100 prozent erneuerbar stiftung

Powiat Hajnowski

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Renewable Power-to-Heat in Hajnówka

Feasibility study for the changeover of the heating network from coal to renewable energies in the City of Hajnówka, Poland.

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Contents

Glossary

Ca^2	Calcium
CO_2	Carbon dioxide
COP	Coefficient of performance,
EEA	European Enviroment Agency
EUA	European Union Allowance
EUKI	European Climate Initiative
GJ	Gigajoule
Kw	Kilowatt
KWh	Kilowatt-hour
KWK	Combined heat and power
Mg^2	Magnesium
mval	Milliequivalent
MWh	Megawatt-hour
MWhel	Megawatt-hours electricity
NECP	National energy and climate plans
PEC Hajnówce	Hajnówka heating plants
PGG	Prawo geologiczne i górnicze
PLN	Polish zloty
PV	Photovoltaic
RES	Renewable Energies Systems
ROP	Regional operational programmes
to	Tonne
WP	Heat pump

1. Introduction

According to the European Environmental Agency (EEA 2022), the greenhouse gas intensity of electricity generation has decreased in recent years in Europe and, particularly, in Poland. Poland, along with Greece and Estonia, was still reporting the highest intensities in 2010. No comparable progress can be seen, however, in the heating sector (Forum Energii 2019).

The 100 prozent erneuerbar stiftung wishes to address this problem in a pilot region in eastern Poland through the funded project 'Renewable Power to Heat in Hajnówka'. Together with local and European partners, the stiftung is proposing an innovative solution for significantly contributing to decarbonisation that also furthers the level of integration of the energy system: the use of electricity from renewable energies for the generation of heat (renewable power to heat).

The idea is to develop an energy concept in which electricity from regional wind turbines and PV systems can be used for large-scale heat pumps and thus replace coal in the existing district heating system in Hajnówka[1] (city and county). The concept is intended to serve as a feasibility study, which will then serve as the basis for detailed design for the development of a completely renewable and nearly completely decarbonised integrated district heating system in this region.

The project funded by the European Climate Initiative (EUKI) aims to create a basis for public and private investments. It may also be possible to activate funds from the European Economic Recovery Plan for realising the decarbonisation of the district heating system in Hajnówka County (Powiat Hajnówka).

The Hajnówka project is intended to serve as a beacon for further projects and an example of best practices in Poland due to the good agreement with the National Energy and Climate Plans (NECPs) but should also become known in other EU Member States.

The current district heating system in Hajnówka in eastern Poland relies heavily on a central coal-fired plant and operates at a high temperature (130 degrees Celsius). The main heat source is operated by a regional company specialising in coal, oil and biomass heating. The heating network is operated by a local company that also functions as the seller of heat to consumers.

This district heating system is very CO2-intensive, which is also due to the fact that mainly low-grade coal with a low energy content is burned in the coal-firing plant.

Hajnówka County holds great potential for the use of renewable energies, in particular for wind energy and photovoltaics and thus for decarbonisation of the region. This potential remains unharnessed today (EFV 2018). The current Polish government, after a period of stagnation and investment uncertainty, has now given the green light for the installation of systems for using renewable energies in the region.

At the time of preparation of this analysis, an 10H distance regulation for wind turbines[2] still applied in Poland. This feasibility study shows that, in principle, it is technically and economically possible to operate the district heating network for the city of Hajnówka with large-scale heat pumps and renewable energies. The feasibility study is not a substitute for detailed design. Distance regulations for wind turbines and other legal frameworks pertaining to pumping of groundwater as a heat source or for public participation should be given due consideration in a detailed design for the project.

[1] The city of Hajnówka lies at the edge of the UNESCO Natural World Heritage Site and Biosphere Reserve of Białowieża National Park. This park is one of Europe's last natural primeval forests. The national park is also home to European bison. All of the world's living members of the species can be traced back to this region.

[2] The distance between wind turbines and residential buildings in development areas or built-up districts must at least be ten times the total height. The total height is made up of the hub height and the rotor radius of the turbine. This would mean, for example, that for a wind turbine with a height of 200 metres, the minimum distance to residential buildings would be 2 kilometres.

2. Energy market in Poland – taxes, surcharges and fees

Through the rising electricity prices on the market and Russia's war of aggression on Ukraine, the term 'energy self-sufficiency' has taken on a whole new meaning. More and more local municipalities in Poland are deciding to invest in their own decentralised renewable energy generation systems. These solutions, which are installed on the sites of the local municipalities, supply their consumers with electricity and contribute to ensuring a reliable energy supply.

The vast majority of renewable energy plants are subsidised by up to 85 per cent within the scope of regional operational programmes (ROPs) in projects for local authorities[3]. Stimulated by the sectoral integration policy of the European Union, the ROPs of the individual voivodeships are also increasingly including renewable energies in the regulations for competitions for heating modernisation and for heating and energy efficiency in general. Solutions that support the generation of heat and supply of energy-efficient buildings with heat or rely entirely on renewable energy sources, for example in the form of heat pumps in combination with an onsite photovoltaic system, are being promoted[4]. However, the financing conditions for investments in renewable energy in the period 2021–2027 may not be as favourable as they were in the previous years. In any case, changes can be expected.

The energy market is quickly evolving towards decentralised energy generation from renewable energy sources, particularly for self-consumption or for local communities, in turn making adaptation of the products of the professional energy sector to the new model of a decentralised energy market necessary. The current impetus for maintaining the high rate of change on the energy market is being provided by the dynamic increase in the price for carbon permits and, consequently, energy prices. In 2022 the carbon permit price exceeded the EUR 90 per tonne mark. The electricity price listed on the POLPX[5] in the base product 'BASE_Y' for 2023 was close to PLN 2,000 (EUR 400) per MWh for a long time and peaked at over PLN 2,500 (EUR 550) per MWh. Following introduction of the act on freezing of energy prices in 2023, this price is now about PLN 1,000.00 (EUR 220) per MWh. Added to this are additional charges such as the electricity fee introduced on 1 January 2021 and in 2023 amounting to PLN 102.40 (EUR 22.50) per MWh (PGE Dystrybucja S.A 2023).

The rise in consumer prices for energy is greatly accelerating the development of generation for internal demand and demand for potential customers. Electricity prices in Poland in relation to income are some of the highest in the world (Wysokienapiecie.pl 2021).

EU energy policy aims to gradually phase out carbon-based (mainly coal-based) energy generation technologies and develop decentralised energy supply on the basis of renewable energy sources. A few years ago, a mechanism for trading and assessment of European Union CO2 emission allowances (EUAs) was introduced. According to its initiators (Biznes.gov.pl 2021), this mechanism should encourage power producers and heavy industry to reduce emissions by acknowledging them as environmental costs. The system is based on the obligation to buy permits for the generated emissions.

