

3.4.1.2.10 Wood and wood products

Energy consumption in ktoe, in he wood and wood products industry is characterized by very high shares of electricity (53.4%) and firewood (45.1%) in energy mix. Consumption of other energy sources is significantly lower. The share of derived heat in 2021 was 0.1%

3.4.1.2.11 Construction

Historical consumption by energy source, in ktoe, in the Construction sub-sector, say that the highest shares of consumption were related to diesel (54.1%) and electricity (43.6%). there was no consumption of derived heat in 2021.

3.4.1.2.12 Textile and leather

Data about historical consumption by energy source, in ktoe in Textile and leather sub-sector say that in 2021 the largest share of consumption was related to electricity (34.7%), followed by natural gas (35.9%) and firewood (1.3%), while the share of derived heat was 1.3%.

3.4.1.2.13 Not elsewhere specified industry

Highest shares of consumption by energy source in ktoe, in the not elsewhere specified industry, were related to electricity (59.2%), and heat (15.6%).

3.4.1.3 Heat consumption in industry by sub-sectors

Data about heat[12] consumption by sub-sectors in 2021 are presented in Table 3.11.

Table 3.11. Heat consumption in industry by sub-sector (2021) in ktoe

Sub-sector	Heat	
	In ktoe	In GWh
Iron and steel	55.94	651
Chemical and petrochemical	59.71	694
Non-ferrous metals	7.02	82
Non-metallic minerals	1.19	14
Transport equipment	0.89	10
Machinery	0.50	6
Mining and quarrying	0.00	0
Food, beverages and tobacco	26.71	311
Paper. pulp and printing	17.11	199
Wood and wood products	0.02	0.2
Construction	0.00	0
Textiles and leather	1.12	13
Not elsewhere specified (Industry)	22.23	259

Energy consumption of combustible energy sources is dominantly related to heat production at the place of consumption, except for gasoline and diesel, whose utilization is subjected to internal combustion engines.

Table 3.12. presents data about produced heat due to direct utilization of fuels. For the calculation of useful heat, harmonized efficiency reference values for separate production of heat[13] were applied.

Table 3.12. Useful heat (2021)

Sub-sector	Produced heat (combustion of fuels)	
	In ktoe	In GWh
Iron and steel	150.91	1,755
Chemical and petrochemical	124.88	1,452
Non-ferrous metals	27.79	323
Non-metallic minerals	170.77	1,986
Transport equipment	3.99	46
Machinery	36.54	425
Mining and quarrying	1.89	22
Food, beverages and tobacco	198.39	2,307
Paper, pulp and printing	26.81	312
Wood and wood products	7.32	85
Construction	1.20	14
Textiles and leather	45.51	529
Not elsewhere specified (Industry)	28.37	330
Total	**824.37**	**9,587**

[12] Generated in district heating plants, CHP, autoproducers and thermal power plants. Carriers of heat: hot water to 110ºC, boiling water over 110ºC and steam.
[13] COMMISSION DELEGATED REGULATION (EU) 2015/2402 of 12 October 2015 reviewing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2012/27/EU of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/877/EU

3.4.2 Energy related Carbon dioxide emission from industry

3.4.2.1 Direct CO_2 emission from industry

Direct carbon dioxide emissions are calculated by applying Default IPCC emission factors[14] . Results are summed in Table 3.13.

Table 3.13. Direct carbon dioxide emission from industry

Sub-sector	Emission, thousand tons	Emission factor for direct emission, $kgCO_2/MWh$
Iron and steel	432.12	0.102
Chemical and petrochemical	397.88	0.107
Non-ferrous metals	59.14	0.071
Non-metallic minerals	1,015.8	0.294
Transport equipment	17.36	0.064
Machinery	89.87	0.062
Mining and quarrying	135.1	0.112
Food, beverages and tobacco	359.3	0.074
Paper, pulp and printing	166.55	0.171
Wood and wood products	5.4	0.019
Construction	71.43	0.090
Textile and leather	66.3	0.065
Non elsewhere specified	62.13	0.102
Total	**2,878.38**	**1.333**

3.4.2.2 Total energy-related carbon dioxide emission from industry

Total energy-related carbon dioxide emissions from industry result from direct emissions, as well as indirect emissions due to production of heat and electricity.

Table 3.14. Indirect, direct and total energy-related emissions in industry in Serbia

Sub-sector	Indirect emission due to heat production, thousand t	Indirect emission due to electricity generation, thousand t	Direct emissions, thousand t	Total energy related emission, thousand t
Iron and steel	354.36	1128.28	432.12	1,914.76
Chemical and petrochemical	378.28	950.06	397.88	1,726.22
Non-ferrous metals	44.50	258.86	59.14	362.50
Non-metallic minerals	7.56	645.80	1,015.8	1,669.16
Transport equipment	5.64	149.76	17.36	172.76
Machinery	3.17	652.57	89.87	745.61
Mining and Quarrying	0.00	407.94	135.1	543.04
Food, beverages and tobacco	169.21	1166.23	359.3	1,694.74
Paper, pulp and printing	108.38	302.23	166.55	577.16
Wood and wood products	0.12	111.81	5.4	117.33
Construction	0.00	258.66	71.43	330.09
Textiles and leather	7.07	265.64	66.3	339.01
Not elsewhere specified (Industry)	140.80	737.28	62.13	940.21
Total	**1,219.08**	**7,035.13**	**2,878.38**	**11,132.59**

[14] https://www.ipcc-nggip.iges.or.jp/

3.4.3 Map of industrial areas with a total annual heating and cooling consumption in excess of 20 GWh

As per data of the Statistical Office of Serbia[15], 374 registered industrial areas (zones) existed in Serbia in November 2020. The territory of the Republic of Serbia comprises 145 municipalities, 28 cities and the territory of the City of Belgrade, i.e. 174 units of local self-government (LSG). The industrial areas are spread over 133 municipalities and cities in Serbia. The overall surface area of industrial zones in Serbia amounts to 28,980 ha. Out of this, approximately 45%, or 13,123 ha, is used area, while the remaining 55% is available for new businesses. As of November 2020, 64 new industrial areas were being built, with overall surface area of 3,700 ha.

For evaluating the heating and cooling demands of industrial zones, overall areas, in ha, as well as the usage of these areas, in %, and the indicator of infrastructural equipment level[16] can be used.

Based on used areas within these industrial zones, assumed energy demand of industrial buildings of 250 kWh/m^2/year[17], as well as assumed share of buildings within these areas of 25%, it is estimated the industrial areas listed in Table 3.15 to have the potential heating and cooling demands equal to or higher than 20 GWh/year.

Table 3.15. Largest industrial zones in Serbia

LSG unit	Industrial zone	Area (ha)	Area used (ha)	Infrastructure index	Natural gas grid
Pančevo	South industrial zone Pančevo	1,680	1,680	8	Yes
Stara Pazova	Central work zone	696	556	7	Yes
Stara Pazova	South work zone Krnješevci	696	556	6	Yes
Bor	Economy zone in the old part of the city	538	538	7	No
Pećinci	Work zone Šimanovci	800	350	7	Yes
Zrenjanin	Industrial Zone South-East	507	350	7	Yes
Kragujevac	RZ "Zastava"	353	332	7	Yes
Smederevo	Industrial zone of Smederevo	1,476	300	8	Yes
Smederevo	Industrial zone of the new steel mill	300	300	8	Yes
Kostolac	PD TEKO Kostolac	753	300	5	No
Sremska Mitrovica	Old industrial zone	280	280	8	Yes
Zemun	Upper Zemun	270	270	8	Yes
Vladičin Han	Industrial zone Vladičin Han	350	250	7	No
Kragujevac	WZ "Filip Kljajić - 21.oktobar"	221	203	7	Yes
Inđija	North-East work zone	636	200	7	Yes
Kraljevo	Industrial zone "Sport airfield"	264	200	7	Yes
Šabac	East industrial zone	200	200	8	Yes
Kruševac	Economy/work zone East	229	170	8	Yes
Senta	South	259	162	8	Yes
Stara Pazova	East work zone	172	155	7	Yes
Šabac	North-West work zone	600	150	7	Yes
Zemun	"Motorway" economy zone	138	138	7	Yes
Ruma	West	195	136	8	Yes
Kragujevac	WZ "Service"	155	135	7	Yes
Stara Pazova	South work zone	158	134	5	Yes
Bečej	Industrial zone in Bečej	437	130	5	Yes
Bačka Palanka	International port with internal terminal	128	128	7	Yes
Kruševac	Economy-work zone North	500	120	8	Yes

[15] https://www.stat.gov.rs/sr-latn/vesti/20201123-registar-industrijskih-zona/
[16] This indicator is the number of fulfilled infastructural requirements out of 8 in total (roads, electrical grid, gas installations, telecommunications, rail, water supply, sewerage, waste management).
[17] K.B. Lindberg, S.J.Bakker, I.Sartori, "Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts", *Utilities Policy 58 (2019), 63-88*
https://www.researchgate.net/publication/333538587_Modelling_electric_and_heat_load_profiles_of_non-residential_buildings_for_use_in_long-term_aggregate_load_forecasts,

LSG unit	Industrial zone	Area (ha)	Area used (ha)	Infrastructure index	Natural gas grid
Kraljevo	Industrial zone "Šeovac" Kraljevo	173	120	7	Yes
Sremska Mitrovica	Industrial zone East	299	120	7	Yes
Zrenjanin	Industrial zone Bagljaš Airfield	119	119	6	No
Niš - Crveni Krst	Industrial zone North - 1, 2, 3	100	100	6	Yes
Niš - Mediana	Industrial zone East - 1, 2, 3, 4	100	100	6	Yes
Niš - Palilula	Industrial zone West - 1, 2, 3	100	100	6	Yes
Inđija	South-East work zone	89	89	7	Yes
Surčin	Work zone Surčin - Dobanovci	211	88	6	Yes
Lajkovac	Industrial zone Lajkovac	105	85	7	No
Stara Pazova	West work zone	82	74	5	Yes
Lapovo	Work zone 1	175	70	8	Yes
Stara Pazova	North work zone	85	68	5	Yes
Novi Sad	Work zone North 2	260	65	7	Yes
Leskovac	58	71	64	7	Yes
Čajetina	Branešci	264	64	6	No
Stara Pazova	North work zone	69	62	7	Yes
Novi Sad	Work zone North 3	80	60	7	Yes
Leskovac	North	64	54	7	Yes
Bački Petrovac	Maglić	111	53	7	Yes
Subotica	Economy zone "Mali Bajmok"	53	53	7	Yes
Loznica	Industrial zone "Šepak" Loznica	83	52	7	Yes
Pančevo	North business-industrial zone Pančevo	100	50	8	Yes
Novi Sad	Work zone East	60	50	7	Yes
Novi Sad	Work zone North 1	250	50	6	Yes
Petrovac na Mlavi	Industrial zone 1	89	50	7	Yes
Bački Petrovac	Bački Petrovac	177	50	6	Yes
Zaječar	Business zone "East"	152	50	6	No
Aleksinac	Kukiš	62	48	7	Yes
Aleksinac	Aleksinac mine	75	46	5	No
Bačka Palanka	North work zone Bačka Palanka	162	46	7	Yes
Novi Sad	Work zone Rimski Šančevi	120	45	6	Yes
Obrenovac	Industrial zone "Urovci"	54	43	5	No
Kovin	Block 119	44	42	7	Yes
Leskovac	Njegoševa	62	41	7	Yes
Knjaževac	Zone left of the main road to Zaječar	41	41	7	No
Sombor	Industrial zone Sombor	480	40	8	Yes
Novi Sad	Work zone North 4	900	40	7	Yes
Inđija	Location 15	170	40	6	Yes
Vranje	Industrial zone - Radnička street	50	40	7	No
Požega	Industrial zone	133	40	3	No
Ada	Industrial zone I Ada	83	39	7	Yes
Sevojno	Industrial zone Sevojno	55	38	8	Yes
Bor	Economy zone next to the state road Selište-Bor-Zaječar DP IB-37	57	38	6	No
Ruma	South 1	60	38	7	Yes
Obrenovac	Industrial zone "Barič"	44	35	6	Yes
Kovin	Block 117	35	35	7	Yes
Ivanjica	Business zone Senjak - Work zone 2	33	33	7	Yes
Gornji Milanovac	South industrial zone	63	32	7	Yes
Lapovo	Work zone 4	829	32	6	Yes
Bačka Palanka	First work zone Čelarevo	32	32	7	Yes
Lazarevac	Economy-business zone (work zone) in Lazarevac	78	32	4	No

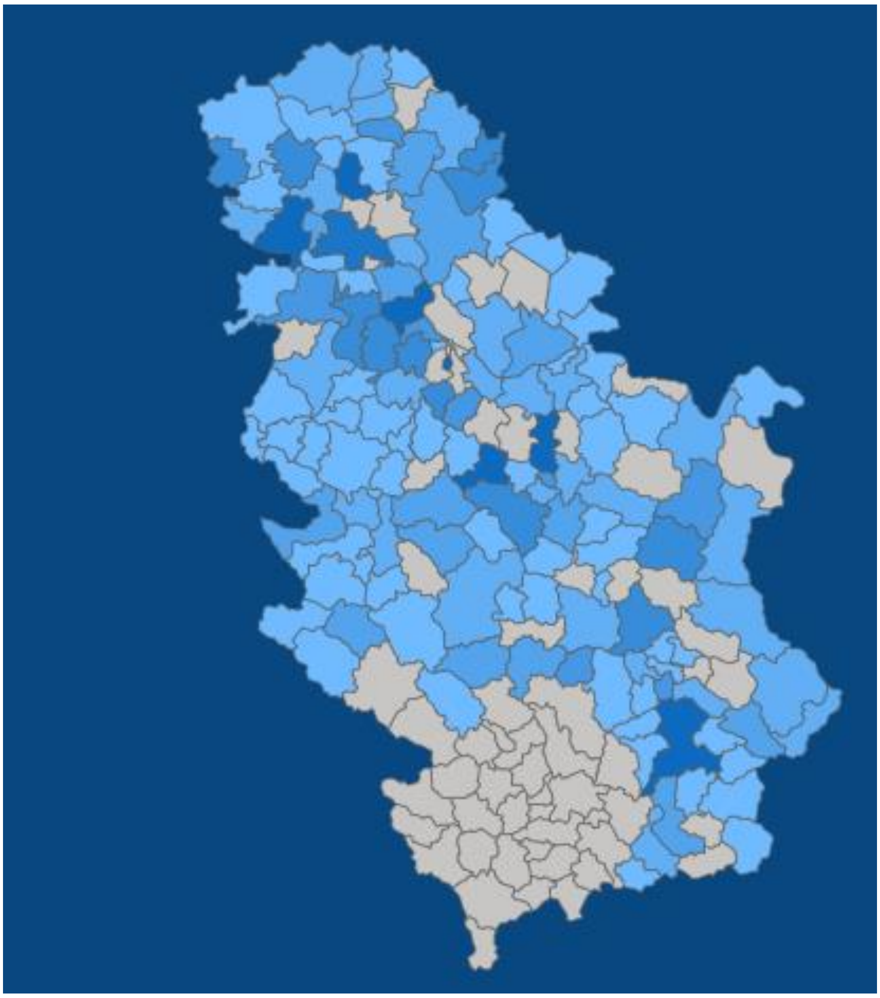

Figure 3.10. Industrial areas in municipalities and cities in Serbia – distribution by number of industrial areas per municipality/city

4. Cogeneration in the national stock of power plants

4.1 Thermal power stations

The list of installed and operating coal-fired thermal power plants (TPP) is shown in Table 4.1. The total installed generating capacity (power) of all coal TPPs is 4,390 MWe. The TPPs that are in Kosovo* (TPP Kosovo A and TPP Kosovo B) are not included in the list. With the establishment of the UNMIK administration in Kosovo on 1 July 1999, Serbia lost access to the local coal mines and power plants, including TPP Kosovo A and TPP Kosovo B power plants.

Table 4.1. List of coal-fired TPPs in Serbia

Thermal Power Plant	Power (MW_e)	Average annual electricity generation [GWh]
TPP “Kolubara”	225	1,241
TPP “Morava”	100	
TPP “Kostolac A”	310	5,875
TPP “Kostolac B”	700	
TPP “Nikola Tesla A”	1,560	17,031
TPP “Nikola Tesla B”	1,220	
Total	**4,390**	**24,147**

4.2 Cogeneration (CHP) plants

CHP plants convert fuel energy into two useful forms of derived energies: Electricity, and Heat. Compared with conventional plants that are traditionally used for generation of electricity – classic thermal power plants (TPP) – fuel energy is converted into electricity with efficiency between 30 – 33%. The efficiency of generating of electricity of most modern coal-fired and open gas cycle TPPs doesn’t exceed efficiency of 42 % of the fuel energy content. Even in the CCGT power plants with “H” type of gas turbines (according to GE turbines classification), efficiency doesn’t exceed 60%. The balance of the thermal energy is rejected to the environment.

The principle of the CHP is to use the remaining heat from power generation usefully, for heating of buildings or in industrial processes as process heat. CHP technologies are more and more used for district heating supply or to supply industries with process heat, but CHP can be used in agriculture, the residential sector, and the tertiary sector.

Use of the generated heat is a challenge due to the distribution losses and energy spent for heat (mostly in form of hot water) transport up to the location of consumption. As a consequence of these losses when transporting heat in pipes or networks, CHP installations should be established as near as possible to the consumers of the heat.

It is important to make clear distinction between technologies of the CHP plants. Different CHP technologies are used in practice. CHP plants can be separated into two groups:

- Flexible units, with adjustable power-to-heat ratio.
- CHP units which cannot adjust to the heat demand, i.e. with constant heat production.

In the first group are categorized the installations using steam to run a turbine (steam turbines with extraction of the steam). In CHP installations with steam turbine, part of the steam in the turbine is extracted from the extraction port of the turbine or from pipeline and is used to provide heat. The steam that is extracted is not contributing to electricity generation anymore. This results in a loss of electricity generation, but is used for generation of useful heat within the same process. These technologies can be operated in full cogeneration mode and in full condensing mode. The power-to-heat ratio varies along these extreme operating regimes. The way how such CHP installations are operated depends on the demand for heat.

The second group of CHP installations operate with constant heat production. If there is no heat demand, they reject the generated heat to the environment. Very often the CHP plants that generate heat for use in DH systems, are equipped with heat only boilers (HoB), which might be used instead of the CHP unit e.g. in low load regimes when there is little heat demand or in high load regime (peaks) for covering peak load.

The CHP performance must be estimated correctly, to estimate realistic efficiencies, to evaluate status of a CHP (is it hgh efficient), estimate primary energy saving, and correctly estimate the financial viability and emissions of a CHP plant.

It is important to make distinction between CHP and non-CHP plant`s parameters. In the process of separating the production of the cogeneration plant from the total production, four general principles should be applied consistently and accurately:

1. All useful heat generated in CHP units must be recorded (regardless of whether the heat energy is used, in industry, district heating or by some other, and whether it is sold or not),
2. As many parameters as possible should be measured. If this is not possible and measured data are not available, these parameters must be calculated.
3. It is necessary that the calculation and reporting forms be clear and simple to be understandable.
4. It is necessary to consider that there are different types of CHP plants, as it is shown in Table 4.2. and Figure 4.1.

Table 4.2. Review of different CHP technologies[18]

Numbering in the legislation	Numbering in the reporting template rows	Name of the Technology
a) *	1 and 8	Combined cycle gas turbine with heat recovery including a steam condensing extraction turbine– ***flexible power-to-heat ratio***
a) **	1 and 8	Combined cycle gas turbine with heat recovery without a condensing extraction turbine
b)	4 and 11	Steam back pressure turbine
c)	5 and 12	Steam condensing extraction turbine - ***flexible power-to-heat ratio***
d)	2 and 9	Gas turbine with heat recovery
e)	3 and 10	Internal combustion engine
f)	6 and 13	Microturbines
g)	6 and 13	Stirling engines
h)	6 and 13	Fuel cells
i)	6 and 13	Steam engines
j)	6 and 13	Organic Rankine cycles
k)	6 and 13	Any other type of technology or combination thereof falling under the definition laid down in Article 2(30)

[18]Directive 2012/27/EU

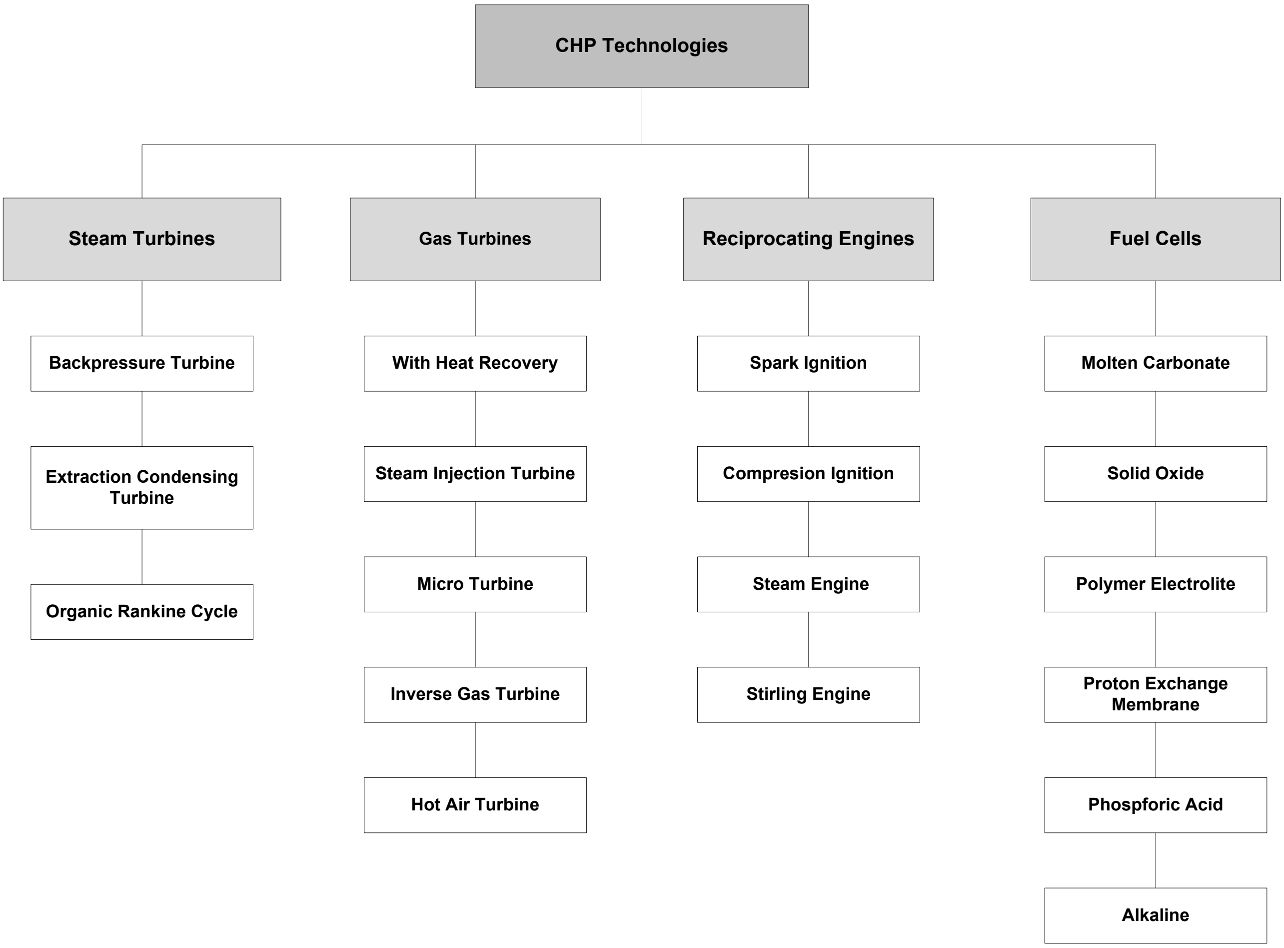

Figure 4.1. Review of CHP technologies

4.2.1 CHP plant operational mode

Ddefinitions for understanding of the CHP plant operating modes are important to understand the methodology that applies EUROSTAT for evaluate effectiveness of CHP plants for primary energy savings. There are two different operational modes of the CHP plants:

- Full cogeneration mode (maximum heat generation), and
- Full condensing mode (no useful heat generation, but maximum electricity generation).

If a CHP plant is operating with its maximum technically possible heat recovery from the CHP unit itself, it is categorized as *operating in full cogeneration mode*. All electricity generated during this period is CHP electricity. If a CHP unit is not operated in full cogeneration mode, in addition to the CHP - electricity and CHP heat also non-CHP-electricity is generated.

If a CHP unit operates with no useful heat production at all, it only generates non-CHP - electricity, and it is then categorized as *operating in full condensing mode*. This is only possible for certain CHP technologies ((a)* Combined cycle gas turbine with heat recovery – and (c) Steam condensing extraction turbine), in which, for generation of useful heat, steam is extracted from the turbine. If there is no demand for useful heat, no steam is extracted; however, all steam is condensed in the plant condenser for purpose of generating electricity. Such a case represents the mode that is opposite to the full cogeneration mode.

4.2.2 CHP technologies

Technologies mentioned in Table 4.2. under a)* and c) work based on steam condensation. By extracting a certain quantity of steam from the turbine, they can regulate their heat and electricity generation. They can operate in full CHP mode, or in full condensing mode, with no useful heat production. They can be regulated to operate according to the heat demand. Full CHP mode maximum production of CHP products (CHP-electricity and useful heat), while the condensing mode implies only non-CHP-electricity generation. These technologies represent a reasonable compromise, i.e.:

Technologies mentioned in in Table 4.2. under a)**, b), d), e), f), g), h), i), j) and k) cannot regulate their heat production when they are generating electricity. If a certain quantity of heat is needed (demanded), it will be used for some covering of a useful need. If no heat is needed, the heat produced during electricity generation will be rejected to the environment, or it could be accumulated in a heat storage, if such device is available as part of CHP plant.

4.2.3 CHP plant parameters

1. Heat (H)

- Heat from a plant for the combined production of heat and electricity (HCHP) is the main product of any CHP unit. CHP heat is: heat from a CHP scheme delivered to satisfy an economically justifiable demand for heat or cooling; heat that is used for process or space heating and/or delivered for subsequent cooling purposes, heat delivered to district heating/cooling networks; exhaust gases from a cogeneration process that are used for direct heating and drying purposes”[19]. The demand is important, because only the electricity generated at the same time as the useful heat can be qualified as CHP-electricity. If there is no demand for the heat and the heat is just released to the environment, this heat is non-CHP heat. Consequently, the electricity generated at the same time.
- Supplementary heat is the heat which is produced outside of the cogeneration system boundaries or the CHP unit (for example the heat produced on a conventional or “peak heat” produced by an auxiliary boiler). The heat produced by the auxiliary boilers usually during times of low load, or during peak load, when outside temperatures are low.
- Total heat is the heat produced by the boiler of the installation of which the CHP unit might be only a part.

2. Electricity (E):

- Total electricity generated is the total gross amount of electricity generated by a CHP unit regardless of whether it is CHP-electricity or not.
- CHP-electricity (ECHP) is the electricity generated in a process related to the production of useful heat.
- Non-CHP-electricity is electricity generated by a CHP unit at times when the CHP unit doesn’t generate useful heat (or a part of the heat is not useful i.e. is rejected to the environment because there is no demand).

3. Fuel (F):

- The total fuel used is subdivided into fuel used in the CHP unit and fuel used for supplementary heating (auxiliary boiler), and is not not fuel used by the CHP unit.
- Fuel used in the CHP unit can be further divided into fuel used for CHP products (FCHP) and fuel used for generation of non-CHP-electricity in a CHP unit. To distinguish fuel used for CHP products from fuel used for non-CHP products FCHP and F non-CHP need to be calculated according to the CHP technology used.

4. Efficiencies that can be calculated for different processes:

- Overall efficiency of a CHP unit,
- Efficiency of useful heat production defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and CHP-electricity,

[19] COMBINED HEAT AND POWER (CHP) GENERATION Directive 2012/27/EU of the European Parliament and of the Council Commission Decision 2008/952/EC

- Efficiency of total electricity generation of the CHP unit for CHP units without steam condensation technologies: a) **, b), d), e), f) etc.,
- Efficiency of CHP-electricity generation defined as annual CHP-electricity divided by the fuel input used to produce the sum of useful heat output and CHP-electricity,
- Efficiency of total electricity generation of the CHP unit for CHP units with steam condensation technologies: a) * and c)) (to simulate the efficiency of the unit running in full condensing mode).

4.2.4 Power-to-heat ratio (PHR)

PHR is a characteristic of each CHP technology and unit. It represents the ratio between electricity from cogeneration and useful heat when operating in full cogeneration mode.

- If the unit operates in full cogeneration mode during certain periods, the plant operator can manipulate with actual heat and electricity output from the cogeneration unit. These data will allow him/her to determine the actual PHR. These data will allow him to determine the actual PHR. (PHR actual).

4.3 Cogeneration (CHP) plants in Serbia

4.3.1 Coal fired TPPs

For the heating of the cities of Obrenovac, Požarevac/Kostolac and Lazarevac, TPP "Nikola Tesla A", TPP "Kostolac A" and TPP "Kolubara" operate in CHP regime with steam condensation. The need for heat basically depends on outside temperature and the city regulation of heating. Cogeneration with steam extraction from the turbine is capable to respond to such variable regimes. The PHR is estimated by balancing of steam flow through the turbine, considering the temperature (pressure) at which the steam is extracted, the quantity of steam extracted and coefficient of efficiency of relevant turbine stages, and the size of the unit.
The TPP "Nikola Tesla A" is composed of 6 units. The review of its units and energy characteristics is shown in Table 4.3.

Table 4.3. Units composing TPP "Nikola Tesla A"

Unit	A1	A2	A3	A4	A5	A6
Electric power (MWe)	210	210	329	308.5	340	347.5
Steam pressure (bar)	140	140	182	182	182	182
Steam temperature (°C)	540±5	540±5	543±5	543±5	543±5	543±5
Coal consumption (t/h)	350	350	440	440	440	490
Lower fuel heating value (kJ/kg)	6,700	6,700	6,700	6,700	6,700	6,700

Besides the City of Obrenovac, also cities of Lazarevac, Kostolac and Požarevac, are heated from TPP "Kolubara" and TPP "Kostolac A", respectively.

The production – delivered heat energy – for each of above listed TPPs is given below:

1. TPP TENT A, units A1 and A2 → The City of Obrenovac: 250,000 MWh;
2. TPP "Kostolac A", units A1 and A2 → The cities of Kostolac and Požarevac successively: 150,000 and 220,000 MWh;
3. TPP "Kolubara" The City of Lazarevac: 130,000 MWh.

4.3.2 Natural gas fired TPPs

TPPs that produce power and heat (TE-TOs) firing natural gas, exist in the Autonomous Province of Vojvodina (APV), there are no TPPs that generate only power, and there are no TPPs firing coal. These facilities generate electricity for the needs of the electric power system of Serbia, heat for the needs of district heating systems in Novi Sad, Zrenjanin, and Sremska Mitrovica, and process steam for the needs of industry.

Table 4.4. Natural gas-fired CHP Units

Thermal Power Plant	Nominal Power (MW_e)	Nominal Thermal Capacity for Heating (MW_t)	Nominal Thermal Capacity for Process Steam (t/h)
TE-TO „Novi Sad“	245	332	320
TE-TO “Zrenjanin”	120	140	310
TPP “Sremska Mitrovica”	32	40	200
CCGT “Pančevo”	189		

Except in Pančevo, the units are relatively old, the plants were not or were occasionally and incompletely modernized. In the year 2021 three natural gas-fired CHP units generated only 892,502 MWh altogether. In the year 2021, coal fired TPPs generated 23,733,678 MWh of electricity. Even wind parks in 2021 generated 1,084,541 MWh of electricity. These figures witness that these three CHP plants (TE-TOs) operated for a very small number of hours[20].

In 2021, the new CCGT power plant in the city of Pančevo has been completed. It is planned that CCGT Pančevo will deliver about 1,400 gigawatt-hours (GWh) of electricity in 2023, which is enough to supply around 300,000 average households in Serbia annually. The produced electricity will be delivered to national electricity grid. The rest of CHP plants in Serbia have smaller capacities (installed electric power less than 10 MWe).

There is a significant number of small biogas CHP plants that deliver produced electricity to the electricity distribution network. These plants mostly use produced heat for their own needs. The total installed capacity of biogas plants amounts to 110,767 kW (34,286 kW of eligible producers and 76,841 kW of temporary eligible producers)[21].

4.3.3 City Waste

At the waste landfill “Vinča” a CHP plant is constructed that will fire the city waste. EPS Snabdevanje is expected to off-take the electricity generated by the facility, while “Beogradske Elektrane“ is expected to off-take the heat. French company “Suez” will be responsible for the operation and maintenance of all facilities under this Belgrade waste-to-energy project. Apart from generation of electricity and heat, the Belgrade waste-to-energy project involves the closure and remediation of the existing Vinča landfill, the construction of a new leachate-controlled seven million cubic meters (mcm) capacity landfill, a recycling unit to treat approximately 200,000 tons per annum of construction and demolition waste, and an engineered landfill with biogas recovery facility.

The waste-to-energy facility will be capable of processing up to 43 t of waste per hour and up to 340,000 t of municipal waste a year, which is equivalent to approximately 66% of the total waste generated in Belgrade. The nominal electric power of the facility is 29.2 MW, achieved at an ambient temperature of 20°C and a condensation pressure of 0.11 bar. This is so-called summer - condensation mode of operation. In the case of cogeneration, the so-called winter heating operation mode, the turbine delivers 20.6 MW of electrical power and 56.5 MW of heat at an ambient temperature of -12°C and a condensation pressure of 0.06 bar. The electricity generated by the facility will be delivered to the national grid, while the heat will be supplied to Belgrade’s municipal district heating company. The CHP plant is designed to generate 192 GWh/y of electricity and 172 GWh/y of heat. Necessary pipeline for connecting the CHP plant “Vinča” and DHC BE is already constructed.

4.4 High-efficiency cogeneration (CHP) plants in Serbia

According to the Law on Energy Efficiency and Rational Use of Energy, in Serbia, an energy entity or a natural person can acquire the status of privileged producer for the power plant or the part of the power plant

[20] https://www.stat.gov.rs/media/358404/bilans-elektricne-energije-2021-prethodni-podaci.pdf
[21] https://mre.gov.rs/sites/default/files/registri/RegistarPovlasPro12-8-2022.html#Sec_Biogas

for high-efficiency combined production of electricity and heat with an installed power of up to 10 MW, if it has:

1) a facility to achieve high-efficiency combined production of electricity and heat with a minimal annual efficiency of 75%. Efficiency is calculated as the ratio between the total produced energy (electricity and heat) and the energy content of the fuel used.

2) measuring devices for measurement of produced energy end delivered energy, as well as used fuel; and

3) a concluded contract on the sale of produced heat or the proof for using produced heat for own needs (heating buildings or consumption for production processes).

Currently, 13 energy entities and their facilities fulfill previously listed conditions and these plants are considered high-efficiency cogeneration.

4.4.1 High-efficiency CHP: plant technologies

Except in the CHP plant installed in AD "Milan Blagojević", the gas engines (reciprocating spark-ignition internal combustion engines) are the only CHP technology implemented in high-efficiency CHP plants in Serbia. This type of gas engines has high efficiencies, even in small sizes. They are available as small units (15–1,000 kW) or medium power systems (1–6 MW).

Small units are mostly delivered as so-called "packaged CHP" , that are designed as complete units that can be easily connected to a building's electrical and heating systems. Medium power systems are typically designed and built to meet the specific requirements of the site. The electrical generating efficiency of gas engines is typically around 30%-40%, and units can be operated at reduced load with very little drop in engine efficiency. The energy balance for a typical gas engine is presented in 2. The ratio of recoverable heat to electricity generated (heat to power ratio) is typically around 1.5:1 for a gas-engine package and from about 1:1 to 2:1 for medium power systems[22]. The engine's cooling system provides heat in the form of hot water, typically at around 80°C, but some engines can operate using pressurised hot water, which delivers heat at up to 120°C. If the recovered heat is not all required by the site, the surplus must be dissipated using a cooling system. Alternatively, the power output must be modulated to match heat demand. Gas engines can achieve high levels of availability (typically 85-90%).

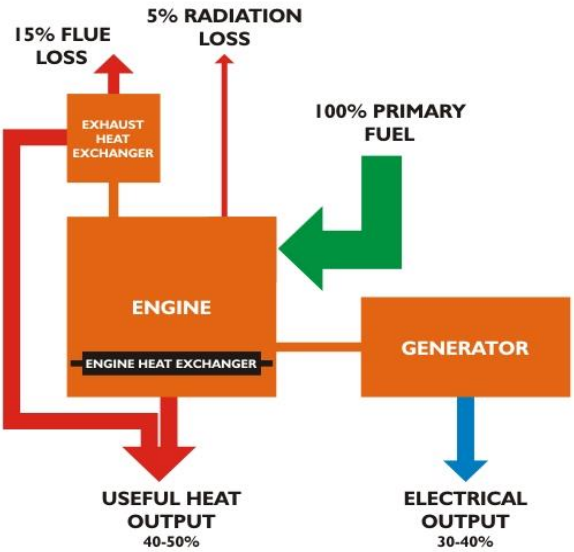

Figure 4.2. The energy balance for a typical gas engine[23]

The implemented CHP technology in one facility is steam turbine fueled by coal. This technology requires a separate boiler or "HRSG" (Heat Recovery Steam Generator) to create working fluid – high-pressure steam. High-pressure steam is 'let down' through the turbine, generating electricity and providing lower pressure steam or hot water for site use.

Steam turbine CHP is very reliable, and turbines can achieve a long-term availability of up to 99%. Units are

[22]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/961492/Part_2_CHP_Technologies_BEIS_v03.pdf

available with power outputs of 0.5 MW upwards. Steam turbine CHP is particularly suited to sites where the heat requirement is high in relation to the power demand. The ratio of usable heat to power in a steam turbine CHP set is unlikely to be less than 3:1 and may be 10:1 or more.

The power produced in steam turbines depends on how far the steam pressure can be reduced through the turbine before being extracted to meet other site heat energy needs. The simplest is the back-pressure turbine, where all the steam flows through the machine and is exhausted from the turbine at the pressure required by the site. Where more than one grade of heat is required, the higher grade is supplied by extracting 'pass-out' steam at the appropriate pressure part-way along the turbine. The rest of the steam continues to the exhaust, thereby generating further power, and exits to the process at the lower pressure. Power output may be maximised by expanding the steam down to a vacuum using a condenser and ejectors to maintain the vacuum. This produces heat at such a low grade that it is not generally useful thereafter. Steam turbine sets are designated by their operating mode(s), e.g. back-pressure, pass-out/back-pressure, condensing and pass-out/condensing. A schematic representation and energy flow diagram of a back-pressure steam turbine CHP is presented in Figure 4.3.

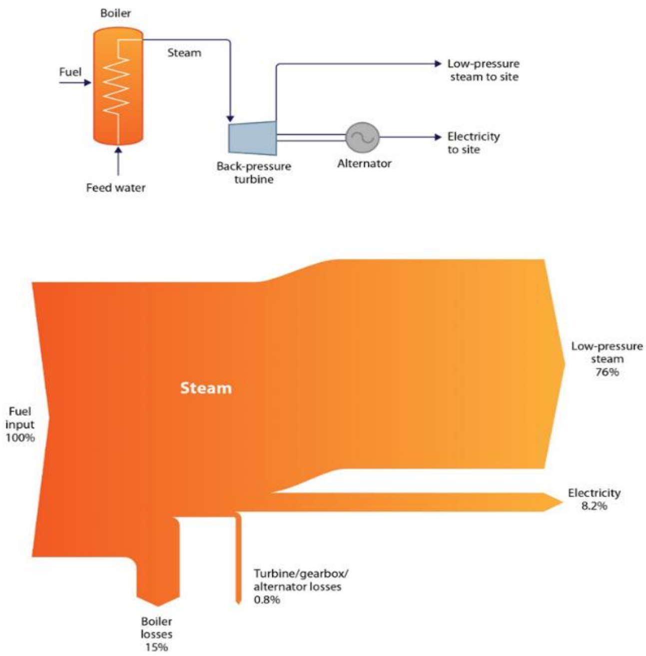

Figure 4.3. Schematic representation and energy flow diagram of a back-pressure steam turbine CHP[24]

4.4.2 High-efficiency CHP: sectors of use

Out of 13 HE CHPs in Serbia, 9 are used in the industry sector, 1 in health care institution, and 3 in district heating systems. Two additional CHP plants in industry are used in the food, beverages, and tobacco sub-sector (Imlek AD, Padinska Skela, Belgrade and Agriculture Company "Sava Kovačević", Vrbas). Both companies where these plants operate are connected to milk processing. One CHP plant in the industry sector operates in the chemical and petrochemical sub-sector. The heat produced in this CHP plant is also used for district heating of the Lučani settlement. Three high-efficiency CHP plants are used in district heating systems in Novi Sad (2 units) and Belgrade (1 unit) to produce domestic hot water. One CHP plant was installed in a health care institution.

[24]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/961492/Part_2_CHP_Technologies_BEIS_v03.pdf

4.5 Overview of the national stock of power plants

The total net installed capacity (nominal power) of the power plants in the Republic of Serbia in 2021 amounted to 8,244 MW[25]:

- Thermal Power Plants (TPP), net output capacity of these plants is 4,079 MW,
- Combined Heat and Power Plants (CHP), with net output capacity 496 MW,
- Hydro Power Plants (HPP) with net output capacity 3,101 MW (including small hydro power plants),
- Wind Power Plants, with net output capacity 398 MW,
- Solar Power Plants, with net output capacity 12 MW,
- Biogas Power Plants, with net output capacity 36 MW,
- Biomass Power Plants, with net output capacity 2 MW,
- Waste Power Plants, with net output capacity 1 MW,
- Industrial Power Plants, with net output capacity 92 MW, and
- CHP Plants, with net output capacity 25 MW.

The total electricity production in 2021 was 38,235 GWh. The largest part of production was realized in thermal power plants (62%, 23,734 GWh) and hydro power plants (31%, 11,984 GWh). Combined heat, wind power plants and industrial power plants in total electricity production together accounted for about 7%. Import of electricity was 6,984 GWh, export 6,333 GWh, so that net gross import amounted to 651 GWh. Power consumption of the energy sector in the same year amounted to 11% of the total generated electricity (gross production). Losses in the transmission and distribution system amounted to 11.72% of the total electricity production (gross production) [26].

[25] Security of Supply Statement, Ministry of Mining and Energy, 2022.
[26] Statistical Office of the Republic of Serbia, http://www.stat.gov.rs/en-US/

5. District heating

The district heating/cooling system is the transmission of thermal energy from the place of thermal energy production, through the distribution network of thermal energy, to several buildings, for the purposes of heating or cooling the space or for the needs of technological processes[27]. This chapter describes the current state of the district heating system in the Republic of Serbia. The data were obtained by collating from the two sources: District heating business association "Toplane Srbije" (DHBA Serbia), and Energy balances of the Republic of Serbia

In 2021, the heat produced from plants serving district heating networks amounted to 6,902 GWh, while the thermal energy supplied to customers amounted to 6,047 GWh and losses during heat distribution were 855 GWh (12.4% of the energy produced). Cooling energy is not delivered to end customers from the district heating system in the Republic of Serbia.

5.1 Sectors of use

The largest part of the thermal energy that is delivered to the final customers through the distribution networks of the district heating system goes to the residential premises, shown in Figure 5.1. In the Republic of Serbia, only two tariff groups of customers are defined, namely:

- residential premises, and
- commercial premises.

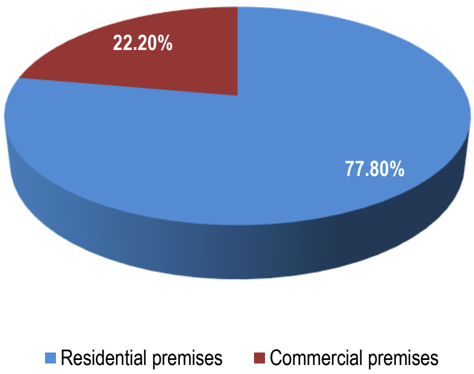

Figure 5.1. DHS heat energy customers in the Republic of Serbia by tariff groups, 2021

The structure of heated premises and the use of domestic hot water in the DHS of the Republic of Serbia are shown in Figure 5.2. The percentage of use refers only to consumers heated from DHS.

Table 5.1. Heated premises and domestic hot water in DHS, 2021

DHS	Residential DHW	Residential premises	Commercial premises
	%	m²	m²
Beograd	5.84	18,505,357.00	4,282,237.00
Novi Sad	27.53	5,131,520	1,900,000
Kragujevac		1,093,315	469,454
Niš	0.52	1,665,941	516,011
Pančevo	3.86	703,177	157,655

[27] Law on energy efficiency and rational use of energy "Official Gazette of RS", 40/2021.

DHS	Residential DHW	Residential premises	Commercial premises
	%	m²	m²
Bor	8.8	561,795	135,930
Subotica		539,848	233,172
Kruševac		438,155	174,997
Zrenjanin		400,876	74,264
Kraljevo		369,816	92,282
Čačak		466,320	120,432
Jagodina		218,061	73,990
Šabac		384,050	99,529
Trstenik		84,772	40,498
Požarevac		775,500	209,500
Užice		311,628	61,424
Smederevo		271,381	56,981
Lazarevac		410,413	114,589
Sremska Mitrovica		160,977	77,623
Kikinda		146,488	68,352
Loznica		150,064	68,969
Valjevo		263,134	147,213
Obrenovac		768,171	124,150
Leskovac		226,719	109,905
Pirot		125,468	57,621
Sombor		209,430	65,154
Majdanpek		116,647	20,857
Priboj		81,957	32,342
Zemun		51,602	18,457
Ruma		86,728	16,984
Kladovo		93,576	44,238
Bečej		60,171	46,791
Novi Pazar		63,000	27,994
Negotin		74,978	12,551
Vrbas		74,447	19,989
Bajina Bašta		51,000	27,000
Vranje		65,706	101,362
Nova Varoš		33,687	21,591
Knjaževac		37,744	11,463
Prijepolje		33,110	13,713
Gornji Milanovac		53,500	1,500
Beočin		33,673	10,282
Zaječar		148,180	49,497
Bačka Palanka		38,814	25,502
Velika Plana		27,499	24,508
Kovin		44,000	33,000
Kosjerić		10,973	6,234
Mali Zvornik		14,297	10,609

DHS	Residential DHW	Residential premises	Commercial premises
	%	m²	m²
Pećinci		5,243	14,057
Temerin		15,029	17,858
Srbobran		10,136	17,047
Žitište		3,405	8,411
Stara Pazova		94,318	29,411
Senta		112,085	45,325
Grocka		8,885	5,889
Total	**5.05**	**35,926,766**	**10,246,394**

5.2 Evolution of district heating in the Republic of Serbia

District heating systems in the Republic of Serbia began to develop more intensively in the second half of the 20th century. In the beginning, they used coal and fuel oil as the primary energy source, and later, with the completion of the section of the transport gas pipeline Mokrin-Kikinda-Elemir-Velika Greda-Pančevo in 1963, they started using natural gas.

In the Republic of Serbia, there are 60 organized district heating systems that regularly submit their data to DHBA Serbia. Heat is produced from plants that produce only heat, and only Novi Sad and Belgrade own CHP plants with a capacity of 14 MWe and 10 MWe, respectively. Boiler houses are in 256 locations. From the data in Table 5.2. the number of working hours at the peak of the production capacity is relatively small (about 1,100 h/year) and that there is a clear potential for the growth of newly connected consumers to the district heating system in urban areas.

Table 5.2. General indicators of DHC in the Republic of Serbia

Year	Installed capacity	Distribution network	Residential	Heated area of residential	Heated area of commercial	Total heated area	Energy	Production efficiency, η_p	Distribution efficiency, η_d	Total efficiency, η	Specific consumption
	MW_t	km	No	m²	m²	m²	GWh	%	%	%	kWh/m²*a
2008	5,830	2,081	585,362	32,410,594	7,764,228	40,174,822	6,975	82.0	84.5	69.3	120.3
2016	5,883	2,311	622,703	34,247,803	9,025,603	43,273,406	6,890	88.8	88.7	78.8	125.4
2017	5,876	2,354	627,458	34,440,634	9,065,402	43,506,036	6,894	89.1	87.8	78.2	123.9
2018	5,961	2,393	634,050	35,015,810	8,213,869	43,229,679	6,927	88.9	86.0	76.5	122.5
2019	5,986	2,409	636,880	35,074,994	9,644,141	44,719,135	6,803	88.5	87.3	77.3	117.6
2020	5,976	2,686	642,457	35,454,008	9,858,310	45,312,318	7,437	89.6	87.9	78.8	129.3
2021	6,022	2,727	650,599	35,926,767	10,246,394	46,173,161	7,593	90.9	87.6	79.6	130.9

The length of the distribution networks of all district heating systems is 2,727 km.
The development of the district heating sector in the period 2008-2021, i.e. increase of the heated area and expansion of the distribution network, are presented in the Figure 5.2. In the period 2017-2021, the heated space increased by about 1.2% per year, while the length of the distribution network increased by about 3.2% per year. There are 27,720 heating stations in district heating systems in 2021. The largest number of heat substations in DHC have a capacity ranging from 101 to 500 kW.