With old coal-fired blocks, the emissions can exceed 1,000 kg CO2 MWh, which theoretically means that the full EUA value is included in the price for 1 MWh. The economic situation for the largest CO2 emitters for power generation has been improved through the system of free emissions granted in Poland and distributed by the central authorities. Nevertheless, the offering of permits is being systematically reduced. This is precipitating a rise in emissions costs for the producers. Thus, for example, the PGE Group, which manages, among other things, Europe's largest emitter, the Bełchatów power station (Ember-Climate.org 2022), had to spend PLN 4 billion to fully meet its obligations to surrender allowances for 2020.

[3] https://rpo.wrotapodlasia.pl/
[4] This relates to subsidies for private households or companies
[5] Polish power exchange

The value of the carbon permits was EUR 5–6 per tonne for many years. Most experts are of the opinion that this value was grossly underestimated and should have been well over EUR 30 per tonne (Ember-Climate.org 2023). The permit prices reached this level in September 2019, continuing the upward trend that started at the beginning of 2018. The subsequent decline in price (to EUR 15.6 per tonne) was the result of the crisis brought about by the COVID-19 pandemic. Still, it only took 12 months for the prices to return to the record level of some EUR 30 per tonne at the beginning of 2021. In early 2022, the permit price broke through the threshold for a record high of EUR 90 per tonne, passing the level of EUR 60 per tonne forecast by analysts for 2030. These were very conservative forecasts, because already in 2021, the permit prices were above EUR 80 per tonne. The year 2022 proved to be even more record-breaking, with permit prices even approaching the EUR 100 per tonne mark. For most of the year, it fluctuated between EUR 80 and EUR 90 per tonne. The war with Ukraine only led to a temporary decrease in price.

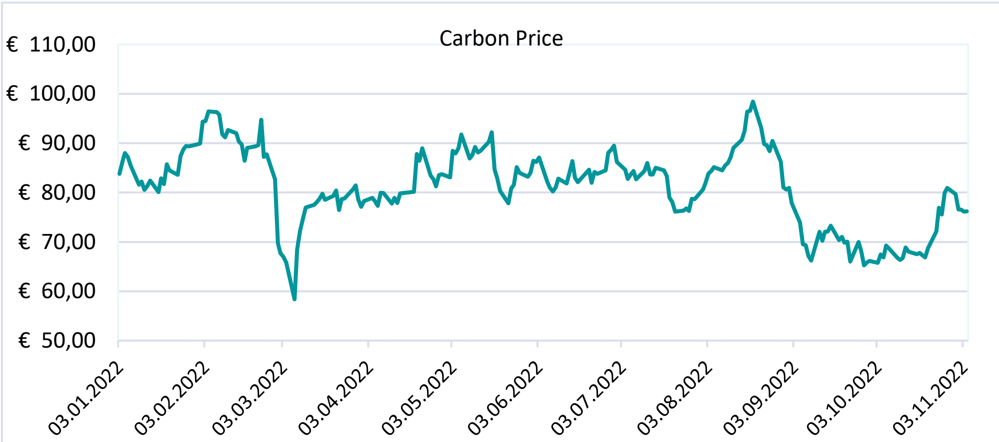


Diagram 1: Price for carbon permits in 2022. Authors' own calculations based on Think Tank Ember Carbon Price Tracker (Ember-Climate.org 2023).

While the short-term fluctuations in price of emissions permits are directly related to the European economy and the fluctuations in electricity demand, the long-term trend will be shaped by political decisions. These will lead to a clear shift in the European energy industry towards the Green Deal. The number of emissions permits offered will be reduced and this in turn will provide incentives for investment in clean, low-carbon or carbon-free power generation technologies.

The EU sets reduction targets for the emissions values and employs mechanisms for reducing the excess supply of permits in relation to demand. According to the latest forecasts, the return to growth of the EU economy and the introduction of new – higher – emissions reduction targets in the EU (60 per cent higher in 2030 than in 2005) will drive emissions permit prices up to nearly EUR 48.5 per tonne in 2025 and nearly EUR 58.95 per tonne in 2030.[6] These are extremely conservative forecasts, because the price for emissions permits already reached the EUR 100 per tonne mark in 2022.

Based on the unit prices for electricity, the costs for 1 MWh of electricity generated in a coal-fired power station include more than three quarters of a tonne of CO_2 (according to the KOBiZE report (2022), generation of 1 MWh together with the energy transmission to the consumers is associated with emission of about 719 kg CO_2). Such a significant share of CO_2 in the power generation in Poland, which is still based on coal, has sensitive consequences for the energy price as soon as the EUA permit prices change. For a CO_2 price of 90 EUA permits, the cost of permits for 1 MWh of electricity in Poland is approximately PLN 300–400[7].

[6] Authors' own calculations based on Think Tank Ember Carbon Price Tracker *(Ember-Climate.org 2023).*
[7] EUR 66–88.

The energy market is currently characterised by a low-price stability. The 'Electricity Act[8]' introduced at the end of 2018 was supposed to be an effective means of counteracting price increases, according to the ministry of energy. On a long-term scale, however, the prices for energy and other related services, including power distribution services, rose again after 2020. In 2020 the energy prices were impacted by the coronavirus pandemic such that they fell. This price freeze was a one-off measure for consumers. In 2020 compensation for individual consumers in the lowest tax bracket (with annual income of less than PLN 85,528 / EUR 18,978) was introduced.

As a result of the armed conflict in Ukraine, the upwards trend in energy prices became more pronounced at the start of 2022, reaching a record high of PLN 2,000 / EUR 444 per MWh in August and September.

The mechanisms introduced in connection with the so-called shields and the legal stipulation of a fixed energy price are not sustainable solutions to the problem, but rather represent state interventions designed to stabilise the market. As of this writing, it is known that the protection period will come into effect in 2023, but price increases will probably still occur. In 2022 the value added tax on energy was 8 per cent and the price fixed for 2023 was given as a net amount. If the value added tax rate reverts back to the former rate of 23 per cent due to the EU intervention, the final price will increase. Possible increases in distribution tariffs and electricity market fees in 2023 must also be taken into account.

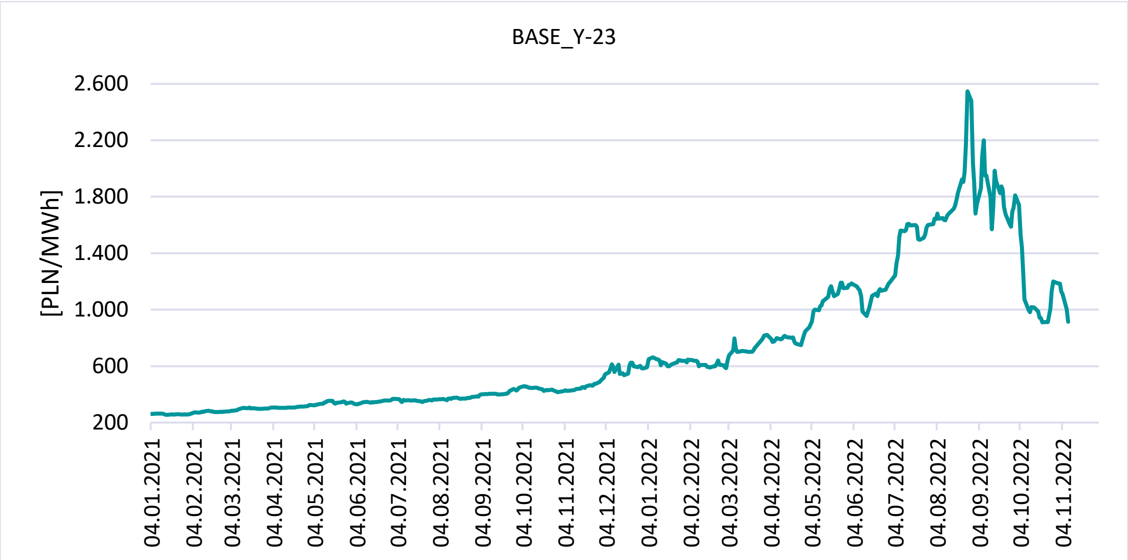


Diagram 2: BASE_Y annual product rates with delivery in 2023. Authors' own calculations based on the Polish Power Exchange (TGE).

At the beginning of 2023, there was a sharp decline in the energy price in the BASE_Y_23 product, for which, in connection with the introduction of regulatory mechanisms, the stock market indices did not exceed PLN 900 / EUR 200 per MWh (price without any additional charges). Nevertheless, increases in energy prices can also be expected in the coming years – even if perhaps not on the same scale as during the 2022–2023 transition.

These factors and market conditions are leading to redefinition of the terms 'energy self-sufficiency' and 'self-consumption'. Local authorities and companies are increasingly deciding to invest in their own decentralised renewable energy generation sources[9]. These solutions, which are installed on the sites of the local authorities and companies, supply the consumers and thus contribute to ensuring a reliable energy supply and price stability.

[8] Rozporządzenie Ministra Energii z dnia 19 lipca 2019 r. w sprawie sposobu obliczenia kwoty różnicy ceny i rekompensaty finansowej oraz sposobu wyznaczania cen odniesienia.
[9] Based on empirical values.

A further energy-related area is the independent energy distribution, which as a licensed activity is subject to the regulatory mechanisms of the Energy Regulatory Office. Independently of this, cost increases can also be expected here, as the distribution network operators must bear the costs for network modernisation and expansion, e.g., for introduction of smart metering systems.

The distribution costs have two components:

- fixed costs, which depend on the ordered plant capacity and are basically stand-by costs for drawing of energy from the network which we cannot lower, and
- variable costs, which depend on the amount of energy taken from the network, i.e., the metering and billing numbers. The variable fees are not charged when the electricity is generated in the PV system and consumed in the plant; this leads to savings in this component of the energy distribution costs.

A sharp increase in variable distribution costs results from the so-called electricity market fee introduced in Poland in January 2021.

Table 1: Electricity market fees for 2023.

Tariff group	Fee amount
G	2.30 to 13.25 PLN net per month (depending on annual electricity consumption)
Other groups	102.60 PLN/MWh net (for energy consumed Monday to Friday between 7 am and 10 pm)

Source: PGE Dystrybucja S.A.

For consumers in G tariffs (individuals), the electricity market fee is calculated on the basis of the annual energy consumption and lies between PLN 2.30 and PLN 13.25[10] net per month. For other customers a fee of PLN 102.60 / EUR 22.50 per MWh net is calculated for energy consumed Monday to Friday between 7 am and 10 pm. For some of them, a fee is calculated on the basis of the standard profile for the relevant tariff group and the energy amount is determined based on this. For customers with smart meters, the fee is calculated based on the actual hourly energy consumption. This means that an energy source that generates energy and at the same time significantly reduces the energy consumption of the plant significantly lowers the costs of the electricity market fee.

The electricity market fees can increase annually in practice. For consumers with standard tariffs[11], the fee in 2022–2023 is PLN 102.60 / EUR 22.50 per MWh. The higher the energy consumption during peak times, the greater the increase. In the worst-case scenario – for a consumer that only consumes energy at peak times – the costs yielded from the electricity market fee are the highest. The fact that in 2021 the electricity market fee was still PLN 76.20 per MWh confirms that the amount of this fee can rise in the years ahead. The following table shows the variable distribution fees and their current and forecast amounts.

Table 2: Comparison of variable distribution fees in 2022–2023 for tariffs of group 'B'.

Fee type	Purpose	Tariff year 2022 [PLN/MWh]	Tariff year 2023 [PLN/MWh]
Renewable energy fee	Renewable Energy Financing Mechanism calls for proposals	0.9	0
CHP fee	Funding regulation for combined heat and power	4.06	4.96
Quality fee	Operating costs of the TSO	9.49	24.21
Variable distribution fee	Variable costs for the DSO operations	68.98	97.15
Electricity consumption	Costs on the electricity market	102.6	102.6
Total fee reduction potential for internal generation plant		186.03	228.92

Source: PGE Dystrybucja S.A.

[10] EUR 0.50 to EUR 2.90.
[11] Tariffs B and C are for public buildings and companies.

A possible way of reducing the variable costs of the distribution fees is by creating an energy cluster (in light of the considered legislative changes which could facilitate the establishment) in which discounts based on the degree of self-consumption of electricity from internal generation sources are applied for cluster members. For clusters that produce at least 30 per cent of the generated electricity from renewable energy sources, it is assumed that 40 per cent of the annual balance is covered by internal sources and that the energy generated from renewable energy sources is exempt from the fees listed in Table 2, with the variable distribution fee being dependent upon the extent of self-consumption. From a self-consumption amount of 40 per cent, there is an exemption of 10 per cent of the variable distribution fee. The exemption increases by 5 per cent for every 10 per cent increase in self-consumption amount.

In summary, for the local authorities, internal renewable energy sources in conjunction with a well thought out cluster initiative is a reasonable decentralised energy and energy strategy approach that has a positive effect on the long-term stability of electricity costs.

3. Hajnówka region

The Hajnówka region lies in eastern Poland, in the south-east of the voivodeship of Podlaskie.