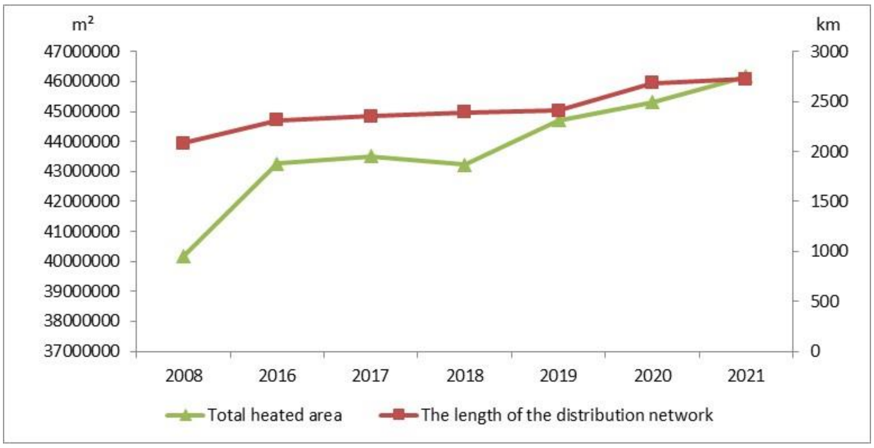

Figure 5.2. Progression in the heated area and length of district heating networks

Heat substation is a heat exchange unit in heating systems, which connects the district heating network with the building's heating system, i.e. with internal heating devices, thus providing the consumer with the contracted amount of heat from the supplier while controlling the heat delivered to the building heating devices. Heat substations are mostly of the indirect type, that is, independent with two different water systems separated by a heat exchanger, and direct, that is, dependent on water for district heating that is used directly in the building's heating systems.

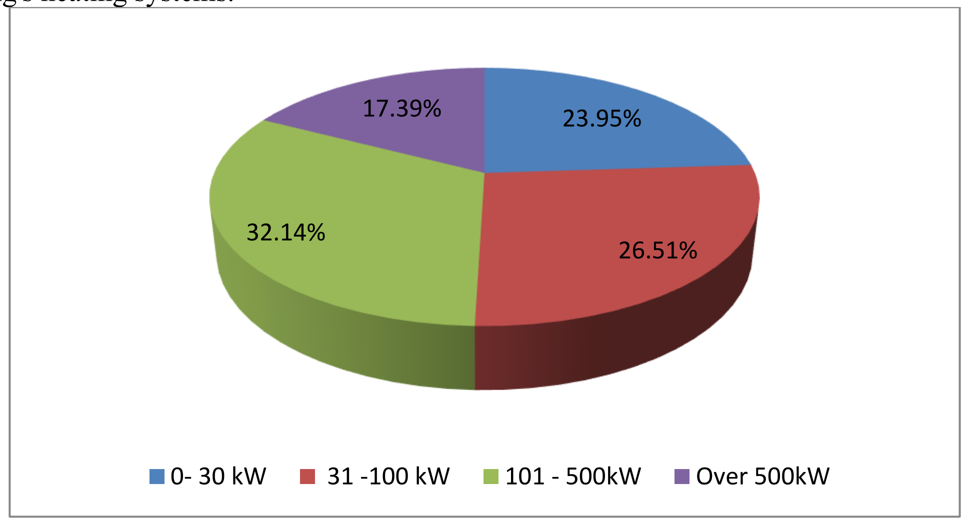

Figure 5.3. Representation of heat substations in DHC by capacity

5.3 Energy sources and technologies

The energy input into the district heating networks in the national territory in 2021, amounted to 6,663 GWh in total. The share of fossil fuels is dominant. The most represented fuel is natural gas with 79,71%, while the least represented are renewable energy sources with only 1.50%, exclusively wood biomass. An amount of oil products is consumed in the production facilities of the district heating system, and the percentage of coal, 13.68%, is high because it is taken into account that four district heating systems (Požarevac, Obrenovac, Lazarevac and Kostolac) are only heat energy distributors that take heat to exchange stations from the PE Electric Power Industry of Serbia, which produces electricity from lignite. Oil derivatives account for 5.12%.

5.4 Regional distribution of district heating units

The distribution of production capacities of DH companies/municipalities/cities in Serbia is as follows:

- Installed capacities up to 20 MW: 28 DH companies/municipalities/cities,

- Installed capacities in the range between 20 MW and 100 MW: 20 DH companies/municipalities/cities,
- Installed capacities in the range between 100 MW and 3,000 MW: 8 DH companies/municipalities/cities,
- Four DHC don't have own production capacities.

The DHCs perform, in accordance with the Energy Law, three energy activities – production, distribution and supply of heat (56 DHCs), while the remaining 4 DHCs perform only distribution and supply of heat.

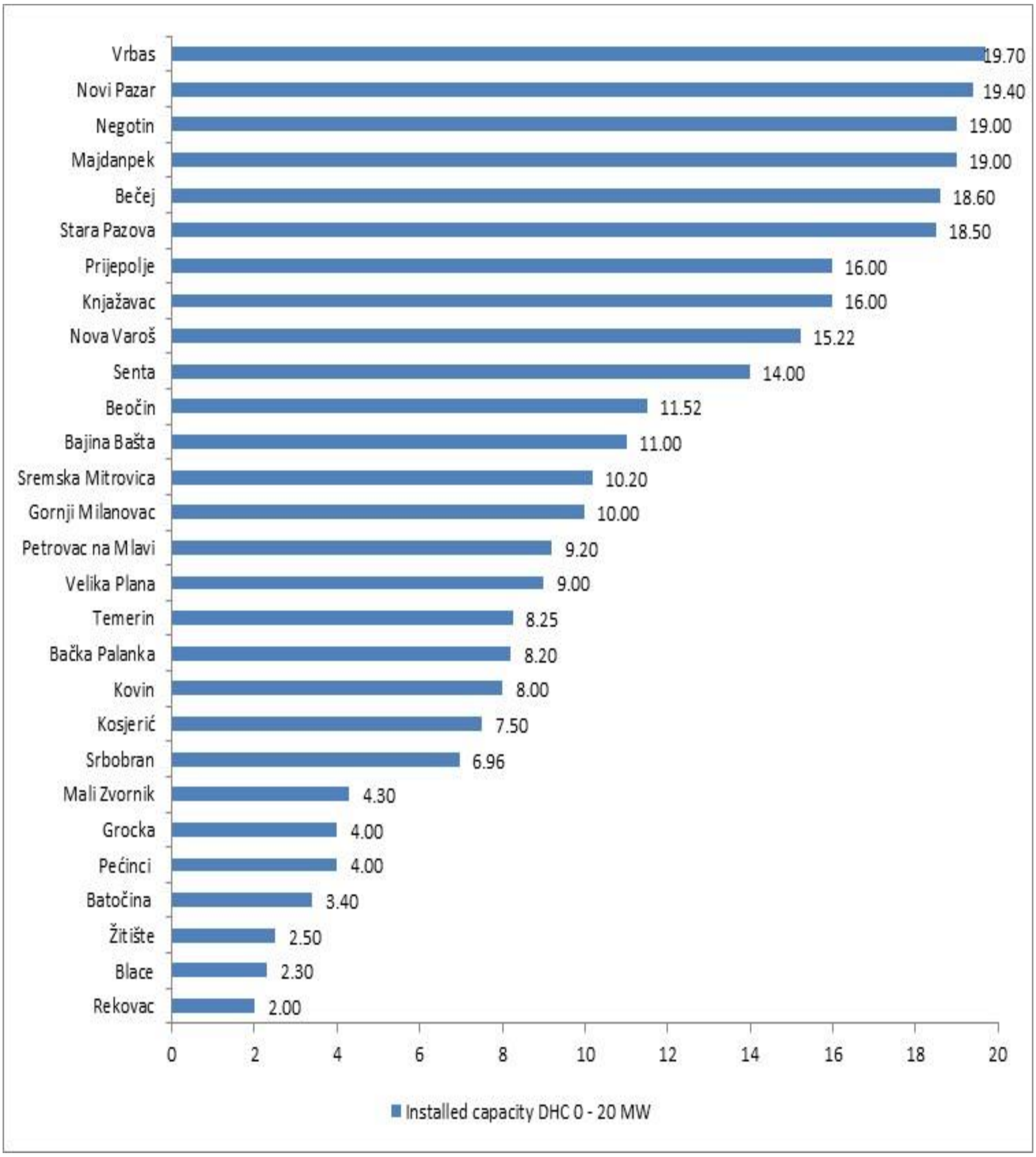

Figure 5.4. DH companies in Serbia with installed capacities up to 20 MW

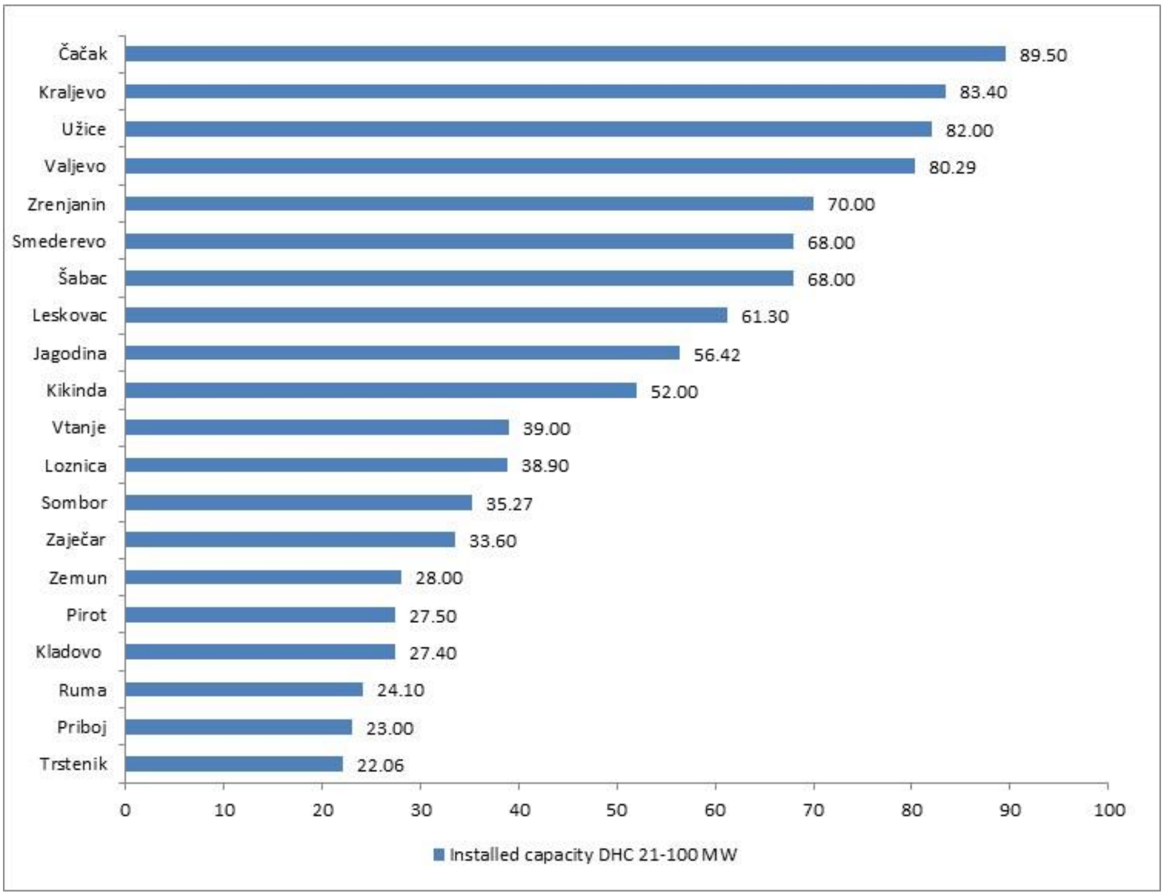

Figure 5.5. DH companies in Serbia with installed capacities in the range 21-100 MW

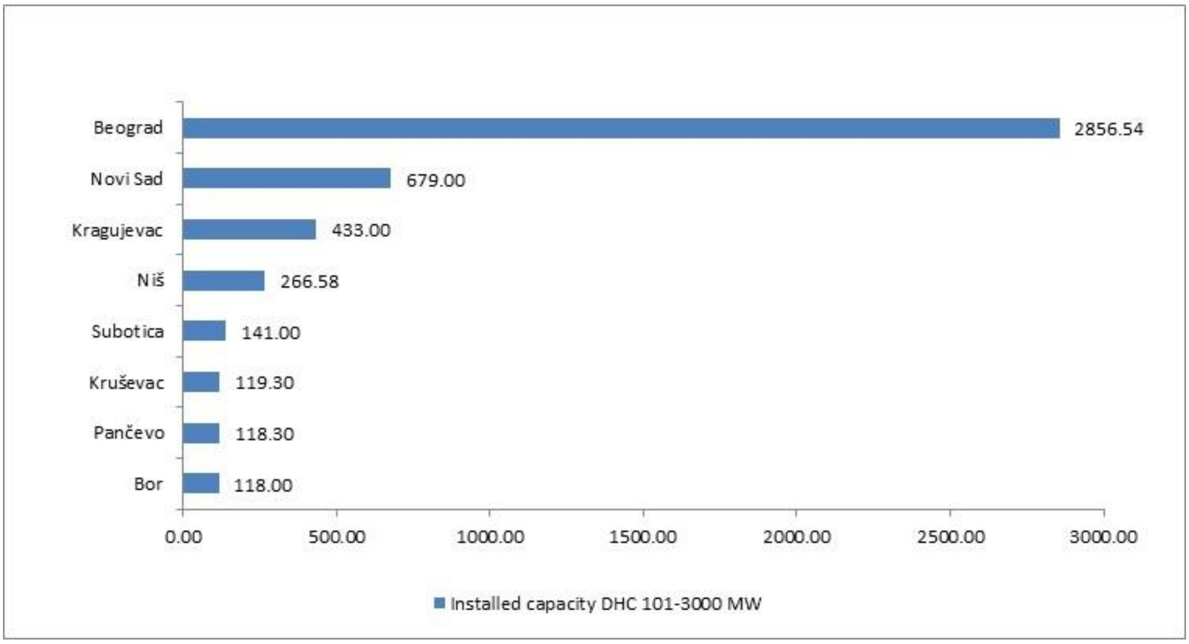

Figure 5.6. DH companies in Serbia with installed capacities in the range 101-3,000 MW

Just as there are large differences in the installed capacities of DHC, the length of the distribution networks shown in Figure 5.7, Figure 5.8 and Figure 5.9, is also very different, and does not necessarily follow the values of the installed capacity.

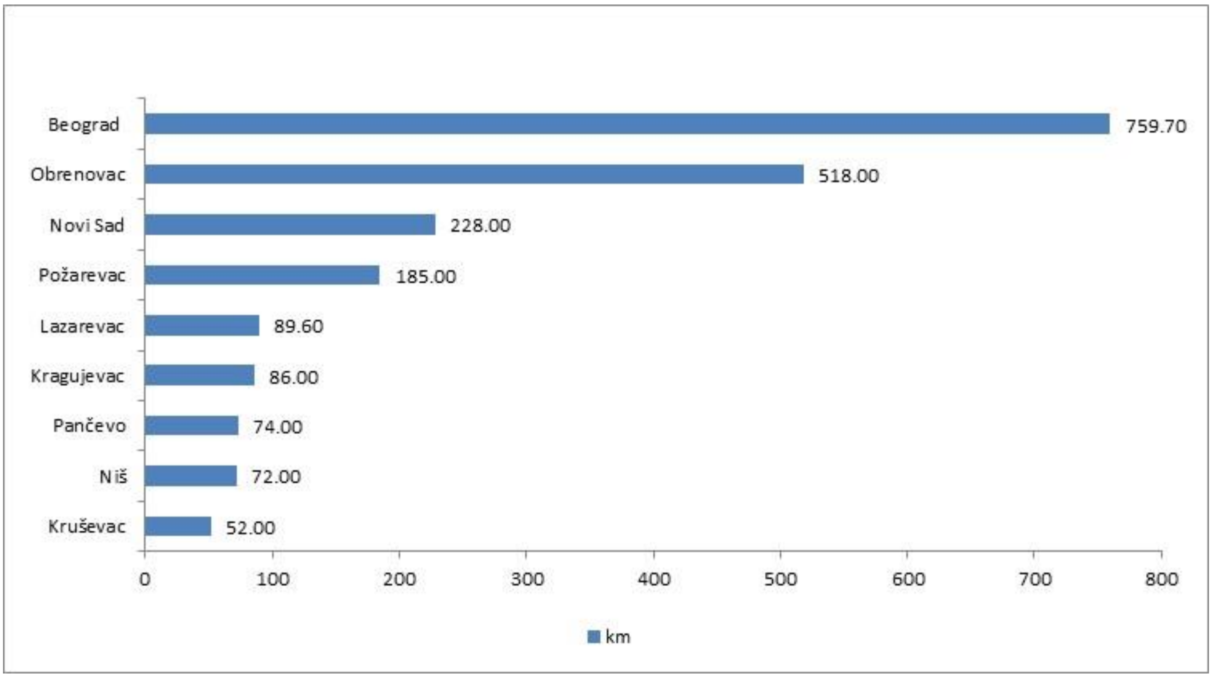

Figure 5.7. DH companies with the length of the distribution network in the range 51-800 km

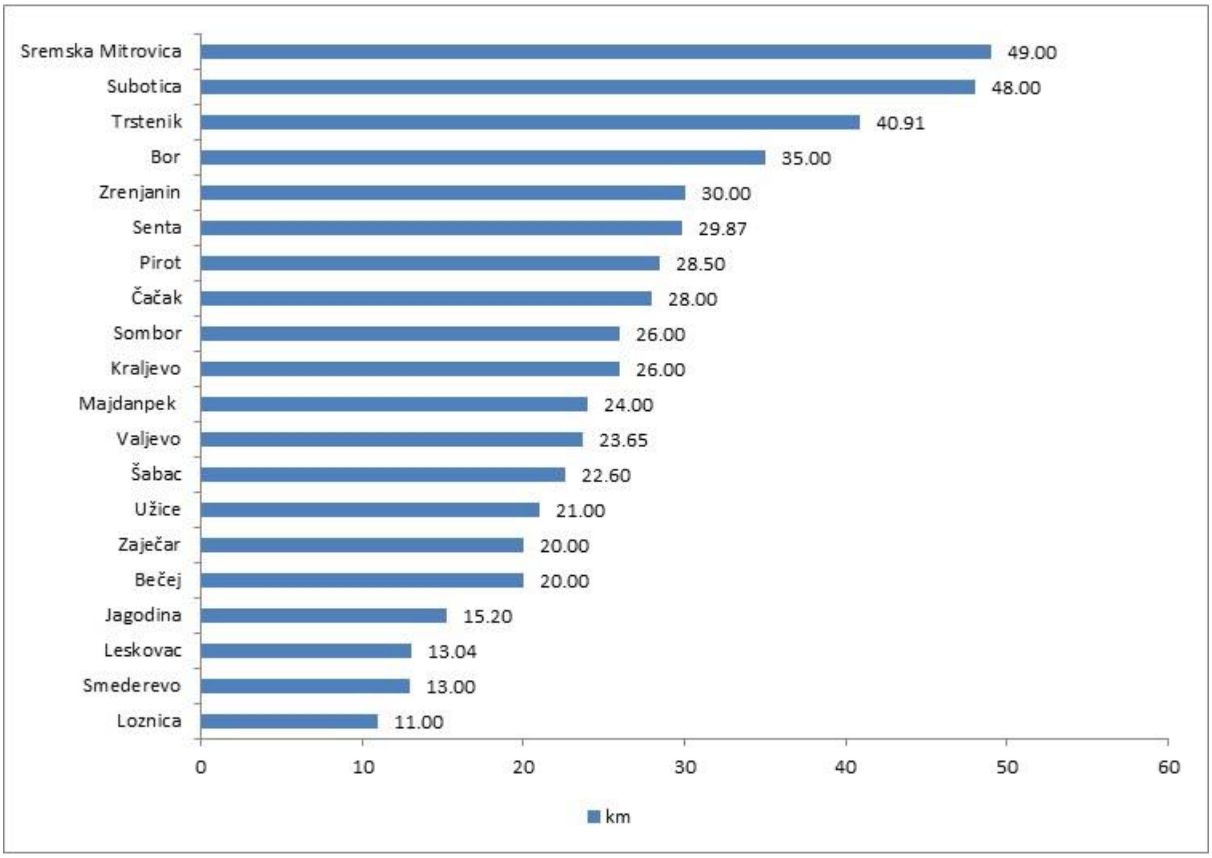

Figure 5.8. DH companies with the length of the distribution network in the range 11-50 km

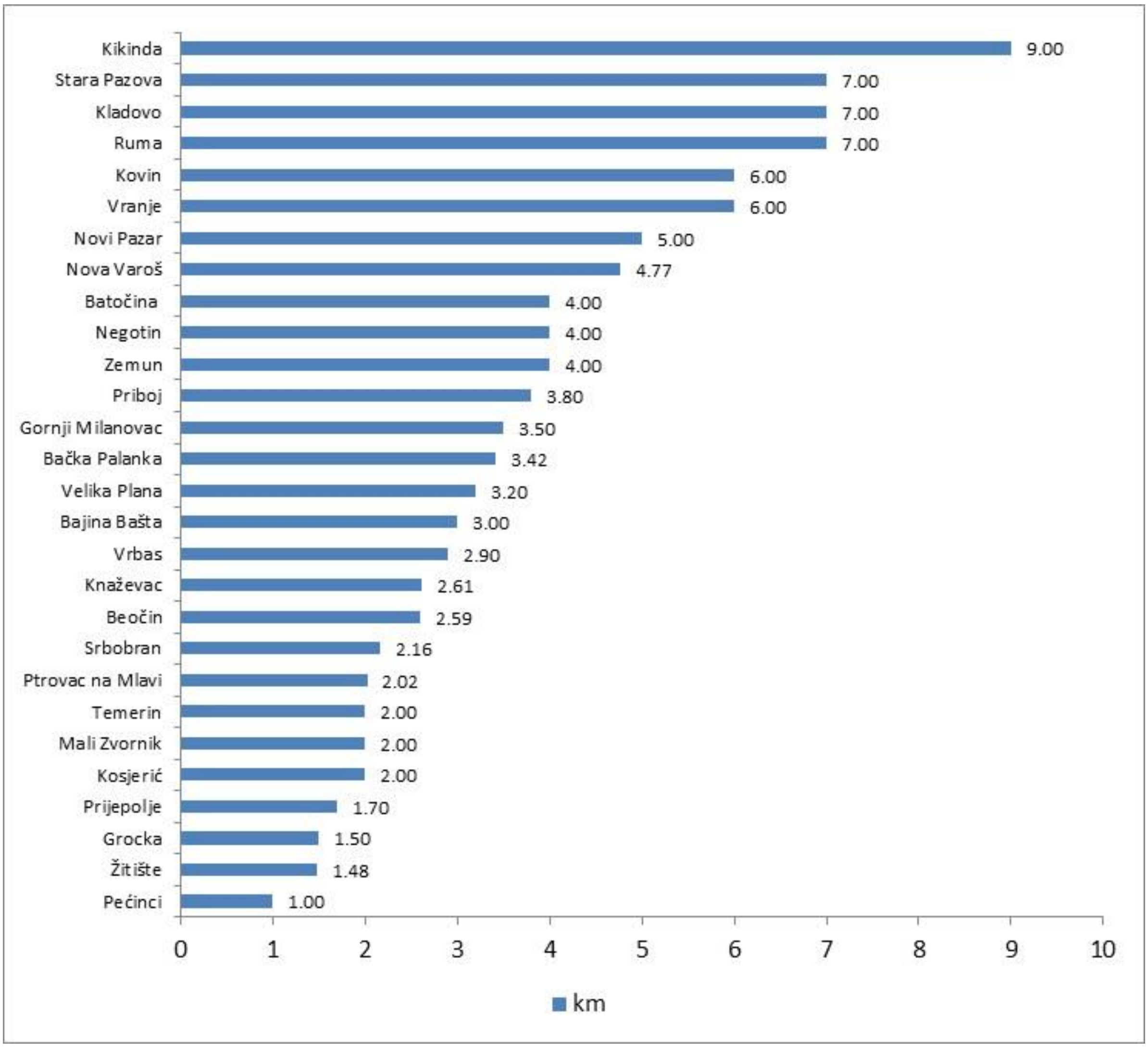

Figure 5.9. DH companies with the length of the distribution network in the range 0-10 km

Linear heat density of a heating grid (Figure 5.10 and Figure 5.11) is defined as the ratio between heat demand (or delivered heat of an existing grid) and heating grid length. It can come in different units, and we use MWh per meter and year - MWh/(m*a). Both types of density are used as indicators for the economic viability of a heating grid. The higher the density, the more heat can be delivered and sold over a unit of the grid, reducing losses and investment costs. Both density types give an important orientation as to a grid's viability, although by far not the only decision parameter for the construction of a heating grid.

Nevertheless, linear heat density has the advantage over yearly energy per hectare of urban space in the fact that non-relevant urban spaces do not enter the measure. The usual problem with yearly energy per hectare of urban space is the definition of the urban space, when it is used as a proxy for the needed grid length. Since the linear heat density directly uses grid length, we consider it as the superior measure of the two[28].

[28] Analysing district heating potential with linear heat density. A case study from Hamburg

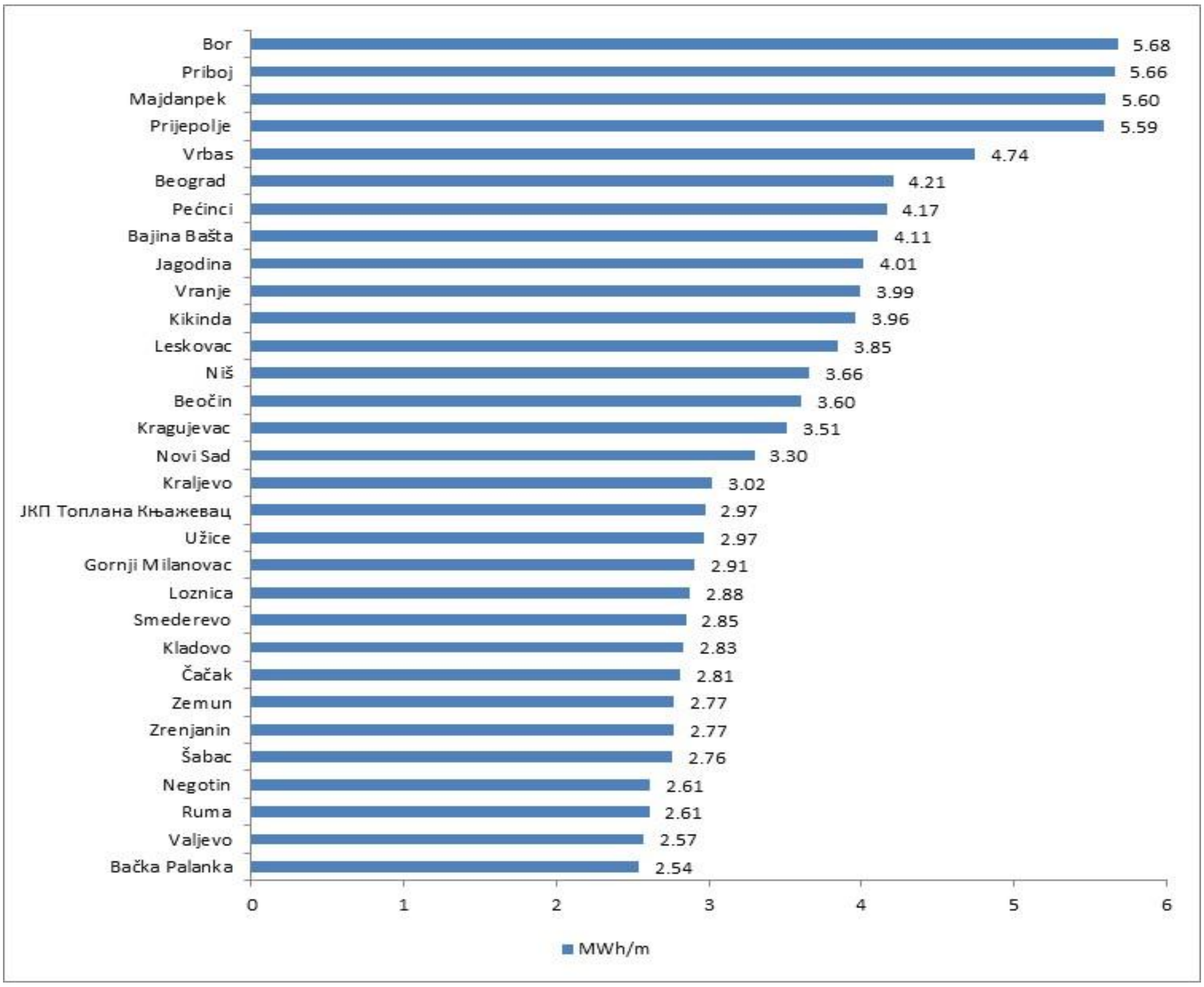

Figure 5.10. Linear heat density (DHC >2.5 MWh/m)

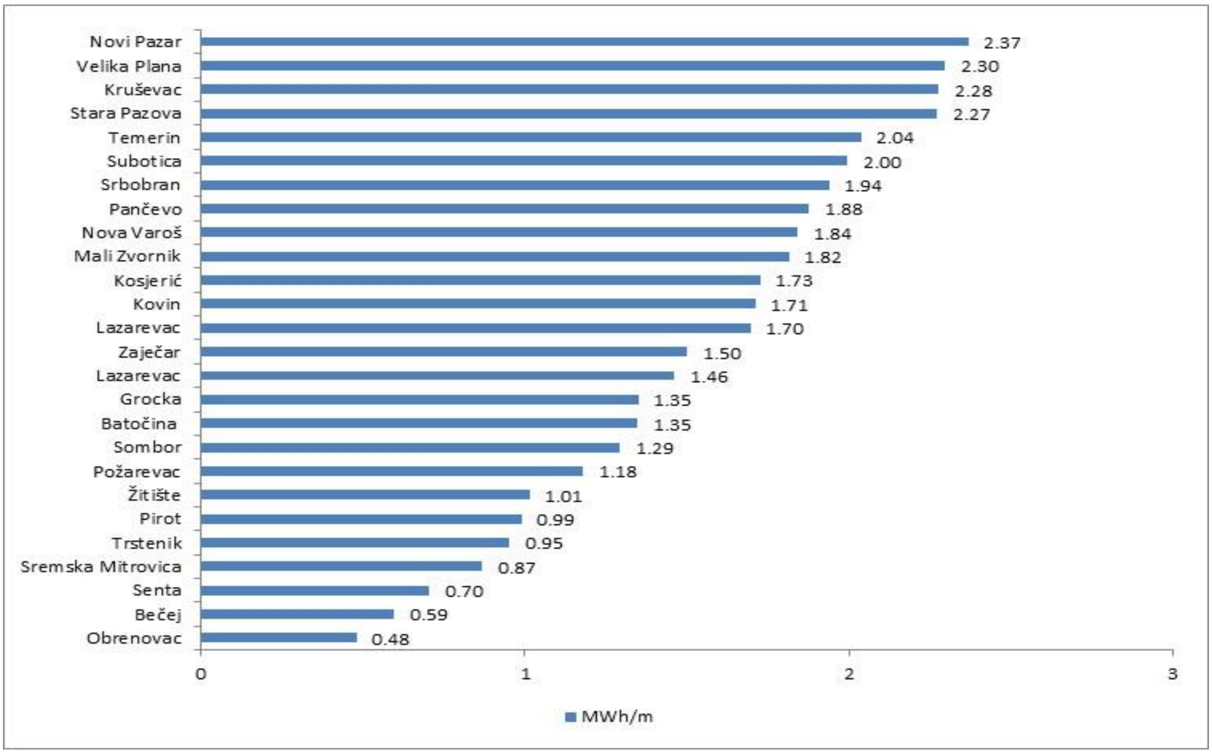

Figure 5.11. Linear heat density (DHC <2.5 MWh/m)

5.4.1 Map of the existing district heating infrastructure and assessment of its efficiency

DHCs in the Republic of Serbia are distributed as shown in Figure 5.12., and they supplied heat to 650,599 households in 2021. The largest DHCs are located in the 4 largest cities of Belgrade, Novi Sad, Kragujevac and Niš, of which Belgrade stands out with almost half of the households supplied by heat, compared to the total number in the Republic of Serbia. The coverage of heat substations with meters is about 96%. Meters in heat substations are the only authoritative devices for charging heat energy. Individual meters in front of the apartments and heat cost allocators are installed in about 10% of the heated area of the living space. Individual meters and heat cost allocators are relative dividers of heat energy costs.

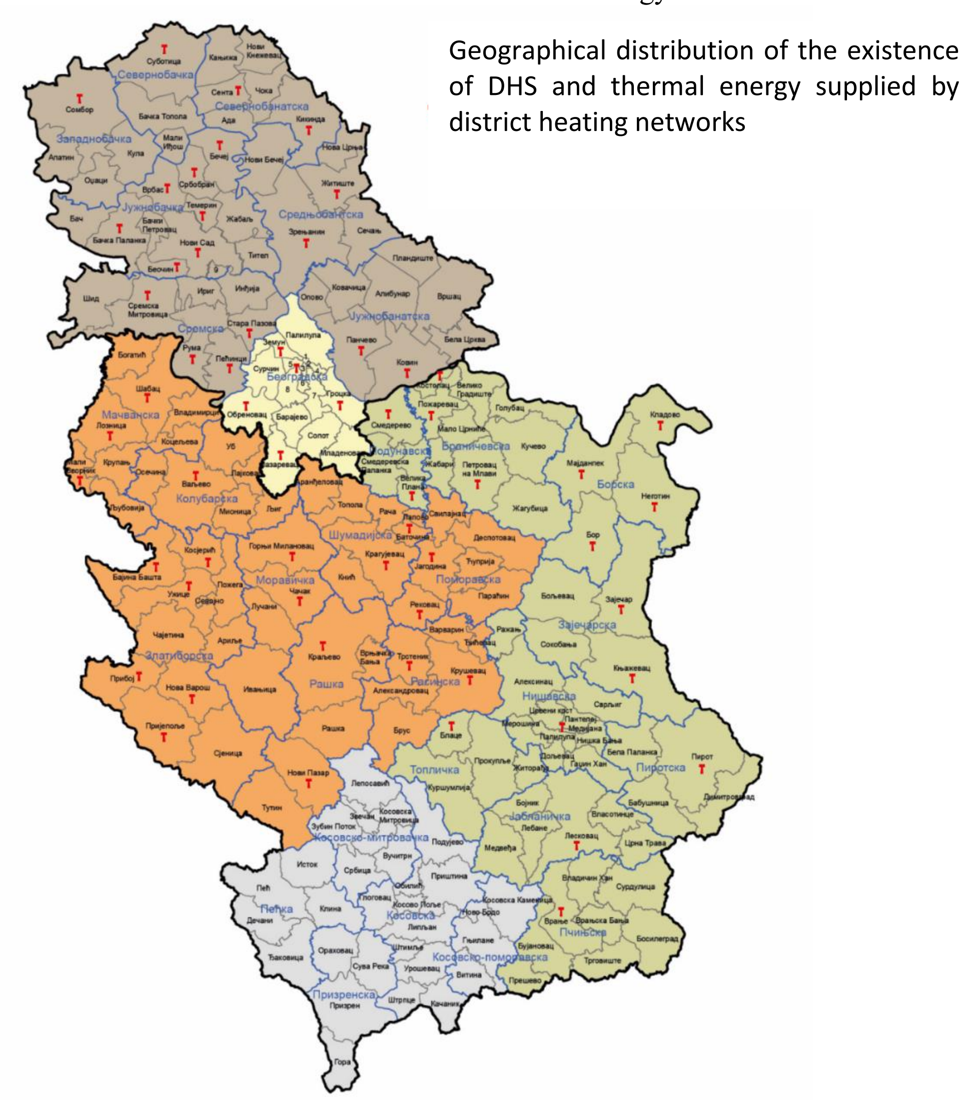

Figure 5.12. Geographical distribution of DH systems across Serbia

5.5 Existing district cooling networks

Currently, there are no district cooling systems in the Republic of Serbia. District cooling systems are still a matter of debate. However, their development will certainly depend on new technologies, the availability of such technologies, degree of technical development and economic profitability. Economic viability will certainly depend on competitiveness of current, conventional cooling systems. It can be concluded that greater incentive to the development of the district cooling system is yet to come. There is some potential for the development of district cooling systems with commercial customers.

6. Supply of thermal energy for direct uses

It has been shown the direct use of heat energy sources in the residential, commercial and industry sectors. The main technologies, i.e. devices used for heating, are listed. In addition to the above, the chapter will also show the theoretical annual availability of forest and agricultural biomass, municipal waste and industrial waste heat.

6.1 Direct uses for heating and cooling by the different sectors

6.1.1 Residential sector

In the year 2021, the residential sector consumed directly almost 34,105 GWh for thermal uses (space heating and DHW production, cooking and cooling). The largest part is produced from renewable sources, i.e. solid biomass. The use of wood biomass should be conditionally understood as CO_2 neutral, because this fact is valid only in the case when forest cutting is followed by planting in an equal amount.
The share of different energy sources is listed in Table 6.1.

Table 6.1. Direct uses for heating and cooling in the residential sector in 2021 (GWh)

Energy sources	Main technologies	Reference data	GWh	%
Renewable sources (solid biomass)	Stoves, boilers	Energy contained in the biomass	16,606.3	48.69%
Oil products	Stoves, boilers	Energy contained in oil products	40.7	0.12%
Natural gas	Stoves, boilers	Energy contained in the gas	3,441.2	10.09%
Coal	Stoves, boilers	Energy contained in the coal	1,720.6	5.05%
Electricity	Stoves, boilers, heat pumps	Electricity consumption	12,295.9	36.05%
Total sources			**34,104.7**	**100%**

The structure of occupied dwellings by regions in Serbia is presented in Table 6.2.

Table 6.2. Structure of occupied dwellings by regions of the Republic of Serbia

Region	Occupied dwellings with district heating	Number of occupied dwellings with central heating	Number of occupied dwellings without district and central heating installations
Belgrade region	45.92%	17.47%	36.61%
Region of Vojvodina	18.20%	24.99%	56.82%
Region of Šumadija and Western Serbia	12.10%	21.07%	66.83%
Region of Southern and Eastern Serbia	12.70%	17.80%	69.50%

6.1.2 Commercial sector

In 2021, the commercial sector directly consumed about 9,605 GWh for the production of thermal energy, mostly using electricity and natural gas, 54.15% and 33.66%, respectively, Table 6.3.

Table 6.3. Direct uses for heating and cooling in the commercial sector in 2021 (GWh)

Energy sources		Main technologies	Reference data	GWh	%
Renewable sources	Geothermal	Systems for the collection and direct use of geothermal fluids	Thermal energy obtained by collecting water or steam from underground	17.6	0.18%
	Primary solid biofuels	Boilers	Thermal energy contained in biomass	235.4	2.45%
	Biogases	Boilers	Thermal energy contained in biogas	39.3	0.41%
Oil products		Boilers	Energy contained in oil products	615.2	6.41%
Natural gas		Boilers	Energy contained in gas	3,232.5	33.66%
Coal		Boilers	Energy contained in coal and coal products	262.4	2.73%
Electricity		Boilers, Heat pumps	Electricity consumption	5.199,8	54.15%
Total Sources				**9.602,2**	**100.00%**

6.1.3 Industry

There is no available reliable data about direct uses for heating and cooling in the Serbian industry sector. The energy balances provide data about total energy consumption in the industry sector separated by energy sources, that can be used for space heating/cooling or in different technological processes, but that specific information missing in energy balances.

For estimation of direct energy uses for heating and cooling in industry sector the methodology proposed in reference[29] was used. The final energy demand for space heating and cooling in the industry (FED) results from the activity, number of employees (EMP), and specific energy consumption (SEC). As there are no comprehensive statistics about floor area in industrial sub-sectors, this value was calculated based on employment in each sub-sector (EMP) and the specific floor area per employee (EMPArea). The expression for the final energy demand for space heating in industry sub-sector (*s*) and building type (*b*) is the product of previously mentioned variables, as follows:

$$FED_{s,b} = EMP_s \times EMPArea_{s,b} \times SEC_b \times EHI \qquad (6.1)$$

EHI is the European heating index introduced for differences in SEC among countries. For Serbia, *EHI* value of 94.2/100 is adopted[30].

The number of employees per industry sub-sectors is presented in Table 6.4. Table 6.5. shows representative values of floor area per employee ($EMPArea_{s,b}$) for different industry sub-sectors and two building types (Production facilities and Offices). The specific energy consumption (SEC_b) for heating purposes in these two building types and for seven age classes is presented in Table 6.6.

Using equation (6.1), the final energy demand per industrial sub-sectors for heating is calculated and presented in Table 6.7. Since the classifications of industry sub-sectors in energy balances and employment statistics are not the same, the relationship between these two classifications is presented in Table 6.8.

[29] Matthias Rehfeldt, Tobias Fleiter & Felipe Toro, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency, Vol. 11, 1057–1082, 2018.
The model FORECAST-Industry (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES, Ob- server 2016)
[30] https://www.lsta.lt/files/events/14_werner.pdf

Table 6.4. Registered employment in industry, Republic of Serbia, 2021[31]

Industry – Manufacturing - Total	**493.413**
Manufacture of food products	92.473
Manufacture of beverages	8.319
Manufacture of tobacco products	1.258
Manufacture of textiles	12.443
Manufacture of wearing apparel	36.231
Manufacture of leather and related products	13.222
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	17.356
Manufacture of paper and paper products	9.265
Printing and reproduction of recorded media	9.527
Manufacture of coke and refined petroleum products	4.389
Manufacture of chemicals and chemical products	13.882
Manufacture of basic pharmaceutical products and pharmaceutical preparations	4.565
Manufacture of rubber and plastic products	31.970
Manufacture of other non-metallic mineral products	14.852
Manufacture of basic metals	15.856
Manufacture of fabricated metal products, except machinery and equipment	54.241
Manufacture of computer, electronic and optical products	7.631
Manufacture of electrical equipment	29.294
Manufacture of machinery and equipment n.e.c.	16.735
Manufacture of motor vehicles, trailers and semi-trailers	57.752
Manufacture of other transport equipment	2.313
Manufacture of furniture	21.879
Other manufacturing	7.685
Repair and installation of machinery and equipment	10.274

Table 6.5. Area per employee by industrial sub-sector and building type ($EMPArea_{s,b}$)[32.33]

m^2/employee	**Building type**	
Subsector	**Production**	**Office**
Iron and steel	82	67
Non-ferrous metals	82	68
Paper and printing	82	123
Non-metallic mineral products	82	124
Chemical industry	82	112
Food, drink and tobacco	82	124
Engineering and other metal	67	57
Other non-classified	82	65

[31] Werner (2006). The new European heating index. 10th international symposium on district heating and cooling (September 3– 5, 2006), Section 4 a: Effects on DH from directives, laws and regulations, Hanover. https://www.stat.gov.rs/en-US/vesti/statisticalrelease/?p=8554&a=24&s=2402
[32] Matthias Rehfeldt, Tobias Fleiter & Felipe Toro, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency, Vol. 11, 1057–1082, 2018.
The model FORECAST-Industry (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES, Ob- server 2016)
[33] Biere et al. (2014). Industry—more than just processes: a com- bined stock-model approach to quantify the energy saving potential for space heating in European industry. ECEEE industrial summer study proceedings 2014.
The model FORECAST-Industry (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES, Ob- server 2016)

Table 6.6. Specific energy consumption (SEC) industrial space heating[34,35]

Construction year	Production buildings SEC in kWh/m²	Office buildings SEC in kWh/m²
1950 - 1959	243	270
1960 - 1969	243	240
1970 – 1979	243	180
1980 - 1989	213	140
1990 - 1999	151	120
2000 - 2009	90	100
2010 - 2019	29	55

Table 6.7. Direct uses of heat in industry (space heating)

Subsector	MWh	ktoe
Iron and steel	645.841	55.5
Non-ferrous metals	81.101	7.0
Paper and printing	348.343	30.0
Non-metallic mineral products	276.707	23.8
Chemical industry	448.668	38.6
Food, drink and tobacco	884.129	76.0
Engineering and other metal	663.634	57.1
Other non-classified	1.452.044	124.9
Total	**4.800.468**	**412.8**

Table 6.8. Industrial subsector classification relation

Classification in employment statistics	Classification in energy balances
Manufacture of basic metals	Iron and steel, non-ferrous metals
Manufacture of coke and refined petroleum products	Iron and steel, non-ferrous metals
Manufacture of food products	Food, beverages and tobacco
Manufacture of beverages	Food, beverages and tobacco
Manufacture of tobacco products	Food, beverages and tobacco
Manufacture of chemicals and chemical products	Chemicals
Manufacture of other non-metallic mineral products	Non-metallic minerals
Manufacture of paper and paper products	Paper
Printing and reproduction of recorded media	Paper
Manufacture of machinery and equipment n.e.c.	Machinery and transport
Manufacture of motor vehicles, trailers and semi-trailers	Machinery and transport
Manufacture of other transport equipment	Machinery and transport
Manufacture of rubber and plastic products	Other industry
Manufacture of textiles	Other industry
Manufacture of wearing apparel	Other industry

[34] Matthias Rehfeldt, Tobias Fleiter & Felipe Toro, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency, Vol. 11, 1057–1082, 2018.
The model FORECAST-Industry (Fraunhofer ISI, Fraunhofer ISE, TU Wien, TEP Energy, IREES, Ob- server 2016)
[35] Biere et al. (2014). Industry—more than just processes: a com- bined stock-model approach to quantify the energy saving potential for space heating in European industry. ECEEE industrial summer study proceedings 2014.

Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Other industry
Other manufacturing	Other industry
Manufacture of electrical equipment	Other industry
Manufacture of furniture	Other industry
Manufacture of leather and related products	Other industry
Manufacture of fabricated metal products, except machinery and equipment	Other industry
Manufacture of computer, electronic and optical products	Other industry
Manufacture of basic pharmaceutical products and pharmaceutical preparations	Other industry

By applying selected methodology, the amount of energy used for space heating in Serbian industry sector is estimated to 412.8 ktoe, or 4,800 GWh, what is approximately 19.3% of total final energy consumption in industry sector.

This amount is provided partly from district heating companies, and partly by own production of heat in boilers using thermal energy contained in fossil fuels, biogas, solid biomass and non-renewable waste.

6.2 Availability of thermal energy from biomass and waste

The analysis of the theoretical availability of renewable energy sources – biomass and waste to produce thermal energy includes contributions from sectors, as follows:

- Agriculture,
- Food Industry,
- Forestry, and
- Civil (Waste).

The estimate of the annual availability of renewable energy in total, is **1,783.8** toe.

6.2.1 Agriculture and food industry

Availability of agricultural biomass in Serbia is determined to include theoretical and/or technical energy potential of following categories:

- Harvest residues,
- Pruning residues,
- Oil plants residues for biofuels,
- Manure, and
- Food processing industry.

The applied methodologies for assessment of energy potential of each category are based on the methodologies presented in “Status of Using Agricultural Biomass for Energy Purposes in Serbia”.

6.2.1.1 Harvest residues

Assessment of the harvest residues energy potential includes assessment of mass of residues which can be obtained from data about area under specific crop in the analyzed year, crop/biomass ratio and lower heating values of residues (Table 6.9.).

Table 6.9. Lower heating values of agriculture biomass by crop and crop/biomass ratio[36]

Crop	Crop/biomass ratio	Lower heating value MJ/t
Corn	1:1	13,500
Corn cobs	1:0.2	17,000
Wheat	1:1	14,400
Barley	1:1	14,700
Rye	1:1.12	14,400
Oat	1:1	14,400
Triticale	1:1	14,400
Soybean	1:0.6	15,700
Sunflower	1:2	14,500
Oil beat	1:2	17,400

Data about area under crops and average yield for years 2020 and 2021 are provided from the database of the Statistical Office of Serbia. Main input data and results needed for assessment of theoretical energy potential are given in Table 6.10. Since all theoretical potential cannot be utilized for energy purposes, technical potential is assessed by introducing correction factors. Part of harvest residues that can be collected and utilized is calculated as 30% of the total residues.

Table 6.11. presents result of estimated annual energy technical potential from harvest residues of cereals. It is estimated to be in the range of 1.3-1.5 Mtoe, depending on average yields and area under crops.