3.1.Geological and hydrogeological conditions

The geological survey of the geological conditions of geothermal energy extraction to be expected during potential drilling activities in the Hajnówka region was prepared in light of the legal situation to 31.08.2022. Such a study is necessary to determine, amongst other things, the groundwater quality and availability. There are certain minerals in groundwater and pH values of groundwater that can negatively affect heat pumps.

These drilling activities have shown that in the vicinity of Hajnówka, there is no possibility of extracting geothermal water with a temperature that would be sufficient for direct use for heating.

For this reason, a possible use of the geothermal energy in this region is connected with low-temperature geothermal energy, i.e., with the use of geothermal energy sources with temperatures so low that the energy can only be recovered with the help of heat pumps. In light of natural local conditions and information gathered from experience, it can be stated on the basis of the drilling activities carried out so far that with optimal use of the Hajnówka region and satisfactory energy efficiency of geothermal heat pumps, boreholes with a depth of at least several tens of metres will be required. If open systems are used, boreholes with a depth of more than 100 m should be drilled in the Hajnówka vicinity.

In the Hajnówka region, the use-relevant quaternary aquifer does not differ significantly from the tertiary aquifer in terms of its hydrogeological parameters. In both cases, layers with average filter properties are involved.

Although the hydrogeological parameters of the two described aquifers in the Hajnówka region do not differ significantly, the tertiary aquifer is much more important and should bear the main load for use of the groundwater. This is connected with its distribution throughout the region and the considerably higher stability of the water pipeline in various parts of the city. This makes it possible to extract much greater amounts of water from this aquifer. From a purely technical and chemical point of view, there are no objections to use of groundwater as a heat source.

3.1.1. Legal requirements for completion of geological work

An evaluation of the legal situation in Poland shows that there are legal ways to extract groundwater for heating projects. However, the right way cannot be conclusively determined in advance. Depending upon the drilling depth, extraction volumes and other factors, different authorities are responsible for granting the permit.

The basic legal regulations for carrying out the above-mentioned work associated with the use of geothermal energy are yielded from the provisions of the Geological and Mining Act of 9 June 2011 (Journal of Laws 2022, item 1072, as amended). In the case of geothermal energy extraction through open systems, geological work must be carried out; according to the law, this means execution of all work below the surface of the ground within the scope of the geological work (Article 6(1)(11) Pgg). All work using geological work must be carried out according to the design and execution procedure specified in the Geological Act.

3.2. Socio-economic information

Hajnówka County is an administrative unit with a low population and a low population density (Urzad Statystyczny w Bialymstoku 2021a). There are 39,710 people living on an area of 1624 km^2, corresponding to just 24.4 people her km^2. The county's population is continuing to decline drastically, due to a low birth rate and a net population outflow. This trend is consistent with the demographic situation in the entire voivodeship, the population of which has been declining for many years.

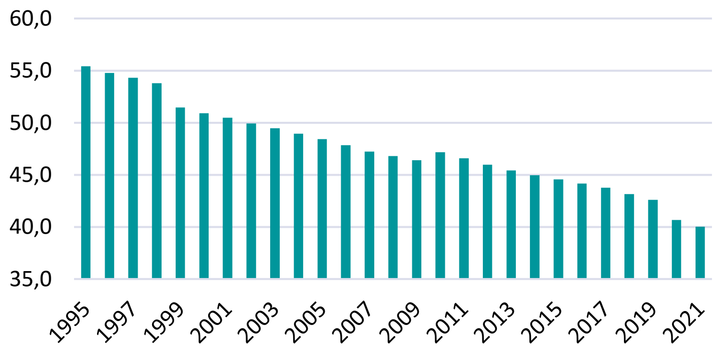


Diagram 3: Population dynamics in Hajnówka County for the period 1995–2021. (Urzad Statystyczny w Bialymstoku 2021a).

In the city of Hajnówka, around 24.8 per cent of the population is gainfully employed; of those employed, 53.7 per cent are women and 46.3 are men. The registered unemployment rate in 2021 was 6.8 per cent (5.9 per cent amongst women and 7.5 per cent amongst men) and was thus somewhat lower than the unemployment rate in the voivodeship of Podlaskie (7.8 per cent) and much higher than the overall unemployment rate in Poland (5.8 per cent) (Urzad Statystyczny w Bialymstoku 2021b).

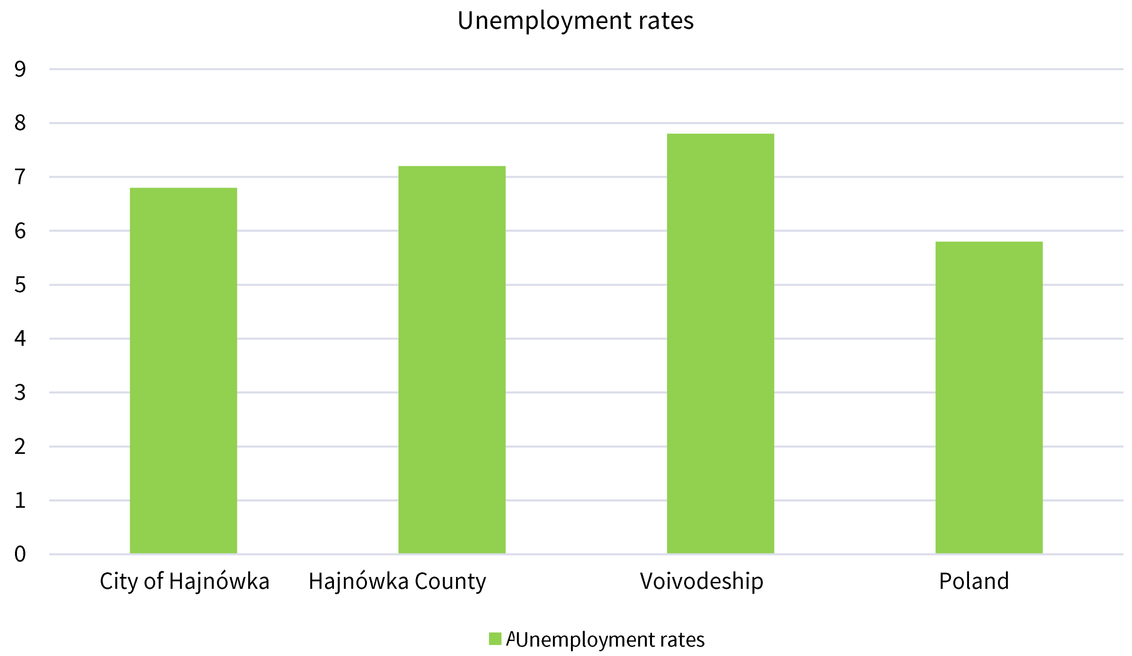
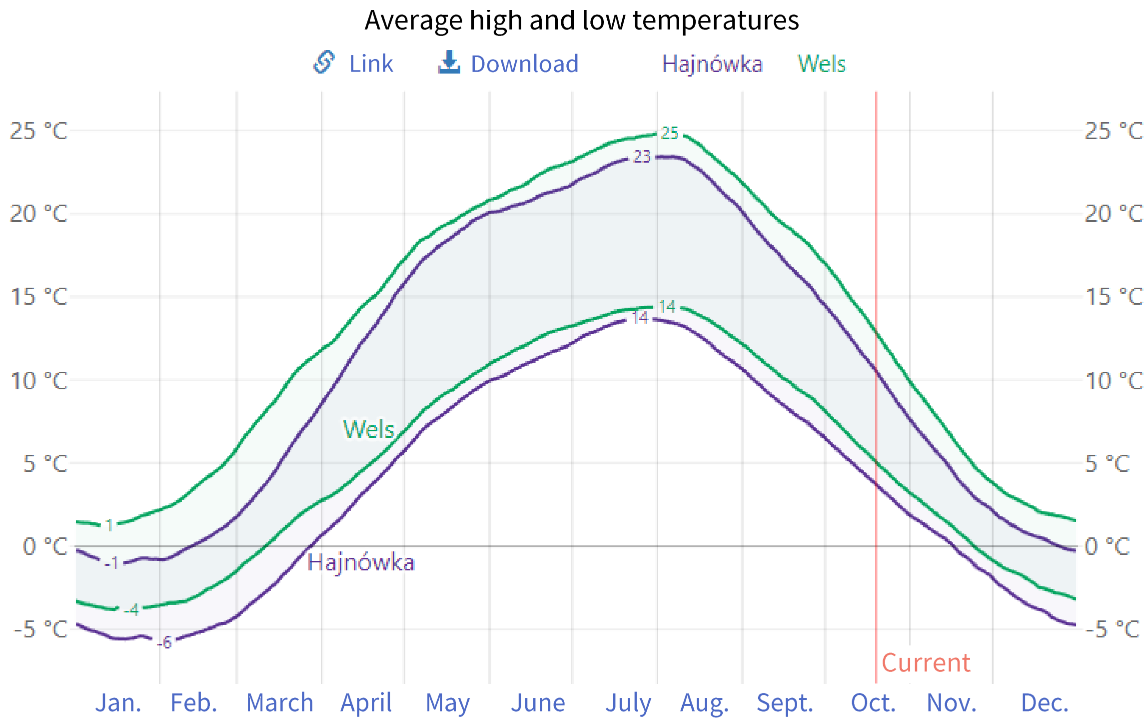


Diagram 4: Hajnówka city, county, voivodeship and national unemployment rates, status as of 2020 (Polska w Liczbach 2021b)

All in all, it can be said that the region, similarly to rural regions in Germany, has to deal with a declining population and declining employment, even if the unemployment rate is on average lower than in the voivodeship as a whole.

3.3.Regional climate

Temperatures in Hajnówka are pleasant and the skies are occasionally cloudy in the summer. The winter is long and cold, snowy, windy, and for the most part cloudy. As shown in the following figure, temperatures over the course of the year usually range from –6 to +23 degrees Celsius, rarely dropping below –16 or rising above +29 degrees Celsius.



*Daily average high and low temperatures measured at **2 metres** above ground.*

High	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hajnówka	-1 °C	0 °C	5 °C	12 °C	18 °C	21 °C	23 °C	22 °C	17 °C	11 °C	4 °C	1 °C
Wels	2 °C	4 °C	9 °C	15 °C	19 °C	22 °C	24 °C	24 °C	19 °C	13 °C	6 °C	2 °C

Low	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hajnówka	-5 °C	-5 °C	-2 °C	3 °C	8 °C	11 °C	13 °C	12 °C	8 °C	4 °C	-0 °C	-4 °C
Wels	-4 °C	-3 °C	1 °C	5 °C	9 °C	12 °C	14 °C	14 °C	10 °C	5 °C	1 °C	-2 °C

Diagram 5: Comparison of temperature profiles for Hajnówka (Poland) and Wels (Austria).
Source WeatherSpark.com

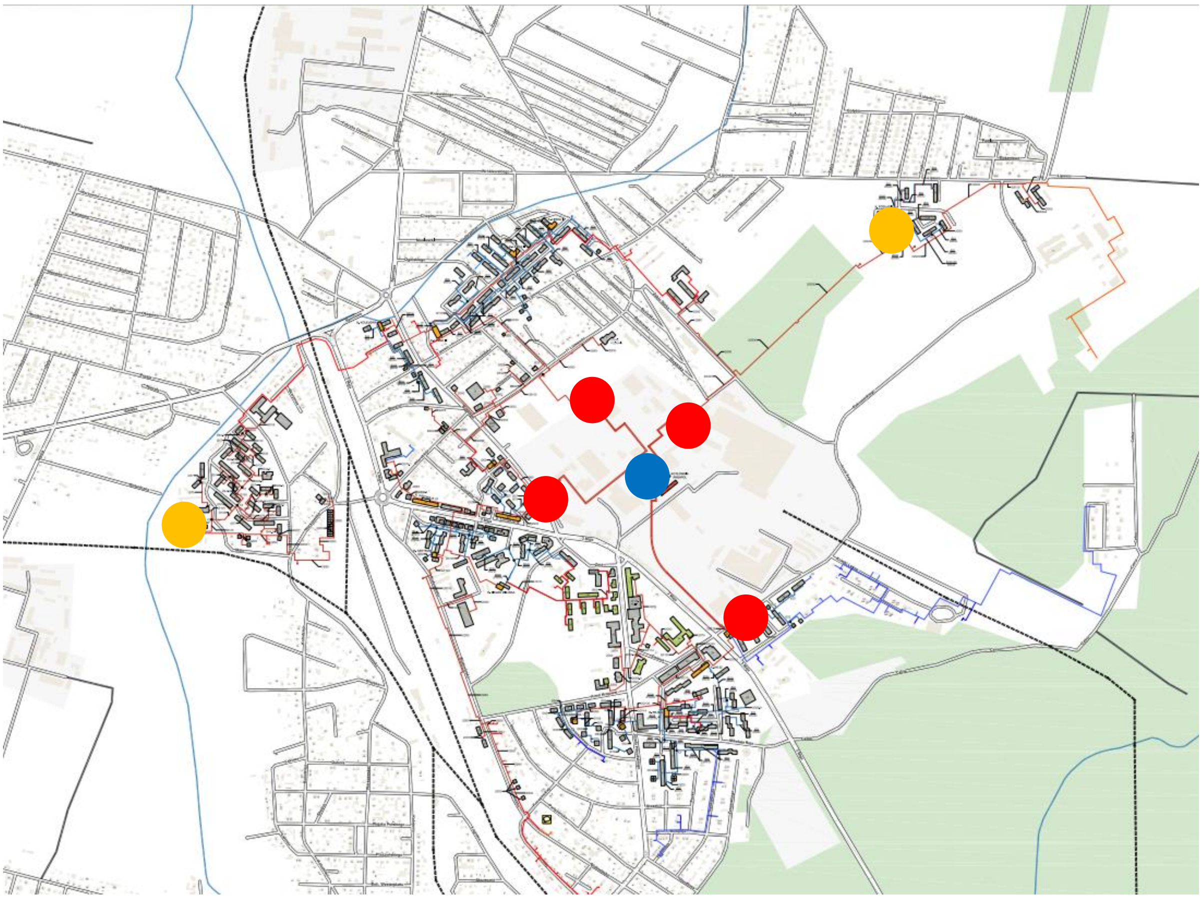
The temperatures over the course of the year are similar in Hajnówka and in the Austrian city of Wels. For that reason, similar empirical values from earlier projects in the Austrian region completed by Ochsner Process Energy Systems (OPES) were taken for further considerations.