Table 6.10. Area under crops, average yield and estimated energy potential of harvest residues

Crop	Area under crop[37], ha		average yield[38] t/ha[39]		Total biomass, Mt		Energy- theoretical potential, t	
	2020	2021	2020	2021	2020	2021	2020	2021
Corn	996,527	1,020,337	7.9	5.9	7.873	6.020	106.279,6	81.269,8
Corn cobs	996,527	1,020,337	7.9	5.9	1.575	1.204	26.766,7	20.468,0
Wheat	581,128	598,735	4.9	5.7	2.848	3.413	41.004,4	49.144,2
Barley	106,318	98,495	4.6	5.6	0.489	0.552	7.189,2	8.108,1
Rye	4,725	4,943	3.2	3.8	0.017	0.021	243.9	302.9
Oat	17,116	17,725	3	3.2	0.051	0.057	739.4	816.8
Triticale	28,495	24,746	4.4	5.1	0.125	0.126	1.805,4	1.817,3
Soybean	236,758	237,036	3.2	2.3	0.455	0.327	7.136,8	5.135,6
Sunflower	221,149	212,736	2.9	2.9	1.283	1.234	18.598,6	17.891,1
Oil beat	24,638	22,705	3	3.2	0.148	0.145	2.572,2	2.528,4

Table 6.11. Technical energy potential from harvest residues of cereals in Serbia, toe

	2020	2021
Corn	761.679,0	582.440,3
Corn cobs	191.830,3	146.688,7
Wheat	293.868,1	352.203,8
Barley	51.523,3	58.108,8
Rye	1.747,6	2.171,1
Oat	5.299,2	5.853,6
Triticale	12.939,2	13.024,5
Soybean	51.147,9	36.805,7
Sunflower	133.291,7	128.221,0
Oil beat	18.434,4	18.120,6
Total	**1.521.760,5**	**1.343.637,9**

[36] http://biomasa.undp.org.rs/wp-content/uploads/2019/01/Agricultural-Biomass_12_01_2019_1_engleski.pdf
[37] https://data.stat.gov.rs/Home/Result/130102?languageCode=sr-Cyrl
[38] https://data.stat.gov.rs/Home/Result/130102?languageCode=sr-Cyrl
[39] https://data.stat.gov.rs/Home/Result/130102?languageCode=sr-Cyrl

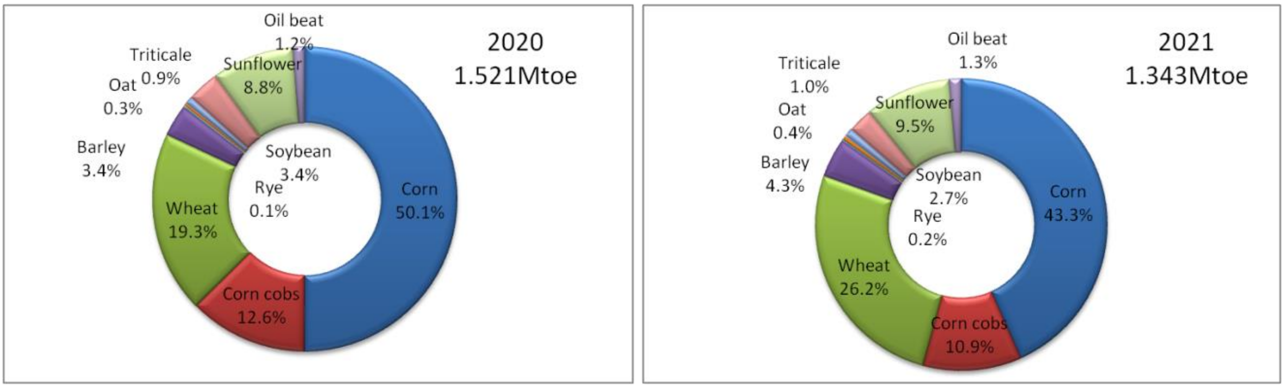

Figure 6.1. Structure of energy potential from harvest residues of cereals for 2020 and 2021

More than 80% of available annual energy is originated from residues of crops of corn and wheat. This is important due to specifics of combustion properties of different origin of agricultural biomass.

6.2.1.2 Pruning residues

Assessment of energy potential of pruning residues is carried out based on data on area under fruits and grapes, annual yields and lower heating values of residues (Table 6.12.). Data used for estimation are taken from the database of the Statistical Office of the Republic of Serbia for 2017[40].

Table 6.12. Energy potential from pruning residues

	Area under fruits, ha	Annual Yield	Pruning residues	Lower heating value or residue	Theoretical energy potential		Technical potential
	2017	t	t	MJ/t	GJ	toe	toe
Apple	25,134	378,644	123,059.3	15,300	1,882,807.3	44,978.7	35.982,9
Pear	5,703	52,291	16,994.6	15,300	260,017.0	6,211.6	4.969,3
Apricot	5,707	41,320	13,429	15,800	212,178.2	5,068.8	4.055,0
Cherry	4,613	27,323	8,879.9	15,900	141,191.6	3,372.9	2.698,4
Sour cherry	17,566	91,660	29,789.5	15,900	473,653.1	11,315.2	9.052,1
Peach	4,974	54,585	17,740.1	15,800	280,294.0	6,696.0	5.356,8
Plum	72,024	330,582	107,439.2	15,800	1,697,538.6	40,552.8	32.442,2
Quince	1,901	10,378	3,372.8	16,500	55,652.0	1,329.5	1.063,6
Hazelnuts	3,218	4,196	1,363.7	16,500	22,501.1	537.5	430.0
Other fruits	35,023	183,692	59,699.9	15,300	913,408.5	21,820.6	17.456,4
Grapes	21,781	162,646	74,329	14,000	1,040,606.0	24,859.2	19.887,4
Total							133.394,1

Structure of energy distribution of pruning residues indicates that more than 65% of estimated annual energy potential is related to pruning residues of apples, plums and grapes (Figure 6.2).

[40] https://data.stat.gov.rs/?caller=1305&languageCode=sr-Latn

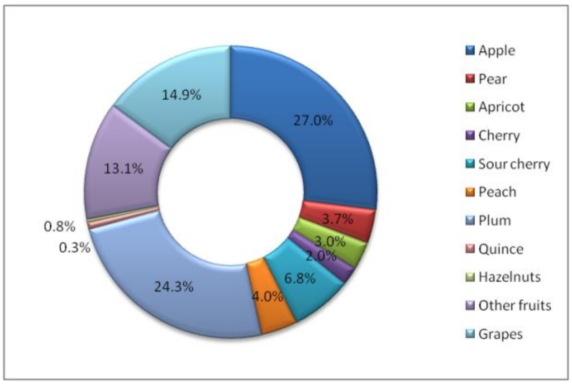

Figure 6.2. Structure of energy potential from cutting residues

6.2.1.3 Manure

Annual energy potential of manure is determined based on the number of animals, annual manure production per animal and yield of methane in manure[41] (Table 6.13., Figure 6.3.).

Table 6.13. Annual energy potential of manure

	Number of animals in thousands[42]		Production of manure per animal annually, t	Estimation of produced methane, m^3 per ton of manure	Total manure produced annually, in 10^3 t		Theoretical potential, toe		Technical potential, toe	
	2020	2021	/	/	2020	2021	2020	2021	2020	2021
Cattle	886	860	12.35	13.6	148,812.6	144,445.6	127,624.7	115,597.9	76,574.83	69,358.7
Pigs	2,983	2,868	1.6	14.4	68,728.3	66,078.7	58,942.8	52,881.9	35,365.7	31,729.1
Sheep/goat	1,685	1,695	0.5	48	40,440.0	40,680.0	34,682.2	32,555.6	20,809.31	19,533.4
Poultry	15,249	15,348	0.07	51.2	54,652.4	55,007.2	46,871.0	44,021.5	28,122.62	26,412.9
Total									**160.872,5**	**147.034,2**

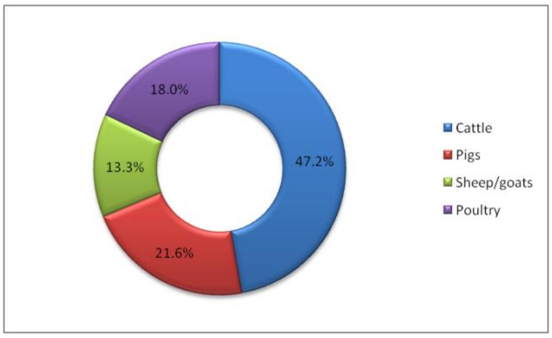

Figure 6.3. Structure of energy potential from manure in 2021

6.2.1.4 Oil plants

The total quantity of biodiesel that could be produced from oil plants such as soybean, sunflower and oil beats, according to data on area under crops and yields, is about 256.629 tons of biodiesel. Technical potential is estimated to 142.770 toe.

[41] http://biomasa.undp.org.rs/wp-content/uploads/2019/01/Agricultural-Biomass_12_01_2019_1_engleski.pdf
[42] https://data.stat.gov.rs/?caller=1305&languageCode=sr-Latn

6.2.1.5 Agricultural biomass energy potential – summary

The Table 6.14. summarizes the annual energy potential of agricultural biomass in Serbia.

Table 6.14. Annual potential of agricultural biomass in Serbia

Source	Annual energy potential, toe
Harvest residues	1.343.637,9
Pruning residues	133.394,1
Oil plants	142.770
Manure	147.034,2
Total	**1.766.836,2**

Total annual energy potential from agriculture in Serbia is assessed to be 1.766.836,2 toe (Table 6.14.). The major share (more than 75%) of agricultural biomass energy potential is originated from harvest residues.

6.2.2 Food processing industry

Additional source for energy recovery is food processing industry: dairy processing industry, livestock processing industry and sugar industry. Annual energy potential from these industry sub-branches is estimated to account for 17.070 toe[43].

6.2.3 Forestry

In the Republic of Serbia, there are 2.252.400 ha under forests. The ownership structure and natural increase (volumetric yield) are shown in Table 6.15.

Table 6.15. Ownership structure of forests in the Republic of Serbia

Ownership	Area		Volume yield		
	ha	%	m^3	%	m^3/ha
State-owned	896.400	39,80	4.241.214	47	4.7
Private	1.175.200	52,20	4.213.022	46	3.6
Other	180.800	8,00	625.537	7	3.5
Total	2.252.400	100	9.079.773	100	4

According to the data[44] in 2021, the volume of wood felled, shown by property sector, refers to the total gross volume of wood felled in state forests, private forests and felling of individual trees or groups of trees outside the forest.

The felled volume of wood, which is shown by types of felling, refers to the felling of trees in forests that was carried out in accordance with the previously approved plan and specific felling rate, Table 6.16. Data for the Region of Kosovo and Metohija are not available.

If we consider the consumed wood for heating households (1.428,1 ktoe) as well as industrial (173,5 ktoe), commercial (20,2) and agricultural and forestry (1,9 ktoe) sectors, it is seen that the remaining amount of wood for these purposes is only 33.6 ktoe, i.e. 390.4 GWh.

If the strategic decision was to use wood biomass in CHP plants or in district heating systems, an acceptable way of converting the existing fuel would have to be found for the households using fuel wood.

[43] http://biomasa.undp.org.rs/wp-content/uploads/2019/01/Agricultural-Biomass_12_01_2019_1_engleski.pdf
[44] Forestry in the Republic of Serbia, 2021

Table 6.16. Logging in forests and outside of forests by felling operators, 2021

Category	Total	Belgrade region	Region of Vojvodina	Region of Šumadija and Western Serbia	Region of Southern and Eastern Serbia
	m³	m³	m³	m³	m³
Total	**3,355,435**	**78,543**	**735,647**	**1,257,498**	**1,283,747**
Industrial and technical wood	1,342,807	51,090	427,805	554,811	309,101
Fuelwood	1,710,614	21,070	234,241	582,383	872,920
Residues	302,014	6,383	73,601	120,304	101,726
Forestry companies	**1,708,585**	**69,878**	**479,636**	**640,448**	**518,623**
Wood industry	**424,211**	**290**	**99,614**	**105,153**	**219,154**
Other companies	**189,454**	**-**	**70,617**	**71,037**	**47,800**
Citizens (retail)	**1,033,185**	**8,375**	**85,780**	**440,860**	**498,170**

Table 6.17. Wood felled inside Serbian forests – total, 2021

Category	Type of felling					Felled inside forests			
	Total felling	Regular felling			Occasional felling	High forests		Coppice forests	Other forest categories
		Overall	Regular felling	Thinning and clearing		Uneven-aged	Even-aged		
Total	3,335,761	3,083,183	2,024,550	1,057,633	252,578	597,441	1695,644	977,870	64,806
Pure stands of	2,491,508	2,305,716	1,547,988	757,728	185,791	321,577	1,470,240	641,105	58,586
Broadleaved	2,276,592	2,117,435	1,463,914	653,521	159,156	279,518	1,325,333	639,862	31,879
Coniferous	214,916	188,281	84,074	104,207	26,635	42,059	144,907	1,243	26,707
Mixed stands of	844,253	777,467	476,562	299,905	66,787	275,864	225,404	336,765	6,220
Broadwood	590,646	555,978	301,524	253,454	34,669	53,770	197,476	333,378	6,022
Coniferous	82,891	66,463	42,813	23,650	16,428	66,352	14,824	1,539	176
Broadleaved – coniferous	170,716	155,026	132,225	22,801	15,690	155,742	13,104	1,848	22

Any consideration of a more massive use of wood biomass in CHP plants or directly in district heating systems would leave individual households, currently heated directly with biomass, without fuel. Now, it does not make much sense considering the geographical distribution of these households, their ownership of small, unregistered forest plots from which they have been using firewood for years or a whole decade without control and making new plantations.

6.2.4 Civil sector (waste)

As part of the EU accession negotiations, the Republic of Serbia, through Chapter 27, has begun the process of establishing a waste management system and adapting it to the goals and acquis of the EU. The Waste Management Program in the Republic of Serbia for the period 2022-2031 was preceded by the Waste Management Strategy for the period 2010-2019, based on which the conditions were set for the establishment and development of an integrated waste management system in the Republic of Serbia. The goals set by this Strategy have not been fully achieved, primarily in the scope of organized waste collection, the degree of primary separation of waste and recycling, the construction of infrastructure and the cessation of waste disposal in unsanitary landfills and landfills, the application of economic instruments and the establishment of a sustainable waste management financing system.
Data on quantities, types and composition of waste represent the starting point in the waste management planning process. Regions for waste management are formed by the cooperation of local self-government units. Out of the 26 regions for waste management as foreseen by the measures of the Strategy, regional companies for waste management have been established in 13 regions, and another 12 regions have signed inter-municipal agreements, but no regional companies have been established in them yet. Some municipalities have joined other regions in relation to

those in which they were foreseen by the Strategy, while some regions are joining together. The level of changes required in institutions in the Republic of Serbia, in a relatively short period of time, is recognized as one of the main challenges for the successful implementation of the Landfill Directive, Table 6.17.[45]. Data on quantities, types and composition of waste represent the starting point in the waste management planning process, Table 6.18.

Table 6.18. Regions for waste management in the Republic of Serbia (Source: Specific plan for the implementation of EU Directive 1999/31/EC on landfills)

Region	Municipalities
Sremska Mitrovica	Bogatić, Ruma, Sremska Mitrovica, Šabac, Šid
Pančevo	Kovin, Kovačica, Opovo, Pančevo
Inđija	Inđija, Irig, Pećinci, Sremski Karlovci, Stara Pazova
Užice	Arilje, Bajina Bašta, Čačak, Čajetina, Ivanjica, Kosjerić, Lučani, Požega, Užice
Pirot	Babušnica, Bela Palanka, Dimitrovgrad, Pirot
Kikinda	Ada, Bečej, Kikinda, Nova Crnja, Novi Bečej
Lapovo	Despotovac, Lapovo, Rača, Svilajnac
Jagodina	Ćuprija, Jagodina, Paraćin, Smederevska Palanka, Velika Plana
Leskovac	Bojnik, Crna Trava, Lebane, Leskovac, Medveđa, Vladičin Han, Vlasotince
Subotica	Bačka Topola, Čoka, Kanjiža, Mali Iđoš, Novi Kneževac, Senta, Subotica.
Valjevo	Barajevo, Koceljeva, Lajkovac, Lazarevac, Ljig, Mionica, Obrenovac, Osečina, Ub, Valjevo, Vladimirci, Krupanj, Loznica, Mali Zvornik, Ljubovija
Zrenjanin	Sečanj, Titel, Žitište, Zrenjanin
Nova Varoš	Nova Varoš, Priboj, Prijepolje, Sjenica
Vranje	Bosilegrad, Bujanovac, Preševo, Surdulica, Trgovište, Vranje
Beograd	Čukarica, Grocka, Mladenovac, Novi Beograd, Palilula, Rakovica, Savski venac, Sopot, Stari Grad, Surčin, Voždovac, Vračar, Zemun, Zvezdara
Novi Sad	Bačka Palanka, Bački Petrovac, Beočin, Novi Sad, Srbobran, Temerin, Vrbas, Žabalj
Niš	Aleksinac, Gadžin Han, Kuršumlija, Doljevac, Žitorađa, Merošina, Niš, Prokuplje, Ražanj, Sokobanja, Svrljig
Sombor	Apatin, Bač, Kula, Odžaci, Sombor
Vršac	Alibunar, Bela Crkva, Plandište, Vršac
Zaječar	Boljevac, Bor, Kladovo, Knjaževac, Majdanpek, Negotin, Zaječar
Smederevo	Golubac, Smederevo, Veliko Gradište
Kragujevac	Aranđelovac, Batočina, Gornji Milanovac, Knić, Kragujevac, Topola, Rekovac
Kraljevo	Kraljevo, Vrnjačka Banja, Trstenik
Raška	Novi Pazar, Raška, Tutin
Kruševac	Aleksandrovac, Brus, Ćićevac, Kruševac, Varvarin, Blace
Požarevac	Kučevo, Malo Crniće, Petrovac, Požarevac, Žabari, Žagubica

Table 6.19. Quantities of materials from municipal waste by group

Municipal waste	Generated utility waste	Separate collection	Preparation for reuse	Recycling	Energy utilization	Other utilization
	t					
Total	**2,947,496**	**482,515**	**0**	**455,457**	**5.86**	**16.58**
Metals	153,848	47,853	0	47,288	66	22
Metals separated after waste incineration	0	0	0	0	0	0
Glass	120,838	22,238	0	21,998	0	0
Plastic	356,021	55,293	0	45,219	3,606	6,012
Paper and cardboard	382,802	229,973	0	225,049	2,025	626
Bio waste	1,179,870	11,469	0	11,183	71	102
Bio-waste separated and recycled at source	0	0	0	0	0	0
Wood	99,429	27,945	0	17,867	89	9,808
Textiles	81,405	61	0	60	0	0
Electrical and electronic equipment	166,698	60,704	0	60,094	3	0
Batteries	70	21	0	20	0	0
Bulky waste	1,359	422	0	418	0	0
Mixed waste	354,957	0	0		0	0
Other	50,199	26,536	0	26,261	0	10

[45] Waste management program in the Republic of Serbia for the period 2022 - 2031

In the Republic of Serbia, construction of three plants for controlled burning of municipal waste is planned. Construction of one plant is underway in Belgrade, with an incineration capacity of 340,000 t/year, with an installed electricity production capacity of 25 MW and a heat production capacity of 56 MW. The design of plants for controlled incineration of municipal waste and production of electricity and heat from non-recyclable waste is underway in Niš and Kragujevac. Lines for secondary separation of waste exist in some local governments: Belgrade, Novi Sad, Subotica, Sremska Mitrovica, Pirot, Užice, Jagodina and Leskovac and others with smaller capacity and functionality.

The calculation of the total amount of municipal biodegradable waste in the Republic of Serbia is based on the results obtained based on measurements and analyses of the composition of waste in the municipalities of the Republic of Serbia. The following sources of biodegradable municipal waste were identified to be considered: garden waste and food waste (100%), paper and cardboard (90%) and all remaining waste (35%) which contains biodegradable categories such as textiles, wood, leather, fine elements, etc. The amount of biodegradable waste originating from parks and public areas should also be considered. In the Republic of Serbia, in 2008 (as a potential reference year), about 67.5% of the total amount of municipal waste was biodegradable waste, what corresponds to the mass of 1,602,525 tons, i.e. 214 kg per inhabitant per year. The projections of the quantities of municipal waste that will be generated by 2030 take into consideration changes in the number of inhabitants and changes in the standard of living of citizens, Table 6.19. Using the results obtained by modelling, the projected values of the generated biodegradable municipal waste as of 2030 are shown in Table 6.20.[46]

Table 6.20. Projected quantities of generated municipal waste for the Republic of Serbia in the period from 2022 to 2030

Year	Amount of generated waste		
	kg/resident/day	kg/resident/ year	tons per year
2022	1.19	434.3	3.033.876
2023	1.21	442.0	3.080.319
2024	1.23	450.0	3.129.084
2025	1.26	458.4	3.180.295
2026	1.28	467.1	3.234.082
2027	1.30	476.1	3.290.582
2028	1.33	485.5	3.349.939
2029	1.36	495.4	3.412.307
2030	1.39	505.6	3.477.846

Table 6.21. Projection of the quantity of biodegradable municipal waste for Serbia in the period from 2022 to 2030 (t/year)

Year	Total - municipal waste (t/year)	Different sources of biodegradable municipal waste (t/year)				Total biodegradable waste (t/year)
		Bio-waste (garden and food))	Paper and Cardboard	Other (textile, wood, leather, fine elements, etc.)	Green waste (parks and public areas)	
2008* - potential reference year	2.374.375	1.602.525				
2022	3,033,876	1,181,580	360,328	271,778	91,016	**1,904,702**
2023	3,080,319	1,183,116	368,705	275,947	92,410	**1,920,178**
2024	3,129,084	1,185,130	377,422	280,294	93,873	**1,936,718**
2025	3,180,295	1,187,640	386,497	284,827	95,409	**1,954,373**
2026	3,234,082	1,190,665	395,950	289,556	97,022	**1,973,193**
2027	3,290,582	1,194,223	405,803	294,490	98,717	**1,993,234**
2028	3,349,939	1,198,335	416,078	299,639	100,498	**2,014,550**
2029	3,412,307	1,203,021	426,798	305,014	102,369	**2,037,202**
2030	3,477,846	1,208,302	437,989	310,625	104,335	**2,061,251**

[46] Waste management program in the Republic of Serbia for the period 2022 – 2031

6.3 Waste heat from industrial sites

The waste heat from industrial site is considered part of the heat content of all streams (gas, water, air, etc.) which are discharged from an industrial process at a given moment and that can be internally or externally usable heat, technically and economically[47]. Sources for waste heat in industries can be single machines or whole systems that release waste heat into the environment. These sources include furnaces, waste water from washing, drying or cooling processes, and also refrigeration systems, motors or the exhaust air from production halls[48]. Depending on characteristics, waste heat can be used for power generation, and for heating/cooling (without upgrading or after upgrading, by heat pumps).

The data about waste or surplus heat from industrial installations is not systematically recorded in international and national energy statistics. Waste heat recovery potential is sector-specific and even for a same product depends on site-specific process routes[49]. Therefore, different approaches to estimating the industrial waste heat potential are applied (Figure 6.4.). In general, these approaches can be considered as top-down and bottom-up.

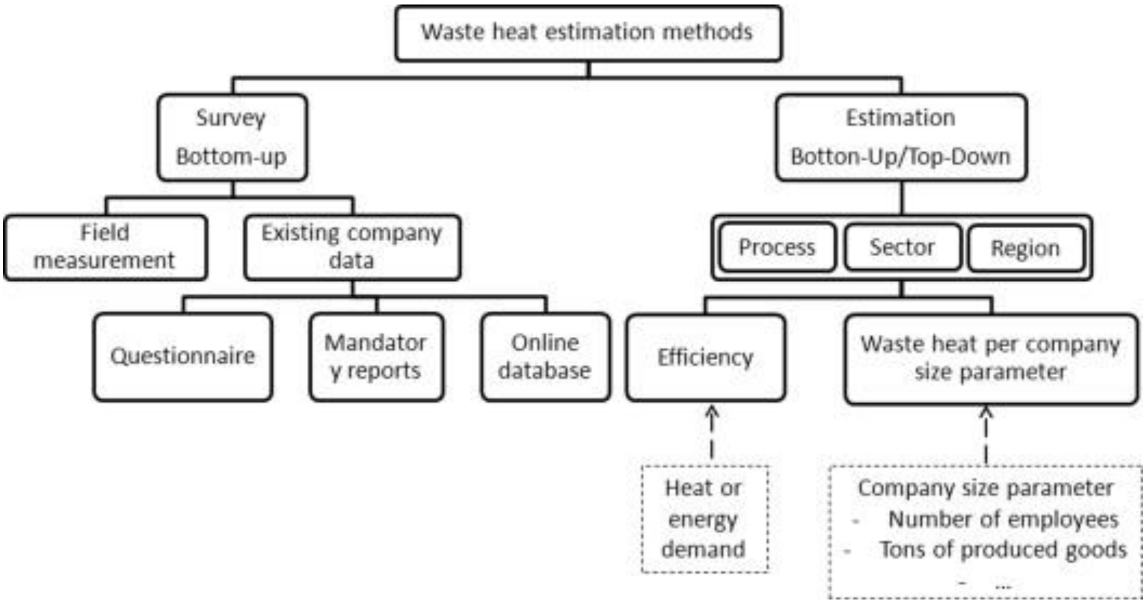

Figure 6.4. Classification of approaches for industrial waste heat determination[50]

Top-down approach is based on the use of primary energy, the assumptions about energy efficiency and energy distribution. It allows only rough estimation of the potential of waste heat in different industry sectors, without conclusions about the temperature and availability of waste heat.
Bottom-up approach is based on specific data on representative companies collected through questionnaires or even measurements. Depending on the level of detail of the questionnaire, this method allows conclusions to be drawn about the technical potential of a particular company or sector. Measurements are the most complex method. Several companies/sites need to be reviewed and re-measured and there may be a conflict with the confidentiality of process data[51]. Mentioned approaches could also be combined.
For estimation of waste heat from the energy input of the industrial facility recoverable in district heating systems, the procedure proposed in literature[52] will be used. This procedure is a combination of bottom-up and top-down approaches. The scheme of the procedure is presented in Figure 6.5.

[47] Industrial Excess Heat Recovery –Technologies and Applications. Final report Phase 1, 5 May 2015. Prepared by Thore Berntsson CIT Industriell Energi AB, Sweden, Anders Åsblad CIT Industriell Energi AB, Sweden. Supported by Denmark, Germany, Norway, Portugal, US and Sweden.
[48] Brueckner et all., Methods to estimate the industrial waste heat potential of regions – A categorization and literature review, Renewable and Sustainable Energy Reviews, Volume 38, October 2014, Pages 164-171
[49] Jakubcionis, M., Santamaria, M., Kavvadias, K., Piers de Raveschoot, R., Moles, C., Carlsson, J., Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level; EUR 27605 EN, doi: 10.2790/79453
[50] Brueckner et all., Methods to estimate the industrial waste heat potential of regions – A categorization and literature review, Renewable and Sustainable Energy Reviews, Volume 38, October 2014, Pages 164-171
[51] Possibilities of using waste heat and waste cooling in the heating and/or cooling sector and the assessment of Estonia's potential for efficient district heating and cooling, Final report, KPMG, 2021.
[52] Denarie et all., Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy, Smart Energy, 1(2001), 100008

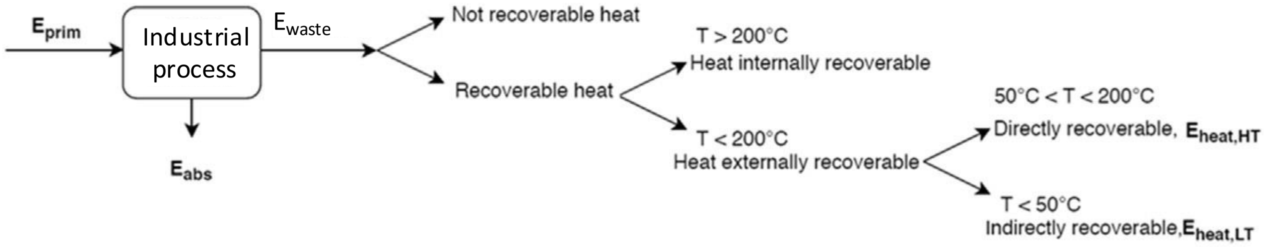

Figure 6.5. Procedure for calculating the industrial waste heat, recoverable in a district heating system[53]

In order to calculate the technical potential, some recovery factors η_{tech} need to be applied; they consider the technological efficiencies in the recovery process, such has heat exchanger efficiency, and the eventual temperature upgrade.

$$E_{heat,tech}=\eta_{tech} \cdot (E_{heat,steam} + E_{heat,HT} + \eta_{HP} \cdot E_{heat,LT}) \text{ [MWh]} \qquad (6.1)$$

The technical recovery potential of waste heat calculated through (6.1) represents the fully recoverable waste heat considering heat quality and technological efficiency.

Simplified method to take into account the time correspondence between waste heat availability and the heat demand in DH. The time dependent profile of heat effluents in the production plants is often quite flat and so it does not match with the required heat profile by users in a DH system. Therefore, to have a full recovery of $E_{heat,tech}$ an important storage capacity would be required. The recovery in DH is precautionarily considered without the inclusion of a seasonal storage so that the correspondence in time is taken into account by considering the ratio between the equivalent operating hours hh of the industrial process, usually around 7,000 ($hh_{process}$), and of DH, which have been considered as 2,500 (hh_{DH}) for Serbia. Only the fraction (25%) of waste heat coming from steam processes is considered to be available for external waste heat recovery. The majority of the high-level temperature waste heat is going to be recovered internally.

The equation can be rewritten considering the technological integration in DH, which is direct in case of high temperature levels of waste heat, or indirect, needing a heat pump, in case of low temperature waste heat so that the final heat recoverable in DH:

$$E_{heat,DH} = E_{heat,HT,DH} + \eta_{HP} \cdot E_{heat,LT,DH} = E_{prim} \cdot (\eta_{DH,HT} + \eta_{DH,LT} \cdot \eta_{HP}) \cdot hh_{DH}/hh_{process} \qquad \text{[MWh] (6.2)},$$

Where is:

$\eta_{DH,HT} = \eta_{tech} \cdot (25\% \eta_{steam} + \eta_{HT})$ and $\eta_{DH,LT} = \eta_{tech} \cdot \eta_{LT}$.

In literature[54,55,56,57] , for the cases when gathering of data from individual industrial installations is not available, the proposed methodology for determination of industrial waste heat is based on combined approach and on using of site-specific data contained in the EU ETS database for determination of primary energy consumption (E_{prim}), but such data do not exist. For the estimation of primary energy input consumed by the specific industry sub-sectors the data taken from national energy balances are used. It is assumed that the primary energy consumption in the specific sub-sector (Table 6.22.) is equal to final energy consumption reduced by final electricity and heat consumption. It means that the electricity is used mainly for purposes with the low ability for energy recovery (mechanical work, lighting, etc.), and that the heat is used with a high efficiency.

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53 Denarie et all., Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy, Smart Energy, 1(2001), 100008

54 Jakubcionis, M., Santamaria, M., Kavvadias, K., Piers de Raveschoot, R., Moles, C., Carlsson, J., Best practices and informal guidance on how to implement the Comprehensive Assessment at Member State level; EUR 27605 EN, doi: 10.2790/79453

55 Denarie et all., Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy, Smart Energy, 1(2001), 100008

56 Persson et all., Heat Roadmap Europe: Identifying strategic heat synergy regions, Energy Policy, Vol. 74, November 2014, Pages 663-681

57 R.C.McKennaJ.B.Norman, Spatial modelling of industrial heat loads and recovery potentials in the UK, Energy Policy, Vol. 38, Issue 10, October 2010, Pages 5878-5891

Table 6.22. Estimation of primary energy consumption (E_{prim}) by the specific industry sub-sectors in the Republic of Serbia in 2021

Industry sub-sector	E_{prim} (MWh)
Iron and steel	2,070,943
Chemical and petrochemical	1,761,178
Non-ferrous metals	411,193
Non-metallic minerals	2,583,812
Transport equipment	59,315
Machinery	568,539
Food, beverages and tobacco	2,982,523
Paper, pulp and printing	372,010
Wood and wood products	130,126
Textiles and leather	653,857
Not elsewhere specified (Industry)	419,101

The calculation of waste heat according to different temperature levels is calculated through the coefficients (Table 6.23.) These coefficients have been derived by the study[58] for the specific industrial categories. The result, the estimation of waste heat from industrial sites in the Republic of Serbia that could be recovered directly in district heating systems (Table 6.24.), obtained by the proposed methodology and by using equation.

Table 6.23. Recovery coefficients defined by industrial sector, according to the temperatures of both the heat source and district heating system[59]

Activity Sector	Waste heat				DH recovery	
	η_{steam}	η_{HT}	η_{LT}	η_{loss}	$\eta_{DH,HT}$	$\eta_{DH,LT}$
Fuel supply and refineries	–	–	–	–	28.10%	–
Food products and beverages	18.20%	3.60%	28.10%	2.10%	6.10%	21.10%
Pulp, papers and printing	36.10%	7.90%	0.50%	1.80%	12.70%	0.30%
Basic chemicals	8.30%	11.20%	6.50%	–	9.90%	4.90%
Other non-metallic mineral products	6.40%	11.00%	2.60%	–	9.50%	2.00%
Capital goods manufacturing	7.80%	7.80%	7.80%	2.60%	7.30%	5.90%
Fine chemical products	12.50%	16.80%	9.80%	–	14.90%	7.30%
Iron and steel	3.50%	3.50%	3.50%	1.20%	3.30%	2.70%
Fabricated metals products	4.50%	4.50%	4.50%	1.50%	4.20%	3.30%
Textile	7.80%	7.80%	7.80%	2.60%	7.30%	5.90%
Others	15.60%	15.60%	15.60%	5.20%	14.60%	11.70%

Table 6.24. Waste heat from industrial sites in Serbia that could be recovered directly in district heating systems[60]

Industry sub-sector	High temperature water recoverable waste heat	Low temperature water recoverable waste heat	Total heat for district heating systems*
	$E_{heat,HT,DH}$ (MWh)	$E_{heat,LT,DH}$ (MWh)	$E_{heat,DH}$ (MWh)
Iron and steel	24,408	19,970	50,967
Chemical and petrochemical	62,270	30,821	103,262
Non-ferrous metals	4,846	3,965	10,120
Non-metallic minerals	87,665	18,456	112,211
Transport equipment	1,546	1,250	3,209
Machinery	8,528	6,701	17,440
Food, beverages and tobacco	64,976	224,754	363,900
Paper, pulp and printing	16,873	399	17,403
Wood and wood products	5,902	139	6,088
Textiles and leather	17,047	13,778	35,371
Not elsewhere specified (Industry)	21,853	17,512	45,145
Total	**315,915**	**337,744**	**765,115**

58 M. Berthou, D. Bory, Overview of waste heat in the industry in France, (2012), pp. 453-459
59 Denarie et all., Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy, Smart Energy, 1(2001), 100008
60 Denarie et all., Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy, Smart Energy, 1(2001), 100008

* Recovery of low-temperature waste heat was assumed by utilization of heat pumps with COP = 4.

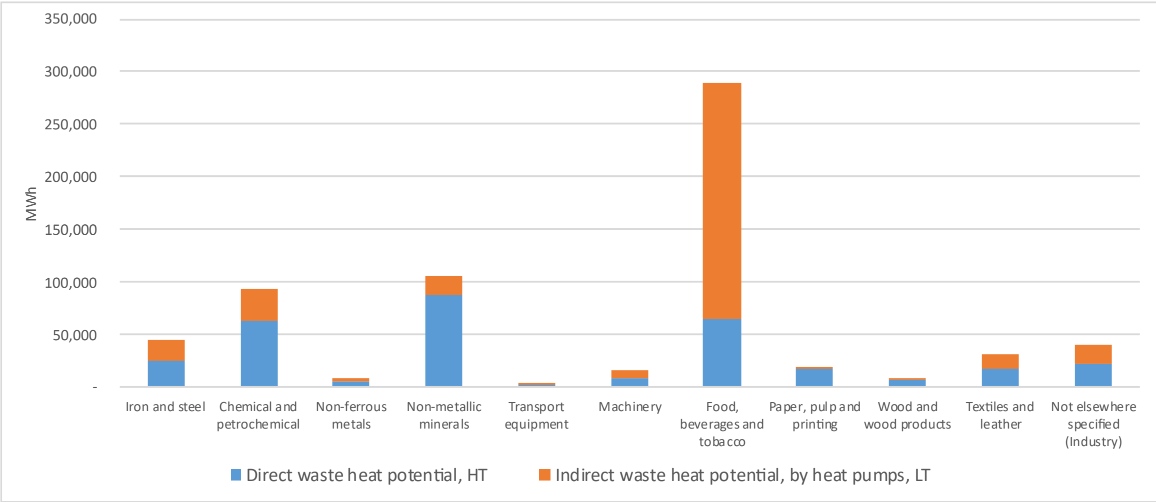

Figure 6.6. Waste heat from industrial sites in the Serbia that could be recovered directly in district heating systems

7. Technical potential for HE CHP

7.1 Method used to analyse the technical potential for high-efficiency CHP and key for interpreting results

The assessment of the potential for developing high-efficiency cogeneration has been done based on an analysis of the characteristics of energy consumption in the residential, services, and industrial sectors. All necessary data about the electric and thermal energy demand of consumers in these sectors are included.

Analysis of the existing consumption enables the identification of the consumers suitable for the installation of CHP systems and assessment of the size of CHP systems, as well as the energy that can be produced in these facilities. The first phase is the identification of the technical potential for HE CHP development. This potential corresponds to the greatest share of heat demand which, based on technical constraints, can be met by CHP installations, regardless of any economic-financial consideration. In detail, the technical potential has been assessed through the following steps[61]:

1. Selection of consumers suitable for cogeneration. The selection includes the determination of indicators and technical constraints (the heat demand, available installation, required temperature of the heat, heat/electricity ratio, installation constraints, etc.);
2. Selection of the size of the CHP facility and simulation of its operation. This means assumptions of the typical heat demand and applying specific performance indicators obtained from the installations in operation;
3. Estimation of the maximum amount of electricity and heat technically obtainable in the sectors where HE CHP could be installed.

7.2 HE CHP potential in the residential sector

In the Republic of Serbia, 293,523 households have an individual connection to natural gas, while the total potential, is somewhere close to 1,000,000 households. The following structure is considered for assessment: residential buildings with 1 dwelling - 95%, residential buildings with 2 dwellings - 2%, and residential buildings with 3 and more dwellings (8 dwellings) - 3%. The following table summarizes the structure of residential buildings in Serbia, as well as the investments needed for applying CHP in these buildings.

Table 7.1. CHP potential in the residential sector – number of buildings and needed investment

Residential	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings (8 dwellings)
Number of buildings	671,153	7,065	2,649
Investment (€)	5,369,224,000	84,780,000	104,503,050

The data presented in the above table are based on the following assumptions. The number of households assessed as potential for wood conversion with micro CHP is 706,477. Of these, 95% are residential buildings with 1 dwelling, 2% residential buildings with 2 dwellings and 3% Residential buildings with 3 and more dwellings (8 dwellings).

7.2.1 Characteristics of heat demand in the residential sector

The characteristic heat consumption of the residential sector is given according to the data submitted to Eurostat. The National Fund includes 2,423,208 inhabited dwellings according to the 2011 Census.

The case of applying CHP to residential buildings from Table 7.1. was considered, whose annual consumption of thermal energy is 15,795 kWh, 28,817 kWh and 69,073 respectively, while annual consumption of electricity in households of the Republic of Serbia is at the level of 420 kWh/month.

[61] Gestore dei Servizi Energetici, Assessment of the National Potential for High-Efficiency Cogeneration and Efficient District Heating, December 2015

7.2.2 Technical potential in the residential sector

Residential buildings with 1 dwelling, with 2 dwellings and with 3 and more dwellings were treated, with individual average areas of apartments of 85 m^2, 73 m^2 and 56 m^2 respectively. Equivalent operating hours of HE CHP imply the number of hours during which the CHP plant operates at full capacity. CHP systems are dimensioned so that all available thermal energy is used, because there is no heat energy market in the Republic of Serbia and there is no possibility to market it to other customers. Excess electricity will be returned to the electricity grid. The selected CHP systems for simulation, with their thermal and electrical efficiency levels, are shown in Table 7.2.

Table 7.2. Technical parameters for "typical" HE CHP systems in the residential sector for categorized average areas

Value / Building type	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings (8 dwellings)
Electrical capacity of CHP system (kWe)	2	4	15
Thermal capacity of CHP system (kWt)	5.41	9.87	23.66
Heat/electricity ratio of the system	2.7	2.5	1.6
Electrical efficiency of CHP system	24.29%	26.24%	35.70%
Thermal efficiency of CHP system	65.71%	64.76%	56.30%
Total efficiency of CHP system	90%	91%	92%
Equivalent hours under HE CHP (h)	2,920	2,920	2,920

The difference between the produced and required thermal energy is negligible, and excess electricity, with the amounts of 800 kWh, 1,600 kWh and 3,480 kWh respectively, is handed over to the electric network, thus benefitting from a faster return on investment.

Table 7.3. Energy from the simulation of CHP system operating conditions and annual consumption in the residential sector

Value / Building type	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings (8 dwellings)
Heat produced by the CHP system (kWh/year)	15,797	28,820	69,076
HE CHP electricity produced by the CHP system (kWh/year)	5,840	11,680	43,800
Annual heating energy demand (kWh/year)	15,795	28,817	69,073
Annual electricity demand (kWh/year)	5,040	10,080	40,320
Excess electricity (kWh/year)	800	1,600	3,480
Excess heating energy (kWh/year)	2	3	2
Electricity injected into the grid (kWh/year)	800	1,600	3,480
Self-consumed electricity (kWh/year)	5,040	10,080	40,320
Consumption of HE CHP system (kWh/year)	24,041	44,506	122,691

The following table summarizes applicable investment and O&M costs, useful life of a CHP system, as well as utility prices (natural gas, off-taken electricity). Specific investment values of CHP systems are taken from the literature[62].

[62] Application of a cost-benefit model to evaluate the investment viability of the small-scale cogeneration systems in the Portuguese context, 2021 and CODE2 Cogeneration Observatory and Dissemination Europe Micro-CHP potential analysis European level report

Table 7.4. Basic costs and fuel prices

Value / building type	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings (8 dwellings)
Specific Inv. cost of CHP system (€/kW)	4,000	3,000	2,630
Investment costs (€/dwelling)	8,000	12,000	39,450
CHP O&M annual cost (€/year)	192	288	946.8
Useful life of CHP system (hours of operation)	58,400	58,400	58,400
Useful life of CHP system (calendar years)	20	20	20
Price of CHP gas (€/MWh)	34.76	34.76	34.76
Price of offtaken electricity (€/MWh)	86.91	86.91	86.91

Residential buildings that make sense to treat as technical potential for replacing current wood heating with a new micro HE CHP on natural gas, as well as their annual needs and costs of firewood, are shown in Table 7.5.

Table 7.5. Energy costs of dwellings in Serbia, currently heated by fuelwood

Energy cost - current situation	Residential buildings with 1 dwelling	Residential buildings with 2 dwellings	Residential buildings with 3 and more dwellings (8 dwellings)
Wood average consumption m^3/year	8.78	17.56	39.00
Wood price (€/m^3)	80.00	80.00	80.00
Heating energy costs (€/a)	702.40	1,404.80	5,619.20
Total CHP system consumption (MWh/a)	24.04	44.51	122.69

7.3 Potential for HE CHP in the services sector

The potential for HE CHP in the service sector was estimated by characterizing the demand for thermal energy. Through this analysis, with the application of technically logical factors and limitations, an assessment of the identification of the share that could technically be satisfied by high-efficiency cogeneration was given. This share is defined as technical potential. By economic analysis of feasibility according to different scenarios of installation of CHP facilities, the economic potential, in terms of production of the amount of heat using HE CHP from the installed units, was examined.

7.3.1 Characterisation of heat demand in the services sector

In 2021 the consumption of thermal energy in the services sector considered to be of interest for this study was 4,402.4 GWh. Observed by sub-sectors, heating is used in health facilities (11.24%), sports facilities (11.18%), hotels (about 6%) and public services (19%). According to the consumption level, the average size of the demand points and the typical annual consumption profile, the most promising sub-sectors for HE CHP installations are healthcare, hotels and a subset of sports facilities, namely swimming pools, i.e. where the highest number of equivalent working hours can be realized. The aggregate consumption of these sub-sectors amounts to about 29% of the total heating consumption by services. Natural gas covered almost 75% of the consumption in the services sector in year 2021. The share of oil derivatives was 14%, and the heat obtained from renewable energy sources, i.e. biomass, was about 6%. Reference fuels, where natural gas CHP plants can be installed, are heavy fuel oil and natural gas.

7.3.2 Technical potential in the services sector

The analysis was done by selecting those customers with high simultaneous demand for both heat and electricity, such as hospitals, sports facilities and hotels. Among the sports facilities, only those with swimming pools were selected, because they have a high consumption of energy with a very high consumption of heat throughout the year, and previously they used fuel oil or natural gas only to satisfy their heating needs. These consumers tend to have a high demand for heat energy throughout the year, not just in the winter months, this significantly increases the operating hours of the CHP system, and therefore reduces the time for return on investment. Table 7.6. summarizes the annual energy demands of health service facilities, hotels and sports facilities in Serbia.

Table 7.6. Energy demand from standard customers in the services sector

Annual demand	Health service facility			Hotels		Sports facilities
	Health centre	Hospital	Clinical centre	Small hotel	Large hotel	Swimming pool
Heating energy (MWh)	168	5,250	14,700	400	2,000	2,919
Electricity (MWh)	80	2,500	7,000	133	700	1,776

When selecting HE CHP equipment, the energy demand points of the listed sub-sectors were considered, Table 7.7.The catalogue of TEDOM Group[63] was used. The operating conditions have been simulated in such a manner that a heating boiler fired on fuel oil was not used, and the surplus of produced electricity is delivered to the electricity distribution grid.

Table 7.7. Technical parameters and energy outputs of HE CHP systems for the services sector

Value / Facility	Health service facility			Hotels		Sports facilities
	Health Centre	Hospital	Clinical centre	Small hotel	Large hotel	Swimming pool
Electrical capacity of CHP system (kWe)	50	1,092	2,875	104	430	528
Thermal capacity of CHP system (kWt)	81	1,300	3,450	155	668	738

[63] https://www.tedom.com/en/chp-units/natural-gas/

Heat/electricity ratio of the system	1.62	1.19	1.20	1.49	1.55	1.40
Electrical efficiency of CHP system	0.36	0.42	0.42	0.37	0.37	0.39
Thermal efficiency of CHP system	0.59	0.51	0.51	0.55	0.57	0.55
Total efficiency of CHP system	0.95	0.93	0.93	0.92	0.94	0.94
Equivalent hours under HE CHP (h/year)	2,950	4,260	4,300	2,700	3,000	3,800
Thermal efficiency of boilers (heavy oil)	0.82	0.82	0.82	0.82	0.82	0.82
Heat produced by the CHP system (MWh/year)	238.95	5,538	14,835	418.5	2,004	2,804.4
Heat generated by backup boiler (MWh/year)	0	0	0	0	0	114.6
HE CHP electricity produced by the CHP system (MWh/year)	147.50	4,651.92	12,362.50	280.80	1,290.00	2,006.40
Electricity injected into the grid (MWh/year)	67.5	2,151.92	5,362.5	147.8	590	230.4
Electricity exchanged with the grid (MWh/year)	67.5	2,151.92	5,362.5	147.8	590	230.4
Consumption of HE CHP system (MWh/year)	406.79	10,945.13	29,313.97	760.11	3,489.41	5,101.59
Consumption of backup boiler (MWh/year) -heavy oil	0	0	0	0	0	114.6
Electricity price (€/MWh)	136.33	136.33	136.33	136.33	136.33	136.33
Natural gas price (€/MWh)	36.13	36.13	36.13	36.13	36.13	36.13
Specific Inv. cost of CHP system (€/kW)	2,200	1,400	1,200	2,200	1,650	1,400
Investment costs (€)	110,000	1,528,800	3,450,000	228,800	709,500	739,200
Heavy oil (€/kg)	0.81	0.81	0.81	0.81	0.81	0.81

The total number of facilities in terms of potential for HE CHP in the services sector is shown in Table 7.8.

Table 7.8. Potential number of CHP facilities in the services sector

Service	Health service facility			Hotels		Sports facilities
	Health Centre	Hospital	Clinical centre	Small hotel	Large hotel	Swimming pool
Number	32	36	1	60	60	34
Investment (€)	3,520,000	55,036,800	3,450,000	13,728,000	42,570,000	25,132,800

7.3.3 Demand evolution scenarios in the services sector and impact on analysis of potential

Final consumption in the service sector should decrease in the period 2021-2030, mainly because of the implementation of energy efficiency measures, especially when it comes to heat energy. This trend is very likely, because only the number of commercial supermarket chains can be expected to increase. The decrease in consumption expected in all sub-sectors of the service sector will affect the technical potential of HE CHP. The expected decrease in consumption is a consequence of building envelope measures (adding insulation, replacing windows), low temperature DH, replacing of pipelines, consumption-based billing. Therefore, no increase in facilities in this sub-sector is expected.