3.4.City’s heating network – current status

The heating network for the city of Hajnówka consists of three active boiler houses in which heat is produced for the heating network. A fourth boiler house is currently inactive and will be modernised.

One of the four boilers and the associated feeder are operated by a private company called Solor, whereas the other three and the heating network themselves belong to the city utilities (and thus the city itself).

Two boiler houses important for this study, the Podlasie boiler house and the Mazury boiler house, are owned by the city. The feeders from the Solor boiler house to the transfer nodes are owned by Solor. They also supply a few properties in the vicinity of the boiler house.



Legend: ● Active boiler house owned by the city ● Heat nodes

—— Heating pipes at 130/70 degrees Heating —— pipes at 90/70 degrees

Figure 1: Map of the Hajnówka heating network.

The two active boiler houses for the city are shown as yellow dots: Podlasie in the north-east and Mala in the west. The red dots show the heat nodes from Solor. The blue dot represents Solor's boiler house. The red lines are the heating pipes, which are operated at 130 degrees Celsius in the feed direction and at 70 degrees Celsius in the return direction. The pipe network sections that are operated at 90 degrees Celsius for the feed and 70 degrees Celsius for the return are shown in blue. Source. PEC.

The network is heated with pulverised coal firing and operated at a temperature of 130 degrees Celsius in the feed line and 70 degrees Celsius in the return line (shown in red). The temperature level is lowered according to the outside temperature. There are also pipe network sections that are operated at 90 degrees Celsius for the feed and 70 degrees Celsius for the return (shown in blue).

The network is divided up into four sectors (see the figure 'PEC – Heating sectors on the next page).

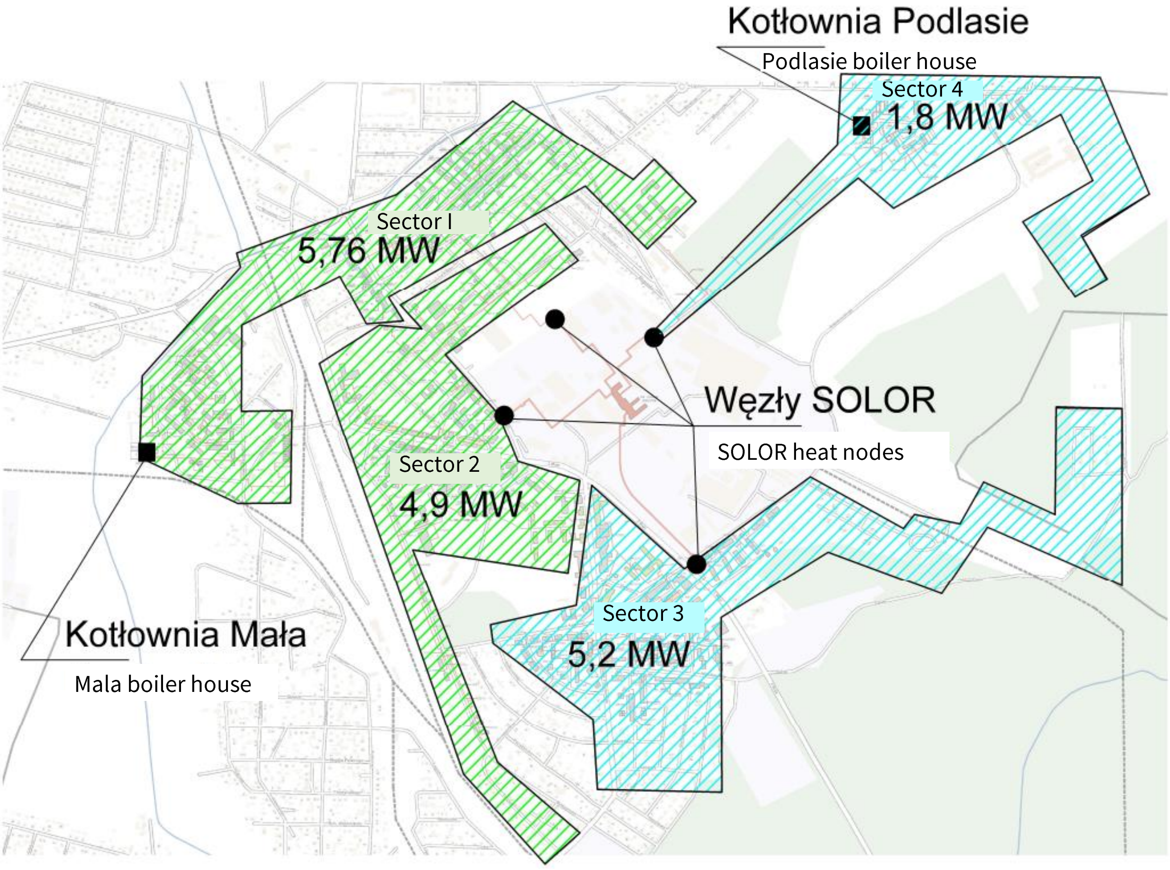


Figure 2: 'PEC – Heating sectors': Map showing the Hajnówka heating network sectors.

According to the city utilities' plans, connection of sectors one and two and of sectors three and four should take place in the future. The installed output of the four sectors yielded from this can be seen in the following table.

Table 3: Currently installed outputs in the four sectors.

Sector	Installed output
Sector 1	5,76 MW
Sector 2	4,9 MW
Total centre 1 Mazury/Mala	10,66 MW
Sector 3	5,2 MW
Sector 4	1,8 MW
Total centre 2 Lipowa/Podlasie	7,0 MW
Total	17,66 MW

3.4.1. Network temperatures – fluctuation ranges

According to the city utilities, temperatures in the winter can be lowered to 105 degrees Celsius in the feed line of the network and 60/55 degrees Celsius in the return line of the network. This was performed on a test basis for winter 2022–2023. With a lower network temperature, the heat pumps would have to deliver less heat, which in turn would increase the efficiency of the plants.

Temperatures in the network feed and return lines in the summer could drop to 65–70 and 45–50 degrees Celsius, respectively. In between these, the feed temperature is flexibly regulated as a function of the outside temperature.

3.4.2. Measurement of actual network temperatures

One of the most important questions is that regarding what the actually required feed and return temperatures in the Hajnówka heating network are. The corresponding measuring devices were installed both at the three Solor distribution nodes and in the Mala Mazury boiler house to provide certainty. Operation and monitoring of the heating network began in late autumn of 2022 at the planned lower temperatures (105 degrees Celsius for the feed and 50 degrees Celsius for the return in winter).

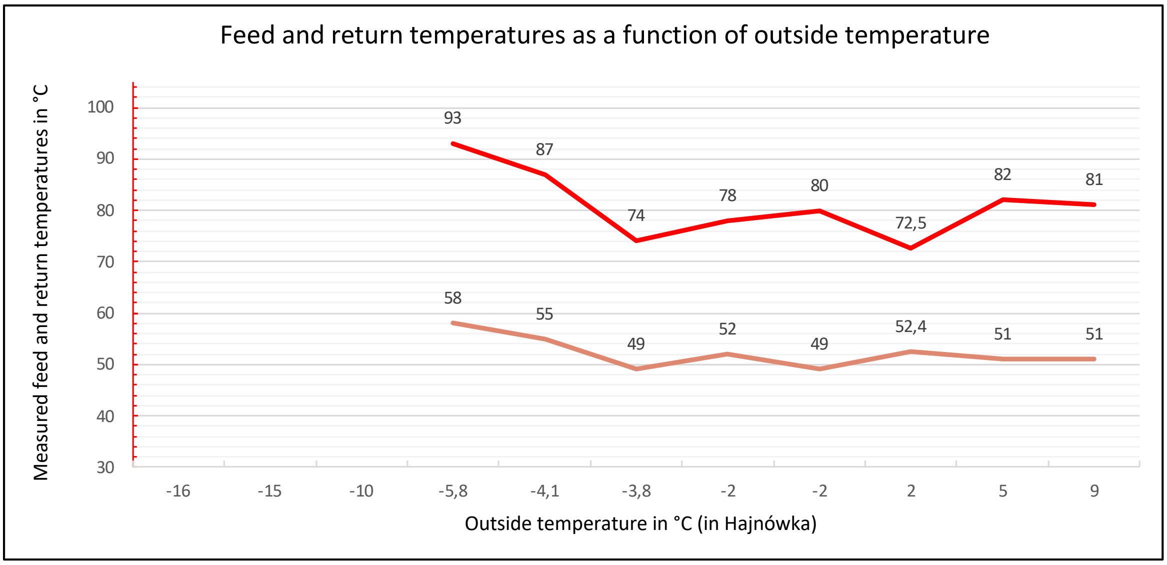


Diagram 6: Feed and return temperatures in the heating network as a function of outside temperature.

It can be seen that the planned lowering of the temperatures to 105 degrees Celsius and 50 degrees Celsius is actually possible in practice. However, the entire winter period, including the network temperatures on even colder days, should be taken into account in the detailed design.

4. Heat pump concept

Based on the findings from monitoring, the heat pump stations were designed such that the return temperature of the network is raised from 50 degrees Celsius to 80 degrees Celsius through the heat pumps. Depending on requirements and the outside temperature, the boiler plants then increase the feed temperature further to 105 degrees Celsius. The heat pump centres thus cover the network load alone down to about –2 degrees Celsius. Through the bivalent parallel operation in accordance with DIN 4701, this results in about 90 per cent coverage of the annual heating work; see the specifications from DIN 4701 in the table on the next page.

Table 4: Coverage of the annual heating work with bivalent parallel operation

Bivalence point [°C]	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
Output share µ (-)	0.77	0.73	0.69	0.65	0.62	0.58	0.54	0.5	0.46	0.42	0.38	0.35	0.31	0.27	0.23	0.19
Coverage α_{Hg} [-] for bivalent parallel operation	1	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.93	0.9	0.87	0.83	0.77	0.7	0.61
Coverage α_{Hg} [-] for bivalent alternative operation	0.96	0.96	0.95	0.94	0.93	0.91	0.87	0.83	0.78	0.71	0.64	0.55	0.46	0.37	0.28	0.19

Source: DIN 4701.

With bivalent parallel operation, the heat pump and an alternative heat source work together starting from a certain outside temperature, meaning that the heat pump continues to run and the boiler raises the temperature as much as necessary. With bivalent alternative operation, the heat pump switches off at a certain outside temperature and the alternative heat source (boiler) assumes the entire load. The switch point is called the bivalence point.

Regarding the coverage of the annual heating work in accordance with DIN 4701, the following can be said: a district heating network or a heating plant provides a certain annual heating work, which is the total amount of heat delivered. The plants only run at full output for a few hours in the year, usually running continuously in the part-load region. As a result, with a heat pump output of 46 per cent of the total output, 90 per cent of the annual heating work can be performed. The coverage load of 90 per cent can be visualised through a diagram.