7.4 Potential for HE CHP in the industrial sector

Due to the permanent and simultaneous demand for electricity and heat throughout the year, the industry should be the optimal sector for CHP implementation. The survey of energy consumption in the various industrial sub-sectors, and their demand for electricity and heat, is the starting point in the analysis of the potential for the development of high-efficiency cogeneration in the industrial sector. In the case of Serbia, this survey was based on EUROSTAT/SORS[64] energy balances, as there is no deeper research per sub-sectors or individual companies.

Estmation of the technical potential for HE CHP in the industry sub-sectors has been done based on the specific consumption of 'typical' companies and the method for optimization of the HE CHP technology in each sub-sector. An economic feasibility analysis determined the share of the technical potential of HE CHP which is sustainable from the economic viewpoint in each industrial sub-sector considered, and in the overall industrial sector.

7.4.1 Characterisation of heat demand in the industrial sector

Total final energy consumption in the Serbian industry sector amounted to 24,575 GWh in 2021. The trend of energy consumption in the last 10 years (Figure 7.1.) shows a relatively low variation in consumption per industry sub-sector and a relatively constant share of sub-sectors in total consumption.

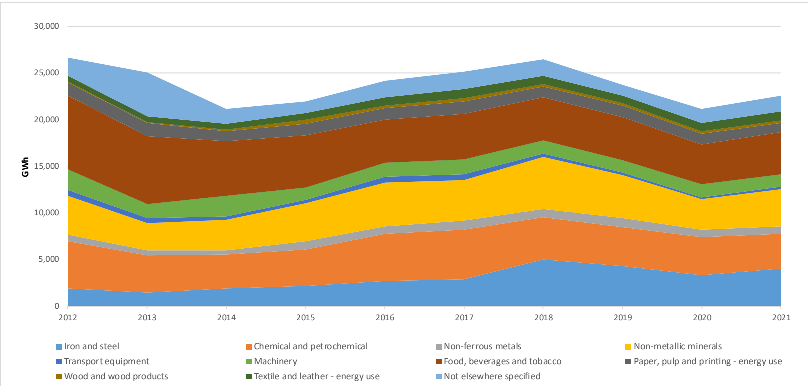

Figure 7.1. Energy consumption in industry per subsectors, 2012-2021

Calculated heat demand in the Serbian industry sector in the year 2021 amounted to 11,825.5 GWh. This is a sum of heat, produced in the industry sector by fuel consumption, and the heat that industry entities take over from other sources. Heat demand is mainly covered by the direct consumption of fossil fuels 81%. The remainder, about 19%, is derived heat (which includes the heat produced in cogeneration mode in industry entities and externally). The electricity demand of the Serbian industry is mainly covered by off-taking from the national grid and is presented in Table 7.9. According to the official energy balance, only about 5.5% of used electricity is self-produced, but it is not visible, from the energy balance, in which sub-sector the self-production exists. Four sub-sectors with the highest share in heat and electricity demand are Iron and steel, Chemical and petrochemical, Non-metallic minerals, and Food, beverages, and tobacco. Their heat demand is 77.55% of the total industry demand, while in electricity it amounts to 55.3%. This means that these four sub-sectors should be of special interest for HE CHP introduction.

Table 7.9. Heat and electricity demand in Serbian industry (2021) by sub-sectors

Sub-sector	Heat							Electricity		
	Supplied		Produced		Total					
	ktoe	GWh	ktoe	GWh	ktoe	GWh	%	ktoe	GWh	%
Iron and steel	55.94	650.58	150.91	1,755.08	206.9	2,405.7	20.34	129.4	1,504.92	16.04%
Chemical and petrochemical	59.71	694.43	124.88	1,452.35	184.6	2,146.8	18.15	108.9	1,266.51	13.50%
Non-ferrous metals	7.02	81.64	27.79	323.20	34.8	404.8	3.42	29.7	345.41	3.68%

[64] Statistical Office of the Republic of Serbia

Non-metallic minerals	1.19	13.84	170.77	1,986.05	172.0	1,999.9	16.91	74.0	860.62	9.17%
Transport equipment	0.89	10.35	3.99	46.40	4.9	56.8	0.48	17.2	200.04	2.13%
Machinery	0.50	5.82	36.54	424.96	37.0	430.8	3.64	74.8	869.92	9.27%
Mining and Quarrying	0.00	-	1.89	21.98	1.9	22.0	0.19	46.8	544.28	5.80%
Food, beverages and tobacco	26.71	310.64	198.39	2,307.28	225.1	2,617.9	22.14	133.7	1,554.93	16.58%
Paper, pulp and printing	17.11	198.99	26.81	311.80	43.9	510.8	4.32	34.7	403.56	4.30%
Wood and wood products	0.02	0.23	7.32	85.13	7.3	85.4	0.72	12.8	148.86	1.59%
Construction	0.00	-	1.20	13.96	1.2	14.0	0.12	29.7	345.41	3.68%
Textiles and leather	1.12	13.03	45.51	529.28	46.6	542.3	4.59	30.5	354.72	3.78%
Not elsewhere specified (Industry)	22.23	258.53	28.37	329.94	50.6	588.5	4.98	84.5	982.74	10.46%
Total	**192.4**	**2,238.1**	**824.3**	**9,587.4**	**1,016.8**	**11,825.5**	**100**	**806.55**	**9,381.92**	**100%**

To assess the technical potential for HE CHP it is necessary to carry out an in-depth analysis of the demand for heat and power in these sub-sectors. In the absence of more detailed studies, for specific processes in industrial sub-sectors, their specific energy consumption, process heating temperature distribution, and the share of total electricity demand used for process heat are taken from the references and presented in Table 7.10.

Table 7.10. Specific energy consumption, process heating temperature distribution and the share of total electricity demand used for process heat[65]

Sub-sector	Process	Energy demand		Share of electricity demand used for process heat	Temperature distribution				
		Fuels (MWh/t)	Electricity (MWh/t)		< 100°C	100 - 200°C	200 - 500°C	500-1000°C	> 1000°C
Iron and steel	Sintering	0.622	0.036	0.00	-	-	0.20	0.80	-
	Blast furnace	3.233	0.167	0.00	0.01	0.01	0.11	0.20	0.67
	Electric arc furnace	0.272	0.633	0.95	-	0.01	-	0.10	0.89
	Rolled steel	0.664	0.167	0.10	-	-	-	0.20	0.80
	Coke oven	0.889	0.033	0.00	-	-	-	0.20	0.80
	Smelting reduction	4.167	0.117	0.00	-	-	-	0.20	0.80
	Direct reduction	4.167	0.117	0.00	-	-	0.20	0.80	-
Non-metallic minerals	Container glass	1.606	0.392	0.04	0.02	0.19	0.19	0.30	0.30
	Flat glass	3.033	0.922	0.00	0.02	0.21	0.43	0.12	0.22
	Fiber glass	1.367	0.503	0.20	0.02	0.19	0.19	0.30	0.30
	Other glass	3.189	1.403	0.17	0.02	0.22	0.22	0.22	0.32
	Houseware, sanitary ware	6.732	1.338	0.01	0.30	-	-	0.05	0.65
	Technical, other ceramics	3.364	0.897	0.01	0.30	0.15	0.15	0.25	0.15
	Tiles, plates, refractories	1.517	0.246	0.01	0.07	0.11	0.07	0.18	0.57
	Clinker calcination-dry	0.972	0.039	0.00	-	-	0.10	0.60	0.30
	Clinker calcination-semidry	1.111	0.044	0.00	-	-	0.10	0.60	0.30
	Clinker calcination-wet	1.528	0.044	0.00	-	-	0.10	0.60	0.30
	Gypsum	0.278	0.056	0.00	-	0.50	0.30	0.20	-
	Bricks	0.389	0.056	0.00	0.20	-	-	0.60	0.20
	Lime burning	1.028	0.039	0.00	-	-	-	0.40	0.60
Basic che	Adipic acid	7.475	0.400	0.00	-	0.50	0.25	0.25	-

[65] Matthias Rehfeldt, Tobias Fleiter & Felipe Toro, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency, Vol. 11, 1057–1082, 2018.

Sub-sector	Process	Energy demand		Share of electricity demand used for process heat	Temperature distribution				
		Fuels (MWh/t)	Electricity (MWh/t)		< 100°C	100 - 200°C	200 - 500°C	500-1000°C	> 1000°C
	Ammonia (synthesis gas)	3.132	0.133	0.00	-	-	-	0.66	0.33
	Calcium carbide	1.700	2.311	0.95	-	-	-	-	1.00
	Carbon black	17.986	0.494	0.00	-	-	-	-	1.00
	Chlorine, diaphragm	0.000	2.969	0.00	-	-	-	-	-
	Chlorine, membrane	0.514	2.789	0.00	-	1.00	-	-	-
	Chlorine, mercury	0.000	3.561	0.00	-	-	-	-	-
	Ethylene	9.973	0.000	0.00	-	-	-	1.00	-
	Methanol (synthesis gas)	4.176	0.135	0.00	-	-	-	0.22	0.78
	Poly carbonate	3.572	0.739	0.00	-	1.00	-	-	-
	Polyethylene	0.178	0.567	0.00	-	1.00	-	-	-
	Polypropylene	0.221	0.319	0.00	-	1.00	-	-	-
	Polysulfones	6.802	0.850	0.00	-	1.00	-	-	-
	Soda ash	3.147	0.092	0.00	0.30	0.40	-	-	0.30
	TDI	7.414	0.767	0.05	-	1.00	-	-	-
	Titanium dioxide	9.507	0.928	0.00	-	0.30	0.23	0.35	0.12
Food, beverages and tobacco	Sugar	1.251	0.196	0.00	0.10	0.60	-	0.30	-
	Dairy	0.436	0.147	0.05	0.90	0.10	-	-	-
	Brewing	0.270	0.109	0.05	0.55	0.45	-	-	-
	Meat processing	0.566	0.430	0.05	0.40	0.60	-	-	-
	Bread & bakery	0.667	0.402	0.45	0.20	0.33	0.47	-	-
Pulp and paper	Paper	5.50	1.91	0.01	0.05	0.88	0.05	0.02	-
	Chemical pulp	12.65	2.30	0.01	-	1.00	-	-	-
	Mechanical pulp	-2.01	7.92	0.01	1.00	-	-	-	-
	Recovered fibres	0.54	0.94	0.01	-	1.00	-	-	-
Non-ferrous metals	Copper, primary	8.00	2.79	0.20	-	-	-	-	1.00
	Copper, secondary	4.00	2.33	0.10	-	-	-	1.00	-
	Copper further treatment	2.00	3.78	0.15	-	-	1.00	-	-
	Zinc, primary	1.00	15.90	0.01	-	-	-	-	1.00
	Zinc, secondary	1.00	0.60	0.01	-	-	1.00	-	-

7.4.2 Technical potential in the industrial sector

Demand characterization for the sub-categories of the industrial sector served to estimate the share of heat which, from a technical viewpoint, can be supplied in part, by a high-efficiency CHP system. For each industrial sector, bottom-up studies of production processes should be conducted, identifying the specific demand (per unit of product/turnover) and defining the share of heat demand which can be covered by CHP. In the lack of such studies for the Serbian industry sector, the estimation of HE CHP technical potential in the industry has been done based on the experiences of EU countries[66,67]. The assumptions used for this estimation are, as follows:

- The selected technologies are based on the currently mostly implemented technologies: internal combustion engines (ICE, for sizes below 10 MW_e), gas turbines (GT), and combined cycle gas turbines (CCGT, for sizes over 10 MW_e);

[66] Gestore dei Servizi Energetici, Assessment of the National Potential for High-Efficiency Cogeneration and Efficient District Heating, December 2015

[67] Gobierno de Espana, Ministro di Industria, Energia y Turismo, Full Assessment of the Potential Use of High-Efficiency Cogeneration and Efficient District Heating And Cooling Systems, April, 2016.

- The size of the HE CHP systems is selected to maximize coverage of the heat and power demand by the industrial process. This means minimizing the amount of electricity fed into the national grid and maximizing the heat made available by the CHP facility. In this case, CHP systems reach the greatest efficiency in terms of HE CHP generation and primary energy savings. The calculated ratio of average electrical and heat capacity $(H/E)_{customer\_chp}$ which could be met by CHP is less than $(H/E)_{cog}$ ratio of the specific cogeneration technology. The CHP facility is selected to cover the heat demand of the process, while the electricity shortfall not met by the CHP system is drawn from the national grid.

In the estimation of technical potential, the existing capacities for electricity and/or heat production in the industry should be taken into consideration. The electricity production per industrial subsectors in auto-producers during 2021 is presented in Table 7.11.

Table 7.11. Electricity production in auto-producers (2021)

Industry sub-sector	MWh
Iron and steel	64,048
Chemical and petrochemical	148,669
Mining and Quarrying	76,004
Food, beverages, and tobacco	58,676

The overall technical potential of the new HE CHPs has been calculated and presented Table 7.12. The estimated technical potential of thermal energy and electricity obtainable from HE CHP amounts to 2,021.4 GWh of heat and 1,806.6 GWh of electricity. This production corresponds to a capacity to be installed of about 751 MWt and 669 MWe respectively. These values constitute the theoretical maximum amount of heat and electricity technically obtainable in the sub-sectors and produced by CHP facilities, without considering economic and financial factors.

Table 7.12. Technical potential for the development of new HE CHP in Serbia

Sub-sector	Heat			Electricity		
	GWh	toe	MW_t	GWh	toe	MW_e
Iron and steel	174.7	15.0	58.9	144.7	12.4	49.0
Chemical and petrochemical	516.6	44.4	168.7	437.0	37.6	143.1
Non-ferrous metals	20.7	1.8	5.3	29.3	2.5	7.5
Non-metallic minerals	117.2	10.1	40.1	151.1	13.0	51.6
Transport equipment	21.6	1.9	7.4	27.2	2.3	9.3
Machinery	102.8	8.8	52.9	69.7	6.0	35.9
Food, beverages and tobacco	664.1	57.1	231.5	608.0	52.3	216.0
Paper, pulp and printing	191.3	16.4	50.0	140.9	12.1	38.3
Wood and wood products	28.9	2.5	14.1	32.7	2.8	16.0
Textiles and leather	119.9	10.3	53.3	108.8	9.4	47.6
Not elsewhere specified (Industry)	63.6	5.5	68.8	57.2	4.9	55.0
Total	**2.021,4**	**173.8**	**750.8**	**1.806,6**	**155,3**	**669,2**

The results obtained are heterogeneous. Two industrial sub-sectors (Chemical and petrochemical – Refinery, and Iron and steel) have already saturated their technical development potential. The refinery invested in CHP installation, with the aim of reducing energy bills, including the wholesale of electricity. The only Serbian ironwork has already used blast furnace gas for electricity and/or heat production.

7.4.3 Demand evolution scenarios in the industrial sector and impact on analysis of potential

According to scenarios developed during the preparation of new strategic documents in the Serbian energy sector (National Energy and Climate Plan, and Energy Strategy), final energy consumption in the industrial sector should have a slight increase by 2030 (Figure 7.2.)

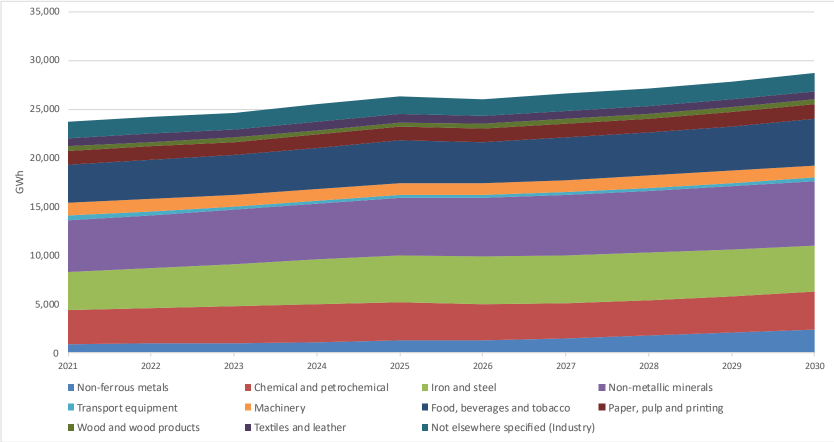

Figure 7.2. Final consumption evolution scenario in the industrial sector[68]

The most significant increase can be expected in the Non-ferrous metals sub-sector, where the final energy consumption in the year 2030 could increase 2.8 times compared to the year 2021. In other sub-sectors, the expected increase is between 9% and 20%, except Transport equipment, Machinery and Textiles, and Leather sub-sectors. In these three sub-sectors, decreasing of 32%, 6%, and 9%, respectively, is envisaged until 2030.

[68] https://www.mre.gov.rs/en/dokumenta/ostalo/integrated-national-energy-and-climate-plan-republic-serbia-until-2030

8. The potential for the development of efficient district heating and cooling

8.1 Heat demand

The data concerning the district heating system in the Republic of Serbia were obtained from the "Report on the operation of the district heating system in the Republic of Serbia for the year 2021"[69]. 1,824 GWh of thermal energy can be additionally supplied through the existing DHS networks in the Republic of Serbia. The criterion used is that linear thermal density should not be less than 2.5 MWh/m.

The specific annual heat consumption in the DHS of the Republic of Serbia is presented in Figure 8.1. Values of specific consumption differ a lot in the DHS of the Republic of Serbia, and these values are not the result of different climate zones, but the lack of automation and management of the system. The average value for heat energy customers from the DHS in 2021 was 130.9 kWh/m^2*a. The last two values of specific consumption, which are unusually low, in Figure 8.1. (Bečej, Žitište) are not authoritative, because customers in these two systems are supplied with DHS heat in other ways, not only from the DHS.

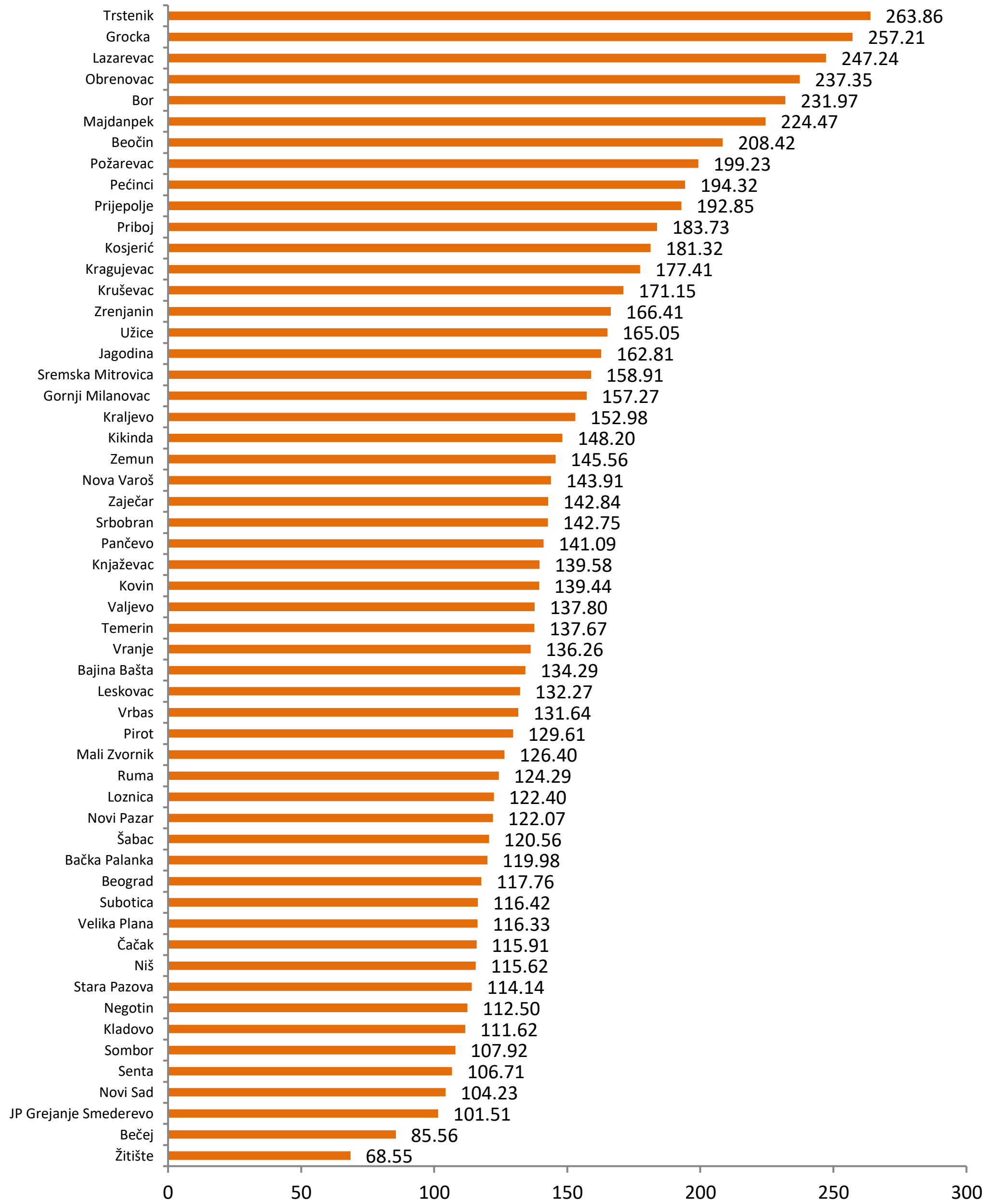

Figure 8.1. Specific heat consumption, kWh/m^2*a, 2021

[69] https://www.toplanesrbije.org.rs/uploads/ck_editor/files/izvestaj%202021.pdf

8.2 Technical potential for District Heating and Cooling

The total potential for increasing the connection to the district heating system of new customers needs to be looked at very carefully. Changes to the System Operation Rules must be considered during the analysis of the total potential for increasing the connection to the district heating system of new customers. Table 8.1. presents an overview of DHSs in Serbia with linear heat density below 2.5 MWh/m, where there is room for connecting new customers. Bearing in mind that some of the listed DHSs (Trstenik and Senta), in Table 8.1., do not have the possibility to theoretically achieve the number of working hours with the full capacities of their production systems during the winter period, the total shown potential must be reduced to the value of 1,700 GWh.

Table 8.1. Linear density and potential of the district heating system

No.	DHS	Linear heat density	Heat energy	Calculated heat energy	Difference
		MWh/m	MWh	MWh	MWh
1	Pančevo	1.88	138,916	185,000	46,084
2	Subotica	2.00	95,419	119,500	24,081
3	Kruševac	2.28	118,441	130,000	11,559
4	Trstenik	0.95	38,887.16	102,275	63,387.84
5	Požarevac	1.18	221,976.9	470,000	248,023.1
6	Lazarevac	1.46	131,376.5	225,000	93,623.5
7	Sremska Mitrovica	0.87	42,499	122,500	80,001
8	Obrenovac	0.48	249,171	1,300,000	1,050,829
9	Pirot	0.99	28,190	71,250	43,060
10	Sombor	1.29	32,960.05	63,795	30,834.95
11	Bečej	0.59	11,897.6	50,000	38,102.4
12	Novi Pazar	2.37	12,074	12,750	676
13	Nova Varoš	1.84	8,777	11,920	3,143
14	Zaječar	1.50	31,374	52,250	20,876
15	Velika Plana	2.30	7,118.4	7,750	631.6
16	Kovin	1.71	11,117	16,250	5,133
17	Kosjerić	1.73	3,450	5,000	1,550
18	Mali Zvornik	1.82	3,630	5,000	1,370
19	Temerin	2.04	4,972.22	6,102.5	1,130.28
20	Srbobran	1.94	4,185.31	5,397.5	1,212.19
21	Žitište	1.01	1,013	2,500	1,487
22	Stara Pazova	2.27	15,220	16,750	1,530
23	Senta	0.70	21,004.5	74,677.5	53,673
24	Batočina	1.35	2,022.222	3,750	1,727.778
Total			**1,235,692**	**3,059,418**	**1,823,726**

In further analysis, the DHS connection costs shown in Table 8.2. were used, which have a stake in connecting new customers to DHS.

Table 8.2. DHS connection costs

Cost/price	Amount
Costs of connection to the distribution network DHS (€)	9,325.15
Cost of the heat substation (€)	7,400.00
Semi-deep connection costs (€/kW)	7,000.00
Other costs (€)	332.12
Total costs (€)	24,057.26
Area of a typical building (m²)	1,692.00
Unit cost of the apartment to be connected (€/m²)	14.22
Heating price (€/m²)	0.81
Investment costs of connection (€)	853.09

The average size of a thermal substation in the DHS of the Republic of Serbia is at the level of 200 kW. Estimated costs amount to €14.22/m^2 of heated area.

Considering that there is no district cooling in the Republic of Serbia, but there is potential in "organized" cooling in the service sector, in the sub-sectors of health, education and school and student dormitories as one of the potentials. Total cooling energy is 1,299 GWh, however if we consider only the potential cooling energy for the mentioned sub-sectors, the amount is 252.68 GWh. The number of days when the average temperature was such that cooling was needed for the year 2021 was 53.

The situation regarding district cooling can be solved by apply eingin, shown in th example of the Trigeneration Plant layout in Clinical Center (KC) is shown in Figure 8.2. The layout includes:

- A gas engine (generation of electricity and heat),
- A heat pump (supplying energy for heating and cooling), and
- BOT equipment.

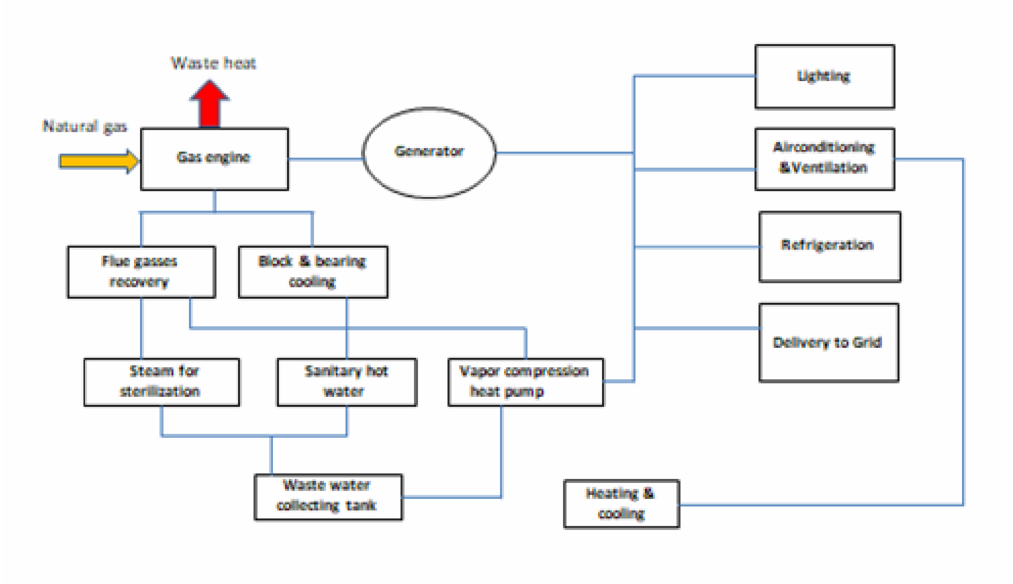

Figure 8.2. Layout of the Trigeneration Plant

Basically, the process runs as follows:

1. Gas engine produces electric power and heat energy from cooling of the block and bearing, and heat recovered from heat recovery from flue gases;
2. Heat recovered from flue gases are used for producing steam for sterilization (SS); flue gases have the temperature high enough for production of SS with temperature between 120 and 130°C;
3. Heat recovered from cooling of the block of engine and bearings is used for preparation of domestic hot water (DHW), as it is required that temperature of DHW is 60°C;
4. Both SS and SHW must be filtrated and if necessary, treated in accordance with norms required by law for realizing such water to sewage, and mixed in one tank to serve as the heat source for heat pump (HP) plant;
5. Heat pump uses water from the tank for evaporating the refrigerant in HP`s evaporator. After evaporating, refrigerant is compressed in the compressor and condensed at required temperature to be used for heating during heating season. If the temperature of condensation is selected to be 75°C, it can assure temperature of heating water of 70°C;
6. Selection of condensing temperature of 75°C looks as one good compromise taking into account from one side the temperature sliding diagram, and high COP of HP from other side.

Temperature of heating water of 70°C will be sufficient for the largest part of the load duration curve; In case of cold days (low outside air temperature) can be increased by re-directing of flue gases or in the existing boiler. High value of COP promises significant reduction of consumption of primary energy (natural gas). In the summer, thermodynamic cycle of HP is reversed and HP delivers cooling to the consumer. The wastewater generated by the trigeneration plant, after energy recovery, will be discharged into the sewerage system.

Two aspects have to be considered:
1. Radiators that are installed in the space of the consumer are not appropriate for cooling, and should be replaced with fan coils;
2. There are some spaces in the KC that require cooling the whole year round (for example surgery halls), which require additional re-configuration of the HP, i.e. probably installation of two HP units, to assure delivery of cooling over the whole year.

As the boiler house needs a relatively small quantity of electricity for operation, other options must be considered:
1. Using of available electricity by other parts of heating plant.
2. Making of a contract with some trader of electricity, i.e. selling the electricity at the market.
3. Concluding a contract for delivering of electricity under feed-in contract.

The first option is a valid one in case that price of electricity is high. The second option can assure regular additional income for each month. Trading of electricity is a very profitable business, especially when selling electricity generated by cogeneration/trigeneration plants.

Sizing of the Trigeneration Plant

Selection of Prime Mover is always a key element of a cogeneration/trigeneration plant. The factors that should be considered are primary energy source, load, energy efficiency and emissions of pollutant gases. In case of configuring of the trigeneration plant from the KC example, in the boiler house, the only feasible option is installation of a reciprocating gas engine (RGE). Main characteristics of RGE technology are listed in Table 8.3.

Table 8.3. Main Characteristics of RGE

Characteristics	Description
Size range	Reciprocating engines for trigeneration/cogeneration are available in sizes from 100 kW_e to10 MW_e. Multiple engines can be combined to assure maneuverability of the plant. The majority of trigeneration/cogeneration plants with reciprocating engine are below 5 MW_e.
Thermal output	Thermal energy can be recovered from the engine exhaust, cooling water, and lubricatingoil, and then used to produce hot water, low pressure steam, or chilled water (with an absorption chiller).
Part-load operation	Reciprocating engines perform well at part-load and are well suited for both baseload andload following applications.
Fuel	Reciprocating engines can use a wide range of gas and liquid fuels. For cogeneration, natural gas is the most common fuel.
Reliability	Reciprocating engines are a matured technology operating with high reliability.
Other	Reciprocating engines have relatively low installed costs and are widely used in trigeneration/cogeneration applications. Reciprocating engines start quickly and operate on typical natural gas delivery pressures with no additional gas compression required.

Performances of RGE

It is expected that RGEs that will be used in the trigeneration plant in KC would have power capacities that would be between 1.141 kWe и 3.325 kWe.

8.2.1 Technical potential for efficient DH from natural gas

In the district heating systems of the Republic of Serbia, there are three CHP plants that use natural gas, with a total power of 34 MWe and 34 MWt (Novi Sad and Belgrade). The natural gas network of Serbia has been developed so that 35 out of a total of 60 district heating systems have the possibility of using natural gas in their production facilities.

A potential DHS that can convert from coal to natural gas is Bor, which supplies consumers with sanitary potable water. The thermal capacity of the plant is about 50 MWt, and due to the delivery of sanitary hot water, it makes sense to consider construction of a CHP installation. A more massive construction of CHP plants in DH is not expected unless the existing situation is overcome with local plants for the delivery of sanitary drinking water to households and district cooling in the service sector, which would be managed by DHS. This solution is imposed due to the limitations of the technical solutions of the production and distribution systems of DHC.

8.2.2 Technical potential for efficient DH from waste incineration

Currently, in the district heating systems of the Republic of Serbia, there are no plants that use heat and electricity from waste incineration. The plant in Belgrade, has started operating and is expected to start delivering heat energy to the distribution network of DHS Belgrade in 2023. To determine the technical potential for efficient DH from waste incineration for Niš and Kragujevac, which are defined by the Waste management program in the Republic of Serbia for the period 2022 - 2031, the energy data of the constructed plant in Belgrade were used for assessment. Relevant technical data are presented in Table 8.4. All produced heat energy from the plants listed in Table 8.4. should be handed over to the DHS distribution networks, and electricity to the national grid.

Table 8.4. Technical potential for efficient DH from waste incineration

City	Heat		Electricity	
	MW_t	GWh	MW_e	GWh
Beograd	56.5	200	25	175
Niš	27.4	97	12	85
Kragujevac	24.9	88	11	77
Total	**108.8**	**385**	**48**	**337**

8.2.3 Technical potential for efficient DH from biomass

Several district heating systems in the Republic of Serbia use wood biomass. These DHSs are energy plants that produce only thermal energy. Available wood biomass has an energy potential of 390.4 GWh. District heating systems that could use the available wood biomass are shown in Table 8.5.

It should be considered that the European Parliament adopted on 14/09/2022 a new biomass amendment introducing a gradual reduction of harmful subsidies for burning whole trees (woody biomass that has the most negative impact on climate and forest biodiversity) for energy.

Member States should avoid promoting the use of quality roundwood for energy, except in well-defined circumstances, for example forest fire prevention and so-called sanitary logging.

Table 8.5. DHSs that can use wood biomass in the period 2023-2030

DHS/year	2023	2024	2025	2026	2027	2028	2029	2030
	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Novi Pazar	12.08	12.08	12.08	12.08	12.08	12.08	12.08	**12.08**
Kruševac	0.08	0.08	0.08	0.08	0.08	0.08	0.08	**112.45**
Vranje	0	28.21	28.21	28.21	28.21	28.21	28.21	**28.21**
Zaječar	0	35.36	35.36	35.36	35.36	35.36	35.36	**35.36**
Smederevo	0	0	39.49	39.49	39.49	39.49	39.49	**39.49**
Nova Varoš	0	0	10.69	10.69	10.69	10.69	10.69	**10.69**
Knjaževac	0	0	16.64	16.64	16.64	16.64	16.64	**16.64**
Gornji Milanovac	0	0	12.32	12.32	12.32	12.32	12.32	**12.32**
Novi Pazar	0	0	0	12.08	12.08	12.08	12.08	**12.08**
Bajina Bašta	0	0	0	0	0	0	12.48	**12.48**
Bor	0	0	0	0	0	0	0	**77.87**
Total	**12.16**	**75.73**	**154.87**	**166.95**	**166.95**	**166.95**	**179.43**	**369.67**

8.2.4 Technical potential for efficient utilization of wastewater heat pump in DH systems

Wastewater was officially recognized by the European Union as a renewable source of energy. In this way, wastewater treatment plants (WWTP) appeared as a source of a significant amount of low-temperature heat and wastewater heat recovery became a valuable option for greenhouse gas emissions reduction. WWTPs are usually located near urban areas, which implies that wastewater heat meets the requirement for the proximity of a heat source to the DH network. After treatment in WWTP, the temperature of treated (purified) water is usually significantly over the outdoor temperature. This water temperature is characterized by seasonal, predictable, and relatively low variation. However, the variations in treated water flow rate are unpredictable and significantly higher.

Purified wastewater heat energy can be effectively utilized by the integration of wastewater heat pumps (WWHP) in existing district heating systems (DHS). To achieve maximal technical and economic feasibility, the WWHP is used for baseload cover, while the fossil fuel-fired heat plants will be used to cover the remaining heat demand, including peak load. The typical scheme of an existing district heating system with integrated WWHP is presented Figure 8.3.

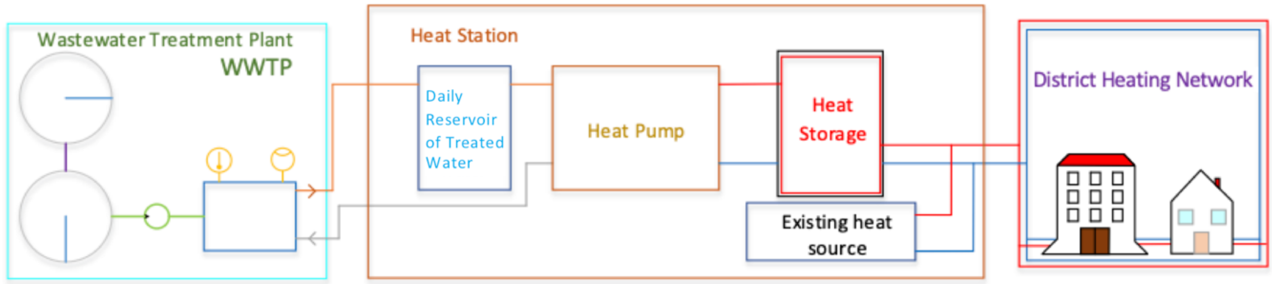

Figure 8.3. General scheme for WWTP integration in DH system

The optimal location of a WWHP is in the near vicinity of the existing district heating plant. The reason is that costs of water transport and heat losses are in this way minimized. The treated water is pumped to the heat pump evaporator by uninsulated pipes, while the transport of hot water, after the heat pump, requires an insulated supply and return pipelines. The desirable option is to discharge treated water at the heat pump location if it is possible. Otherwise, the treated water must be pumped in a loop, back to the WWTP, and discharged at a regular location. A daily reservoir of treated water is installed at the discharge of the WWTP, before the heat pump. This reservoir operates as a "buffer" to optimize the amount of treated water introduced into a heat pump, to reduce the variability of the wastewater flow into a heat pump during the day. When the flow rate from the WWTP is higher than the maximum acceptable flow rate for the operation of a heat pump, this reservoir would be supplied with excess water. The water from the reservoir later would be used as an additional input to the heat pump, in cases of insufficient flow from the WWTP.

The purpose of a heat storage installation is to ensure the maximal economic and environmental effects of heat pump operation. The produced heat substitutes energy that otherwise would be produced by the combustion of fossil fuel. The introduction of heat storage enables a longer period of heat pump operation during a heating season. In periods without heat supply to consumers, produced energy is stored and distributed when the demand exists.

There are only nine wastewater treatment plants in operation in Serbia. Sewage waste heat is not utilized at all and there are no available data about sewage waste heat potential at the level of the state, regions, or cities.

The determination of the technical potential of sewage wastewater heat is related to the determination of the recoverable heat energy potential of treated sewage wastewater. The heat energy that could be produced from the WWTP is calculated for the selected city (Šabac) with WWTP in operation. The obtained energy amounts are set in relation to the number of inhabitants of the city. In that way, the indicator of energy availability (provides information about heat energy produced utilizing waste heat per capita) is obtained. These indicators provide the basis for the estimation of recoverable heat energy potential for other cities, with district heating systems and plans for WWTP construction, as well as for the evaluation of the effects of utilization of full potential.

By using this methodology, it was calculated that 379.8 kWh of heat energy per inhabitant per heating season can be produced by heat pump utilization. This value can be used for a rough determination of the theoretical potential of this energy source in Serbia: 6,360 TJ (151,906 toe, 1,766 GWh). This amount of energy corresponds to 470 MW of WWHPs' nominal power. The estimation of WWHP capacities and corresponding heat production in some DH systems in Serbia is presented in Table 8.6.

Table 8.6. Expected contribution of WWHP to selected DHSs in Serbia

DHS	Heat pump	
	Nominal power (MW)	Delivered heat (GWh)
Belgrade	187	486
Novi Sad	40	101
Kragujevac	20	49
Niš	20	50
Subotica	15	39
Pančevo	10	25
Zrenjanin	9	22
Čačak	9	22
Kraljevo	7	17
Kruševac	6	16
Šabac	6	15
Bor	4	9

8.2.5 Technical potential of utilization of Solar Energy

Among different technologies, which are developed in the recent years, solar photovoltaic and solar heat generation have got the high level of attraction. There is a growing interest in using solar energy in underfloor heating systems.

Solar energy technologies encompass:

- Photovoltaic (PV) solar technology, and
- Thermal (TS) solar technology.

Each of the above listed technologies according to size (scale), positioning and potential consumers, can be further categorized into three categories:

- **TS solar technology:**
  - Residential,
  - Commercial,
  - Utility-scaled.
- **PV solar technology**:
  - Residential rooftop systems, monocrystalline silicon modules 3 kW–11 kW,
  - Commercial rooftop with ballasted racking and fixed-tilt ground mounted systems, monocrystalline silicon modules 100 kW–2 MW,
  - Utility-scale ground-mounted systems, monocrystalline silicon modules, fixed-tilt and one-axis tracking 5–100 MW.

8.2.5.1 Solar heat generation

The basic process of solar heat generation is to transfer the solar radiation energy into heat with the use of thermal collectors. Depending on the grade of heat required, different types of solar collectors can be used. For high-grade heat generation (high temperature applications) concentrating or evacuated tube solar collectors can be preferred instead of flat plate collectors.

Components of solar thermal systems

Solar Collectors

In general, a solar collector refers to solar hot water panels that contain water pipes with insulation on its sides and bottom, and glass on the top. Energy is absorbed by the absorber plate and heat is transferred to the fluid. The absorption of the sun's energy by the collectors creates the heat energy. The role of the collectors is to convert solar rays into heat energy and transfer it to the consumers.

Definitions that describe solar collectors are:

- The gross surface area is the product of outside dimensions, and defines the minimum amount of the roof space that is required for installing collectors;
- The aperture area corresponds to the light entry the collector; i.e. that is the area through which the solar rays passes to the collector; and
- The absorber area (also called the effective collector area) corresponds to the area of the actual absorber surface of the collector.

Thermal Storage

The energy supplied by the sun is not available always when the heat is required in the thermal system. Solar energy is available only during daytime only when the weather is sunny, so the heat generated by the solar energy must be stored, if the consumers would like to use it in non-sunny hours. It is appropriate to use a thermal storage tank which can store water and also improve the efficiency of solar thermal systems.

Solar Facility (Installation)

The heat generated by the collectors is transported to the storage tank that is a part of the solar facility, and consists of the following elements:

- The pipelines, which connect the collectors on the roof (or on the ground) to the storage unit,
- The solar fluid that transports the heat from the collector to the store,
- The pump which circulates the solar fluid in the solar facility,
- The heat exchanger, which transfers the heat to the domestic hot water to the storage,
- The fittings and the equipment for filling, emptying, and bleeding,
- The safety equipment, and
- The expansion vessel and safety valve that protect the system from damage (leakage) by volume expansion or high pressures.

Controller

The controller of a thermal solar system has a simple role to control the operation of the circulating pump to keep the solar facility operating in the optimum regime. Mostly, this controls the temperature difference, but controllers also can control system circuits of the facility, and are capable to measure heat distribution and delivery, and can perform data logging and error diagnostics.

Space heating system

Space heating system provides heating of the floor (space). This system compensates the heat losses from the floor by radiators, by convertors or by some other heating devices, for example floor heating. This system adds to personal comfort by avoiding the hot and cold spots that are inevitable with radiators. There are many reasons in favour of low temperature heating.

Two types of solar collectors are used in order to compare their performance under the same conditions:

- **Flat Plate Collector (FPC)**: The collectors are connecting to each other in a way that their array consists of collectors connected in a series as well as parallel collectors. In this collector arrangement, the total collector array thermal performance is determined by the specific properties of each module and the number of them in a series.
- **Compound Parabolic Collector (CPC):** This type has two parts, the concentrating reflector and the absorber. The CPC collectors are sensitive to both beam and diffuse radiation which approach the aperture within a critical angle called the half-acceptance angle.

A storage tank (depending on height) but usually stratified is commonly used, as the thermal stratification improves the overall performance of the systems. Thermal stratification occurs when two types of steam with different temperatures come into contact. Their temperature difference causes the colder and heavier water to settle at the bottom of the pipe while allowing the warmer and lighter water to float over the colder water. Significant improvements in yearly performance of solar energy systems may be realized if stratification can be maintained in the storage tank. In solar thermal tanks, the cold fluid is withdrawn from the bottom to be heated at the heat source, i.e. in solar collectors, and returned to the top of the tank at a relatively higher temperature.

IEA Solar Heating and Cooling Program (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Program was founded as one of the first multilateral technology initiatives of the International Energy Agency. Its mission is to enhance knowledge and application of solar heating and cooling through international collaboration, to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050. The topics include:

- Solar Space Heating and Water Heating,
- Solar Cooling,
- Solar Heat or Industrial or Agricultural Processes,
- Solar District Heating,
- Solar Buildings/Architecture/Urban Planning,
- Solar Thermal and PV,
- Materials/Components for Solar Heating and Cooling,
- Standards, Certification, and Test Methods, and
- Storage of Solar Heat.

Screening for Potentials by Applying Trends of a Well-Established Market

To reach a high solar fraction for a specific town, and assuming that collectors can be mounted at the roofs rather than on the ground, the large number of roof-mounted solar collector systems will in general be required. The size of each specific roof solar system is limited by the roof area available and the roof “suitability” for field of collectors mounting (roof angle, flatness, orientation toward south, lack of shadowing, etc). The long-term engineering investment practice shows that the economies of scale of ground-mounted solar collector systems can most probably compensate the extra costs. But, the EU strictly recommends using of roofs for mounting of collectors instead of ground/land.

This practically faces decision-makers with the dilemma whether it is more feasible to place large solar collector fields outside of a town and supply heat to the district heating (DH) network through a transmission pipe, or to install many smaller solar heating systems on rooftops within the town. The additional aspects that must be considered are measurement, regulation, metering, and billing.

Pretty strong solar district heating (SDH) can be seen in Denmark. It is interesting to see what the characteristics, and also the operating regime of an SDH in Denmark, if similar SDH system would be constructed in Serbia.

The size of each specific town affects the feasibility of SDH. It implies that for identifying of the potential of SDH over the country, the characteristics of the local DH networks must be considered. However, the focus of the study is not on specific results for each DH network, but rather trends in terms of potential of the country.

There are some limitations and restrictions that must be considered:

- If some amount of waste heat energy is available that can be used in the DH system, in that case the availability of waste heat should have priority compared with SDH; if some “stickler for clean energy” should oppose, he has to be faced with the problem to find a rational solution for dissipation of available waste heat energy;
- The analysis should be restricted to estimating of the potential for cities with existing DH networks;
- The main focus should be to map available areas near towns with existing DH network, because for SDH it is necessary to have land, customers, and affordable cost; and

- For identification of relevant cities for SDH, the following criteria[70] are applied:
    1. The town doesn’t have an excess heat source within 20 km;
    2. The town doesn’t have available waste heat source within 20 km;
    3. Suitable land (preferably non-irrigated arable land) for solar collector construction is available in the town vicinity (< 1 km).

The focus therefore should be on the most obvious possibilities for SDH. There must exist explicit and justified reasons why not to use available waste heat energy. To identify the full potential of SDH, larger cities and newly built DH networks should be considered in future studies (up to the year 2050), where solar heating systems may be located even further away from the end users – possibly combined with different heat sources and with large-scale heat storages, so as to improve the overall feasibility.

Summarizing the possibilities to effectively use SDH, the estimate of the potential should be based also on the CBA figures that will be developed for the SDH solution. The results can then be grouped and ranked over the country to indicate where SDH deployment would be most feasible. Targeting a solar fraction (FSH) of 5 or 10 % of the annual heat demand in the investigated DH networks, the SDH analysis identifies a group of DHS with capacity up to 20 MW_t identified as the group with potential for SDH. Such approach focuses on the analysis to small towns.

Annual Solar Energy Availability in Serbia

The estimate of the potential of solar energy in Serbia is based on data provided by the World Bank through the Global Solar Atlas, a free, web-based tool providing the latest data on solar resource potential globally. It is accompanied by country factsheets, downloadable from the Global Solar Atlas, that provide a summary of the resource potential and how it compares to other countries and is presented in Figure 8.4.

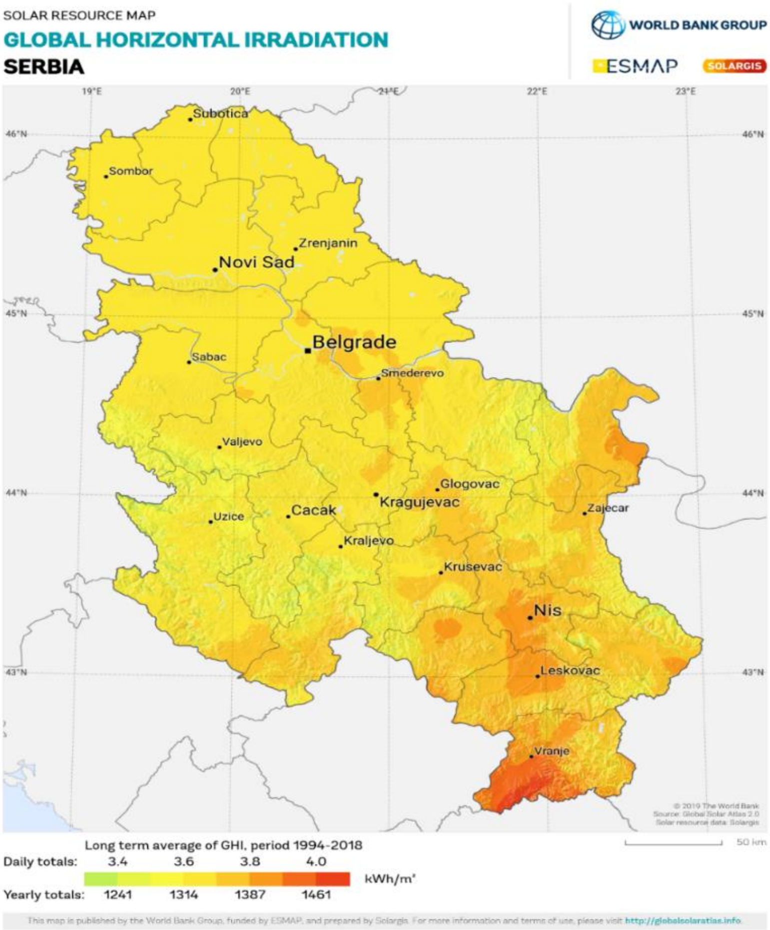

Figure 8.4. Distribution of global horizontal radiation over Serbia

[70] SOLAR DISTRICT HEATING TRENDS AND POSSIBILITIES, Plan-Energy, 2018

The potential of solar energy is given as average irradiated solar energy on horizontal area of 1 m^2. This energy – according to the angle of the collector is recalculated and converted into useful energy. The data presented in the solar map of Serbia make possible to evaluate or compare solar energy potential at any site in the country. The difference in yearly average potential between sites with the highest potential (the darkest color) and the lowest (green color) is 220 kWh/m^2 (15%).

Besides solar energy availability, the potential for growth in the solar industry depends on energy needs, supportive policies, costs and payback time, related risks, stability of energy prices, predictability, and other technical, social, and economic factors.

Optimal Tilt Angle of Solar Collector

Rotation of the Earth around own axis, its rotation around the Sun and the angle of Earth's axis cause differences in solar collector tilt angle optimality. Also, the optimality depends on the latitude of the town. The latitude of towns/cities in Serbia takes values that are between 46° for the city of Subotica and 42° 33` for the city of Vranje. Optimal tilt angle of solar collector is determined for two cases:

- Fixed solar collector, and
- Seasonally adjusted solar collector.

Defining of Land Area Required for Mounting of Solar Collectors

Theoretically the fraction of solar heat FSH can take any value between 0 and 100%. Usage of solar energy for heating at the moment is very low. DH of Pančevo uses solar energy for sanitary hot water preparation, but not for heating. There are not any incentives that would promote and support solar heating. Considering that the period between 2022 and 2030 is relatively short, assumption of the FSH should be really moderate.

Necessary steps in the process of estimating and evaluating an SDH are presented in Figure 8.5. To estimate how much land would be necessary for a planned or desired FSH, the corresponding solar collector area needs to be defined first. This can be done by estimating how much solar heat can be produced by an optimally oriented collector field, depending on the solar radiation at the specific location.

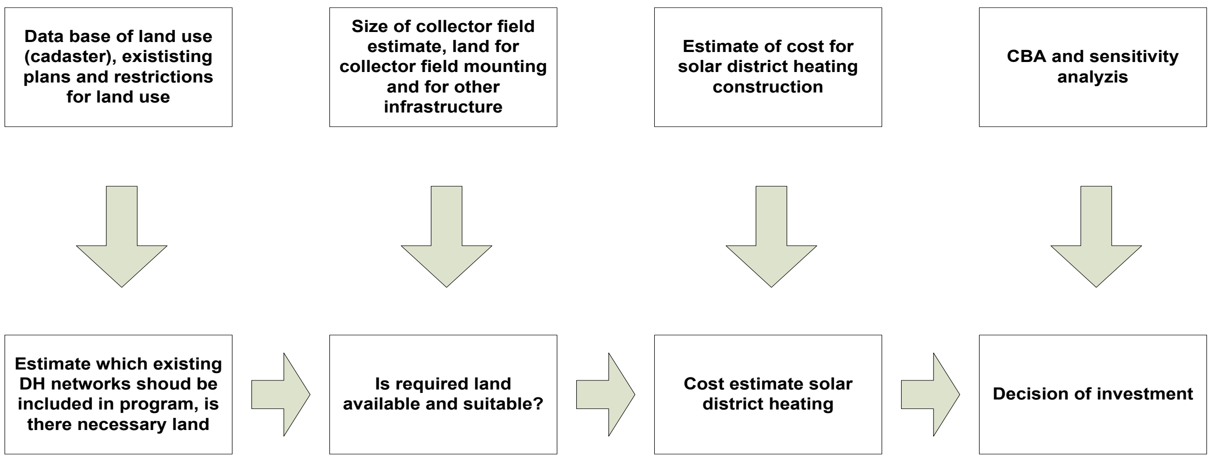

Figure 8.5. Steps in the process of estimating and evaluation of SDH

The needed land for mounting (construction) of a field of solar collectors is proportional to the area of the collectors multiplied by factor 3.5. This means that for mounting (construction) of one square meters of solar collector area, it is necessary to have 3.5 square meters of land[71]. The quantity of delivered solar heat energy to the DH system can be estimated when transmission heat losses and heat storage losses are subtracted from the solar energy collected by the field of solar collectors.

The planned or desired solar heat production (Q_{sol}) to cover a certain share (FSH) of the annual DH demand (Q_a DH) is found using the equation : $Q_{sol} = SHF \cdot Q_a\ DH$ (kWh/a). (8.1)

The solar collector area (A_c) needed to deliver a certain amount of solar heat per year is calculated as

$A_c = Q_{sol} / (C_{hv} \cdot IR_h)$ (m^2), (8.2)

[71] SOLAR DISTRICT HEATING TRENDS AND POSSIBILITIES, Plan-Energy, 2018

Solar Collectors Field

A field of solar collectors includes:

- Solar collectors,
- Mounting, installation, and piping,
- Heat exchangers and pumps,
- Instruments, control, regulation and management, and
- Water-glycol fluid and expansion vessels.

The price function is estimated based on Danish experience:
Price [€/m^2 gross] = 1000 · A_c (exp−0.16), if 1000 m² ≤ A_c < 75,000 m²; and 166 if A_c ≥ 75,000 m². (8.3)

Heat Energy Storage

The volume of the heat energy storage for a specific system depends on the solar heat energy generation and the heat energy consumption. It is assumed that the ratio between storage volume and collector area is a function of the FSH. Such assumption looks reasonable, and also links the basic sizes of solar heating system:

$$V_s/A_c \, [m^3/m^2] = 0, \text{ if FSH} \leq 5\,\%; \; 0.2, \text{ if } 5\,\% < \text{FSH} < 30\%; \; 3, \text{ if FSH} \geq 30\,\% \qquad (8.4)$$

It is estimated that if the FSH is ≤ 5%, solar heat can always be delivered directly to the DH network, thus eliminating the need for storing of solar energy and avoiding of storage losses. This implies the assumption that it is always possible to use solar heat for heat consumption, and to store the heat in the DH network. For the FSH that are between 5 and 30%, a daily thermal energy storage is certainly required; if the FSH is larger than 30%, a seasonal energy storage is an appropriate solution. In practical applications the relationship V_s/A_c is always the system-dependent. The average V_s/A_c relationship of 0.2 m³/m^2 is adopted in the case that FSH is between 5 % and 30 %. The typical range in practice is situated between 0.1 and 0.5 m³/m². It is estimated that the storage heat losses for systems with FSH up to 30% are about 2% of the yearly gross solar gain.

Solar systems with larger FSH require large storage (please see above). Larger heat energy storages cost more money. The cost structure of an SDH system shows larger impact of the storage investment cost in overall investment cost. A conservative assumption of 3 m³ storage per square meter of collector is used for the seasonal storages installed in SDH systems with SF higher than 30%[72].

Two types of heat energy storage technologies are considered:

- Insulated steel tank, for systems with a storage with volumes below 40,000 m³, and
- Underground pit storage, for storage with volumes above 40,000 m³.

The cost for installation of these two storage types are given by the following expressions[73]:

- Steel tank thermal energy storage:

Price [€/m^3] = 550 if V_s ≤ 300; 5300 · V_s exp (-0.43) if 300 < V_s< 8,000; 110 if V_s ≥ 8,000

- Pit storage:

Price [€/m^3] = 150 if V_s ≤ 1,500; 2,300 · V_s exp (-0.37) if 1,500 < V_s< 200,000; 25 if Vs ≥ 200,000[74].

Cost of Land

The cost of land can be estimated based on country statistics, in statistical yearbooks (in Serbian: Statistički godišnjak). The land cost depends on many factors and can vary from year to year. Determination of the land for construction of an SDH must include analysis that will demonstrate and conform that land is used in the most useful way. It looks that construction of SDH plants should be preferred in the vicinity of smaller cities. In big cities construction of roof-positioned solar installations is preferred.

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[72] Based on data for Danish district heating plants for the period 1998-2013 by the Danish Energy Agency
[73] Ibid
[74] Ibid

8.2.5.2 Solar District Heating

Introduction

Solar District Heating (SDH) plants are relatively large thermal applications (≈ MWt) that occupy large surfaces of land basically for disposition of field of solar collectors and storage tanks. Such plants are rarely stay-alone plants and are more frequently integrated into local district heating network of heat energy supply (local district heating system – DHS), from large collector`s field via network (main, distributive, and connecting pipes) toward residential and commercial consumers. Usually operate in some way in parallel with other energy sources, that are usually based on fossil fuels. In transitional months of the heating season, depending on capacity, the DHS is usually capable to cover all, or large part of the heat load.

Concept

SDH is a ground-based plant that supplies heat energy (hot water) to the local DHS. Also, SDH plants improve quality of air in the city, replacing boilers that burn fossil fuel with clean and renewable solar energy. However, there are some disadvantages in DHS:

- Solar energy (SE) is basically available only during daytime,
- SE is least available in winter when days are short,
- Position of the Sun at horizon is low, what amplifies problem of shadowing,
- During the winter the weather is saturated with cloudy days and precipitations, and
- Heat losses of solar collectors depend on the temperature difference, and basically are larger during the winter.

There are attempts to overcome these shortcomings of SE by using short-time and long-time (seasonal) heat storages. These facilities complicate the structure of SDH plants, making them more expensive for investment and operation, but also significantly increase possibilities for using SE. Use of large capacity of seasonal heat storages makes collecting and storing of solar energy during non-heating months (in the summer months, when SE is the most abundant), and using it in heating season, feasible.

There is an increasing interest in SDH, mainly from utilities, but also from local authorities and the housing sector. SDH has a large potential in Europe, which experts estimate at 5% of district heat from solar with an annual solar heat production of 100 PJ.

In Figure 8.6. the look and dimensions of solar collector field in an SDH plant is shown. It is important that low quality land – is there is such land in the vicinity – is selected as site for construction of an SDH plant.

Figure 8.6. Look of an SDH plant

The cost of the solar thermal system includes investing in solar collectors, heat storage and the pump(s), as well as the operational expenses of the plant for the electricity used to run the pump(s). Additional costs may arise if it was necessary to extend the existing DH network or construct new DH network. The SDH cannot fully replace a heat or cogeneration plant in a DHS, so this so that must be taken into account.

Operating Temperatures of SDH

Operating temperatures of SDH depend on the type of collectors that are used, as it is shown in the diagram in Figure 10.7.

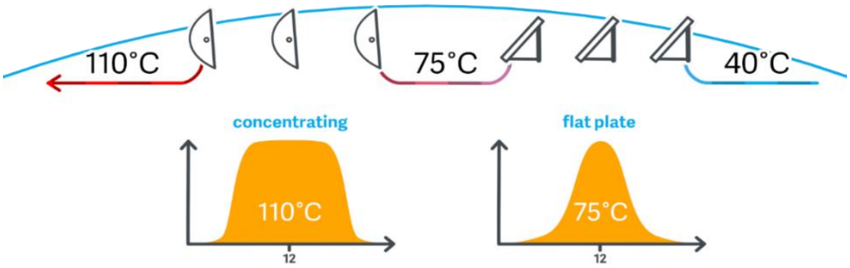

Figure 8.7. Operating temperatures of different types of solar collectors

The most suitable solar collectors for heating are flat solar collectors mounted on fixed supporting structure, oriented towards the South and inclined for optimized angle towards the horizon. Most applied solar installations for domestic hot water preparation and solar heating use flat solar collectors. Operating temperatures of flat collectors, according to the diagram in Figure 8.7. is 75 °C. Temperature of 40°C is more suitable for domestic hot water preparation.

Due to of high prices of energy and high prices of CO_2 emissions, in some countries (Sweden, Denmark etc.) SDH plants have been constructed with concentrating collector that produces heat with the temperature of 110°C, which is usual temperature in district heating. Using of concentrating collectors is more appropriate for process and electric power purposes. Analysis is based on use of flat collectors (the evacuated type of collectors).

The temperature of up to 75°C – if the assumption is made that return water from the DHS is entering the field of solar collectors – could limit use of SDH. Application of SDH depends on forward and return temperatures and outside temperature. SDH can be used during the time when forward temperature of the SDH is higher than return temperature of the DHS. It is necessary to note that SDH, as well as heat pumps, don't "like" high temperature of heating, and prefer low temperature heating systems, like the fourth generation of DH systems. Otherwise, SDH can be used to supply heat to new buildings that are constructed with new standards of well insulated buildings.

Heat Energy Generated by Field of Flat Solar Collectors

Serbia is not a big country, and that solar radiation is relatively uniformly distributed over the whole country. Optimizations of the angle of inclination of flat solar collectors is done for latitude of 45 and 46°. Optimal angle for winter is for both latitudes (45° and 46°) the same, i.e. 70°. Optimal angles are different for non-heating months. The difference is just one degree and can be neglected as the reduction of incident solar radiation is small.

The problem can arise if the SDH plant would be used in summer time for producing domestic hot water or generating heat for running of absorption cooling plants. In that case the structure that supports the solar collector should have the capability to be positioned according to two or three angles.

Calculation of solar potential is done for the SDH plant positioned at latitude of 45° only, because only a few DHSs in Serbia produce and distribute domestic hot water, and no one is supplying district cooling.

For SDH plants to operate in the group of DHSs that have heating capacities < 20 MW_t. Basically, this group of cities is relatively numerous, so the effects could be significant. It is also assumed that capacity of the SDH plant should be over 5 – 10% of the overall capacity of DHS, i.e. 1 – 2 MW_t. Construction of an SDH plant with the same capacity (in %) in the DHS of Belgrade would imply a plant of 150 MWt (5%) or 300 MWt (10%), which looks too big related to land that should be occupied in the vicinity.

Estimate of Intensity of Solar Energy for District Heating

Estimate of intensity of solar energy is done using the following software:

- The Pacific Energy Center Spreadsheet that calculates intensity of solar radiation by hours based on the ASHRAE methodology, and
- T *SOL simulation program that calculates the yield of a solar thermal system dynamically over the year.

The intensity of solar radiation, is generated by the Pacific Energy Center software, for latitude of 46º, collector tilt of 70º, ground reflectance of 0.2, for each month in a year (with specifics according to monthly declination, sunrise hour, cloudiness factor, day length and collector efficiency), for collectors with absorber area of 2.32 m^2. The values of daily solar radiation must be corrected by the factor that takes into account the number of rainy days. Flat collectors are sensitive to diffuse radiation, but in rainy days there is not even diffuse radiation. In the diagram in Figure 8.8., the corrective factor depending on the number of rainy days and cloudiness is shown.

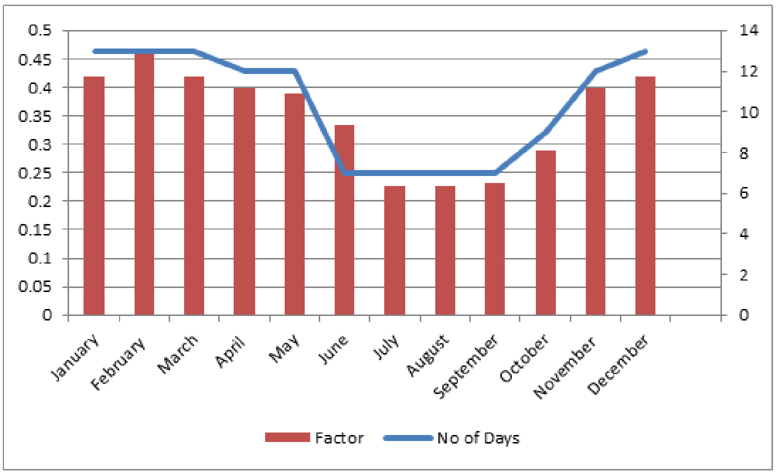

Figure 8.8. Number of rainy days and correction factor regarding cloudiness

Solar Collector Efficiency

Efficiency of a solar collector with selective absorber has been calculated from the set of typical commercial data that the manufacturers supply. The collector efficiency curve is approximated by the regression equation efficiency = a + b*x + c*x^2, where x is the difference of the absorber temperature and average monthly ambient temperature for the city of Negotin, that was selected for the analysis. Monthly average, monthly maximum, and monthly minimum temperature for the city of Negotin are shown in the diagram in Figure 8.9.

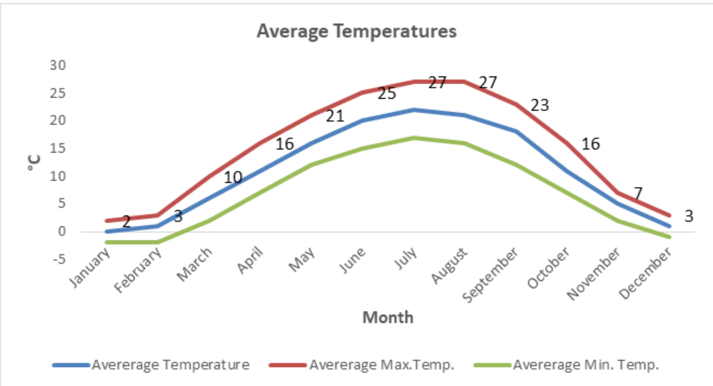

Figure 8.9. Average monthly temperatures

The collector efficiency curve is shown in Figure 8.10.

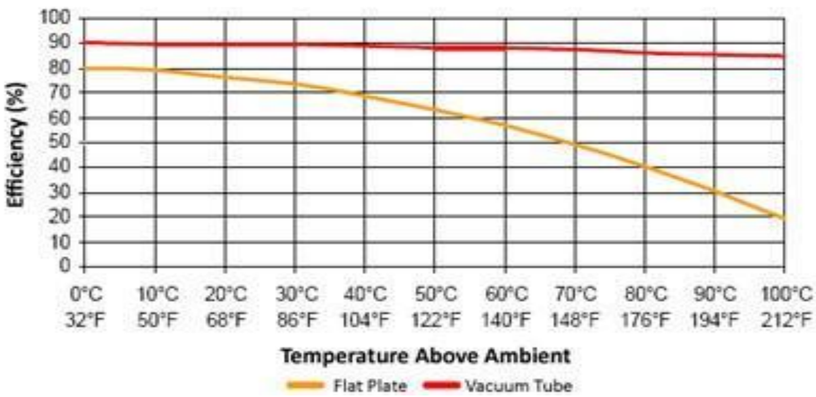

Figure 8.10. Efficiency of flat and vacuum (evacuated) tube collectors

Efficiency curves for two types of collectors are shown in Figure 8.10.:

- flat plate collector, and
- collector made of evacuated tubes.

Vacuum type of collector has much better and much "flatter" efficiency curve than the flat collector. Efficiency of vacuum-type collector is less sensitive to the temperature difference between the absorber and the environment. This type of collector is also more costly than the flat collector, but is more suitable for higher temperature application. Flat collectors are good enough for SDH applications.

The monthly energy efficiency of flat collectors is shown in Table 8.7. The collector efficiency is calculated for absorber temperature of 70°C.

Table 8.7. Monthly flat collector efficiency

Month	Jan	Feb	Mar	Apr	Oct	Nov	Dec
Average Temperature (°C)	0	1	6	11	11	5	1
Collector Efficiency (%)	50	50	55	59	55	53	50

Capacity of an SDH plant cannot be defined in the same way as usually defined for fossil DH plants. The capacity depends on intensity of solar radiation, as it is shown in Table 8.8. It can be seen, that with the field of 30,000 m^2, the capacity of SGH is about 6.4 % of thermal capacity of existing DHS.

Table 8.8. Thermal capacity of an SDH plant (MWt)

Month	Collector Field Area: 20,000 m^2 (MW$_t$)	Collector Field Area 30,000 m^2 (MW$_t$)
January	0.536	0.804
February	0.521	0.781
March	0.749	1.123
April	0.687	1.031
October	0.828	1.242
November	0.567	0.851
December	0.471	0.707
Total	4.359	6.539

The land area that is necessary to install a field of solar collectors should be approximately estimated. It is assumed that the land area is flat and has square form, and that one flat plate solar collector has an area of 2.4 m^2. For installing the field of 20,000 m^2 (8,333 solar collectors), it would be necessary to occupy 29,266 m^2, i.e. a piece of land with dimensions 171x171 m. For installing the field of 30,000 m^2 (12,500 solar collectors), it would be necessary to occupy a land piece with dimensions 209x209 m.

Calculated energy that could be delivered to the DHS is presented in Table 8.9.

Table 8.9. Solar energy delivered to DHS

Solar energy delivered to DHS (MWh/month)	Jan	Feb	Mar	Apr	Oct	Nov	Dec
Field Area: 20,000 m^2	910.672	885.127	1,272.885	1,167.988	1,407.781	964.723	801.417
Field Area: 30,000 m^2	1,366.008	1,327.69	1,909.328	1,751.981	2,111.671	1,447.08	1,202.1262

8.2.5.2.1 Solar PV energy generation

Mounting and supporting structures

PV panels arrays must be mounted on a firm structure that can support the array and withstand wind, rain, snow, and be corrosion-resistive over a few decades. These structures enable tilting of the PV array usually at a fixed angle determined by the local latitude, orientation of the structure or terrain. To obtain the highest annual energy output, modules in the northern hemisphere are pointed due south and inclined at an angle equal to the local latitude. For PV panels arrays mounted on the ground, tracking mechanisms that automatically move panels to follow the sun across the sky, which provides more energy, are sometimes used. However, such tracking mechanisms are more expensive. One-axis trackers are typically designed to track the sun from East to West. Two-axis trackers allow for modules to remain pointed directly at the sun throughout the day.

Energy storages

Batteries are used for the storage of electric energy that is generated from solar energy by PV panels. Stored electric energy can be used to power buildings and homes at night or during non-sunny days. The batteries are playing an increasingly important role for solar and wind energy in utilities.

Operation and Maintenance

PV operation and maintenance (O&M) costs are estimated using a PV O&M cost model that provides a line-item cost estimate of measures that correspond to the PV O&M services described in "Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems"[75]. O&M cost drivers for PV modules and inverters in the model are based on actuarial failure and repair, but current default values for other measures that occur on fixed intervals are based on best judgement.

Addition of insurance costs increased the annual cost substantially in the 2021 update. Different types of insurances that may be needed by a PV plant operator could be found in relevant literature. The two major categories of insurance are:

- property insurance, which insures the PV plant hardware against hazards, and
- liability insurance, which insures against claims of harm by others.

Property insurance is included in the insurance cost because it can be associated with a single PV plant, whereas liability and other types of insurance are often written as an umbrella policy to cover exposure of a company, rather than a PV plant.

For residential systems, the factor may vary from 0.004 to 0.006 of investment costs per year, which is translated to $12.03/kW/yr. For commercial and utility-scale plants, the factor varies a lot, and the value of 0.002522 times capital cost per year can be used for property insurance. This is translated to a range of $2.06–$12.37/kW/year.

For a 100 MW utility scale single-axis tracking system is the common system. Microinverters are assumed for residential systems and DC optimizers (three-phase) for commercially roof-mounted PV systems. A commercial roof-mounted string inverter with a 12- year warranty incurs slightly more replacement cost than

[75] https://www.nrel.gov/docs/fy19osti/73822.pdf

a residential roof-mounted microinverter with a 25-year warranty. Also, the analysis based on the period of 30 years for the commercial system and 25 years for the residential system is common in practice. Because of its longer lifetime, the commercial roof-mounted PV project owners will need to repair the inverter more often.

O&M costs in the PV O&M cost include preventative maintenance, scheduled at regular intervals, as well as corrective maintenance to replace components. The maintenance measures in the cost model should be sorted into inverter replacement, operations, module and components replacement, inspection, monitoring, PV module cleaning, vegetation and pest control, land lease, property taxes, insurance, asset management, and security.

The current cost estimate is:
- $28.97/kW-DC/a (residential),
- $17.92/kW-DC/a (commercial; roof-mounted),
- $17.10/kW-DC/a (commercial; ground-mounted),
- $14.61/kW-DC/a (utility-scale, fixed-tilt), and
- $16.06/kW-DC/a (utility-scale, single-axis tracking).

LCOE of Stand-Alone PV and PV-Plus-Storage Systems

LCOE is an imperfect metric to measure the competitiveness of PV within the energy marketplace. The LCOE of PV-plus-storage does not focus on value of electricity but can help track improvements to all costs of a PV-plus-storage system over time, and can provide limited comparisons with other dispatchable electricity generation technologies (e.g., natural gas).

Utility Scale PV (USPV)

The USPV systems are constructed based on EPC + developer approach and corresponding contracts. Investment cost in that case include EPC construction costs and developer costs. EPC soft costs are driven by labour rates and labour productivity. EPC costs include design and engineering cost and EPC hardware costs (that include module and battery racking, mounting, wiring, containerization, and foundation), and related EPC soft costs (including related labour and equipment hours).

Commercial PV (CPV)

Construction of the CPV requires to some degree respecting of customer`s preferences. Customer's preference for specific characteristics of CPV are based on several factors, including:
- cost,
- load profile, and
- planned usage in shifts, which influences storing energy in one period for use in a later period.

Generally, the customers that operate their systems with high peaks of short duration, may require installing of a high kW battery capable to satisfy high peaks during operation. The customers that operate the systems without high peaks may prefer a high kWh battery that would be capable to discharge energy in longer period.

Residential PV panels

For estimating of components` costs and system prices for PV-plus-storage installed, it is used adapted component - and system - level modelling approach for the PV in the year 2021.
Cystem configuration refers to four characteristics that determine a PV-plus-storage system's functionality: PV system capacity (kW), Battery energy capacity (kWh), Battery power capacity (kW), and Whether the battery is DC- or AC-coupled.

A PV panels array, a battery, and a battery-based inverter are the fundamental components of every PV plus-storage system. Additional component requirements are determined by whether the system is DC- or AC-coupled. A DC-coupled system often requires a charge controller to step down the PV output voltage to a level that is safe for the battery, whereas an AC-coupled system requires a grid-tied inverter to feed PV output directly to the customer's load or the grid.

Building Integrated PV

The most of PV panels are supported by special mounting structures. PV panels can also be integrated directly into building structures, mostly in roofs and façades. These systems are known as building-integrated PV.

Inverters

Inverters are used to convert the direct current (DC) electricity generated by solar photovoltaic modules into alternating current (AC) electricity, which is the generally used form of electricity. It is practice that the power of the inverters is designed applying the factor of 1.2-1.25 to the power of PV panels field. Inverters in practice in PV facilities are used in two forms:

- one inverter that converts the electricity generated by all of the modules, or
- microinverters that are attached to each individual module.

A single inverter is generally less expensive and can be more easily cooled and serviced when needed.
There are now advanced ("smart") inverters that allow two-way communication between the inverter and the electric utility. This can help balancing supply and demand automatically or in communication with utility operators.

Potential Estimate

The basic idea of the potential estimate is that Solar PV would be used by DH plants for own needs (running pumps, ventilators, burners, etc.). As the DH plants operate in the period between October 15 and April 15, during the heating season, the same estimates are used for SDH and Solar PV.
All DHCs in Serbia in the year 2021 generated 6,901,953 MWh of heat, and consumed 228,315 MWh of electricity. This shows that for generation of one MWh of thermal energy it was necessary to spend 0.033 MWh of electric energy.

In case of the DHS of the City of Negotin, the DHS spent 416 MWh of electricity for generation of 10,976 MWh of heat. The thermal capacity of DHS of the City of Negotin is 19 MWt. This results in the following ratios: 21.89 MWh/MWt, and 0.029 MWh-e/MWh-t.

As the DHS delivers heat only during the heating season (when also the most of electricity is spent), a certain number of solar PV panels should be installed that would support generation of electric energy during the heating season, but to continue to generate electric energy during non-heating months. Generated electric energy during non-heating months could be delivered to the national grid, and replaced by corresponding quantity in the heating season that would be used for running the pumps, fans and burners, and other needs. Otherwise, generated electric energy in non-heating months can be sold on spot market.

Both the heating and non-heating seasons last approximately for six months, each. As days are longer in non-heating season, the quantity of electricity generated during non-heating season would be larger by roughly 20%, which can compensate possible differences in summer and winter prices of electric energy. Solar PV panel should be mounted on the roofs of boiler houses or/and DHC head office buildings, at the roof areas that are oriented towards the South. Solar PV panels could be positioned at the ground but inside the fence of DHC`s objects. Positioning of solar PV panels on the land that is not in possession of the DHC, would have different character. Tilt of the solar PV panels, as they should produce electricity over the year, should be optimized for such operating conditions.

Solar PV panels are today produced as monocrystalline and polycrystalline. Monocrystalline PV panels operate with efficiency of 22-23%, while polycrystalline operate with efficiency of 18%. Besides this, polycrystalline solar PV panels are very sensitive to the temperature.

Solar PV panels for roof-mounting are manufactured in size of 2 m^2 (2x1 m) with power of 0.5 kW. For estimating the effects of installing the field of solar PV, a simplified calculation is applied. It is assumed that solar PV plant has the power of 30 kW, which implies that 60 PV panels are installed. It is assumed PV panels produce electric energy 7 h/day in the heating season, and 10 h/day in non-heating season. The same cloudiness factors used for calculation of solar thermal collectors are applied.

It is estimated that the field of PV panels generates 63 MWh of electric energy per year. Out of this, 46.5 MWh of electric energy would be exchanged with the electric company (or sold at the market), and 16.5 MWh would be generated by the PV plant in the heating season. This calculation shows that installing of 60 PV panels would reduce buying of electricity by 15.15%. CBA will show whether this would be a profitable investment.

If the solar PV panels were mounted on the roofs, the necessary area of the roof for mounting of the PV panels would be 120 m^2. If the PV panels were mounted on flat land, required area for mounting would be the same as for solar thermal collectors. The problem of disposition is the same: the panels arrayed in the previous row overshadow panels in the next row. This problem is especially significant in winter months when Sun is low over the horizon.

Cost of Investment

Other investment cost of a PV plant includes: Design, Permitting, Inverter, Battery bank, Control, and Connection. The price (in $/W) of PV panels sustained a drastic reduction of prices. From approximately 120 $/W in the year 1975, the price fell to approximately 0.2 $/W in the year 2021.

8.2.6 Technical potential for efficient DH from industrial waste heat

The technical potential of waste heat in the Republic of Serbia, that could be recovered directly in district heating systems of high-temperature water, amounts to 315,915 MWh and additional 337,744 MWh of low-temperature water recoverable waste heat. By utilization of heat pumps (COP = 4), the total technical potential for efficient DH from Industrial waste heat amounts to 765,115 GWh.

9. Environmental impact of utilizing the potential for HE CHP

This chapter summarizes the emission reductions resulting from switching from conventional heating, either individually by wood or by fossil fuel-fired DH systems, to heating with improved energy efficiency (i.e. expansion of the DH network by connecting new consumers, utilization of waste heat, utilization of waste for energy, using solar thermal collectors, and inclusion of HE CHP). Options of substituting the electricity produced in TPPs with PV or HE CHP electricity have also been considered. Cumulative emission reductions spread over the Action Plan period (2022-2030), , are presented in the following tables (Table 9.1 – Table 9.12.)

Table 9.1. Emission reduction – Measure APM 1.1 - Increasing the degree of connection of new customers of heat energy

Increasing the degree of connection of new customers of heat energy									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	4575.4	12658.5	21199.2	30235.5	39729.4	49718.9	60166.0	71032.5	81975.2
tNOx	6.7	18.5	31.0	44.2	58.1	72.7	88.0	103.9	119.9
tSOx	38.5	106.4	178.2	254.1	333.9	417.9	505.7	597.0	689.0
tPM2.5	8.3	23.1	38.6	55.1	72.4	90.6	109.6	129.4	149.3
tPM10	8.8	24.4	40.8	58.2	76.5	95.8	115.9	136.8	157.9

Table 9.2. Emission reduction – Measure APM 1.2 – CHP in DHS

CHP in DHS									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	0.0	0.0	24240.0	24240.0	24240.0	24240.0
tNOx	0.0	0.0	0.0	0.0	0.0	53.6	53.6	53.6	53.6
tSOx	0.0	0.0	0.0	0.0	0.0	453.3	453.3	453.3	453.3
tPM2.5	0.0	0.0	0.0	0.0	0.0	57.9	57.9	57.9	57.9
tPM10	0.0	0.0	0.0	0.0	0.0	62.7	62.7	62.7	62.7

Table 9.3. Emission reduction – Measure APM 1.3 – Use of biomass in DHS

Use of biomass in DHS									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	3917.0	24339.0	49738.0	53624.0	53624.0	53624.0	57637.0	118711.0
tNOx	0.0	7.0	41.0	83.0	89.0	89.0	89.0	96.0	198.0
tSOx	0.0	20.0	124.0	254.0	274.0	274.0	274.0	295.0	607.0
tPM2.5	0.0	-4.0	-26.0	-54.0	-58.0	-58.0	-58.0	-63.0	-129.0
tPM10	0.0	-4.0	-26.0	-52.0	-57.0	-57.0	-57.0	-61.0	-125.0

Table 9.4. Emission reduction – Measure APM 1.4 – Use of waste in DHS

Use of waste in DHS									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	40400.0	40400.0	40400.0	40400.0	40400.0	59994.0	59994.0	59994.0
tNOx	0.0	53.2	53.2	53.2	53.2	53.2	79.0	79.0	79.0
tSOx	0.0	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.6
tPM2.5	0.0	0.6	0.6	0.6	0.6	0.6	0.9	0.9	0.9
tPM10	0.0	0.6	0.6	0.6	0.6	0.6	0.9	0.9	0.9

Table 9.5. Emission reduction – Measure APM 1.5 – Use of heat pumps in DHS

Use of heat pumps in DHS									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	6060.0	6060.0	6060.0	15190.4	15190.4	22846.2
tNOx	0.0	0.0	0.0	8.0	8.0	8.0	20.0	20.0	30.1
tSOx	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2
tPM2.5	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3
tPM10	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3

Table 9.6. Emission reduction – Measure APM 1.6 – Use of solar thermal in DHS

Use of solar thermal in DHS									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	0.0	1664.9	7514.3	85582.4	91431.9	97281.4
tNOx	0.0	0.0	0.0	0.0	3.8	17.3	196.6	210.0	223.5
tSOx	0.0	0.0	0.0	0.0	0.8	3.4	39.1	41.8	44.5
tPM2.5	0.0	0.0	0.0	0.0	0.2	0.7	8.2	8.8	9.3
tPM10	0.0	0.0	0.0	0.0	0.2	0.8	9.5	10.1	10.8

Table 9.7. Emission reduction – Measure APM 1.7 – Using solar PV

Using solar PV									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	141.8	378.1	850.8	2268.9	3686.9	5104.9
tNOx	0.0	0.0	0.0	0.2	0.6	1.5	3.9	6.3	8.7
tSOx	0.0	0.0	0.0	1.2	3.1	7.1	18.9	30.7	42.5
tPM2.5	0.0	0.0	0.0	0.2	0.4	0.9	2.4	3.9	5.5
tPM10	0.0	0.0	0.0	0.2	0.4	1.0	2.6	4.3	5.9

Table 9.8. Emission reduction – Measure APM 1.8 – Cooling

Cooling									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	766.0	1532.0	2298.0	3447.0	4596.0	6128.0
tNOx	0.0	0.0	0.0	8.4	25.1	50.2	87.8	137.9	204.8
tSOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tPM2.5	0.0	0.0	0.0	47.5	95.0	142.5	213.7	285.0	379.9
tPM10	0.0	0.0	0.0	0.6	1.8	3.7	6.4	10.1	15.0

Table 9.9. Emission reduction – Measure APM 2.1 – Industrial waste heat utilization in district heating systems

Industrial waste heat utilization in district heating systems									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	1314.5	3074.6	6594.8	13211.9	21143.5	32172.0	44091.7
tNOx	0.0	0.0	2.1	4.9	10.5	21.1	33.7	51.3	70.3
tSOx	0.0	0.0	2.4	5.7	12.2	24.5	39.1	59.6	81.6
tPM2.5	0.0	0.0	0.4	0.9	2.0	4.0	6.4	9.8	13.4
tPM10	0.0	0.0	0.4	1.0	2.2	2.9	5.5	9.1	13.0

Table 9.10. Emission reduction – Measure APM 2.2 – Introduction of HE CHP systems in industry

Introduction HE CHP systems in industry									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	2816.2	6579.4	14105.9	28236.6	45183.6	68734.9	94155.3
tNOx	0.0	0.0	6.4	15.1	32.3	64.6	103.4	157.3	215.5
tSOx	0.0	0.0	6.3	14.7	31.5	63.0	100.8	153.4	210.1
tPM2.5	0.0	0.0	0.9	2.1	4.5	9.0	14.4	21.9	30.0
tPM10	0.0	0.0	1.0	2.3	5.0	9.9	15.9	24.2	33.1

Table 9.11. Emission reduction – Measure APM 3.1 – HE CHP in the residential sector

HE CHP in the residential sector									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	37185.0	95475.0	153765.0	212055.0	270345.0	328635.0	386925.0
tNOx	0.0	0.0	11.5	29.5	47.4	65.4	83.4	101.4	119.4
tSOx	0.0	0.0	7.0	18.1	29.1	40.1	51.1	62.1	73.2
tPM2.5	0.0	0.0	106.0	272.2	438.3	604.5	770.7	936.9	1103.0
tPM10	0.0	0.0	108.0	277.4	446.8	616.1	785.5	954.8	1124.2

Table 9.12. Emission reduction – Measure APM 3.2 – HE CHP in the service sector

HE CHP in the service sector									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cumulative emission reduction									
tCO_2	0.0	0.0	0.0	210.7	632.0	632.0	842.6	1053.3	1263.9
tNOx	0.0	0.0	0.0	2.3	6.9	6.9	9.2	11.5	13.8
tSOx	0.0	0.0	0.0	0.9	2.8	2.8	3.7	4.6	5.5
tPM2.5	0.0	0.0	0.0	0.2	0.5	0.5	0.7	0.9	1.0
tPM10	0.0	0.0	0.0	0.2	0.6	0.6	0.8	1.0	1.2

10.Cost-benefit analyses (CBA)

10.1 Economic potential of HE CHP in Serbia

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The determination of the economic potential for HE CHP development implies an estimation of the economic-financial sustainability of the operation of proposed HE CHP systems. In the evaluation of the feasibility, the current regulatory framework and market conditions are considered. For this evaluation, the prices of commodities have been calculated considering the current prices of commodities. In addition, the various tariff schemes, incentives, and discounts offered by support schemes are included in the calculation. The costs of CHP facilities (investment and maintenance) were obtained from the survey of the Serbian and EU market.

For different types of customers, a detailed business case was analysed to identify the cash flows and associated indicators of the economic-financial performance of the investment in the CHP system. The economic feasibility of HE CHP systems was assessed based on the financial indicators (NPV, payback period,…).

The economic potential represents a part of technical potential and includes projects with positive NPV and acceptable payback period. The potential was determined by multiplying the feasibility percentage by the technical potential. It is important to point out that the assessment of the economic potential of HE CHP can be interpreted as probabilistic. This means that it has rational foundations and reflects the current regulatory and market conditions, but on the other side, it does not include non-technical factors and barriers (availability of funding, business and management policies, decision-making processes, authorization processes, etc) which could have a significant (positive or negative) impact to the process of CHP development.

The technical and economic potentials for the development of HE CHP have been expressed for selected sectors (residential, services, industrial), in terms of CHP capacity (electricity and heat power) that can potentially be installed and of the estimated amount of produced heat and electricity. In calculation of these potentials, the scenarios for development of heat demand in residential, services, and industrial sectors until 2030 were taken into consideration.

10.2 Cost-benefit analysis – assumptions and methodology

10.2.1 Introduction

In such a complex area, CBA is expected to define the economic limits of project profitability and enable comparison of projects from very different fields. Therefore, it is necessary to clearly define the starting assumptions, criteria, and methodology that will be applied.

10.2.1.1 Methodology

All data were taken from the previous technical parts of the study, and were converted in financial terms taking care that the following aspects are clearly visible:

- situation without a project,
- the project itself, and
- situation with the project.

CO_2 emission is regarded as a very important and these aspects were separately presented through situations without and with the project.

All mentioned aspects were summarized through economic flows and the final criteria were defined through:

- Net Present Value (NPV),
- Internal Rate of Return (IRR), and

- Simple Pay-back period.

To cover all the aspects of project influence, it is prepared the numeric interactive model with eight degrees of freedom. It enables measurement and analysis of the influence on selected criteria (NPV, IRR, simple pay-back period) of changes in:

- energy prices: gas, fuel oil, electricity, variety of feed-in tariffs, fuel wood, CO_2 price,
- working hours, and
- investment.

10.2.2 DH network sizing and costs

In order to determine the costs of development of district heating system networks, it is important to determine the specific costs of the networks (€/m), which depend on the diameter of the pipes to be installed.

The average diameter of the existing distribution networks of the district heating sector is 0.17 m, so the selected average diameter of pre-insulated pipes will be DN 200.

10.2.3 Heating plant sizing and costs

The variety of large-scale heating technologies that can be incorporated in district heating (DH) networks is as large as the diversity in heat demand, which ranges from low to high temperature, from constant to thermo-sensitive demand throughout the year.

Due to the technological progress and the enhanced utilisation of sustainable heat sources, the technical solutions for DH systems become even more diverse, yet featuring different technological maturity and costs[76].

10.2.4 Plants fuelled by natural gas

The initial investment costs of plants that use natural gas are relatively low and environmentally acceptable in the phase of the transition period of the green agenda.

10.2.5 Plants fuelled by biomass

Biomass plants, in no case should be a strategic decision in the future.

Oone should consider their relatively high initial investment compared to CHP plants that use geothermal energy and natural gas. Investments must be economically justified, financially profitable and environmentally sustainable.

The CO_2 emissions of plants that use biomass are almost 2 times higher than plants that use natural gas, i.e. 109.6 kgCO_2/GJ versus 56.10 kg CO_2/GJ[77].

10.3 Cost-benefit analysis of the introduction of the CHP system to residential houses

CBA analysis of the introduction of HE CHP into different residential buildings (three cases: buildings with one dwelling, with two dwellings, and with 3-8 dwellings) presents different results. The basic characteristics of the current situation and the proposed introduction of the CHP system are presented in the following table.

[76] Cost efficient district heating development, Metis studies
[77] Quaschning. V, Specific Carbon Dioxide Emissions of Various Fuels, https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php.

Table 10.1. Basic characteristics of residential buildings and proposed CHP System

Residential buildings		1 dwelling	2 dwellings	3-8 dwellings
Annual heat consumption (2021)	kWht	15,795	28,817	69,073
Annual electricity consumption (2021)	kWhe	4,800	9,600	38,400
Annual energy consumption				
Wood (8.78;17.56;39.00 m³, 3000 kWh/m³)	kWhw	26,340	52,680	117,000
Electricity	kWhe	4,800	9,600	38,400
Total value of energy consumption	EUR	1,120	2,239	6,457
Value of energy costs per heat production unit	EUR/kWht	0.0445	0.0487	0.0452
CHP system	h	2,920		
Annual heat production	kWht	17,520	30,076	75,920
Annual electric production	kWhe	5,840	14,600	43,800
Annual energy consumption				
Gas	kWhg	25,956	49,095	130,130
Electricity	kWhe			
Total value of energy consumption	EUR	902	1,707	4,523
Unit value of energy production				
Heat	kWht	0.03862	0.03820	0.03778
Electricity	kWhe	0.03862	0.03820	0.03778

The influence of the CHP system on residential buildings is shown in Table 10.2.

Table 10.2. The situation with the project: physical and financial influences

Influences, physical quantities				
CHP to dwellings, heat	kWht	15,795	28,817	69,073
CHP, excess of heat	kWht	1,725	1,259	6,847
CHP to dwellings, electricity	kWhe	4,800	9,600	38,400
CHP, excess of electricity	kWhe	1,040	5,000	5,400
Influences, values				
CHP to dwellings, heat, cost reduction	EUR	92	304	510
CHP, excess of heat	EUR			
CHP to dwellings, electricity, cost reduction	EUR	232	468	1,886
CHP, excess of electricity	EUR	107	515	398
Dwellings - cost reduction and revenue	**EUR**	**431**	**1,287**	**2,795**
Dwellings - current energy costs with CHP	**EUR**	**796**	**1,192**	**4,125**

As expected, investment heavily depends on the type of the resident building (3).

Table 10.3 Investment cost

In €

No	Item	Amount		
		1 dwelling	2 dwellings	3-8 dwellings
1	CHP system	8,000	15,000	39,450
3	Other Investment Costs	50	100	200
4	Contigency (5%)	403	755	1,983
	Total	**8,453**	**15,855**	**41,633**

Operating costs are divided into four sections. The first one is presenting the operating costs of the proposed CHP system. In the second part, previous costs are defined. The third section is dealing with the costs with the CHP system, and at the end, it is presented overall cost reduction. There might be some other operating costs, but these are neglected because they are the same in all cases.

Table 10.4. Operating cost

No	Description (EUR/year)	Amount		
		1 dwelling	2 dwellings	3-8 dwellings
1	***CHP system costs***			
	Gas	902	1,707	4,523
	Maintenance& other costs (2.4%)	203	381	999
	Total	**1,105**	**2,087**	**5,523**
2	***Dwellings - Previous costs***			
	Wood	702	1,405	3,120
	Electricity	417	834	3,337
	Maintenance& other costs (2.4%)	27	54	155
	Total	**1,146**	**2,293**	**6,612**
3	***Dwellings - costs with CHP system***			
	CHP system costs	1,105	2,087	5,523
	Revenue from electricity	107	515	398
	Total	**998**	**1,572**	**5,124**
2-3	**Cost reduction with CHP system**	**148**	**721**	**1,488**

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units (Table 10.5.)

Table 10.5. CO_2 emissions

		1 dwelling	2 dwellings	3-8 dwellings
Influence of CHP system on CO2 emission				
Previous heat consumption	*kg*	*8,780*	*17,560*	*39,000*
Current heat consumption	*kg*	*5,243*	*9,917*	*26,286*
Reduction by heat consumption	kg	3,537	7,643	12,714
Previosus electric consumption	*kg*	*3,840*	*7,680*	*30,720*
Current electric consumption	*kg*	*970*	*1,939*	*7,757*
Reduction by current electric consumption	kg	2,870	5,741	22,963
Reduction by excess of electricity	kg	622	2,990	3,229
Reduction of CO_2 emission	**kg**	**7,029**	**16,374**	**38,906**
Annual value of reduction of CO_2 emission	**EUR**	**588**	**1,371**	**3,257**

The Economic Flow and a breakdown of the basic criteria (NPV, IRR, simple pay-back period) are presented in Table 10.6. and Table 10.7. respectively.

Table 10.6. Economic flow

In EUR, 2920 h				
Description			**2023**	**2024-42**
Inflow				
	1 dwelling			2,192
	2 dwellings			4,898
	3-8 dwellings			12,870
	Improvement	1 dwelling		1,604
		2 dwellings		3,527
		3-8 dwellings		9,613
	CO_2	1 dwelling		588
		2 dwellings		1,371
		3-8 dwellings		3,257
Outflow				
	Investment	1 dwelling	8,453	
		2 dwellings	15,855	
		3-8 dwellings	41,633	
	Operating costs	1 dwelling		998
		2 dwellings		1,572
		3-8 dwellings		5,124
Net flow, without CO_2				
		1 dwelling	**-8,453**	**605**
		2 dwellings	**-15,855**	**1,955**
		3-8 dwellings	**-41,633**	**4,488**
Net flow, with CO_2				
		1 dwelling	**-8,453**	**1,194**
		2 dwellings	**-15,855**	**3,326**
		3-8 dwellings	**-41,633**	**7,745**

Table 10.7. Breakdown of the investment criteria

	Discount rate		**6%**			
	1 dwelling		**2 dwellings**		**3-8 dwellings**	
	- CO2	**+ CO2**	**- CO2**	**+ CO2**	**- CO2**	**+ CO2**
NPV (20y)	**-1,604**	**4,591**	**5,623**	**20,052**	**7,968**	**42,255**
IRR (20y)	**3.29%**	**12.65%**	**10.47%**	**20.36%**	**8.49%**	**17.77%**
Simple pay-back period, years	**13.97**	**7.08**	**8.11**	**4.77**	**9.28**	**5.38**

10.4 Cost-benefit analysis of the introduction of the CHP system to commercial entities

Influence of the introduction of CHP systems is divided by their primary purpose (hotels and service facilities and health services facilities), and by the kind of heating (heavy oil and gas). There are 4 parts:

- Health services facilities:
  - Heating by using heavy oil,
  - Heating by using gas;
- Hotels and sports facilities:
  - Heating by using heavy oil, and
  - Heating by using gas.

10.4.1 Health services facilities using heavy oil

CBA analysis of the introduction of HE CHP into different Health services facilities (three cases: health centres, hospitals, and clinical centres) presents different results. The basic characteristics of the current situation and the proposed introduction of the CHP system (Table 10.8).

Table 10.8: Basic characteristics of Health services facilities

Health service facility (HF)		Health Center	Hospital	Clinical centre
Annual heat consumption (2021)	kWht	168,000	5,250,000	14,700,000
Annual electricity consumption (2021)	kWhe	80,000	2,500,000	7,000,000
Annual energy consumption				
Gas	kWhw			
Heavy oil	t	17.8	556.7	1,558.9
Electricity	kWhe	80,000	2,500,000	7,000,000
Total value of energy consumption	EUR	25,327	791,479	2,216,141
Value of energy costs per heat production unit	EUR/kWht	0.0858	0.0858	0.0858
		0.1021	0.1021	0.1021
CHP system				
Annual heat production	kWht	238,950	5,538,000	14,835,000
Annual electric production (η=0.36; 0.425; 0.44)	kWhe	147,500	4,651,920	12,362,500
Annual energy consumption				
Gas	kWhg	406,789	10,945,134	29,313,969
Electricity	kWhe			
Total value of energy consumption	EUR	14,697	395,448	1,059,114
Unit value of energy production				
Heat	EUR/kWht	0.03803	0.03881	0.03894
Electricity	EUR/kWhe	0.03803	0.03881	0.03894

Table 10.9. The influence of the CHP system on health services - The situation with the project – physical and financial influences

Influences, physical quantities				
CHP to HF, heat	kWht	168,000	5,250,000	14,700,000
Additional heat from boiler	kWht	70,950	288,000	135,000
CHP to HF, electricity	kWhe	80,000	2,500,000	7,000,000
CHP, excess of electricity	kWhe	67,500	2,151,920	5,362,500
Influences, values				
CHP to HF, heat, cost reduction	EUR	8,031.6	246,913.2	689,389.3
Additional heat from boiler	EUR	6,094.3	24,738.1	11,596.0
CHP to HF, electricity, cost reduction	EUR	7,863.9	243,806	681,718.9
CHP, excess of electricity, additional revenue	EUR	9,288.9	294,461.7	733,069.1
HF - cost reduction and additional revenue	**EUR**	**25,184**	**785,181**	**2,104,177**
HF - current energy costs with CHP	**EUR**	**20,792**	**420,186**	**1,070,710**

Investment costs depend on the electrical capacity, and they are lower the bigger the CHP system is. For health centres, the costs per installed kW are 22,000 €, for hospitals, it is 1,400 €, and for a clinical centre - 1,200 €.

Table 10.10. Investment cost

In €				
No	Item	Amount		
		Health Center	Hospital	Clinical centre
1	CHP system	110,000	1,528,800	3,450,000
3	Other Investment Costs (1%)	1,100	15,288	34,500
4	Contingency (5%)	5,555	77,204	174,225
	Total	**116,655**	**1,621,292**	**3,658,725**

Operating costs are divided into four sections: the operating costs of the proposed CHP system, previous costs, the costs with the CHP system, and overall cost reduction.

Table 10.11. Operating costs

	EUR/year			
No	Description	Amount		
		Health Center	Hospital	Clinical centre
1	***CHP costs***			
	Gas	14,697	395,448	1,059,114
	Maintenance& other costs (2.4%)	2,800	38,911	87,809
	Total	**17,497**	**434,359**	**1,146,923**
2	***HF - Previous costs***			
	Heavy oil	14,421	450,654	1,261,831
	Electricity	10,906	340,825	954,310
	Maintenance& other costs (2.4%)	608	18,995	53,187
	Total	**25,935**	**810,474**	**2,269,328**
3	***HF costs with CHP***			
	CHP costs	17,497	434,359	1,146,923
	Heavy oil	6,094	24,738	11,596
	Total	**23,591**	**459,097**	**1,158,519**
2-3	**Cost reduction with CHP**	**2,344**	**351,377**	**1,110,809**

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units (Table 10.12).

After analysing the Economic Flow, the breakdown of the basic results of Economic flow analysis is presented in Table 10.13. Investment criteria are summarized in Table 10.14.

Table 10.12. CO_2 emissions

		Health Center	Hospital	Clinical centre
Influence of CHP on CO2 emission				
Previous heat consumption	*kg*	*55,944*	*1,748,250*	*4,895,100*
Current heat consumption	*kg*	*82,171*	*2,210,917*	*5,921,422*
Change by heat consumption	kg	-26,227	-462,667	-1,026,322
Previous electric consumption	*kg*	*64,000*	*2,000,000*	*5,600,000*
Current electric consumption	*kg*	*16,160*	*505,000*	*1,414,000*
Reduction by current electric consumption	kg	47,840	1,495,000	4,186,000
Reduction by excess of electricity	kg	40,365	1,286,848	3,206,775
Reduction of CO_2 emission	**kg**	**61,978**	**2,319,181**	**6,366,453**
Annual value of reduction of CO_2 emission	**EUR**	**5,189**	**194,162**	**532,999**

Table 10.13. Economic flow

In EUR,

	Description	2023	2024-42
Inflow			
	Health Center		**30,373**
	Hospital		**979,342**
	Clinical centre		**2,637,177**
Improvement	Health Center		25,184
	Hospital		785,181
	Clinical centre		2,104,177
CO_2	Health Center		5,189
	Hospital		194,162
	Clinical centre		532,999
Outflow			
Investment	Health Center	116,655	
	Hospital	1,621,292	
	Clinical centre	3,658,725	
Operating costs	Health Center		17,497
	Hospital		434,359
	Clinical centre		1,146,923
Net flow, without CO_2			
	Health Center	**-116,655**	**7,687**
	Hospital	**-1,621,292**	**350,822**
	Clinical centre	**-3,658,725**	**957,254**
Net flow, with CO_2			
	Health Center	**-116,655**	**12,876**
	Hospital	**-1,621,292**	**544,984**
	Clinical centre	**-3,658,725**	**1,490,254**

Table 10.14. Breakdown of the investment criteria

	Discount rate	6%				
	Health Center		Hospital		Clinical centre	
	- CO2	+ CO2	- CO2	+ CO2	- CO2	+ CO2
NPV (20y)	-29,131	25,489	2,163,413	4,207,263	6,624,934	12,235,566
IRR (20y)	2.36%	8.82%	21.07%	33.47%	25.83%	40.67%
Simple pay-back period, years	15.17	9.06	4.62	2.97	3.82	2.46

10.4.2 Health services facilities using gas

The influence of the introduction of the CHP systems on health services facilities that are using gas is very different compared to those using heavy oil. The base data are presented in Table 10.15.

Table 10.15. Basic characteristics of Health services facilities

Health service facility (HF)		Health Center	Hospital	Clinical centre
Annual heat consumption (2021)	kWht	168,000	5,250,000	14,700,000
Annual electricity consumption (2021)	kWhe	80,000	2,500,000	7,000,000
Annual energy consumption				
Gas	kWhg	197,647	6,176,471	17,294,118
Heavy oil	t			
Electricity	kWhe	80,000	2,500,000	7,000,000
Total value of energy consumption	EUR	18,047	563,981	1,579,146
Value of energy costs per heat production unit	EUR/kWht	0.0425	0.0425	0.0425
		0.0728	0.0728	0.0728
CHP system				
Annual heat production	kWht	238,950	5,538,000	14,835,000
Annual electric production (η=0.36; 0.425; 0.44)	kWhe	147,500	4,651,920	12,362,500
Annual energy consumption				
Gas	kWhg	406,789	10,945,134	29,313,969
Electricity	kWhe			
Total value of energy consumption	EUR	14,697	395,448	1,059,114
Unit value of energy production				
Heat	EUR/kWht	0.03803	0.03881	0.03894
Electricity	EUR/kWhe	0.03803	0.03881	0.03894

The influence of the CHP system on health services facilities (the situation with the project) is described in Table 10.16.

Investment costs depend on the electrical capacity, and they are lower the bigger the CHP system is. For health centres the costs per installed kW are 22,000 €, for hospitals, it is 1,400 €, and for a clinical centre - 1,200 €. So, the CHP system is the same as in the previous case with heavy oil (Table 10.17.).

Operating costs are divided into four sections: the operating costs of the proposed CHP system, previous costs, the costs with the CHP system, and overall cost reduction (Table 10.18.).

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units (Table 10.19.).

The economic flow is presented in Table 10.20.

Investment criteria (Net Present Value-NPV, Internal Rate of Return-IRR, Simple Return on Investment) are summarized in Table 10.21.

Table 10.16. The situation with t project – physical and financial influences

Influences, physical quantities				
CHP to HF, heat	kWht	168,000	5,250,000	14,700,000
CHP, excess of heat	kWht	70,950	288,000	135,000
CHP to HF, electricity	kWhe	80,000	2,500,000	7,000,000
CHP, excess of electricity	kWhe	67,500	2,151,920	5,362,500
Influences, values				
GE to HF, heat, cost reduction	EUR	751.7	19,415.3	52,395.2
GE, excess of heat	EUR	0	0	0
GE to HF, electricity, cost reduction	EUR	7,863.9	243,806	681,718.9
GE, excess of electricity, additional revenue	EUR	9,288.9	294,461.7	733,069.1
HF - cost reduction and additional revenue	**EUR**	**17,904**	**557,683**	**1,467,183**
HF - current energy costs with CHP	**EUR**	**14,697**	**395,448**	**1,059,114**

Table 10.17. Investment cost

In €				
No	**Item**	**Amount**		
		Health Center	**Hospital**	**Clinical centre**
1	CHP system	110,000	1,528,800	3,450,000
3	Other Investment Costs (1%)	1,100	15,288	34,500
4	Contingency (5%)	5,555	77,204	174,225
	Total	**116,655**	**1,621,292**	**3,658,725**

Table 10.18. Operating costs

	EUR/year			
No	**Description**	**Amount**		
		Health Center	**Hospital**	**Clinical centre**
1	***CHP costs***			
	Gas	14,697	395,448	1,059,114
	Maintenance& other costs (2.4%)	2,800	38,911	87,809
	Total	**17,497**	**434,359**	**1,146,923**
2	***HF - Previous costs***			
	Gas	7,141	223,156	624,836
	Electricity	10,906	340,825	954,310
	Maintenance& other costs (2.4%)	433	13,536	37,900
	Total	**18,481**	**577,516**	**1,617,046**
3	***HF costs with CHP***			
	CHP costs	17,497	434,359	1,146,923
	Heavy oil	0	0	0
	Total	**17,497**	**434,359**	**1,146,923**
2-3	**Cost reduction with CHP**	**984**	**143,158**	**470,123**

Table 10.19. CO_2 **emissions**

	Unit	Health Center	Hospital	Clinical centre
Influence of CHP on CO2 emission				
Previous heat consumption	*kg*	*39,925*	*1,247,647*	*3,493,412*
Current heat consumption	*kg*	*82,171*	*2,210,917*	*5,921,422*
Change by heat consumption	kg	-42,247	-963,270	-2,428,010
Previous electric consumption	*kg*	*64,000*	*2,000,000*	*5,600,000*
Current electric consumption	*kg*	*16,160*	*505,000*	*1,414,000*
Reduction by current electric consumption	kg	47,840	1,495,000	4,186,000
Reduction by excess of electricity	kg	40,365	1,286,848	3,206,775
Reduction of CO_2 emission	**kg**	**45,958**	**1,818,578**	**4,964,765**
Annual value of reduction of CO_2 emission	**EUR**	**3,848**	**152,251**	**415,650**

Table 10.20. Economic flow

In EUR,

		Description	2023	2024-42
Inflow				
	Health Center			**21,752**
	Hospital			**709,934**
	Clinical centre			**1,882,833**
	Improvement	Health Center		17,904
	Improvement	Hospital		557,683
	Improvement	Clinical centre		1,467,183
	CO2	Health Center		3,848
	CO2	Hospital		152,251
	CO2	Clinical centre		415,650
Outflow				
	Investment	Health Center	116,655	
	Investment	Hospital	1,621,292	
	Investment	Clinical centre	3,658,725	
	Operating costs	Health Center		17,497
	Operating costs	Hospital		434,359
	Operating costs	Clinical centre		1,146,923
Net flow, without CO_2				
		Health Center	**-116,655**	**407**
		Hospital	**-1,621,292**	**123,324**
		Clinical centre	**-3,658,725**	**320,260**
Net flow, with CO_2				
		Health Center	**-116,655**	**4,255**
		Hospital	**-1,621,292**	**275,575**
		Clinical centre	**-3,658,725**	**735,910**

Table 10.21. Breakdown of the investment criteria

	Discount rate	6%				
	Health Center		Hospital		Clinical centre	
	- CO2	+ CO2	- CO2	+ CO2	- CO2	+ CO2
NPV (20y)	-105,763	-65,261	-231,349	1,371,329	-80,400	4,294,951
IRR (20y)	-19.06%	-3.43%	3.99%	15.98%	5.70%	19.42%
Simple pay-back period, years	286.34	27.42	13.15	5.88	11.42	4.97

10.4.3 Hotels and sports facilities using heavy oil

As in the previous case, the influence of the introduction of CHP systems is not divided only by their primary purpose (hotels and sports facilities) but by the kind of heating based on heavy oil or gas. Hence there are 2 parts:

- Hotels and sports facilities heated by heavy oil, and
- Hotels and sports facilities heated by natural gas.

CBA analysis of the introduction of HE CHP into different hotels and sports facilities (three cases: small hotel, large hotel, and swimming pool) presents different results. Here are the current situation's basic characteristics and the CHP system's proposed introduction (Table 10.22.).

Table 10.22. Basic characteristics of hotels and sports facilities

Hotels and sports facilities		Small hotel	Large hotel	Swimming pool
Annual heat consumption (2021)	kWht	400,000	2,000,000	2,919,000
Annual electricity consumption (2021)	kWhe	133,000	700,000	1,776,000
Annual energy consumption				
Gas	kWhw			
Heavy oil	t	42.4	212.1	309.5
Electricity	kWhe	133,000	700,000	1,776,000
Total value of energy consumption	EUR	52,467	267,109	492,686
Value of energy costs per heat production unit	EUR/kWht	0.0858	0.0858	0.0858
CHP System				
Annual heat production	kWht	218,700	1,061,200	2,804,400
Annual electric production (η=0.36; 0.374; 0.395)	kWhe	135,000	728,000	2,006,400
Annual energy consumption				
Gas	kWhg	375,000	1,946,524	5,079,494
Electricity	kWhe			
Total value of energy consumption	EUR	13,549	70,328	183,522
Unit value of energy production				
Heat	EUR/kWht	0.03831	0.03931	0.03815
Electricity	EUR/kWhe	0.03831	0.03931	0.03815

Investment costs depend on the electrical capacity, and they are lower the bigger the CHP system is. For a small hotel, the costs per installed kW are 2,200 €, for a large hotel, it is 1,650 €, and for a swimming pool – 1,400 € (Table 10.24.).

Operating costs are divided into four sections: the operating costs of the proposed CHP system, previous costs, the costs with the CHP system, and overall cost reduction.

Table 10.23. The situation with the project – physical and financial influences

Influences, physical quantities				
CHP tofacilities, heat	kWht	218,700	1,061,200	2,804,400
Additional heat from boiler	kWht	181,300	938,800	114,600
CHP to facilities, electricity	kWhe	133,000	700,000	1,776,000
CHP, excess of electricity	kWhe	2,000	28,000	230,400
Influences, values				
CHP to facilities, heat, cost reduction	EUR	10,395.5	49,379.7	133,744.3
Additional heat from boiler	EUR	15,573.0	80,639.2	9,843.7
CHP to facilities, electricity, cost reduction	EUR	13,037.2	67,916	174,371.3
CHP, excess of electricity, additional revenue	EUR	274.7	3,817.5	31,679.2
Facilities - cost reduction and additional revenue	**EUR**	**23,707**	**121,113**	**339,795**
Facilities - current energy costs with CHP	**EUR**	**29,122**	**150,967**	**193,366**

Table 10.24. Investment cost

In €

No	Item	Amount		
		Small hotel	Large hotel	Swimming pool
1	CHP System	110,000	429,000	739,200
2	Other Investment Costs (1%)	1,100	4,290	7,392
3	Contingency (5%)	5,555	21,665	37,330
	Total	**116,655**	**454,955**	**783,922**

Table 10.25. Operating costs

EUR/year

No	Description	Amount		
		Small hotel	Large hotel	Swimming pool
1	***CHP costs***			
	Gas	13,549	70,328	183,522
	Maintenance& other costs (2.4%)	2,800	10,919	18,814
	Total	**16,348**	**81,247**	**202,336**
2	***Hotels - pool - Previous costs***			
	Heavy oil	34,336	171,678	250,563
	Electricity	18,132	95,431	242,122
	Maintenance& other costs (2.4%)	1,259	6,411	11,824
	Total	**53,727**	**273,519**	**504,510**
3	***Hotels - pool costs with CHP***			
	GE costs	16,348	81,247	202,336
	Heavy oil	15,573	80,639	9,844
	Electricity			
	Total	**31,921**	**161,886**	**212,180**
2-3	**Cost reduction with CHP**	**21,805**	**111,633**	**292,330**

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units. (Table 10.26.)

The economic flow is presented in Table 10.27. and NPV and IRR in Table 10.28.

Table 10.26. CO_2 emissions

		Small hotel	Large hotel	Swimming pool
Influence of CHP on CO2 emission				
Previous heat consumption	*kg*	*133,200*	*666,000*	*972,027*
Current heat consumption	*kg*	*75,750*	*393,198*	*1,026,058*
Reduction by heat consumption	kg	57,450	272,802	-54,031
Previous electric consumption	*kg*	*106,400*	*560,000*	*1,420,800*
Current electric consumption	*kg*	*26,866*	*141,400*	*358,752*
Reduction by current electric consumption	kg	79,534	418,600	1,062,048
Reduction by excess of electricity	kg	1,196	16,744	137,779
Reduction of CO_2 emission	**kg**	**138,180**	**708,146**	**1,145,796**
Annual value of reduction of CO_2 emission	**EUR**	**11,568**	**59,286**	**95,926**

Table 10.27. Breakdown of the economic flow

In EUR,

	Description	2023	2024-42
Inflow			
	Small hotel		**35,276**
	Large hotel		**180,399**
	Swimming pool		**435,721**
Improvement	Small hotel		23,707
	Large hotel		121,113
	Swimming pool		339,795
CO_2	Small hotel		11,568
	Large hotel		59,286
	Swimming pool		95,926
Outflow			
Investment	Small hotel	116,655	
	Large hotel	454,955	
	Swimming pool	783,922	
Operating costs	Small hotel		16,348
	Large hotel		81,247
	Swimming pool		202,336
Net flow, without CO_2			
	Small hotel	**-116,655**	**7,359**
	Large hotel	**-454,955**	**39,866**
	Swimming pool	**-783,922**	**137,459**
Net flow, with CO_2			
	Small hotel	**-116,655**	**18,927**
	Large hotel	**-454,955**	**99,152**
	Swimming pool	**-783,922**	**233,385**

Table 10.28. Breakdown of the investment criteria

	Discount rate		6%			
	Small hotel		Large hotel		Swimming pool	
	- CO2	+ CO2	- CO2	+ CO2	- CO2	+ CO2
NPV (20y)	-32,588	89,187	-9,547	614,528	707,413	1,717,181
IRR (20y)	1.88%	15.10%	5.71%	21.23%	16.58%	29.55%
Simple pay-back period, years	15.85	6.16	11.41	4.59	5.70	3.36

10.4.4 Hotels and sports facilities that are using gas

The performance of introduction of the CHP systems in hotels and sports facilities that are using gas is very different compared to those using heavy oil. The base data are presented in the Table 10.29.

Table 10.29. Basic characteristics of hotels and sports facilities

Hotels and sports facilities		Small hotel	Large hotel	Swimming pool
Annual heat consumption (2021)	kWht	400,000	2,000,000	2,919,000
Annual electricity consumption (2021)	kWhe	133,000	700,000	1,776,000
Annual energy consumption				
Gas	kWhg	470,588	2,352,941	3,434,118
Heavy oil	t			
Electricity	kWhe	133,000	700,000	1,776,000
Total value of energy consumption	EUR	35,134	180,443	366,197
Value of energy costs per heat production unit	EUR/kWht	0.0425	0.0425	0.0425
CHP System				
Annual heat production	kWht	418,500	2,004,000	2,804,400
Annual electric production	kWhe	280,800	1,290,000	2,006,400
Annual energy consumption				
Gas	kWhg	760,109	3,489,407	5,101,591
Electricity	kWhe			
Total value of energy consumption	EUR	27,463	126,072	184,320
Unit value of energy production				
Heat	EUR/kWht	0.03927	0.03827	0.03831
Electricity	EUR/kWhe	0.03927	0.03827	0.03831

The influence of the CHP system on hotels and sports facilities (the situation with the project) is described in Table 10.30. It is obvious that CHP Systems applied, in this case, should be different, and more efficient because heating using gas is more productive than using heavy oil, especially at small plants.

Investment costs depend on the electrical capacity, and they are lower the bigger the CHP system is. For small hotels, the costs per installed kW are 2,200 €, for large hotels, it is 1,650 €, and for swimming pools - 1,400 €. The applied CHP system is the same as in the previous case with heavy oil (Table 10.31.).

Operating costs are devided into four sections: the operating costs of the proposed CHP system, previous costs, the costs with the CHP system, and overall cost reduction. (Table 10.32.)

Special attention was paid to the display of the CO2 footprint. All sources of emissions are shown in their current and projected state, and the results, very different from the previous case, are shown separately, in physical and financial units (Table 10.33.).

Table 10.30. The situation with the project – physical and financial influences

Influences, physical quantities				
CHP to facilities, heat	kWht	400,000	2,000,000	2,804,400
Excess or deficiency of heat	kWht	18,500	4,000	-114,600
CHP to facilities, electricity	kWhe	133,000	700,000	1,776,000
CHP, excess of electricity	kWhe	147,800	590,000	230,400
Influences, values				
CHP to facilities, heat, cost reduction	EUR	1,293.7	8,465.2	11,756.0
Excess or deficiency of heat	EUR	383.5	86.9	-4,871.2
CHP to facilities, electricity, cost reduction	EUR	12,908.7	68,640	174,076.6
CHP, excess of electricity, additional revenue	EUR	20,155.9	81,049.0	31,641.0
Facilities - cost reduction and additional revenue	**EUR**	**34,742**	**158,241**	**217,474**
Facilities - current energy costs with CHP	**EUR**	**27,463**	**126,072**	**189,192**

Table 10.31. Investment cost

In €

No	Item	Amount		
		Small hotel	Large hotel	Swimming pool
1	CHP System	228,800	709,500	739,200
2	Other Investment Costs (1%)	2,288	7,095	7,392
3	Contingency (5%)	11,554	35,830	37,330
	Total	**242,642**	**752,425**	**783,922**

Table 10.32. Operating costs

EUR/year

No	Description	Amount		
		Small hotel	Large hotel	Swimming pool
1	***CHP costs***			
	Gas	27,463	126,072	184,320
	Maintenance& other costs (2.4%)	5,823	18,058	18,814
	Total	**33,286**	**144,130**	**203,135**
2	***Hotels - pool - Previous costs***			
	Gas	17,002	85,012	124,075
	Electricity	18,132	95,431	242,122
	Maintenance& other costs (2.4%)	843	4,331	8,789
	Total	**35,977**	**184,773**	**374,985**
3	***Hotels - pool costs with CHP***			
	CHP costs	33,286	144,130	203,135
	Gas			4,871
	Electricity			
	Total	**33,286**	**144,130**	**208,006**
2-3	**Cost reduction with CHP**	**2,691**	**40,643**	**166,980**

The economic flow is presented in Table 10.34. and NPV and IRR in Table 10.35.

Table 10.33. CO_2 emissions

		Small hotel	Large hotel	Swimming pool
Influence of CHP on CO2 emission				
Previous heat consumption	*kg*	*95,059*	*475,294*	*693,692*
Current heat consumption	*kg*	*153,542*	*704,860*	*1,030,521*
Reduction by heat consumption	kg	-58,483	-229,566	-336,830
Previous electric consumption	*kg*	*106,400*	*560,000*	*1,420,800*
Current electric consumption	*kg*	*26,866*	*141,400*	*358,752*
Reduction by current electric consumption	kg	79,534	418,600	1,062,048
Reduction by excess of electricity	kg	88,384	352,820	137,779
Reduction of CO_2 emission	**kg**	**109,435**	**541,854**	**862,998**
Annual value of reduction of CO_2 emission	**EUR**	**9,162**	**45,364**	**72,250**

Table 10.34. Breakdown of the economic flow

In EUR,

Description			2023	2024-42
Inflow				
	Small hotel			**43,904**
	Large hotel			**203,605**
	Swimming pool			**289,724**
	Improvement	Small hotel		34,742
		Large hotel		158,241
		Swimming pool		217,474
	CO_2	Small hotel		9,162
		Large hotel		45,364
		Swimming pool		72,250
Outflow				
	Investment	Small hotel	242,642	
		Large hotel	752,425	
		Swimming pool	783,922	
	Operating costs	Small hotel		33,286
		Large hotel		144,130
		Swimming pool		203,135
Net flow, without CO_2				
		Small hotel	**-242,642**	**1,456**
		Large hotel	**-752,425**	**14,110**
		Swimming pool	**-783,922**	**14,339**
Net flow, with CO_2				
		Small hotel	**-242,642**	**10,618**
		Large hotel	**-752,425**	**59,474**
		Swimming pool	**-783,922**	**86,589**

Table 10.35. Breakdown of the investment criteria

	Discount rate		6%			
	Small hotel		Large hotel		Swimming pool	
	- CO2	+ CO2	- CO2	+ CO2	- CO2	+ CO2
NPV (20y)	-213,585	-117,142	-561,303	-83,777	-588,609	171,934
IRR (20y)	-16.05%	-1.78%	-8.70%	4.44%	-8.88%	8.83%
Simple pay-back period, years	166.69	22.85	53.32	12.65	54.67	9.05

10.5 Cost-benefit analysis of introducing CHP in the industrial sector

10.5.1 Analysis of costs and economic potential in the industrial sector

Using the experiences of EU countries[78], two technologies for HE CHP have been analysed – internal combustions engines (ICE) and combined cycle gas turbines (CCGT). ICE CHP has been analysed for implementation in all industrial sub-sectors independently of the company size. Using principles for CHP sizing, the CBA was conducted for 3 sizes of ICE CHP (0.3 MWe, 0.9 MWe and 1.9 MWe). The smallest and middle-size ICE CHPs are suitable for implementation in small and medium enterprises in all industrial sub-sectors, except Paper, pulp and printing sub-sectors where only largest facilities are applicable.

Typical selection of ICE CHP size per industrial sub-sectors and their branches is presented in Table 10.36.

CCGT CHP has been analysed for the implementation in large companies in Chemical and petrochemical sector (basic chemicals. fertilizers and nitrogen compounds, oil refining, etc.), Iron and steel sector (manufacture of basic iron and steel manufacture of tubes. pipes. hollow profiles etc.), and Paper, pulp and printing sector (Manufacture of pulp, paper and paperboard). Two sizes of CCGT CHP have been analysed: 2.8. MWe and 12.9 MWe.

Typical selection of CCGT CHP size per industrial sub-sectors and their branches is presented in Table 10.37.

Cost of investments in both cases include costs of facilities and their installation in existing production process. The specific investments costs of ICE CHP decrease significantly with increasing size, while in the case of CCGT the specific investment costs are almost constant, i.e., relatively low sensitive to facility size. Operation costs in both cases include the costs of fuel (natural gas) and maintenance. Maintenance costs are estimated to 2.4% of investment costs.

Table 10.36. ICE CHP size and typical applications[79]

ICE CHP size [MWe]	Industry sector	Branches
0.3	Food, beverages and tobacco	Processing and preserving of fruit and vegetables
		Manufacture of other food products and tobacco
		Manufacture of bakery products and farinaceous products
	Machinery	Manufacture of machinery and equipment for miscellaneous uses
	Iron and Steel	Foundries

[78] https://energy.ec.europa.eu/index_en
[79] Gestore dei Servizi Energetici, Assessment of the National Potential for High-Efficiency Cogeneration and Efficient District Heating, December 2015

	Not elsewhere specified (Industry)	Manufacture of plastic and rubber products
	Textiles and leather	Manufacture of luggage. handbags. saddlery and harness
		Preparation and spinning of textile fibres
		Textiles. manufacture of other textiles. manufacture of wearing apparel
0.9	Chemical and petrochemical	Pharmaceuticals
	Wood and wood products	Manufacture of beverages
	Food, beverages and tobacco	Dairy industry
		Processing and preserving of meat
	Non-metallic minerals	Manufacture of glass and glass products
	Not elsewhere specified (Industry)	Manufacture of other products (furniture. medical equipment)
	Transport equipment	Manufacture of motor vehicles and accessories
	Wood and wood products	Manufacture of wooden. cork and wickerwork goods
1.9	Chemical and petrochemical	Production of soaps. detergents and cosmetics
	Food, beverages and tobacco	Manufacture of grain mill products and starches
		Manufacture of other food products (sugar, cocoa, etc.)
		Production of animal feeds
	Non-metallic minerals	Manufacture of clay building materials (ceramic and other mineral materials)
	Paper, pulp and printing	Manufacture of pulp-paper, paper, paperboard

Table 10.37. CCGT CHP size and typical applications[80]

CCGT CHP size [MWe]	Industry sector	Branches
2.8	Iron and Steel	Manufacture of tubes, pipes, hollow profiles etc.
12.9	Chemical and petrochemical	Basic chemicals, fertilisers and nitrogen compounds
		Extraction and refining of crude petroleum
	Paper, pulp and printing	Manufacture of pulp, paper and paperboard, articles of paper and paperboard and printed articles
	Iron and Steel	Manufacture of basic iron and steel

Table 10.38. summarizes the economic potential for the development of new HE CHP in Serbia in the industrial sector.

Table 10.38. Economic potential for the development of new HE CHP in Serbia

Sub-sector	Heat			Electricity		
	GWh	toe	MW_t	GWh	toe	MW_e
Iron and steel	68.8	5.9	22.9	56.0	4.8	18.6
Chemical and petrochemical	429.1	36.9	137.4	353.6	30.4	112.8
Non-ferrous metals	9.0	0.8	2.0	12.7	1.1	2.9
Non-metallic minerals	96.6	8.3	30.8	124.5	10.7	39.7
Food, beverages and tobacco	488.2	42.0	153.5	437.3	37.6	139.8
Paper, pulp and printing	140.6	12.1	33.1	101.3	8.7	24.8
Wood and wood products	3.3	0.3	1.3	3.7	0.3	1.4
Total	**1,235.5**	**106.2**	**381.1**	**1,089.1**	**93.6**	**340.0**

Final energy consumption in the industrial sector should have a slight increase by 2030 (compared to 2021), with varying increases across sub-sectors. The changing in consumption expected in the sector has a measurable impact on economic potential as shown in the following table.

[80] Gestore dei Servizi Energetici, Assessment of the National Potential for High-Efficiency Cogeneration and Efficient District Heating, December 2015

Table 10.39. Incremental economic potential of HE CHP in the industrial sector on the basis of demand in 2030

Sub-sector	Heat			Electricity		
	GWh	toe	MW_t	GWh	toe	MW_e
Iron and steel	14.2	1.2	4.7	11.6	1.0	3.9
Chemical and petrochemical	41.6	3.6	13.3	34.3	2.9	10.9
Non-ferrous metals	24.8	2.1	5.6	35.1	3.0	7.9
Non-metallic minerals	25.4	2.2	8.1	32.7	2.8	10.4
Food, beverages and tobacco	103.5	8.9	32.5	92.7	8.0	29.6
Paper, pulp and printing	12.5	1.1	2.9	9.0	0.8	2.2
Total	**222.1**	**19.1**	**67.3**	**215.4**	**18.5**	**65.0**

10.5.2 Cost-benefit analysis of the introduction of Combined Cycle Gas Turbine (CCGT) to some industries

CBA analysis of the introduction of Combined Cycle Gas Turbine (CCGT) into two types of industry is presented:

- Manufacture of basic iron and steel manufacture of tubes, pipes, hollow profiles etc;
- Manufacture of pulp, paper and paperboard, articles of paper and paperboard and printed articles.

The results of the analysis point to different results of the application of CCGT. Here are the current situation's basic characteristics of mentioned industries and the proposed Combined Cycle Gas Turbine system's characteristics (Table 10.40.)

Table 10.40. Basic characteristics

Industry		2,8 MWe CCGT CHP	12,9 MWe CCGT CHP
Annual heat consumption (2021)	kWht	170,924,000	105,254,000
Annual electricity consumption (2021)	kWhe	82,032,000	70,115,000
Annual energy consumption			
Gas	kWhw	189,915,556	116,948,889
Electricity	kWhe	82,032,000	70,115,000
Total value of energy consumption	EUR	15,870,719	11,827,194
Value of energy costs per energy unit	EUR/kWht	0.0929	0.1124
Combined Cycle Gas Turbine (CCGT)	h	5,000	
Annual heat production	kWht	17,000,000	95,500,000
Annual electric production	kWhe	14,000,000	64,500,000
Annual energy consumption			
Gas	kWhg	38,888,889	194,848,485
Electricity	kWhe		
Total value of energy consumption	EUR	1,489,444	7,462,697
Unit value of energy production			
Heat	EUR/kWht	0.04805	0.04664
Electricity	EUR/kWhe	0.04805	0.04664

The influence, physical and financial, of applied Combined Cycle Gas Turbine systems on the iron and paper industries are in Table 10.41.

Investment costs depend on the electrical capacity, and they are lower per installed kW the bigger the CCGT system is. Investment costs are presented in Table 10.42.

Operating costs are divided into four sections: the operating costs of the proposed CCGT system, previous costs, costs with the CCGT system, and overall cost reduction. The other operating costs are neglected (Table 10.43).

Table 10.41. The situation with the project – physical and financial influences

Industry			2,8 MWe CCGT CHP	12,9 MWe CCGT CHP
Influences, physical quantities				
	CCGT to industry, heat	kWht	17,000,000	95,500,000
	Additional heat	kWht	153,924,000	9,754,000
	CCGT to industry, electricity	kWhe	14,000,000	64,500,000
	Additional electricity from net	kWhe	68,032,000	5,615,000
Influences, values				
	CCGT to industry, heat, cost reduction	EUR	761,700.3	6,276,858.5
	Additional heat	EUR	6,550,321.3	415,086.9
	CCGT to industry, electricity, cost reduction	EUR	794,547.7	3,751,200
	Additional electricity from net	EUR	7,129,753.6	588,452.0
Industry - cost reduction and additional revenue		**EUR**	**1,556,248**	**10,028,059**
Industry - current energy costs with CCGT		**EUR**	**15,169,519**	**8,466,236**

Table 10.42. Investment cost

In €			
No	**Item**	**Amount**	
		2,8 MWe CCGT CHP	**12,9 MWe CCGT CHP**
1	CCGT	3,360,000	15,000,000
2	Other Investment Costs (1%)	33,600	150,000
3	Contingency (5%)	169,680	757,500
	Total	**3,563,280**	**15,907,500**

Table 10.43. Operating costs

	EUR/year			
No	**Description**		**Amount**	
			2,8 MWe CCGT CHP	**12,9 MWe CCGT CHP**
1	***CCGT costs***			
		Gas	1,489,444	7,462,697
		Maintenance& other costs (2.4%)	85,519	381,780
		Total	**1,574,963**	**7,844,477**
2	***Industry - Previous costs***			
		Gas	7,273,766	4,479,142
		Electricity	8,596,954	7,348,052
		Maintenance& other costs (2.4%)	380,897	283,853
		Total	**16,251,617**	**12,111,047**
3	***Industry - current costs with CCGT***			
		CCGT costs	1,574,963	7,844,477
		Gas	6,550,321	415,087
		Electricity	7,129,754	588,452
		Total	**15,255,038**	**8,848,016**
2-3	**Cost reduction with CCGT**		**996,579**	**3,263,031**

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units (Table 10.44.).

The results of analyses of the Economic Flow and the investment criteria (NPV, IRR, simple pay-back period) are presented in (Table 10.45. and Table 10.46.)

Table 10.44. CO_2 emissions

Description	Units	Amount	
		2,8 MWe CCGT CHP	12,9 MWe CCGT CHP
Influence of CCGT on CO2 emission			
Previous heat consumption	*kg*	*34,526,648*	*21,261,308*
Current heat consumption	*kg*	*7,855,556*	*39,359,394*
Reduction by heat consumption	kg	26,671,092	-18,098,086
Previous electric consumption	*kg*	*65,625,600*	*56,092,000*
Current electric consumption	*kg*	*2,828,000*	*13,029,000*
Reduction by current electric consumption	kg	62,797,600	43,063,000
Reduction by excess of electricity	kg		
Reduction of CO_2 emission	**kg**	**89,468,692**	**24,964,914**
Annual value of reduction of CO_2 emission	**EUR**	**7,490,319**	**2,090,063**

Table 10.45. Breakdown of the economic flow

In EUR,

Description			2023	2024-42
Inflow				
	2,8 MWe CCGT CHP			**9,046,567**
	12,9 MWe CCGT CHP			**12,118,121**
	Improvement	2,8 MWe CCGT CHP		1,556,248
		12,9 MWe CCGT CHP		10,028,059
	CO2	2,8 MWe CCGT CHP		7,490,319
		12,9 MWe CCGT CHP		2,090,063
Outflow				
	Investment	2,8 MWe CCGT CHP	3,563,280	
		12,9 MWe CCGT CHP	15,907,500	
	Operating costs	2,8 MWe CCGT CHP		1,574,963
		12,9 MWe CCGT CHP		7,844,477
Net flow, without CO_2				
		2,8 MWe CCGT CHP	**-3,563,280**	**-18,715**
		12,9 MWe CCGT CHP	**-15,907,500**	**2,183,582**
Net flow, with CO_2				
		2,8 MWe CCGT CHP	**-3,563,280**	**7,471,604**
		12,9 MWe CCGT CHP	**-15,907,500**	**4,273,644**

Table 10.46. Breakdown of the investment criteria

	Discount rate		6%	
	2,8 MWe CCGT CHP		12,9 MWe CCGT CHP	
	- CO2	+ CO2	- CO2	+ CO2
NPV (20y)	-3,558,591	75,288,438	7,978,453	29,979,549
IRR (20y)	#NUM!	209.68%	12.18%	26.56%
Simple pay-back period, years	-190.39	0.48	7.29	3.72

10.5.3 Cost-benefit analysis of the introduction of ICE CHP to the industry

Cost-benefit analysis of the introduction of HE CHP into the industry is based on three characteristic plants:

- 0.9 MWe ICE CHP,
- 1.9 MWe ICE CHP, and
- 0.3 MWe ICE CHP.

Here are the current situation's basic characteristics (situation without the project) of mentioned industries and the proposed CHP system's characteristics (Table 10.47.).

Table 10.47. Basic characteristics

Industry		0,9 MWe ICE CHP	1,9 MWe ICE CHP	0.3 MWe ICE CHP
Annual heat consumption (2021)	kWht	13,052,000	21,556,000	5,631,000
Annual electricity consumption (2021)	kWhe	8,985,000	14,839,000	1,214,000
Annual energy consumption				
Gas	kWhw	14,502,222	23,951,111	6,256,667
Electricity	kWhe	8,985,000	14,839,000	1,214,000
Total value of energy consumption	EUR	1,497,063	2,472,455	366,858
Value of energy costs per energy unit	EUR/kWht	0.1147	0.1147	0.0651
CHP System	h		5,000	
Annual heat production	kWht	4,986,055	10,500,000	1,178,500
Annual electric production	kWhe	4,499,600	9,712,500	1,500,000
Annual energy consumption				
Gas	kWhg	12,161,081	26,250,000	3,571,429
Electricity	kWhe			
Total value of energy consumption	EUR	465,769	1,005,375	136,786
Unit value of energy production				
Heat	EUR/kWht	0.04910	0.04974	0.05107
Electricity	EUR/kWhe	0.04910	0.04974	0.05107

The influence, physical and financial, of applied CHP systems on the dairy, food, and building materials industries are presented in Table 10.48.

Table 10.48. The situation with the project – physical and financial influences

Industry		0,9 MWe ICE CHP	1,9 MWe ICE CHP	0.3 MWe ICE CHP
Influences, physical quantities				
CHP to industry, heat	kWht	4,986,055	10,500,000	1,178,500
Additional heat	kWht	8,065,945	11,056,000	4,452,500
CHP to industry, electricity	kWhe	4,499,600	9,712,500	1,500,000
Additional electricita from net	kWhe	4,485,400	5,126,500	
Influences, values				
CHP to industry, heat, cost reduction	EUR	327,072.2	682,068.3	16,595.2
Additional heat	EUR	343,250.8	470,494.2	189,478.6
CHP to industry, electricity, cost reduction	EUR	250,616.5	534,768	80,598.0
Additional electricita from net	EUR	470,069.9	537,257.2	0.0
Industry - cost reduction and additional revenue	**EUR**	**577,689**	**1,216,836**	**97,193**
Industry - current energy costs with CHP	**EUR**	**1,279,090**	**2,013,126**	**326,264**

Investment costs depend on the electrical capacity, and they are lower per installed kW the bigger the CHP system is (Figure 10.1). Investment costs are presented in Table 10.49.

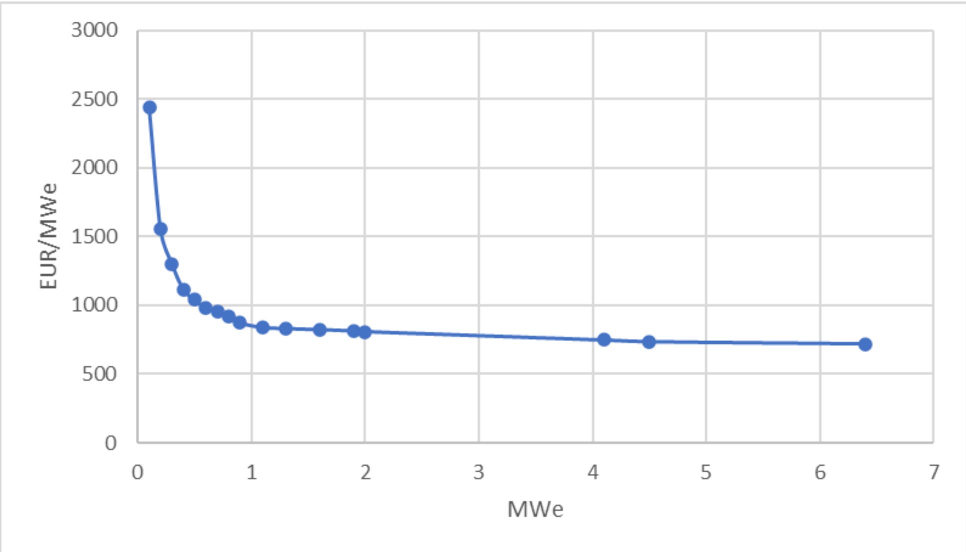

Figure 10.1. Gas engine - Relative investment cost (EUR/MWe)

Table 10.49. Investment cost

In €

No	Item	Amount		
		0,9 MWe ICE CHP	1,9 MWe ICE CHP	0.3 MWe ICE CHP
1	Gas Engine	784,620	1,545,840	390,870
2	Other Investment Costs (1%)	7,846	15,458	3,909
3	Contingency (5%)	39,623	78,065	19,739
	Total	**832,090**	**1,639,363**	**414,518**

Operating costs are divided into four sections. The first one is presenting the operating costs of the proposed CHP system. In the second part, previous costs are defined. The third section is dealing with the costs with the CHP system, and at the end, overall cost reduction is presented. The other operating costs, which are neglected, being the same in all cases (Table 10.50.).

Special attention was paid to the display of the CO_2 footprint. All sources of emissions are shown in their current and projected state, and the results are shown separately, in physical and financial units (Table 10.51.). It should be said that CO_2 emission reduction in these cases is huge.

The analysis of Economic Flow and the calculation of investment criteria is presented in the Table 10.52. and Table 10.53.

Table 10.50. Operating costs

	EUR/year			
No	**Description**	**Amount**		
		0,9 MWe ICE CHP	**1,9 MWe ICE CHP**	**0.3 MWe ICE CHP**
1	***CHP System***			
	Gas	465,769	1,005,375	136,786
	Maintenance& other costs (2.4%)	19,970	39,345	9,948
	Total	**485,740**	**1,044,720**	**146,734**
2	***Industry - Previous costs***			
	Gas	555,435	917,328	239,630
	Electricity	941,628	1,555,127	127,227
	Maintenance& other costs (2.4%)	35,930	59,339	8,805
	Total	**1,532,993**	**2,531,794**	**375,662**
3	***Industry - current costs with CHP***			
	CHP costs	485,740	1,044,720	146,734
	Gas	343,251	470,494	189,479
	Electricity	470,070	537,257	0
	Total	**1,299,060**	**2,052,471**	**336,213**
2-3	**Cost reduction with CHP**	**233,932**	**479,323**	**39,449**

Table 10.51. CO_2 emissions

		0,9 MWe ICE CHP	**1,9 MWe ICE CHP**	**0.3 MWe ICE CHP**
Influence of CHP on CO2 emission				
Previous heat consumption	*kg*	*2,636,504*	*4,354,312*	*1,137,462*
Current heat consumption	*kg*	*2,456,538*	*5,302,500*	*721,429*
Reduction by heat consumption	kg	179,966	-948,188	416,033
Previous electric consumption	*kg*	*7,188,000*	*11,871,200*	*971,200*
Current electric consumption	*kg*	*908,919*	*1,961,925*	*303,000*
Reduction by current electric consumption	kg	6,279,081	9,909,275	668,200
Reduction by excess of electricity	kg			
Reduction of CO_2 emission	**kg**	**6,459,046**	**8,961,087**	**1,084,233**
Annual value of reduction of CO_2 emission	**EUR**	**540,751**	**750,222**	**90,772**

Table 10.52. Breakdown of the economic flow

In EUR,				
Description			**2023**	**2024-42**
Inflow				
	0,9 MWe ICE CHP			**1,118,440**
	1,9 MWe ICE CHP			**1,967,058**
	0.3 MWe ICE CHP			**187,965**
	Improvement	0,9 MWe ICE CHP		577,689
		1,9 MWe ICE CHP		1,216,836
		0.3 MWe ICE CHP		97,193
	CO2	0,9 MWe ICE CHP		540,751
		1,9 MWe ICE CHP		750,222
		0.3 MWe ICE CHP		90,772
Outflow				
	Investment	0,9 MWe ICE CHP	832,090	
		1,9 MWe ICE CHP	1,639,363	
		0.3 MWe ICE CHP	414,518	
	Operating costs	0,9 MWe ICE CHP		485,740
		1,9 MWe ICE CHP		1,044,720
		0.3 MWe ICE CHP		146,734
Net flow, without CO_2				
		0,9 MWe ICE CHP	**-832,090**	**91,949**
		1,9 MWe ICE CHP	**-1,639,363**	**172,116**
		0.3 MWe ICE CHP	**-414,518**	**-49,541**
Net flow, with CO_2				
		0,9 MWe ICE CHP	**-832,090**	**632,701**
		1,9 MWe ICE CHP	**-1,639,363**	**922,338**
		0.3 MWe ICE CHP	**-414,518**	**41,231**

Table 10.53. Breakdown of the investment criteria

	Discount rate		**6%**			
	0,9 MWe ICE CHP		**1,9 MWe ICE CHP**		**0.3 MWe ICE CHP**	
	- CO2	**+ CO2**	**- CO2**	**+ CO2**	**- CO2**	**+ CO2**
NPV (20y)	**182,915**	**5,875,148**	**265,217**	**8,162,450**	**-912,549**	**42,965**
IRR (20y)	**8.84%**	**76.04%**	**8.11%**	**56.25%**	**#NUM!**	**7.37%**
Simple pay-back period, years	**9.05**	**1.32**	**9.52**	**1.78**	**-8.37**	**10.05**

10.6 Cost-benefit analysis: comparison of DHS and heating alternatives

Physically and financially are determined the characteristics of the 8 heating methods, to determine the differences in relation to DHS, and thus to define the profitability threshold for inclusion in DHS. These analyses include the assessment of corresponding CO_2 emissions and their impact on the economic flow and profitability parameters.

Analysed heating methods were:

- TA stove, low tariff,
- TA stove, low tariff + 2 hours of high tariff,
- Electric heaters and boilers,
- Wood,
- Wood pellet,
- Fuel oil,
- Coal – raw lignite, and
- DHS.

Because of different methodologies, we must start with the basics – energy prices and CO_2 emission coefficients (Table 10.54.).

Table 10.54. Energy prices and CO_2 emission coefficients

Energy prices			**CO2 emission coefficients**	
Gas	€/kWhg	0.03830	kgCO2/Whg	0.202
Fuel oil	€/l	0.97	kgCO2/l	2.61438
Electricity	€/kWhe	0.13394	kgCO2/kWhe	0.8
Electricity, low tariff	€/kWhe	0.04814	kgCO2/kWhe	0.8
Electricity, low tariff + 2h of high tariff	€/kWhe	0.06863	kgCO2/kWhe	0.8
Heat	€/m²	0.80513	kgCO2/Whg	0.202
Wood	€/m³	57.1054	kgCO2/m³	615.02089
Wood pellet	€/t	241.5605	kgCO2/t	1,752.76878
Coal raw lignite	€/t	69.0173	kgCO2/t	886.63155
CO2 prices, EU ETS on January 10th, 2023	€/kg	0.08372		

The first energy consumption for an average dwelling of 60 m² for every alternative heating method was defined, in physical and monetary quantities, including into account CO_2 emission as well. The accent is on the difference of every heating method compared to DHS. The results are presented in Table 10.55.
The next step is the investment – i.e. what is the real price for connecting an average dwelling in an average building to the distribution network of the DHS. Investments costs are shown in Table 10.56.
In the third step, the economic flow were created, and the basic criteria – NPV, IRR, and a simple payback period – were determined in Table 10.57.

According to current energy prices and costs of connection to the DHS grid, connecting is not economically viable for those who are heating themselves by TA stove using low tariff, who are using wood, wood pellet, and coal raw lignite. It is advisable for those who are using electricity and fuel oil.
Using a TA stove, at low tariff + 2 hours of high tariff, is on the margin. Considering CO_2 emission and its prices, it is advisable to connect to the DHS.

Table 10.55. Basic characteristics of alternative heating methods and comparison with DHS

Heating for a 60 m² dwelling		TA stove, low tariff	TA stove, low + 2h high tariff	Electric heaters and boilers	Wood	Wood pellet	Fuel oil	Coal raw lignite	DHS
Annual energy consumption	kWhe	15,795							
Electricity, low tariff	kWhe	9,893.1							
Electricity, low tariff + 2h of high tariff	kWhe		9,720.0						
Electricity	kWhe			9,000.7					
Wood	m³				8.5				
Wood pellet	t					2.5			
Fuel oil	l						1,147.9		
Coal raw lignite	t							6.4	
Heat	kWht								9,000.0
Total value of energy consumption	**€**	***476.27***	***667.12***	***1,205.59***	***484.88***	***611.74***	***1,110.13***	***442.19***	***579.69***
Annual energy consumption	units/m²	164.88	162.00	150.01	0.14	0.04	19.13	0.11	150.00
Values of annual energy consumption	€/m²	7.94	11.12	20.09	8.08	10.20	18.50	7.37	9.66
CO_2 emission	kg	7,914.47	7,775.99	7,200.53	5,222.12	4,438.80	3,001.05	5,680.60	1,818.00
CO_2 emission values	€	662.60	651.01	602.83	437.20	371.62	251.25	475.58	152.20
Comparison with DHS									
Heating value differences	€	-103.42	87.43	625.90	-94.81	32.05	530.44	-137.50	
CO_2 emission differences	€	510.40	498.80	450.63	284.99	219.41	99.04	323.38	
Total	€	406.97	586.23	1,076.52	190.18	251.46	629.48	185.87	

Table 10.56. Investment cost

Cost/Parameter	Unit	Amount/Size
Investment costs of connection to DH		
Costs of connection to the distribution network DHC	€	9,325.15
Cost of the heat substation TPS	€	7,400.00
Semi-deep connection costs DTS	€	7,000.00
Other costs	€	332.12
Total value of connection	**€**	**24,057.26**
The unit cost of the apartment to be connected		
Area of a typical building	m²	1,692
The unit cost of the apartment to be connected	€/m²	14.22
Heating price	€/m²	0.81
Investment costs of connection (60 m² dwelling)	**€**	**853.09**

Table 10.57. Breakdown of the investment criteria

Heating for a 60 m² dwelling	TA stove, low tariff	TA stove, low + 2h high tariff	Electric heaters and boilers	Wood	Wood pellet	Fuel oil	Coal raw lignite
Economic flow results							
Without CO_2							
NPV	-1,893	116	5,784	-1,803	-467	4,779	-2,252
IRR		7.78%	73.37%		-3.17%	62.17%	
Simple pay-back period		9.8	1.4		26.6	1.6	
With CO_2							
NPV	3,479	5,366	10,527	1,197	1,842	5,821	1,152
IRR	47.68%	68.71%	126.19%	21.76%	29.25%	73.79%	21.23%
Simple pay-back period	2.1	1.5	0.8	4.5	3.4	1.4	4.6

Negative NPV is telling that connection to DHS brings more costs than benefits, and positive NPV is telling that connection to DHS brings more benefits.
In Serbia there are no taxes on CO_2 at the moment. The future introduction of CO_2 taxes will change the situation drastically. By changing the use of fuel oil, coal, and wood for heating, and connecting these consumers to the DHS grid, most of the air pollution would be solved.

10.7 Sensitivity analysis

10.7.1 Sensitivity analysis of the introduction of the CHP system to residential houses

The performance of the introduction of the CHP system to residential houses depending on a price increase by 20% for natural gas, CO_2, and electrical feed-in tariff and a decrease by the same percentage of the same parameters, but following with a decrease of the value of the investment by mentioned 20%. The results are presented in Table 10.58.

Table 10.58. Sensitivity analysis – residential houses

20 years period							
Description		**Without CO2**			**With CO2**		
		NPV	**IRR**	**Simple Pay-back period**	**NPV**	**IRR**	**Simple Pay-back period**
				years			years
Base case							
	1 dwelling	-1,604	3.29%	13.97	4,591	12.65%	7.08
	2 dwellings	5,623	10.47%	8.11	20,052	20.36%	4.77
	3-8 dwellings	7,968	8.49%	9.28	42,255	17.77%	5.38
Price increase by 20%							
Gas							
	1 dwelling	-3,588	-0.65%	20.29	2,607	9.92%	8.41
	2 dwellings	1,628	7.36%	10.06	16,058	17.75%	5.38
	3-8 dwellings	-1,984	5.35%	11.75	32,303	15.23%	6.12
CO2							
	1 dwelling	-1,604	3.29%	13.97	5,829	14.29%	6.45
	2 dwellings	5,623	10.47%	8.11	22,938	22.20%	4.40
	3-8 dwellings	7,968	8.49%	9.28	49,113	19.48%	4.96
Electricity, feed-in tariff							
	1 dwelling	441	6.70%	10.57	6,635	15.33%	6.09
	2 dwellings	11,448	14.64%	6.32	25,878	24.06%	4.09
	3-8 dwellings	22,254	12.56%	7.12	56,541	21.31%	4.57
Price decrease by 20%							
Gas							
	1 dwelling	380	6.60%	10.65	6,575	15.25%	6.12
	2 dwellings	9,617	13.37%	6.79	24,047	22.91%	4.28
	3-8 dwellings	17,921	11.36%	7.66	52,208	20.25%	4.79
CO2							
	1 dwelling	-1,604	3.29%	13.97	3,352	10.97%	7.86
	2 dwellings	5,623	10.47%	8.11	17,166	18.48%	5.20
	3-8 dwellings	7,968	8.49%	9.28	35,398	16.03%	5.87
Investment decrease by 20%							
	1 dwelling	418	6.83%	10.47	6,612	17.38%	5.48
	2 dwellings	9,415	14.86%	6.24	23,845	26.51%	3.73
	3-8 dwellings	17,927	12.60%	7.10	52,214	23.42%	4.19

NPV behaves differently depending on the movement of the gas price, as shown in Figure 10.2.

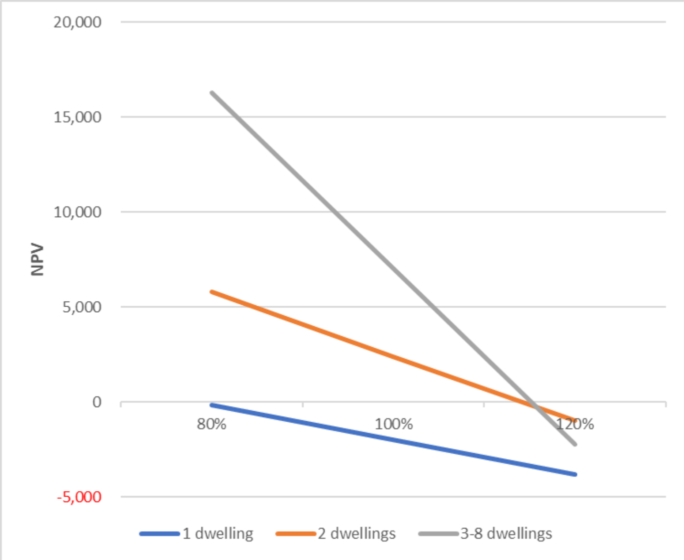

Figure 10.2. Impact of gas price changes on NPV

In the sensitivity analysis, the break-even points were defined, i.e. points when NPV is equalling zero, for main elements: prices of gas, CO_2, and electricity feed-in tariff, and the value of the investment. The break-even points are presented in Table 10.59. Also it was introduced a complex case to see how NPV and IRR are affected by simultaneous changes through an increase in feed-in tariff and a reduction of investments by 10%. This was applied only at the building with one apartment, because only this case had a negative NPV.

Table 10.59. Break-even point when NPV = 0

Change of gas prices			
	Without CO2		**With CO2**
	1 dwelling	**Price decrease of 16.2%**	**Price increase of 46.3%%**
	2 dwellings	**Price increase of 28.15%**	**Price increase of 100.4%%**
	3-8 dwellings	**Price increase of 16.01%**	**Price increase of 84.91%%**
Change of CO2 prices			
	1 dwelling		**Price decrease of 74.1%**
	2 dwellings		**Insensitive**
	3-8 dwellings		**Insensitive**
Electricity, feed-in tariff			
	1 dwelling	**Price increase of 15.7%**	
	2 dwellings	**Price decrease of 19.3%**	
	3-8 dwellings	**Price decrease of 11.15%**	
Investment costs			
	1 dwelling	**Decrease of 15.86%**	**Increase of 45.4%%**
	2 dwellings	**Increase of 29.65%%**	**Increase of 105.7%%**
	3-8 dwellings	**Increase of 16%%**	**Increase of 84.9%%**
Compound case: Increase of feed-in tariff by 10% and decrease investment by 10%			
	1 dwelling	**NPV = 429, IRR = 6.75%**	

Based on the above, the main conclusions are:

- If current CO_2 prices, from EU ETS, are applied, all cases have positive NPV and IRR above the discount rate. Note: in Serbia, CO_2 prices are not mandatory.
- The biggest sensitivity is on gas prices, then, far less, on the feed-in tariff and investment costs.
- Residential buildings with one dwelling: The base case has negative NPV, but it could be turned positive by decreasing gas prices by 21.6% or by decreasing investment by 19.5%. Analysing the compound case with a simultaneous increase of feed-in tariff and decrease of investment, It turns out that a 10% increase in feed-in tariff and a 10% of investment decrease is resulting in positive NPV and IRR = 6.05%. This is very achievable with the appropriate financial policy.

- Residential buildings with two dwellings: The base case is with positive NPV and the break-even point could be reached by a gas price increase of 14.2%, an investment cost increase of 15.8%, or by feed-in tariff decrease of 10%.
- Residential buildings with 3-8 dwellings: NPV is positive, and the break-even point could be reached by a gas price increase of 15.2%, an investment cost increase of 14.1%, or by feed-in tariff decrease of 12.2%.

10.7.2 Sensitivity analysis of the introduction of the CHP system to commercial entities

10.7.2.1 Health services facilities using heavy oil

It is chosen to check the performance of the introduction of the CHP system to health services facilities that are using heavy oil, depending on a price increase by 20% of gas, CO_2, and electrical feed-in tariff; and a decrease by the same percentage of the same parameters but following with a decrease of the value of the investment by mentioned 20%. The results are in Table 10.60.

NPV of each facility performs differently depending on the change in the gas price, as presented in Figure 10.3.

In the sensitivity analysis, the break-even points, i.e. points when NPV is equalling zero, have been defined for the main elements: prices of gas, CO_2, and electricity feed-in tariff, and the value of the investment (Table 10.61.).

A complex case has also been introduced to see how NPV and IRR are affected by simultaneous changes, through an increase in feed-in tariff by 10% and a reduction of investments by 12%. This was applied only for the Health centre, since only this case had a base negative NPV.

Table 10.60. Sensitivity analysis – Health service facilities

20 years period							
Description		Without CO2			With CO2		
		NPV	IRR	Simple Pay-back period	NPV	IRR	Simple Pay-back period
				years			years
Base case							
	Health Center	-29,131	2.36%	15.17	25,489	8.82%	9.06
	Hospital	2,163,413	21.07%	4.62	4,207,263	33.47%	2.97
	Clinical centre	6,624,934	25.83%	3.82	12,235,566	40.67%	2.46
Price increase by 20%							
Gas							
	Health Center	-85,335	-8.19%	49.68	-30,715	2.14%	15.48
	Hospital	521,867	10.08%	8.32	2,565,717	23.57%	4.17
	Clinical centre	2,176,487	13.24%	6.84	7,787,119	28.95%	3.43
CO2							
	Health Center	-29,131	2.36%	15.17	36,413	9.97%	8.38
	Hospital	2,163,413	21.07%	4.62	4,616,032	35.90%	2.78
	Clinical centre	6,624,934	25.83%	3.82	13,357,692	43.60%	2.29
Electricity, feed-in tariff							
	Health Center	-4,170	5.51%	11.60	50,449	11.39%	7.65
	Hospital	2,959,161	25.97%	3.80	5,003,011	38.19%	2.61
	Clinical centre	8,607,906	31.13%	3.19	14,218,539	45.84%	2.18
Price decrease by 20%							
Gas							
	Health Center	27,073	8.99%	8.96	81,692	14.40%	6.40
	Hospital	3,804,959	31.07%	3.20	5,848,808	43.19%	2.31
	Clinical centre	11,073,380	37.63%	2.65	16,684,013	52.26%	1.91
CO2							
	Health Center	-29,131	2.36%	15.17	14,565	7.64%	9.85
	Hospital	2,163,413	21.07%	4.62	3,798,493	31.04%	3.20
	Clinical centre	6,624,934	25.83%	3.82	11,113,439	37.73%	2.64
Investment decrease by 20%							
	Health Center	-1,226	5.82%	11.32	53,393	12.98%	6.95
	Hospital	2,551,237	27.37%	3.62	4,595,086	42.57%	2.35
	Clinical centre	7,500,125	33.16%	3.00	13,110,757	51.50%	1.94

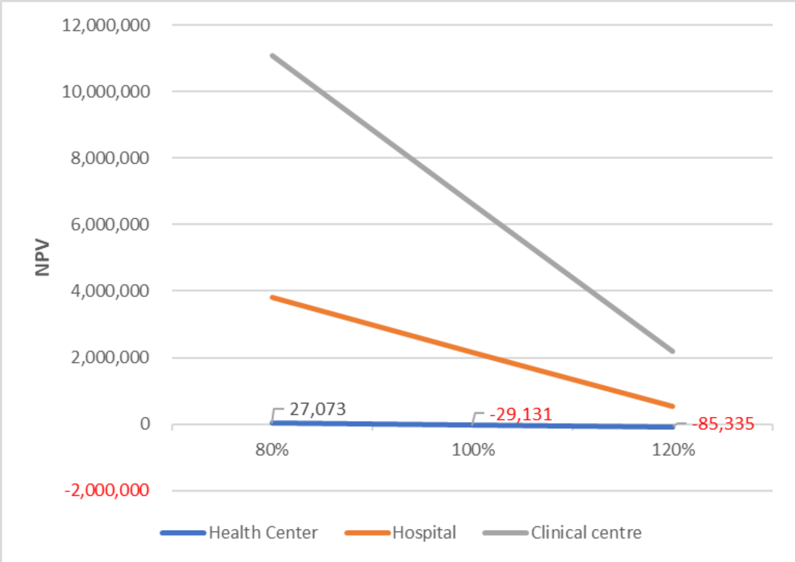

Figure 10.3. Impact of gas price changes on NPV

Table 10.61. Break-even point when NPV = 0

Change of gas prices			
	Without CO2		**With CO2**
	Health Center	**Price decrease of 10.37%**	**Price increase of 9.07%**
	Hospital	**Price increase of 26.36%**	**Price increase of 51.26%**
	Clinical centre	**Price increase of 29.79%**	**Price increase of 55.01%**
Change of CO2 prices			
	Health Center		**Price decrease of 46.66%**
	Hospital		**Insensitive**
	Clinical centre		**Insensitive**
Electricity, feed-in tariff			
	Health Center	**Price increase of 23.35%**	**Price decrease of 20.42%**
	Hospital	**Price decrease of 54.38%**	**Insensitive**
	Clinical centre	**Price decrease of 66.82%**	**Insensitive**
Investment costs			
	Health Center	**Decrease of 20.88%**	**Increase of 18.27%**
	Hospital	**Increase of 111.57%**	**Increase of 216.97%**
	Clinical centre	**Increase of 151.39%**	**Increase of 279.61%**
Compound case: Increase of feed-in tariff by 10% and decrease investment by 12%			
	Health Center	**NPV = 92, IRR = 6.01%**	

Based on the above, the main conclusions are:

- If current CO_2 prices, from EU ETS, are applied, all cases have positive NPV and IRR above the discount rate. Note: CO2 prices are not mandatory in Serbia, so this result should be taken with caution.
- The biggest sensitivity is on gas prices, and far less, on the investment costs and feed-in tariff.
- Health Centres: The base case has a negative NPV, but it could be turned positive (NPV=0) by decreasing gas prices by 10.37% or by decreasing investment by 20.88%. Additionally it has been analysed the compound case with a simultaneous increase of feed-in tariff and decrease of investment. It turns out that a 10% increase in feed-in tariff and a 12% of investment decrease is resulting in positive NPV and IRR = 6.01%. This is very achievable with appropriate financial policy.
- Hospitals: The base case is with positive NPV, the break-even point (NPV=0) could be reached by a gas price increase of 26.36%, an investment cost increase of 111.57%, or a feed-in tariff decrease of 54.38%.
- Clinical Centres: NPV is positive, and the break-even point (NPV=0) could be reached by a gas price increase of 29.79%, an investment cost increase of 151.39%, or by feed-in tariff decrease of 66.82%.

10.7.2.2 Health services facilities using gas

The performance of the introduction of the CHP system in healthcare services facilities that use gas, instead of heavy oil, was tested, depending on a price increase by 20% of gas, CO_2, and electrical feed-in tariff; and a decrease by the same percentage of the same parameters but following with a decrease of the value of the investment by mentioned 20%. The results are shown in Table 10.62. NPV of each facility performs differently depending on the change in the gas price, as depicted in Figure 10.4.

In the sensitivity analysis, there were defined the break-even points, i.e. points when NPV is equalling zero, for the main elements: prices of gas, CO_2, and electricity feed-in tariff, and the value of the investment (Table 10.63.). A complex case has been introduced to see how NPV and IRR are affected by simultaneous changes, through an increase in feed-in tariff by 5% and a reduction of investments by 5%. This was applied only for the Health centre case, because only this case had a base negative NPV.

Table 10.62. Sensitivity analysis – Health service facilities

20 years period							
Description		**Without CO2**			**With CO2**		
		NPV	**IRR**	**Simple Pay-back period**	**NPV**	**IRR**	**Simple Pay-back period**
				years			years
Base case							
	Health Center	-105,763	-19.06%	286.34	-65,261	-3.43%	27.42
	Hospital	-231,349	3.99%	13.15	1,371,329	15.98%	5.88
	Clinical centre	-80,400	5.70%	11.42	4,294,951	19.42%	4.97
Inclusion the value of excess heat							
	Health Center	-60,952	-2.61%	25.01	-20,450	3.50%	13.70
	Hospital	-49,451	5.58%	11.53	1,553,227	17.17%	5.54
	Clinical centre	4,864	6.02%	11.14	4,380,216	19.66%	4.92
Price increase by 20%							
Gas							
	Health Center	-146,933	#NUM!	-33.30	-106,431	-19.96%	339.14
	Hospital	-1,403,084	-14.80%	134.98	199,594	7.62%	9.87
	Clinical centre	-3,213,376	-15.87%	161.65	1,161,976	10.03%	8.35
CO_2							
	Health Center	-105,763	-19.06%	286.34	-57,161	-1.93%	23.22
	Hospital	-231,349	3.99%	13.15	1,691,864	18.07%	5.30
	Clinical centre	-80,400	5.70%	11.42	5,170,021	21.86%	4.47
Electricity							
	Health Center	-82,802	-7.46%	45.06	-42,300	0.48%	18.12
	Hospital	486,192	9.82%	8.47	2,088,869	20.60%	4.72
	Clinical centre	1,928,713	12.47%	7.16	6,304,065	24.96%	3.95
Electricity, feed-in tariff							
	Health Center	-80,803	-6.92%	41.98	-40,301	0.77%	17.61
	Hospital	564,399	10.40%	8.15	2,167,077	21.09%	4.62
	Clinical centre	1,902,572	12.39%	7.19	6,277,924	24.89%	3.96
Price decrease by 20%							
Gas							
	Health Center	-64,594	-3.30%	27.01	-24,091	3.03%	14.29
	Hospital	940,386	13.07%	6.91	2,543,063	23.43%	4.19
	Clinical centre	3,052,575	15.86%	5.92	7,427,927	27.99%	3.54
CO_2							
	Health Center	-105,763	-19.06%	286.34	-73,362	-5.12%	33.47
	Hospital	-231,349	3.99%	13.15	1,050,793	13.83%	6.61
	Clinical centre	-80,400	5.70%	11.42	3,419,881	16.93%	5.60
Investment decrease by 20%							
	Health Center	-77,859	-12.72%	96.47	-37,357	-0.20%	19.38
	Hospital	156,475	7.59%	9.89	1,759,152	21.29%	4.58
	Clinical centre	794,791	9.47%	8.66	5,170,142	25.39%	3.88

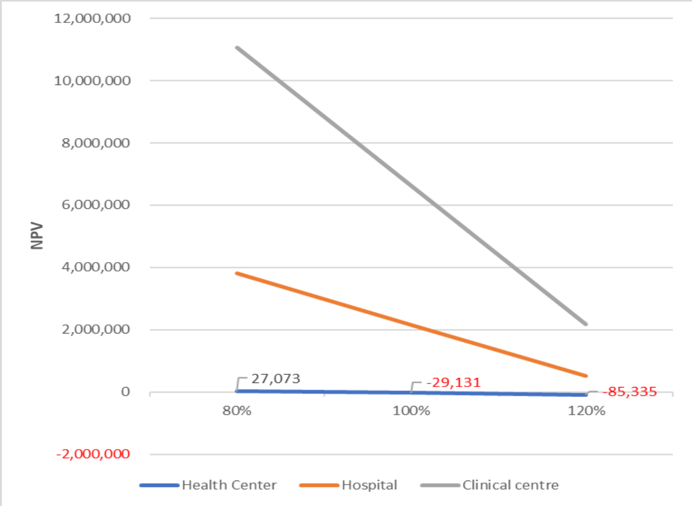

Figure 10.4. Impact of gas price changes on NPV

Table 10.63. Break-even point when NPV = 0

Change of gas price			
		Without CO2	**With CO2**
	Health Center	**Price decrease of 51.38%**	**Price decrease of 31.7%**
	Hospital	**Price decrease of 3.95%**	**Price increase of 23.41%**
	Clinical centre	**Price decrease of 0.51%**	**Price increase of 27.42%**
Change of CO_2 prices			
	Health Center		**Price increase of 161%**
	Hospital		**Price decrease of 85.57%**
	Clinical centre		**Price decrease of 98.16%**
Electricity			
	Health Center	**Price increase of 92.12%**	**Price increase of 56.85%**
	Hospital	**Price increase of 6.45%**	**Price decrease of 38.22%**
	Clinical centre	**Price increase of 0.81%**	**Price decrease of 42.76%**
Electricity, feed-in tariff			
	Health Center	**Price increase of 84.75%**	**Price increase of 52.3%**
	Hospital	**Price increase of 5.82%**	**Price decrease of 34.47%**
	Clinical centre	**Price increase of 0.81%**	**Price decrease of 43.32%**
Investment costs			
	Health Center	**Decrease of 75.8%**	**Decrease of 46.8%**
	Hospital	**Decrease of 11.93%**	**Increase of 70.72%**
	Clinical centre	**Decrease of 1.84%**	**Increase of 98.15%**
Compound case: Increase of feed-in tariff by 5% and decrease investment by 5%			
	Health Center	**NPV = negative**	
	Hospital	**NPV = positive**	
	Clinical centre	**NPV = positive**	

The results show that there is not much sense in introducing HE CHP in health services facilities that are using gas for heating. CHP systems are using more gas than previously for heating, and it couldn't be compensated by the additional production of electricity. Considering the European CO_2 price, most of the facilities are getting NPV-positive, but using that price in Serbia is not mandatory. The bigger the system, the better the results. This is presented in the compound case where the electricity feed-in tariff increased by 5% and decreased the investment by 5%, and only the smallest facility remained with negative NPV. The society can support the introduction of the CHP system in these facilities, especially bigger ones, through investment grants and/or electricity feed-in tariffs, but it entirely depends on the strategic view on price of electricity.

10.7.2.3 Hotels and sports facilities using heavy oil

CBA analysis of the introduction of HE CHP into two types of hotels (small and large) and sports facilities (swimming pool) presents various results. After defining the CBA model, the a complex sensitivity analysis developed, was based on all technical assumptions and prevailing prices. Topics in this analysis were:

- Price increase by 20% for gas, CO_2, and feed-in tariff;
- Price decrease by 20% for: gas, CO_2, and investment cost;
- Establishing break-even points (NPV=0) for: gas, CO_2, feed-in tariff, and investment cost;
- Compound cases, simultaneous variation of multiple elements, in the case of small and large hotels.

All of this was done with and without values for CO_2. The results of the sensitivity analysis for hotels and sports facilities using heavy oil is presented in Table 10.64.

NPV of each facility performs differently depending on the change in the gas price, as shown in Figure 10.5.

Table 10.64. Sensitivity analysis – hotels and sports facilities

20 years period						
Description	Without CO2			With CO2		
	NPV	IRR	Simple Pay-back period	NPV	IRR	Simple Pay-back period
			years			years
Base case						
Small hotel	-32,588	1.88%	15.85	89,187	15.10%	6.16
Large hotel	-9,547	5.71%	11.41	614,528	21.23%	4.59
Swimming pool	707,413	16.58%	5.70	1,717,181	29.55%	3.36
Price increase by 20%						
Gas						
Small hotel	-89,637	-9.56%	60.15	32,139	9.52%	8.64
Large hotel	-305,671	-6.30%	38.77	318,405	14.40%	6.41
Swimming pool	-65,327	4.85%	12.24	944,441	19.74%	4.90
CO2						
Small hotel	-32,588	1.88%	15.85	113,542	17.34%	5.49
Large hotel	-9,547	5.71%	11.41	739,343	23.99%	4.10
Swimming pool	707,413	16.58%	5.70	1,919,135	32.06%	3.10
Electricity, feed-in tariff						
Small hotel	-31,849	1.98%	15.70	89,927	15.17%	6.14
Large hotel	807	6.02%	11.14	624,882	21.46%	4.54
Swimming pool	792,611	17.73%	5.39	1,802,379	30.61%	3.25
Price decrease by 20%						
Gas						
Small hotel	24,460	8.71%	9.13	146,236	20.24%	4.79
Large hotel	286,576	13.63%	6.69	910,652	27.71%	3.57
Swimming pool	1,480,153	26.59%	3.72	2,489,921	39.06%	2.56
CO2						
Small hotel	-32,588	1.88%	15.85	64,832	12.80%	7.02
Large hotel	-9,547	5.71%	11.41	489,713	18.41%	5.21
Swimming pool	707,413	16.58%	5.70	1,515,227	27.03%	3.66
Investment decrease by 20%						
Small hotel	-4,684	5.31%	11.79	117,092	20.25%	4.79
Large hotel	99,281	9.49%	8.66	723,356	27.57%	3.59
Swimming pool	894,932	22.00%	4.44	1,904,700	37.73%	2.64

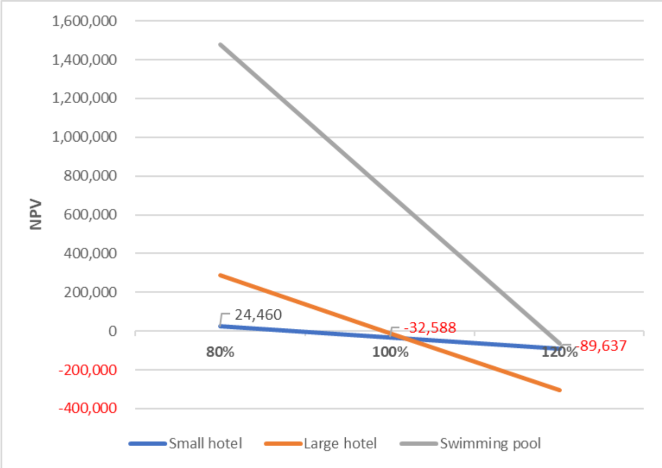

Figure 10.5. Impact of gas price changes on NPV

Table 10.65. Break-even point when NPV = 0

Change of gas prices			
	Without CO2		**With CO2**
	Small hotel	**Price decrease of 11.43%**	**Price increase of 31.27%**
	Large hotel	**Price decrease of 0.01%**	**Price increase of 41.51%**
	Swimming pool	**Price increase of 18.31%**	**Price increase of 44.44%**
Change of CO_2 prices			
	Small hotel		**Price decrease of 73.24%**
	Large hotel		**Price decrease of 98.47%**
	Swimming pool		**Insensitive**
Electricity, feed-in tariff			
	Small hotel	**Price increase of 88.13%**	**Insensitive**
	Large hotel	**Price increase of 18.45%**	**Insensitive**
	Swimming pool	**Insensitive**	**Insensitive**
Investment costs			
	Small hotel	**Decrease of 23.36%**	**Insensitive**
	Large hotel	**Decrease of 1.76%**	**Insensitive**
	Swimming pool	**Increase of 78.45%**	**Insensitive**
Compound case:			
	Small hotel	**NPV is turning positive with a decrease of investment by 10% and a decrease of gas price by 7%**	
		Positive NPV with CO_2 compensates negative NPV without CO_2 by decrease of CO2 price by 46.8% or on 0.04454 EUR/kg.	
	Large hotel	**NPV is turning positive with a decrease of investment by 2% and a increase of feed-in tariff by 1%**	
		Positive NPV with CO_2 compensates negative NPV without CO_2 by decrease of CO2 price by 96.9% or on 0.0026 EUR/kg.	

As in previous cases, the basic finding is – the bigger, the better. The main findings are:

- If current CO_2 prices, from EU ETS, are applied, all cases have positive NPV and IRR above the discount rate. It should be noted that in Serbia, CO_2 prices are not mandatory, so this result should be taken with a lot of caution.
- In all analysed cases the biggest sensitivity is on gas prices, then, far less, on the investment costs and, in the end, on feed-in tariff.
- Small hotels: The base case has a negative NPV, but it could be turned positive (NPV=0) by decreasing gas prices by 10.37% or by decreasing investment by 20.88%. There was additionally analysed the compound case with a simultaneous decrease in gas price and a decrease in investment. NPV is turning positive with a decrease in investment by 10% and a decrease in gas price by 7%. An interesting finding is that positive NPV with CO_2 compensates for negative NPV without CO_2 by decreasing of CO_2 price by 46.8% or at the price level of 0.04454 EUR/kg. In this case, NPV>0 is very achievable by the appropriate financial policy.
- Large hotels: The base case has a negative NPV, but it could be turned positive (NPV=0) by decreasing gas price by 0.01% or decreasing investment by 1.76% or increasing feed-in tariff by 18.45%. Also, NPV is turning positive with a decrease of investment by 2% and an increase of feed-in tariff by 1%. In the end, it

should be said that positive NPV with CO_2 compensates for negative NPV without CO_2 by decreasing the CO_2 price by 96.9% or at the price level of 0.0026 EUR/kg.

- Swimming pool: NPV is positive, and the break-even point (NPV=0) could be reached by a gas price increase of 18.31%, and an investment cost increase of 78.45%.

In the sensitivity analysis, have been defined the break-even points, points when NPV is equalling zero, for main elements: prices of gas, CO_2, and electricity feed-in tariff, and the value of the investment. The results are presented in Table 10.65. Also, a complex case was introduced to see how NPV and IRR are affected by simultaneous changes through an increase in feed-in tariff and a reduction of investments, all for hotels.

10.7.2.4 Hotels and sports facilities that are using gas

CBA analysis of the introduction of HE CHP Systems into two types of hotels (small and large) and sports facilities (swimming pool) presents various results and is substantially different from those that are using heavy oil. There has been developed a complex sensitivity analysis based on all technical assumptions and prevailing prices. The influence of various scenarios on basic criteria (NPV, IRR, and simple pay-back period) were analysed. Topics in this analysis were:

- Price increase by 20% for gas, CO_2, and feed-in tariff;
- Price decrease by 20% for: gas, CO_2, and investment cost;
- Establishing break-even points (NPV=0) for: gas, CO_2, feed-in tariff, electricity and investment cost;

All of this was done with and without values for CO_2. Sensitivity analysis presenting influences of changes of basic inputs is presented in Table 10.66. In the sensitivity analysis, were defined the break-even points, (NPV=0), for main elements: prices of gas, CO_2, electricity, feed-in tariff, and the value of the investment. The results are presented in Table 10.67.

Table 10.66. Sensitivity analysis – hotels and sports facilities

20 years period

Description	Without CO2 NPV	Without CO2 IRR	Without CO2 Simple Pay-back period	With CO2 NPV	With CO2 IRR	With CO2 Simple Pay-back period
			years			years
Base case						
Small hotel	-213,585	-16.05%	166.69	-117,142	-1.78%	22.85
Large hotel	-561,303	-8.70%	53.32	-83,777	4.44%	12.65
Swimming pool	-588,609	-8.88%	54.67	171,934	8.83%	9.05
Price increase by 20%						
Gas						
Small hotel	-293,425	#NUM!	-39.59	-196,982	-11.51%	80.00
Large hotel	-913,168	#NUM!	-38.95	-435,643	-3.88%	28.89
Swimming pool	-1,113,751	#NUM!	-22.05	-353,208	-1.14%	21.36
CO2						
Small hotel	-213,585	-16.05%	166.69	-97,853	-0.25%	19.49
Large hotel	-561,303	-8.70%	53.32	11,728	6.21%	10.98
Swimming pool	-588,609	-8.88%	54.67	324,043	11.16%	7.76
Electricity						
Small hotel	-175,412	-7.89%	47.75	-78,969	1.12%	17.03
Large hotel	-360,391	-1.71%	22.67	117,134	8.04%	9.58
Swimming pool	-78,868	4.60%	12.49	681,675	16.23%	5.81
Electricity, feed-in tariff						
Small hotel	-158,931	-5.82%	36.50	-62,488	2.23%	15.35
Large hotel	-343,129	-1.25%	21.60	134,396	8.33%	9.38
Swimming pool	-503,410	-5.47%	34.95	257,133	10.16%	8.28
Price decrease by 20%						
Gas						
Small hotel	-133,746	-3.24%	26.84	-37,302	3.83%	13.33
Large hotel	-209,437	1.90%	15.83	268,088	10.49%	8.10
Swimming pool	-63,467	4.88%	12.21	697,076	16.44%	5.74
CO2						
Small hotel	-213,585	-16.05%	166.69	-136,431	-3.49%	27.62
Large hotel	-561,303	-8.70%	53.32	-179,282	2.54%	14.93
Swimming pool	-588,609	-8.88%	54.67	19,826	6.34%	10.87
Electricity						
Small hotel	-251,758	#NUM!	-111.78	-155,315	-5.41%	34.71
Large hotel	-762,214	#NUM!	-151.21	-284,689	0.20%	18.63
Swimming pool	-1,098,350	#NUM!	-23.00	-337,807	-0.77%	20.54
Investment decrease by 20%						
Small hotel	-155,544	-11.00%	74.08	-59,100	1.47%	16.48
Large hotel	-381,318	-5.24%	33.97	96,208	8.09%	9.54
Swimming pool	-401,090	-5.40%	34.64	359,453	12.99%	6.94

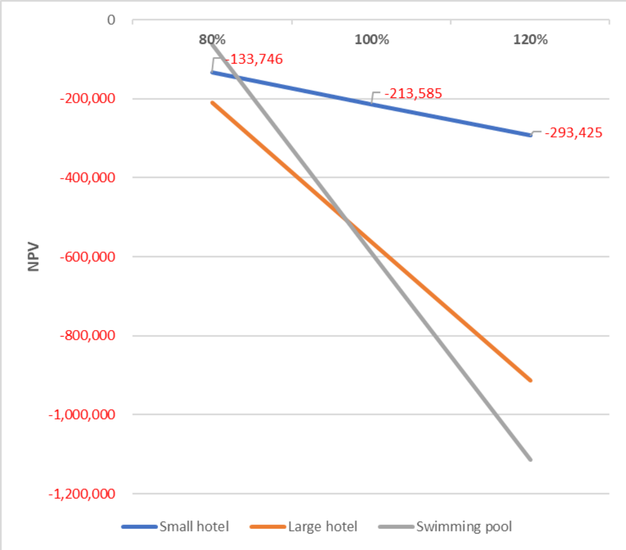

Figure 10.6. Impact of gas price changes on NPV

Table 10.67. Break-even point when NPV = 0

Change of gas price			
	Without CO2		**With CO2**
	Small hotel	**Price decrease of 53.51%**	**Price decrease of 29.35%**
	Large hotel	**Price decrease of 31.9%**	**Price decrease of 4.76%**
	Swimming pool	**Price decrease of 22.42%**	**Price increase of 6.55%**
Change of CO_2 prices			
	Small hotel		**Price increase of 121.5%**
	Large hotel		**Price increase of 17.55%**
	Swimming pool		**Price decrease of 22.61%**
Electricity			
	Small hotel	**Price increase of 111.9%**	**Price increase of 61.37%**
	Large hotel	**Price increase of 55.88%**	**Price increase of 8.34%**
	Swimming pool	**Price increase of 23.1%**	**Price decrease of 6.75%**
Electricity, feed-in tariff			
	Small hotel	**Price increase of 78.15%**	**Price increase of 42.87%**
	Large hotel	**Price increase of 51.45%**	**Price increase of 7.68%**
	Swimming pool	**Price increase of 138.17%**	**Price decrease of 40.36%**
Investment costs			
	Small hotel	**Decrease of 73.6%**	**Decrease of 40.35%**
	Large hotel	**Decrease of 62.37%**	**Decrease of 9.31%**
	Swimming pool	**Decrease of 62.78%**	**Increase of 18.34%**

The results show that there is not much sense in introducing HE CHP in hotels and sports facilities that are using gas for heating. CHP systems are using more gas than previously consumed for heating, and it couldn't be compensated by additional production of electricity.

Considering the European CO_2 price, most of the facilities are getting NPV-positive, but using that price in Serbia is not mandatory. The bigger system, the better the results. The main sensitivity is on changes in gas prices, then, far less, on electricity feed-in tariff, followed by electricity price, price of CO_2, and investment. Small plants have greater sensibility.

The only economic sense can be found through the application of European CO_2 prices, and that only for the largest CHP systems.

10.7.3 Sensitivity analysis of introducing CHP in the industrial sector

10.7.3.1 Sensitivity analysis of the introduction of Combined Cycle Gas Turbine (CCGT) to some industries

After defining the CBA model, a complex sensitivity analysis based on all technical assumptions and prevailing prices has been developed. Topics in this analysis were:

- Price increase by 20% for: gas, CO_2, and increase of working hours by 20%.
- Price decrease by 20% for: gas, CO_2, investment costs, and decrease of working hours by 20%.
- Establishing break-even points (NPV=0) for: gas, CO_2, investment costs, and working hours.
- Compound cases, simultaneous variation of some elements.

All of this was done with and without values for CO_2.The results of the sensitivity analysis are presented in Table 10.68.

Table 10.68. Sensitivity analysis

20 years period						
Description	**Without CO2**			**With CO2**		
	NPV	**IRR**	**Simple Pay-back period**	**NPV**	**IRR**	**Simple Pay-back period**
			years			years
Base case						
2,8 MWe CCGT CHP	-3,558,591	#NUM!	-190.39	75,288,438	209.68%	0.48
12,9 MWe CCGT CHP	7,978,453	12.18%	7.29	29,979,549	26.56%	3.72
Price increase by 20%						
Gas						
2,8 MWe CCGT CHP	-8,306,990	#NUM!	-7.58	70,540,040	197.02%	0.51
12,9 MWe CCGT CHP	-14,887,977	-26.83%	1405.98	7,113,120	11.56%	7.57
CO2						
2,8 MWe CCGT CHP	-3,558,591	#NUM!	-190.39	91,057,844	251.73%	0.40
12,9 MWe CCGT CHP	7,978,453	12.18%	7.29	34,379,769	29.27%	3.39
Increase of working h by 20%						
2,8 MWe CCGT CHP	2,853,520	15.50%	6.04	81,202,097	225.45%	0.44
12,9 MWe CCGT CHP	32,514,814	28.12%	3.52	53,516,335	40.86%	2.44
Price decrease by 20%						
Gas						
2,8 MWe CCGT CHP	1,189,807	10.23%	8.24	80,036,837	222.34%	0.45
12,9 MWe CCGT CHP	30,844,883	27.09%	3.65	52,845,979	40.46%	2.47
CO2						
2,8 MWe CCGT CHP	-3,558,591	#NUM!	-190.39	59,519,032	167.64%	0.60
12,9 MWe CCGT CHP	7,978,453	12.18%	7.29	25,579,330	23.82%	4.13
Investment decrease by 20%						
2,8 MWe CCGT CHP	-2,706,231	#NUM!	-1768.93	76,140,798	262.70%	0.38
12,9 MWe CCGT CHP	11,783,632	16.83%	5.63	33,784,728	34.05%	2.93
Decrease of working h by 20%						
2,8 MWe CCGT CHP	-9,970,703	#NUM!	-5.68	69,374,779	193.92%	0.52
12,9 MWe CCGT CHP	-28,844,922	#NUM!	-12.10	-4,547,385	1.77%	16.01

NPV of each industry performs differently depending on the prime sensitivity factor - change in the gas price. This is presented in Figure 10.7.

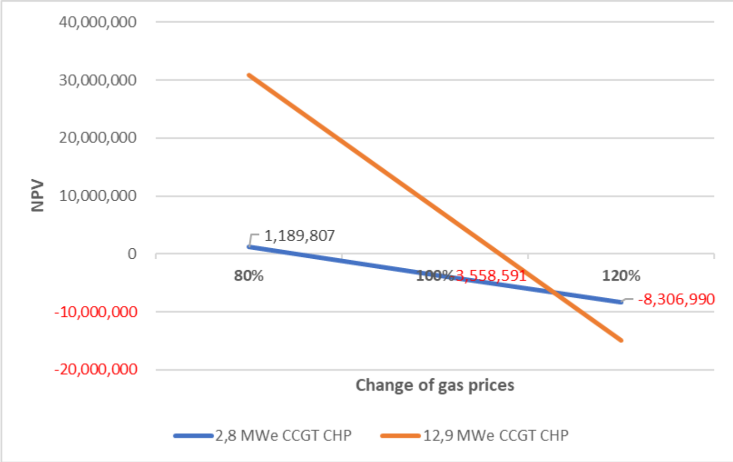

Figure 10.7. Impact of gas price changes on NPV

In the sensitivity analysis, were defined the break-even points, points when NPV is equalling zero, for main elements: prices of gas, CO_2, working hours, and the value of the investment. The results are presented in **Error! Reference source not found.** Table 10.69. A complex case has also been introduced to see how NPV and IRR are affected by simultaneous changes through an increased gas price and working hours.

Table 10.69. Break-even point when NPV = 0

Change of gas prices			
	Without CO2		**With CO2**
	2,8 MWe CCGT CHP	**Price decrease of 14.99%**	**Price increase of 317.1%**
	12,9 MWe CCGT CHP	**Price increase of 6.98%**	**Price increase of 26.22%**
Change of CO_2 prices			
	2,8 MWe CCGT CHP		**Price decrease of 95.5%**
	12,9 MWe CCGT CHP		**Insensitive**
Investment costs			
	2,8 MWe CCGT CHP	**Decrease of 83.5%**	**Insensitive**
	12,9 MWe CCGT CHP	**Increase of 41.9%**	**Increase of 157.6%**
Working h			
	2,8 MWe CCGT CHP	**Increase of 11.1% to 6172 h**	**Insensitive**
	12,9 MWe CCGT CHP	**Decrease of 4.3% to 4576 h**	**Decrease of 17.4% to 3414 h**
Compound case:			
	2,8 MWe CCGT CHP	**In order to sustain NPV positive, with every 1% increase in gas prices there is a need to increase working h by 11.85% or by 1255 h.**	
	12,9 MWe CCGT CHP	**The NPV would remain positive if a 23% increase in the price of gas was compensated by an increase in working hours by 1000.**	

Conclusion is the bigger, the better. Details are in the sheets and the main findings are:

- If current CO_2 prices, from EU ETS, are applied, all cases have positive NPV and IRR above the discount rate. It should be noted that in Serbia, CO_2 prices are not mandatory, so this result should be taken with a lot of caution.
- The biggest sensitivity is on gas prices, and working hours, then, far less, on the investment costs.
- 2.8 MWe CCGT CHP: The base case has a negative NPV, and it is very sensitive to gas prices - NPV is getting positive by a decrease of gas prices by 14.99%. The break-even point (NPV=0) could be reached by increasing annual working hours by 11.1% to 6,172 h. Additionally the compound case with a simultaneous increase in gas price and working hours, has been analysed. In order to sustain NPV positive, with every 1% increase in gas prices there is a need to increase annual working hours by 11.85% or by 1,255 h. If CO_2 is calculated according to EU prices, NPV is reaching 0 with the increase of gas prices by 317.1%.
- 12.9 MWe CCGT CHP: The base case has a positive NPV, but it could be turned negative (NPV=0) by increasing gas prices by more than 6.98% or decreasing annual working hours by more than 4.3% (to 4,576 h). Also, The NPV would remain positive if a 23% increase in the price of gas was compensated by an increase in working hours by 1,000 hours. NPV can sustain an increase in investment by 41.9%.

10.7.3.2 Sensitivity analysis of the introduction of gas engine CHP to the industry

After defining the CBA model, a complex sensitivity analysis based on all technical assumptions and prevailing prices, has been developed. Topics in this analysis were:

- Price increase by 20% for: gas and CO_2;
- Price decrease by 20% for: gas, CO_2, and investment cost;
- Establishing break-even points (NPV=0) for: gas, CO_2, and investment cost.
- Compound cases, simultaneous variation of multiple elements, in the case of the Dairy and Food industry.

All of this was done with and without values for CO_2.The results of the sensitivity analyses are presented in Table 10.70.

Table 10.70. Sensitivity analysis

20 years period						
Description	**Without CO2**			**With CO2**		
	NPV	**IRR**	**Simple Pay-back period**	**NPV**	**IRR**	**Simple Pay-back period**
			years			years
Base case						
0,9 MWe ICE CHP	182,909	8.84%	9.05	5,875,142	76.04%	1.32
1,9 MWe ICE CHP	265,217	8.11%	9.52	8,162,450	56.25%	1.78
0.3 MWe ICE CHP	-912,549	#NUM!	-8.37	42,965	7.37%	10.05
Price increase by 20%						
Gas						
0,9 MWe ICE CHP	-1,331,552	#NUM!	-16.03	4,360,681	58.74%	1.70
1,9 MWe ICE CHP	-3,027,304	#NUM!	-11.65	4,869,929	37.09%	2.69
0.3 MWe ICE CHP	-1,382,916	#NUM!	-4.40	-427,402	#NUM!	-120.05
CO2						
0,9 MWe ICE CHP	182,909	8.84%	9.05	7,013,588	89.03%	1.12
1,9 MWe ICE CHP	265,217	8.11%	9.52	9,741,897	65.41%	1.53
0.3 MWe ICE CHP	-912,549	#NUM!	-8.37	234,068	12.90%	6.98
Price decrease by 20%						
Gas						
0,9 MWe ICE CHP	1,697,370	28.08%	3.53	7,389,603	93.33%	1.07
1,9 MWe ICE CHP	3,557,739	29.36%	3.38	11,454,972	75.34%	1.33
0.3 MWe ICE CHP	-442,183	#NUM!	-85.34	513,331	20.09%	4.82
CO2						
0,9 MWe ICE CHP	182,909	8.84%	9.05	4,736,695	63.03%	1.59
1,9 MWe ICE CHP	265,217	8.11%	9.52	6,583,004	47.08%	2.12
0.3 MWe ICE CHP	-912,549	#NUM!	-8.37	-148,138	0.57%	17.96
Investment decrease by 20%						
0,9 MWe ICE CHP	381,950	13.00%	6.94	6,074,183	95.65%	1.05
1,9 MWe ICE CHP	657,364	12.18%	7.29	8,554,597	70.92%	1.41
0.3 MWe ICE CHP	-813,394	#NUM!	-6.97	142,120	11.34%	7.67

NPV of each industry performs differently depending on the prime sensitivity factor - change in the gas price, as depicted in Figure 10.8.

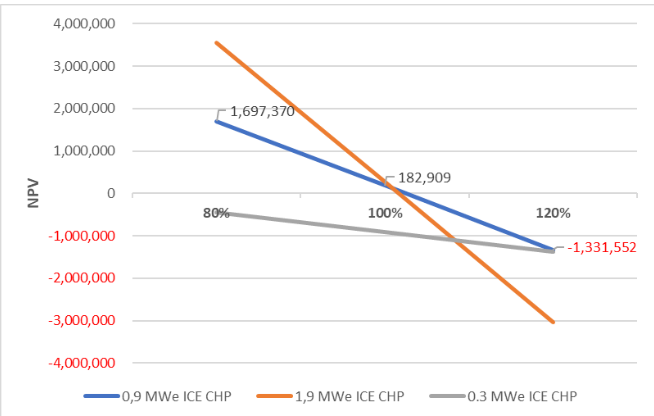

Figure 10.8. Impact of gas price changes on NPV

In the sensitivity analysis, were defined the break-even points, points when NPV is equalling zero, for main elements: prices of gas, CO_2 and the value of the investment. The results are shown in Table 10.71. A complex case has also been introduced to see how NPV and IRR are affected by simultaneous changes through an increased gas price and investment.

Table 10.71. Break-even point when NPV = 0

Change of gas prices			
	Without CO2		**With CO2**
	0,9 MWe ICE CHP	**Price increase of 2.42%**	**Price increase of 77.59%**
	1,9 MWe ICE CHP	**Price increase of 1.61%**	**Price increase of 49.58%**
	0.3 MWe ICE CHP	**Price decrease of 38.8%**	**Price increase of 1.83%**
Change of CO_2 prices			
	0,9 MWe ICE CHP		**Insensitive**
	1,9 MWe ICE CHP		**Insensitive**
	0.3 MWe ICE CHP		**Price decrease of 4.5%**
Investment costs			
	0,9 MWe ICE CHP	**Increase of 18.38%**	**Increase of 590.3%**
	1,9 MWe ICE CHP	**Increase of 13.53%**	**Increase of 416.3%**
	0.3 MWe ICE CHP	**NPV<0 allways**	**Increase of 8.7%**
Compound case:			
	0,9 MWe ICE CHP	**In order to sustain NPV positive, with every 3% increase in gas prices there is a need to decrease investment by 5%**	
	1,9 MWe ICE CHP	**In order to sustain NPV positive, with every 2% increase in gas prices there is a need to decrease investment by 3.3%**	

The basic finding is – the bigger, the better. Details are in the sheets and the main findings are:

- If current CO_2 prices, from EU ETS, are applied, all cases have positive NPV and IRR above the discount rate. In Serbia, CO_2 prices are not mandatory, so this result should be taken with a caution.
- In all analysed cases the biggest sensitivity is on gas prices, then, far less, on the investment costs.
- 0.9 MWe ICE CHP: The base case has a positive NPV, but it is very sensitive to gas prices - NPV is getting negative with an increase of gas prices by more than 2.42%. Also, the break-even point (NPV=0) could be reached by increasing investment by 18.38%. The compound case with a simultaneous increase in gas price and a decrease in investment, has been analysed. NPV sustains positive if every 3% of the increase in gas prices is compensated by a decrease in investment by 5%. If CO_2 is calculated according to EU prices, NPV is reaching 0 with the increase of gas prices by 77.59%.
- 1.9 MWe ICE CHP: The base case has a positive NPV, but it could be turned negative (NPV=0) by increasing gas prices by more than 1.61% or increasing investment by more than 13.53%. In order to sustain NPV positive, with every 2% increase in gas prices there is a need to decrease investment by 3.3%. If CO_2 is calculated according to EU prices, NPV is reaching 0 with the increase of gas prices by 49.58%.
- 0.3 MWe ICE CHP: NPV is negative, and the break-even point (NPV=0) could be reached by a gas price decrease of 38.8%, which does not seem probable.

10.7.4 Sensitivity analysis: comparison of DHS and heating alternatives

In this analysis, we will investigate how the price movement of key energy sources affects NPV and IRR. An interactive numerical model with seven degrees of freedom was developed. The model could also help in defining alternative policies. The changes in NPV and IRR obtained by changing the main elements by +/- 20% and calculating the break-even point (NPV=0) of these main elements were observed.

Analysed heating methods were:

- TA stove, low tariff,
- TA stove, low tariff + 2 hours high tariff,
- Electric heaters and boilers,
- Wood,
- Wood pellets,
- Fuel oil,
- Coal raw lignite.

10.7.4.1 TA stove, using low-tariff electricity

In the comparison of heating using DHS and TA stoves that use low-tariff electricity, the influence of two main elements have been analysed: the price of DHS heating and the price of low-tariff electricity. In the base case, transfer to DHS is not viable, but let us see if price changes would make it different. The results of the sensitivity analysis are shown in Table 10.72. and impact of heating price on NPV in Figure 10.9.

Table 10.72. Sensitivity analyses and break-even points

TA stove, low tariff	NPV	IRR
	€	€
Basic case	-1,893	
Price of DH heating		
20%	-3,114	
-20%	-673	
Price of low tariff electricity		
20%	-891	
-20%	-2,896	
Break-even point (NPV=0)		
Price of DH heating	-31.10%	
Price of electricity	37.75%	

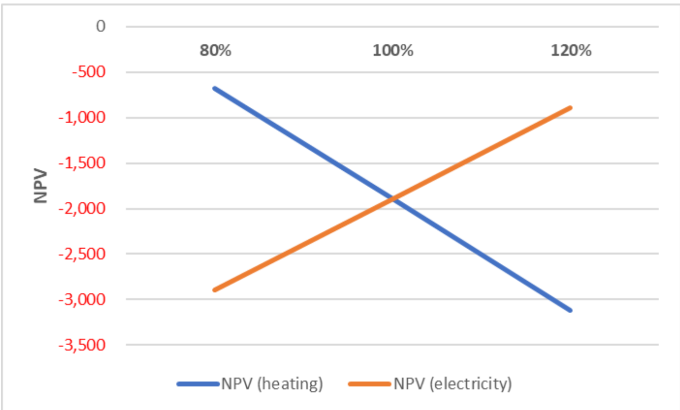

Figure 10.9. Impact of DHS heating price and low-tariff changes on NPV

Result is that 20% changes in mentioned prices would not turn NPV into a positive value. NPV changes to zero by decreasing the price of heating by 31.1% or by increasing the price of low-tariff electricity by 37.75%. Neither of these cases is likely. NPV including CO_2 is always positive and by connection to DHS the CO_2 emission in Serbia could be reduced by 300,000 t.

10.7.4.2 TA stove, using low-tariff + 2 hours of high-tariff electricity

There has been analysed the influence of two main elements: the price of DHS heating and the price of low-tariff and high-tariff electricity. In the base case, transfer to DHS is advised, but let us see how price changes would impact the decision on switching to DHS. The results of the sensitivity analysis are summarized in Table 10.73. impact of heating price on NPV in Figure 10.10.

In the base case, NPV is positive, with an IRR of 7.78% (discount rate is 6%) and a simple pay-back period of 9.8 years. NPV is equalling zero with an increase of the price of heating from DHS for 1.9%, so it is on the edge. It is like the electricity price, an increase in that price will encourage transfer to DHS.

All cases which include the current CO_2 price have a positive value of NPV. Connecting these dwellings to DHS could reduce CO_2 emission by 150,000 t.

Table 10.73. Sensitivity analyses and break-even points

TA stove, low + 2h high tariff			NPV	IRR
	Basic case		116	7.78%
	Price of DH heating			
		20%	-1,105	7.78%
		-20%	1,336	23.40%
	Price of electricity			
		20%	3,205	44.62%
		-20%	-2,413	
Break-even point (NPV=0)				
	Price of DH heating		1.90%	
	Price of electricity		-0.83%	

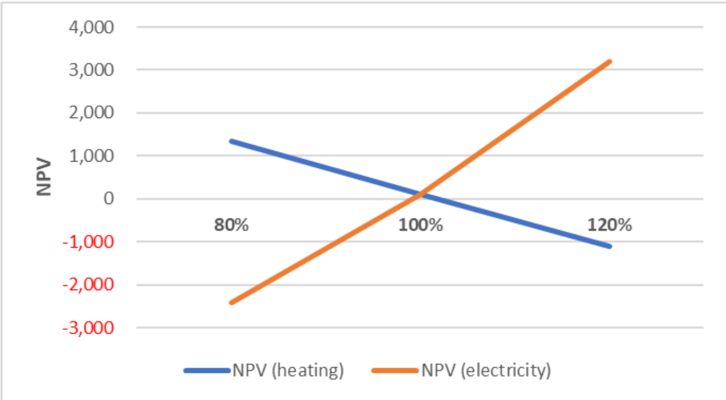

Figure 10.10. Impact of DHS heating price and low-tariff changes on NPV

10.7.4.3 Electric heaters and boilers

We have been are dealing with high-tariff price, and the price of DHS heating. In the base case, NPV is positive, with an IRR of 73.37% and a simple pay-back period of 1.4 years. The transfer from heating using high-tariff electricity to DHS is very advisable. The results of the sensitivity analysis are summarized in Table 10.74 and impact of heating price on NPV in Figure 10.11.

Table 10.74 Sensitivity analyses and break-even points

Electric heaters and boilers			NPV	IRR
	Basic case		5,784	73.37%
	Price of DH heating			
		20%	4,563	59.77%
		-20%	7,004	86.96%
	Price of electricity			
		20%	8,322	101.63%
		-20%	3,246	45.07%
Break-even point (NPV=0)				
	Price of DH heating		94.80%	
	Price of electricity		-45.56%	

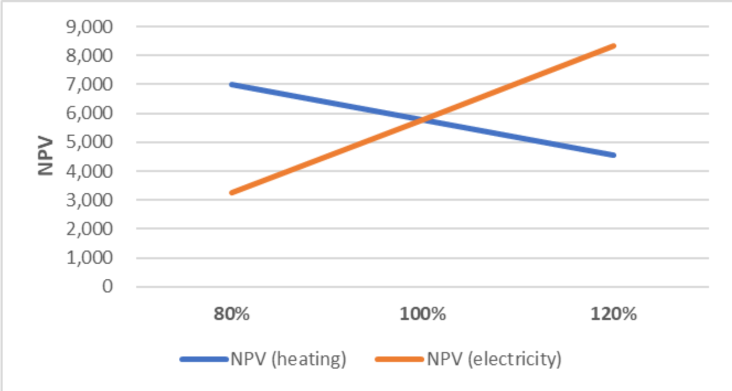

Figure 10.11. Impact of DHS heating price and low-tariff changes on NPV

The transfer to DHS heating in this case is very profitable and it could be changed by increasing the DHS heat price by 94.8% or by decreasing the price of electricity by 45.56%. Either of these cases is not probable.

In the cases with the inclusion of CO_2, it is getting even better. Total CO_2 emission in Serbia, by connecting these entities to the DHS grid, could be reduced by 170,000 t.

10.7.4.4 Heating with wood

It is not easy to establish the price of wood for heating because of the fast and big changes in the last year, because of the huge black market and production for own needs. In this case, sensitivity is very useful in defining price margins for NPV to turn positive. It is strongly advised not to connect to DHS. The results of the sensitivity analysis are presented in Table 10.75. and impact of heating price on NPV in Figure 10.12.

Table 10.75. Sensitivity analyses and break-even points

Wood			NPV	IRR
	Basic case		-1,803	
	Price of DH heating			
		20%	-3,023	
		-20%	-582	
	Price of wood			
		20%	-782	
		-20%	-2,824	
Break-even point (NPV=0)				
	Price of DH heating		-29.55%	
	Price of wood		35.30%	

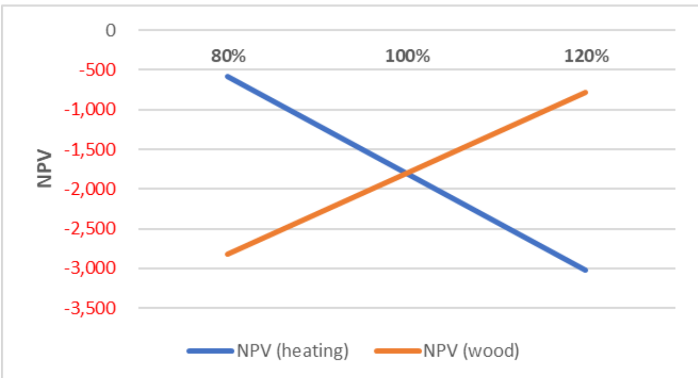

Figure 10.12. Impact of DHS heating price and low-tariff changes on NPV

NPV could turn positive by decreasing DHS heating price by 29.55% or by increasing the price of wood for heating by 35.3%. A decrease in heating price by the DHS is not possible but an increase in the price of wood is not only possible but already happening. The break-even point could be reached with the wood for heating price of 77.26 €/m³, and this price has already been reached and exceeded. So, experts can claim that connection to DHS grid is economically advisable.

The CO_2 story is also interesting due to the fact that by connecting these households to the DHS grid, CO_2 emission in Serbia could be reduced by 522,000 t annually.

10.7.4.5 Heating using wood pellets

The base case is telling us that transferring to DHS is not advisable, but it could be changed by rather small changes in prices, in this case, the prices of wood pellet and DHS heating. Let's see the numbers Table 10.76. Impact of heating price on NPV is shown in Figure 10.13.

Table 10.76. Sensitivity analyses and break-even points

Wood pellet			NPV	IRR
	Basic case		-467	
	Price of DH heating			
		20%	-1,688	
		-20%	753	16.37%
	Price of wood pellet			
		20%	820	17.21%
		-20%	-1,755	
Break-even point (NPV=0)				
	Price of DH heating		-7.67%	
	Price of wood pellet		7.25%	

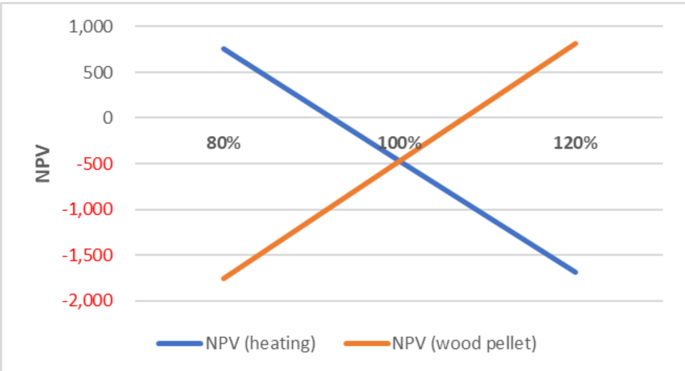

Figure 10.13. Impact of DHS heating price and low-tariff changes on NPV

The basic NPV negative value could be turned to positive by decreasing the price of DHS heating by 7.67% or by increasing the price of wood pellet by 7.25%. Both are very near and an increase in wood pellet price is very probable, if not already done. The introduction of CO_2 is giving a much better picture, but due to rather a small number of households that are using wood pellet for heating, the annual reduction of CO_2, by connecting them to the DHS grid, would amount to 35,500 t.

10.7.4.6 Heating using fuel oil

Transfer of heating from fuel oil to DHS is very profitable – NPV is positive, IRR is 62.17% and the simple pay-back period is 1.6 years. There is no sense in continuing to use fuel oil for heating, neither economically nor ecologically (Table 10.77., Figure 10.14.).

Table 10.77. Sensitivity analyses and break-even points

Fuel oil			NPV	IRR
	Basic case		4,779	62.17%
	Price of DH heating			
		20%	3,558	48.56%
		-20%	5,999	75.77%
	Price of fuel oil			
		20%	7,116	88.20%
		-20%	2,442	36.05%
Break-even point (NPV=0)				
	Price of DH heating		78.30%	
	Price of fuel oil		-40.90%	

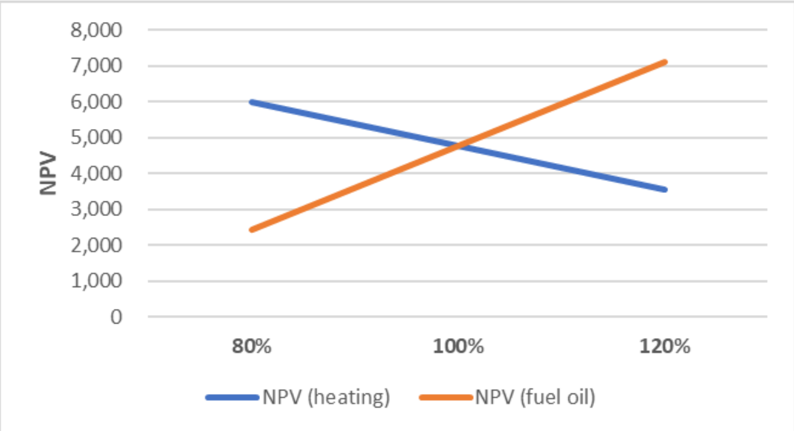

Figure 10.14. Impact of DHS heating price and low-tariff changes on NPV

This type of heating would cease to be cost-effective by increasing the price of DHS heating by 78.3%, or by decreasing the price of fuel oil by 40.9%. Either of these changes is not probable. The CO_2 footprint is not significant because of the small number of households that are using fuel oil (less than 3,000).

10.7.4.7 Heating using coal – raw lignite

It was surprising to find out that, in the basic case, the transfer to DHS heating is not cost-effective - it has a negative NPV. Of course, the inclusion of CO_2 is completely changing the picture. The results of the sensitivity analysis are summarized in Table 10.78. and impact of heating price on NPV in Figure 10.15.

Table 10.78. Sensitivity analyses and break-even points

Coal raw lignite			NPV	IRR
	Basic case		-2,252	
	Price of DH heating			
		20%	-3,473	
		-20%	-1,032	
	Price of coal raw lignite			
		20%	-1,321	
		-20%	-3,183	
Break-even point (NPV=0)				
	Price of DH heating		-36.90%	
	Price of coal raw lignite		48.40%	

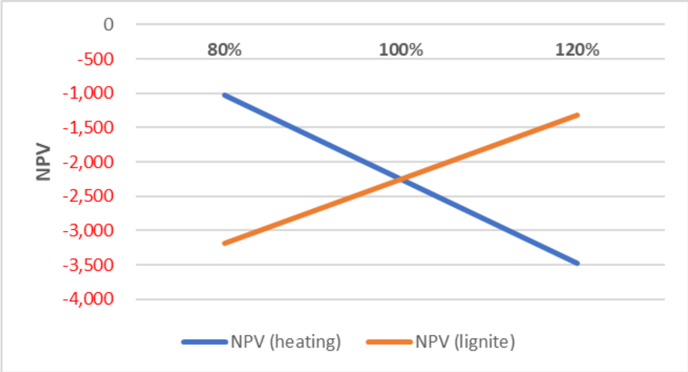

Figure 10.15. Impact of DHS heating price and low-tariff changes on NPV

Connection to the DHS grid could become cost-effective by decreasing the heating price by 36.9% or by increasing the coal price by 48.4%. This will happen sooner or later. If we apply the EU CO_2 price, NPV would become strongly positive. The total annual reduction of CO_2 emission which could be obtained, by connecting all those who are using lignite for heating to DHS, would amount to 62,500 t.

11.Objectives, strategies, and policy measures

11.1 Legal and policy framework relevant for heating and cooling

The field of thermal energy (heat) is directly regulated by several primary pieces of legislation, namely:

- Energy Law[81],
- Law on the Use of Renewable Energy Sources[82],
- Law on Mining and Geological Exploration[83],
- Law on Energy Efficiency and Rational Use of Energy[84],
- Law on Communal Activities[85],
- Law on Public-Private Partnership and Concessions[86].

In addition to the above-mentioned regulations governing the area of thermal energy, which includes district heating and cooling, it should be noted that the by-laws of these regulations apply to this area.

11.1.1 Energy Law

The basic law regulating the thermal energy market is the Energy Law. This law establishes that heat is internal (thermal) energy of hot water, warm water or steam or cooling fluids, used for heating or cooling of premises, heating of domestic hot water or for technological processes. According to the Law, energy activities in the field of heat are as follows:
1) heat distribution, which is the transfer of heat energy for district heating and/or district cooling for multiple residential or business facilities or industrial use that may be using steam, hot water or cooling fluid through distribution systems;
2) supply of heat, which is the sale of heat to final customers at a price determined in accordance with the prescribed methodology;
3) heat production; and
4) combined production of heat and electricity or mechanical power *(cogeneration)*.

All these energy activities, except for the combined production of heat and electricity, are activities of general interest.

For all the above-mentioned activities, licenses are issued for the performance of energy activities. In the procedure of obtaining construction permit, for construction of energy facilities for the performance of mentioned activities, energy permits are issued

Licenses for these energy activities (except for combined production of heat and electricity) is issued by the competent authorities of the local self-government unit. The Energy Agency of the Republic of Serbia issues licenses for the combined production of heat and electricity.

Energy permits for energy facilities are issued by the competent republic authorities or authorities of autonomous province or local self-government units, , depending on the power and the place where they are built.

Based on Energy Law, the local self-government unit has the following responsibilities:
1) issues licenses for performing energy activities: production, distribution and supply of heat,

[81]Energy Law ("Official Gazette of RS" Nos. 145/2014 and 95/2018 - second law and 40/2021).
[82]Law on the Use of Renewable Energy Sources ("Official Gazette of RS" No. 40/2021).
[83] Law on Mining and Geological Exploration ("Official Gazette of RS" Nos. 101/2015, 95/2018 – other laws and 40/2021).
[84]Law on Energy Efficiency and Rational Use of Energy ("Official Gazette of RS" No. 40/2021).
[85]Law on communal activities ("Official Gazette of RS" no. 88/2011, 104/2016 and 95/2018).
[86] Law on Public-Private Partnership and Concessions ("Official Gazette of RS" Nos. 88/2011, 15/2016 and 104/2016).

2) maintains a register of issued licenses and records of thermal energy producers with a capacity of 0.1 MW to 1 MW,
3) determines the conditions of delivery and supply of heat to customers in its area, the rights and obligations of heat producers, distributors, suppliers and heat final customers,
4) adopts a regulation that governs the method of distribution of costs from the common measuring point in the heat transfer station and the conditions and method of maintaining the part of the system from the end of the distribution system to the final customer, including its heating equipment, the rights and obligations of the final customers of heat, especially in case of termination of the contract, as well as the conditions for submitting and resolving the final customer's request for the suspension of the heat supply; and
5) approves heat energy prices and prescribes other conditions for ensuring reliable and safe supply of heat to customers.

The government adopts a methodology for determining the price of supplying heat to the final customer[87].

The Energy Law, in the area of the thermal energy market, establishes the goals of the energy policy, the adoption of strategic documents on the long-term development of the area of thermal energy, energy activities and the manner of their performance in the area of thermal energy, the basis of the regulation of energy activities in the area of thermal energy and the mechanism for ensuring the safety of the heat supply, through the obligation to keep operational reserves of energy sources for the heat production. Regulation of energy activities in the field of thermal energy is transferred to local self-government units.

11.1.2 Law on the Use of Renewable Energy Sources

The Law on the Use of Renewable Energy Sources establishes the basis of incentives to produce thermal energy from renewable sources. Depending on the capacity of the production facility, renewable energy sources can be used for individual or district heating and cooling.

Energy entities that perform the activity of heat production, distribution and supply to customers in an energy-efficient manner can acquire incentive measures if they use high-efficiency cogeneration, waste heat or renewable energy sources:
1) heat pumps,
2) solar energy,
3) geothermal energy,
4) energy of biodegradable waste,
5) biomass,
6) other renewable energy sources.

This law establishes that the local self-government unit prescribes incentive measures, conditions and procedure for acquiring the right to incentive measures and assigns incentive measures in a transparent and non-discriminatory manner, while respecting the rules of state aid, as well as the procedure and conditions for connection to the distribution system for the heat production of from renewable energy sources, highly efficient cogeneration or waste heat.
It should be noted that in accordance with this law, energy from heat pumps is an element for the calculation of the share from renewable sources.

11.1.3 Law on Mining and Geological Exploration

[87] Art 1. of the Methodology for determining the price of supplying heat to the final customers (“Official journal of RS”, No. 63/2015) defines the main elements of that methodology such as: 1) elements for calculation and the method of determining the maximum amount of income of an energy entity that performs the activity of production, distribution and supply of heat (hereinafter: energy entity); 2) elements for calculation and method of calculation of the price of access to the heat distribution system; 3) criteria and rules for the distribution of income of the energy entity; 4) categories of end heat customers, depending on the purpose of using the space; 5) tariff elements, tariffs and the method of calculation of heat supplied by the energy entity to the end customers of heat (hereinafter: customers); 6) conditions and procedure for submitting a request to the competent authority of the local self-government unit, for a change of the heat price.

Geothermal resources represent the sum of renewable geological resources which includes underground water and hot rocks mass from which is possible to extract thermal energy. Geothermal resources can be used, if they have the adequate potential for individual or district heating and cooling.
Monitoring and controlling geological research of geothermal resources for water supply needs or heat supply to residential premises is performed by the unit of local self-government.[88]

If an application for using of geothermal resources is submitted for heat supply purposes, it needs to have a report on the estimated petro-geothermal resources as an appendix.

Competent unit of the local self-government has the obligation to record the cadastre and records of applications of the households on its own territory and deliver the report on the submitted applications and executed controls to the Ministry of Mining and Energy[89].

11.1.4 Law on Energy Efficiency and Rational Use of Energy

The Law on Energy Efficiency and Rational Use of Energy regulates energy efficiency measures in the entire energy cycle of heat, which includes production, distribution, supply and consumption of heat. This law prescribes incentives for construction of high-efficiency cogeneration facilities in the form of subsidies (facilities with an installed capacity up to 500 kWe) and market premiums (facilities of installed capacity of 500 kWe and more up to 10 MWe), and for facilities with installed capacity up to 50 kWe. The Directorate for Financing and Promoting Energy Efficiency will prescribe special incentives. Also, the Law prescribes obligation to analyse the potential for highly efficient cogeneration and the possibility of using efficient district heating/cooling to fulfil the internationally assumed obligations of the Republic of Serbia.

This law establishes many definitions of importance for district heating and cooling, namely:
1) heat in the same way as in the Energy Law,
2) combined production of heat and electricity (cogeneration) is a process of simultaneous production of heat and electrical or mechanical energy, as a part of the same process,
3) high-efficiency cogeneration means cogeneration whose production ensures primary energy savings in relation to the reference values for separate production of heat and electricity for a predetermined percentage, calculated in accordance with the Methodology for determining the efficiency of the cogeneration procedure, and production in small cogeneration and micro-cogeneration units,
4) domestic hot water means water from the water supply network heated by the heat from the district heating systems, intended for consumption by final customers,
5) efficient energy supply in terms of this law means supply of heat and/or electricity by the energy service provider to the user of energy service based on the contract on efficient energy supply,
6) district heating/cooling system means a system for distribution of heat from the heat production point, through a heat distribution grid, into multiple buildings, for the purposes of heating or cooling of premises or technological processes,
7) efficient district heating/cooling system means a district heating/cooling system using at least 50% of energy from renewable energy sources, 50% of waste heat, 75 % of heat produced in cogeneration or 50% of so combined energy production,
8) heat distribution means transfer of heat through a district heating network, i.e. a hot water/warm water/steam district heating network and/or cooling fluid distribution network, from the billing metering point of the heat energy producer to the billing metering point of the customer,
9) heat pump means a device or technical system or installation that transfers heat from natural surroundings such as air, consumable water or ground to buildings or industrial applications by reversing the natural flow of heat such that it flows from a lower to a higher temperature. For reversible heat pumps, it may also move heat from the building to the natural surroundings.

Energy efficiency means the ratio of realised results in services, goods or energy and used energy.[90]

[88] Article 64 of the Law on Mining and Geological Exploration.
[89] There is no information are any lokal self-government units records the cadastre and records application of the housenolds on its territory.
[90] Article 3, paragraph 1, item 10) of the Law on Energy Efficiency and Rational Use of Energy.

This Law establishes that the policy of energy efficiency in the field of heat is regulated by the basic acts that regulate the policy of energy efficiency, namely:

- The Energy Development Strategy of the Republic of Serbia,
- The Program that determines the conditions, method, dynamics and measures for the implementation of the Energy Strategy,
- The Integrated National Energy and Climate Plan.

The basis for the adoption of these acts is prescribed by the Energy Law[91]. The autonomous province and the local self-government unit in their planning documents also plan activities in the field of energy efficiency in accordance with these basic acts.

The method of monitoring the achievement of energy efficiency goals is also prescribed. What is crucial for the realization of these energy efficiency goals in the field of heat is the implementation of energy efficiency[92] *policy measures,* which are instruments for the realization of these goals. Energy efficiency policy measures are implemented through the application of energy efficiency measures.[93] Energy efficiency measures include some of the most diverse activities that contribute to energy efficiency, ie. measurable relationship between the achieved result in services, goods or (thermal) energy and the (thermal) energy used for it. These measures are implemented within the entire energy cycle: from the production of energy, their transportation and sale/supply, to consumption by the Final Customer.

It should be emphasized that measures (or policies) of energy efficiency are simultaneously measures (policies) to fight against climate change because their application controls the influence of CO_2, which is prescribed by the Paris Agreement.[94] Energy efficiency policy measures prescribed by the Law are: energy management system, energy efficiency of thermal energy in buildings, energy services in the field of thermal energy, energy efficiency of performing energy activities in the field of thermal energy, incentives for energy efficiency in the field of thermal energy (e.g. for high-efficiency cogeneration) and others.

11.1.4.1 Energy efficiency of performing energy activities in the field of thermal energy that can be part of the district heating and cooling system

The energy efficiency of performing energy activities in the field of thermal energy is manifested in all segments of the energy cycle.

The Law on Energy Efficiency and Rational Use of Energy prescribes that new and reconstructed energy facilities for heat production and plants for cogeneration, which have a power of 1 MW and more, which use fossil fuels and/or biomass as fuel and serve in order to carry out energy activities or in industry, must meet the minimum requirements in terms of energy efficiency depending on the type and/or power, i.e. the size of the facility.

The fulfilment of these conditions is improved by the study on energy efficiency of energy facilities, which is a part of documentation necessary for obtaining an energy permit., An energy permit shall be attached to the application for obtaining a construction permit or a decision on approval for the execution of construction works if an energy permit is not issued for the construction or reconstruction of a specific facility. In addition to this requirement, the investor of the mentioned facilities is obliged to perform thermomechanical tests of these facilities during the trial run in order to determine whether the energy facility in its finished state meets the requirement of the prescribed minimum energy efficiency.[95]

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[91] Art. 4-6. and 8a. of the Law on Energy.

[92] Energy efficiency policy measures are regulatory, financial, fiscal, or informative instruments determined by authorities and other bodies, as well as other public services in order to create a framework of support or incentives for market participants to provide and procure energy services and apply other energy efficiency measures - Article 3, Paragraph 1, Item 41) of the Law on Energy Efficiency and Rational Use of Energy.

[93] Energy efficiency measures are actions that lead to a verifiable and measurable or estimable increase in energy efficiency and are undertaken as a result of an energy efficiency policy measure; the production of electrical or thermal energy using renewable energy sources is also considered a measure of energy efficiency, provided that the produced electrical or thermal energy is used at the place of production - Article 3, paragraph 1, point 40) of the Law on Energy Efficiency and Rational Use of EnergyLaw.

[94] Law on Ratification of the Paris Agreement ("Official Gazette of RS - International Treaties", No. 4/2017).

[95] Art. 54-57. of the Law on Energy Efficiency and Rational Use of Energy.

In the field of heat distribution, heat distribution systems should meet the minimum requirements of energy efficiency, which will be reviewed through the study on energy efficiency of energy facilities, in the same process as facilities for heat production with or without cogeneration. Heat distributors are also obliged to take individual energy efficiency measures to reduce energy losses.[96]

Heat distributors have an obligation to ensure adequate measurement of the delivered, i.e. consumed heat. Depending on the case and technical feasibility, i.e. cost justification, the Law on Energy Efficiency and Rational Use of Energy stipulates that heat distributors install devices for regulating the supply of heat and for measuring the supplied heat and, where available, consumable hot water for each building, part of the building, for controlled regulation of the supply of heat on each individual heating element, i.e. to install devices for measuring the supplied heat in the building, and where it exists, for measuring the consumption of hot water, i.e. devices for automatic regulation of heat supply to the building. The obligation to install devices with remote reading has been postponed until the beginning of 2027.[97]

Heat energy suppliers have the obligation to determine the prices of heat supply to final customers in accordance with the methodology for determining the price of heat supply to the final customer, adopted in accordance with the Energy Law. When determining the monthly calculation for heat supplied to the final customer, suppliers should take into account the measured heat supplied to the building, which is distributed to customers, based on the registered consumption on the devices for measuring the heat supplied to a part of the building or to the heat distributors on each heating body or on the basis of the area of the building.[98]

In order for final customers of heat to be able to influence their consumption of heat, they need to be able to monitor the effects of their consumption in order to be able to manage and reduce it. Therefore, in accordance with the regulations of the European Union, the Law stipulates that heat energy suppliers must, once a month with or on the invoice for the energy supply, provide the final customer with information on the total amount of supplied energy to the final customer in the billing period and monthly consumption energy during the previous 12 months; the ratio of the delivered amount of energy in the accounting period and in the same calendar accounting period of the previous year; the average price of energy for that customer in that accounting period and other information about their consumption.[99]

This law defines the definition of the district heating/cooling system and the definition of heat distribution. These two legal terms have a very similar content. In order to increase legal certainty, it would be useful to underline the differences between them.

11.1.5 Law on communal activities

The Law on Communal Activities regulates the performance of communal activities that are defined as activites of general interest. This law defines that communal activities are activities of general interest in the provision of communal services that are important for the fulfilment of the life needs of natural and legal persons, where the local self-government unit is obliged to create conditions for ensuring appropriate quality, scope, availability and continuity, as well as supervision over their performance.

In the area of thermal energy, communal activities are the following activities of general interest: heat production, distribution and supply.[100] However, when defining communal activities, this law regulates production and distribution of heat, which includes the centralized production and distribution in several facilities of water vapor, warm or hot water for heating purposes, while the segment of heat supply is not mentioned.[101] This way of regulating performing of energy communal activities is not fully harmonized with the way it is regulated by the Energy Law and the Law on Energy Efficiency and Rational Use of Energy and may represent legal uncertainty for potential new investments.

[96] Art. 54-55 and 48, paragraph 3 of the Law on Energy Efficiency and Rational Use of Energy.
[97] Article 51 of the Law on Energy Efficiency and Rational Use of Energy.
[98] Article 52 of the Law on Energy Efficiency and Rational Use of Energy.
[99] Article 53 of the Law on Article 10a and Annex VIIa of Directive 2012/27/EU (refined text).
[100] Article 2, paragraph 3, item 3) of the Law on Communal Activities.
[101] Article 3 - determination of communal activities, paragraph 1, point 3), of the Law on Communal Activities.

This law regulates the general conditions and manner of performing communal activities, including those in the field of thermal energy. It regulates that communal activities can be performed by: a public company, a company, an entrepreneur or another business entity.

The performance of a communal activity, in case it is not performed by a public company, shall be entrusted in accordance with the Law on Public-Private Partnerships and Concessions (in the case when financing of the communal activity is provided from the budget of the local self-government unit, or when financing of the communal activity is provided in whole or in part by collecting fees from users of communal services).

11.1.6 Recommendation related to the legal framework

The new package of energy regulations of the Republic of Serbia has further developed the legal framework in the field of thermal energy, and has established new definitions, including those that elaborate the concept of district heating and cooling.

The regulations that directly regulate the field of thermal energy in the entire legal system of the Republic of Serbia are not fully harmonized, especially when it comes to energy activities in the field of thermal energy, as stated in the Energy Law, and communal activities in the field of thermal energy, as stated in Law on Communal Activities.
In practice, the definition of district heating and cooling refers to district heating systems, which always imply the existence of an integrated production facility and activity of general interest, as determined by the Law on Communal Activities and the Energy Law. However, in the Energy Law itself, it is stated that the activity of combined heat and electricity production is not an activity of general interest, which indicates that there are two categories of heat production, which leaves room for interpretation. The question of connecting the new high-efficiency cogeneration facility to the existing district heating distribution network and supplying the produced heat to final customers is also open.

There are cases of heat sales (heat energy supply) in business premises in one building. It is not clear whether this type of heat energy supply is considered a communal activity and whether in those cases it is also necessary to entrust the performance of a (communal) activity of general interest. That case represents a legal gap and since it is not regulated by legislation, the option is left for different interpretations and the application of different legal principles or contractual arrangements.

In order to increase legal certainty in the field of thermal energy, legal certainty of investing in district heating and cooling and better utilization of every potential in this field, it is proposed to adopt a special law in the field of thermal energy.

This special law would regulate, in a comprehensive way, activities performed in the field of thermal energy, regulate activities of general interest, the possibility of connecting new facilities to the heat distribution grid, and heat supply to final customers in a competitive manner, all with the aim of efficient and sustainable use of resources.

11.2 General overview of the existing policies and measures as described in the most recent report submitted in accordance with articles 3, 20, 21 and 27(a) of regulation (EU) 2018/1999

Following the goals of international regulations and signed international agreements, and above all the Paris Agreement[102], the European Union first adopted a strategic framework, and then a regulatory framework under the name: "Clean energy for all Europeans".[103] The key legislation from this package was successfully adopted, from the end of 2018 until the middle of 2019. The subject of that legislation is the harmonization of the field

[102] Law on Ratification of the Paris Agreement ("Official Gazette of RS - International Agreements", No. 4/2017).
[103] https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en, 18.02.2023.

of energy with climate protection and has five basic directions, namely: governance of the Energy Union (EU member states), increasing energy efficiency in all segments, especially in buildings, increasing the use of renewable energy sources, and market design of electricity aimed at accepting all the changes that are expected by realizing a new strategic orientation in the field of energy. The Regulation on the Management of the Energy Union and Climate Actions (EU) 2018/1999[104] (hereinafter: the Governance Regulation) is the first document from this package of legislation. This Regulation establishes the legal basis for the adoption of national energy and climate plans and long-term strategies for reducing greenhouse gas emissions, which regulates the planning and strategic framework for this area developed in five dimensions. In addition, the Governance Regulation also has energy poverty for subject.

Decisions of the Ministerial Council of the Energy Community[105] from 2021 and 2022 established the obligation to transpose European Union regulations from the "Clean energy for all Europeans" legislation. Pursuant to the decision of the Ministerial Council of the Energy Community D/2021/14/MC-EnC of November 30, 2021[106], the obligation to transpose the Governance Regulation and the European Commission's regulation to support the implementation of this Regulation was established. Also, pursuant to the Decision of the Ministerial Council of the Energy Community D/2022/02/MC-EnC of December 16, 2022[107] the aforementioned decision of the Ministerial Council was changed, and new goals were established in the area of renewable energy sources, energy efficiency and greenhouse gas emissions for the Contracting Parties for the year 2030.

Article 3 of the Governance Regulation stipulates the obligation for each member state of the European Union/Energy Community Contracting Party to adopt an integrated national energy and climate plan (NECP) every 10 years, which consists of the following prescribed elements: a) reviewing the procedure for adopting the NECP; b) description of national goals related to the dimensions of the Energy Union plus energy poverty; c) a description of the planned policies and measures related to the achievement of the respective goals, as well as a general overview of the investments required to fulfil the respective goals; d) description of the current situation in the aforementioned five dimensions of the Energy Union and level of greenhouse gas emissions and their removal; e) description of regulatory and non-regulatory obstacles to achieving targets in the field of renewable energy sources and energy efficiency; f) evaluation of the effects of planned policies and measures for the achievement of mentioned goals; g) assessment of the effects of planned policies and measures on competitiveness, etc. In terms of planning within the NECP, it is necessary to foresee limiting administrative complexity and costs for all relevant parties, taking into account the connection of all five dimensions of the Energy Union, using reliable and consistent data, especially those related to energy poverty.

Article 4 of the Regulation on management establishes targets in the field of energy efficiency, renewable energy sources and greenhouse gas emissions, which for Serbia, according to the decision of the Ministerial Council no. D/2022/02/MC-EnC of December 16, 2022, are defined such as:

1) for energy efficiency, for the year 2030, targets have been set in terms of primary energy consumption of 14.94 Mtoe and final energy of 9.54 Mtoe;
2) use of renewable energy sources in gross final energy consumption in 2030 at the level of 40.7%; and
3) reduction of emissions by 40.3% compared to the level of 1990, i.e. to 47.82 MtCO_2 eq.

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[104]Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council.

[105] The Ministerial Council is the highest body of the Energy Community established by the Treaty on the Establishment of the Energy Community (Law on the Ratification of the Treaty on the Establishment of the Energy Community between the European Community and the Republic of Albania, the Republic of Bulgaria, Bosnia and Herzegovina, the Republic of Croatia, the Former Yugoslav Republic of Macedonia, the Republic of Montenegro, Romania, of the Republic of Serbia and the United Nations Interim Mission in Kosovo in accordance with Resolution 1244 of the United Nations Security Council - "Official Gazette of RS", No. 62/2006). Based on the decisions of the Ministerial Council of the Energy Community, new obligations are determined for the Contracting Parties regarding the transposition of the European Union's energy regulations into their legal systems.

[106] Decision of the Ministerial Council of the Energy Community No D/2021/14/MC-EnC: amending Article 20 and Annex I to the Treaty establishing the Energy Community and incorporating Directive (EU) 2018/2001, Directive (EU) 2018/2002 , Regulation (EU) 2018/1999, Delegated Regulation (EU) 2020/1044 and implementing Regulation (EU) 2020/1208 in the Energy Community *acquis communautaire*.

[107]Decision of the Ministerial Council of the Energy Community No D/2022/02/MC-EnC on amending Ministerial Council Decision No D/2021/14/MC-EnC amending Annex I to the Treaty Establishing the Energy Community and incorporating Directive (EU) 2018/2001, Directive (EU) 2018/2002, Regulation (EU) 2018/1999, Delegated Regulation (EU) 2020/1044 and implementing Regulation (EU) 2020/1208 in the Energy Community *acquis communautaire*.

In Article 20 of the Governance Regulation, it is determined what the reports on the achievement of targets in the field of renewable energy sources established by the NECP should contain, which refers to: a) the total share of energy from renewable sources in the final gross energy consumption from the years 2021-2023; b) sectoral share of energy from renewable sources in final energy consumption in the same period in the electricity sector, the heating and cooling sector and the transport sector; c) energy production from renewable energy sources according to technologies and sectors in the same period, including expected final gross energy consumption by technology and sector expressed in Mtoe and total planned installed capacity by technology and sector expressed in MW; d) trajectories on bioenergy demand, disaggregated between heat, electricity and transport, and on biomass supply, by feedstock and origin (distinguishing between domestic production and imports), as well as for forest biomass in terms of source assessment and impact on the LULUCF sink; e) as well as other elements.

In addition to the report on the achievement of the targets established by the NECP, it is also necessary to report on the implementation of planned policies and measures, as follows: a) according to sectors and technologies, especially those measures related to financial support, including support from European Union funds; b) the effects of implemented policies and measures that encourage the development of energy consumption from renewable sources produced by self-production or within renewable energy communities; c) measures promoting the use of energy from biomass, especially for new biomass mobilisation, including sustainable biomass availability as well as measures for the sustainability of biomass produced and used; d) the effects of existing measures to increase the share of energy from renewable sources in the heating and cooling sector, as well as in the transport sector; e) and others.

In Article 21 of the Management Regulation, it is determined what reports on the achievement of targets in the field of energy efficiency established by the NECP should contain: a) the indicative trajectory for primary and final annual energy consumption from 2021 to 2030; b) the indicative milestones of the long-term strategy for the renovation of the national stock of residential and non-residential buildings, both public and private, as well as the contribution to the achievement of the targets of increasing energy efficiency.

In addition to the report on the achievement of the targets established by the NECP, it is also necessary to report on the implementation of the planned policies and measures as follows: a) implemented, adopted and planned policies, measures and programs for the realization of the framework national contribution to the increase of energy efficiency for the year 2030 in all planned segments that include the energy efficiency of buildings, utilization of the energy efficiency potential of gas and electric power infrastructure and others; b) the effects of market-based instruments that provide incentives for improvements in energy efficiency, including energy taxes, fees and emission units; c) the results of the national energy efficiency obligation scheme and alternative measures pursuant to Article 7a and 7b of Directive 2012/27/EU; d) long-term building fund renovation strategies; e) the results of policies and measures to encourage energy services in the public sector and measures to remove regulatory and non-regulatory barriers that prevent the acceptance of energy performance contracts and other models of energy efficiency services; f) the effects of financial support measures, both national and from the European Union; d) and others. Article 27a of the Management Regulation establishes the obligation to report on the achievement of the national target of increasing energy efficiency for the year 2020, associated with the aging of the overall national targets for the share of energy from renewable sources in the year 2020, and the delivery of that information to the sectors of electricity, heating and cooling and transport.

It is necessary to point out that the Serbian National Energy and Climate Plan, which the Government should adopt on the basis of Article 8a. of the Energy Law[108], at the time of writing this study, had not been adopted[109].

11.3 Planned contribution to national goals, objectives and contributions achieved through efficiency in heating and cooling

[108] Energy Law ("Official Gazette of RS", no. 145/2014, 95/2018 - second law and 40/2021).

[109] In June 2022, a preliminary public consultation was held on the NECP, https://www.mre.gov.rs/en/node/1429. Various materials and models were presented, eight proposed scenarios, forms for proposals etc. However, no draft of the NECP has been publicly available so far. A draft NECP which would go through public consultations is expected to be released in June 2023.

The Energy sector development strategy of the Republic of Serbia for the period until 2025 with projections by 2030 had proposed some strategic goals for district heating systems, while the rest of the heating/cooling sector, including HE CHP, is treated through the topic of efficient energy use. The elaboration of these strategic goals and determination of specific goals and objectives was envisaged to be done by the adoption and implementation of Programs for the implementation of Energy Strategy The Energy Law, adopted in 2021, envisaged that national goals, objectives, and contributions (achieved through efficiency in heating and cooling) for the year 2030 would be determined in the National Energy and Climate Plan.

On the base of analyses presented, the possible contribution of new, or enhanced high-efficiency district heating systems and HE CHPs to the goals of Serbian energy policy until 2030 is presented in Table 11.1 and Table 11.2.

Table 11.1. Technical potential of high efficiency district heating system until 2030

Implemented measure/technology	Potential (GWh)
Expanding of consumption on the existing network	215
Efficient DH using natural gas in CHP facilities	150
Efficient DH by waste incineration	297
Efficient DH by biomass	369.7
Efficient DH using heat pumps	113.1
Efficient DH using thermal solar	432.4
Waste heat from industry	198

Table 11.2. Technical potential of HE CHP until 2030

Sector	Analysed case/Branch	Heat potential	Electricity potential
Residential	Buildings with 1 dwelling	15,797 kWh/building/year	5,840 kWh/building/year
	Buildings with 2 dwellings	28,820 kWh/building/year	11,680 kWh/building/year
	Buildings with 3 and more dwellings (8 dwellings)	69,076 kWh/building/year	43,800 kWh/building/year
Services	Health centres	2 GWh	1.2 GWh
	Hospitals	51.6 GWh	43.4 GWh
	Clinical centres	3.8 GWh	3.2 GWh
	Small hotels	6.5 GWh	4.3 GWh
	Large hotels	31,2 GWh	20.1 GWh
	Swimming pool	24.7 GWh	17.7 GWh
Industry	Iron and steel	21.5 GWh	17.5 GWh
	Chemical and petrochemical	122.0 GWh	100.6 GWh
	Non-ferrous metals	8.8 GWh	12.4 GWh
	Non-metallic minerals	31.6 GWh	40.8 GWh
	Food, beverages and tobacco	153.4 GWh	137.4 GWh
	Paper, pulp and printing	39.7 GWh	28.6 GWh
	Wood and wood products	0.9 GWh	1.0 GWh