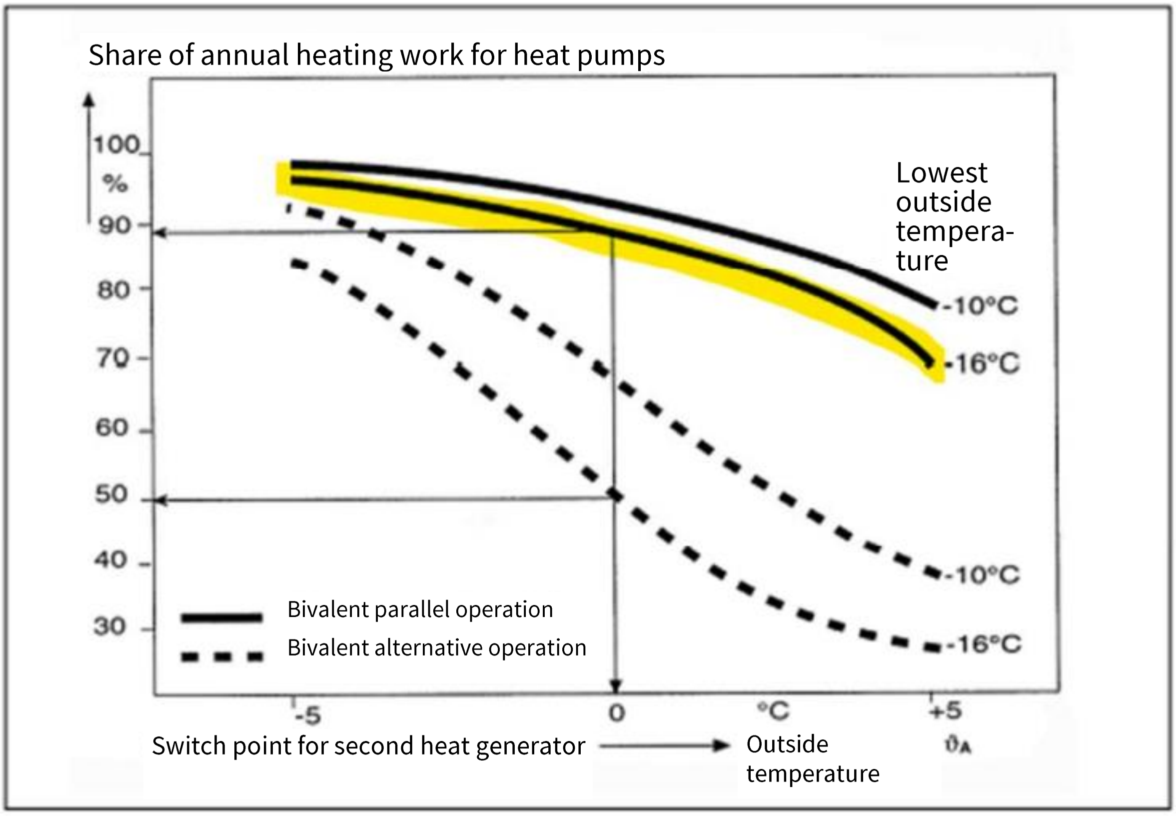


Diagram 7: Coverage of the annual heating work with bivalent parallel operation (Ochsner 2007).

The diagram shows two different minimum outside temperatures (–10 °C and –16 °C) and the share of coverage of the annual heating work by the heat pumps in dependence on the bivalence point. The minimum outside temperature determined for Hajnówka is highlighted in yellow.

If the temperature level in the Hajnówka heating network had not been lowered, alternative parallel operation would not have been possible and bivalent alternative operation would have had to be designed. With such operation the heat pumps would then only have covered 78 per cent of the annual heating work, instead of the approximately 95 per cent with bivalent parallel operation.

Due to the maximum required feed temperature in the heating network of 105 degrees Celsius at a return temperature of 55 degrees Celsius, a monovalent heat pump design no longer makes sense. It would be necessary to use two-stage heat pump systems, whose seasonal coefficients of performance (SCOPs) would no longer be very high. They would be less than 2.0.

Two heat pump stations, one each in the Mala and Podlasie boiler houses, are planned. Sectors 1 and 2 should in the future be supplied with heat by heat pump station 1 and sectors 3 and 4 by heat pump station 2.

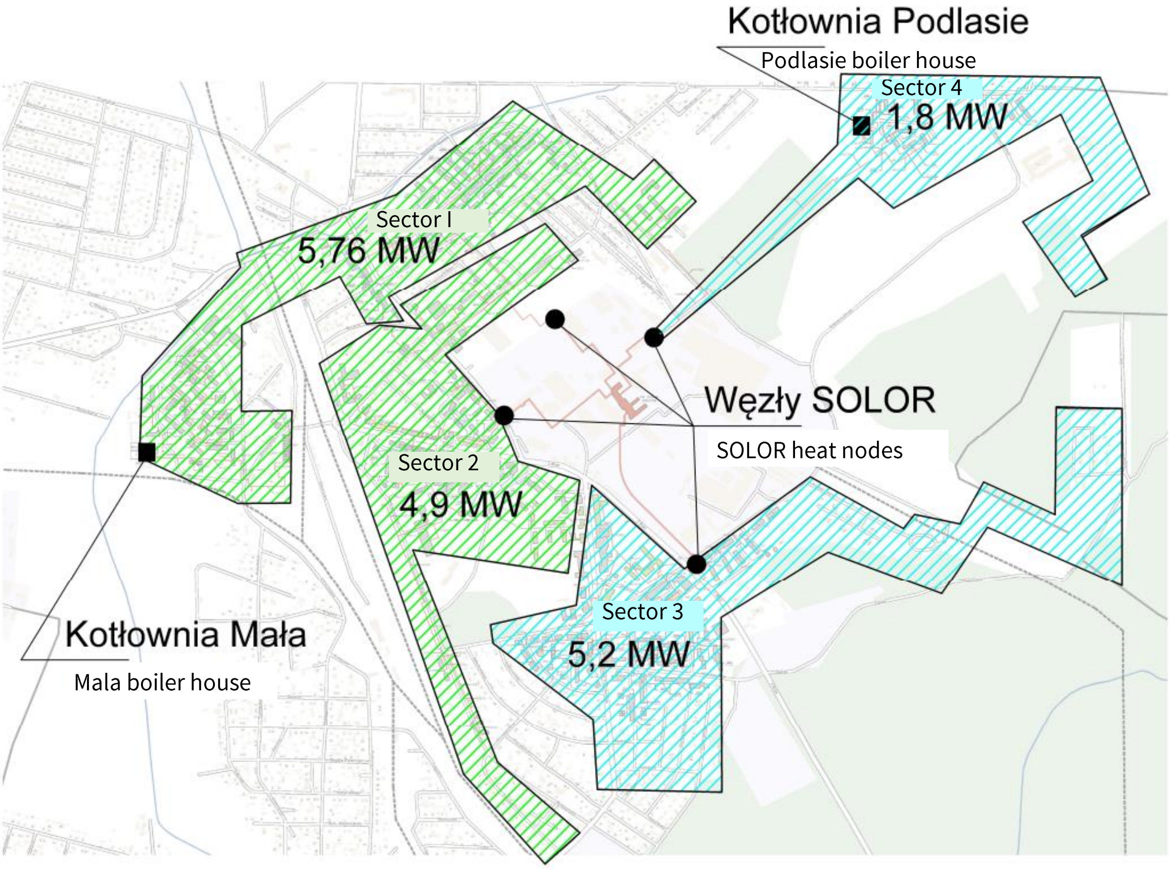


Figure 3: 'PEC – Heating sectors': Map showing the Hajnówka heating network sectors.

Figure 4 on the next page presents a block diagram illustrating how large-scale heat pumps could be integrated into the Hajnówka local heating network (not a block diagram for the hydraulic integration).

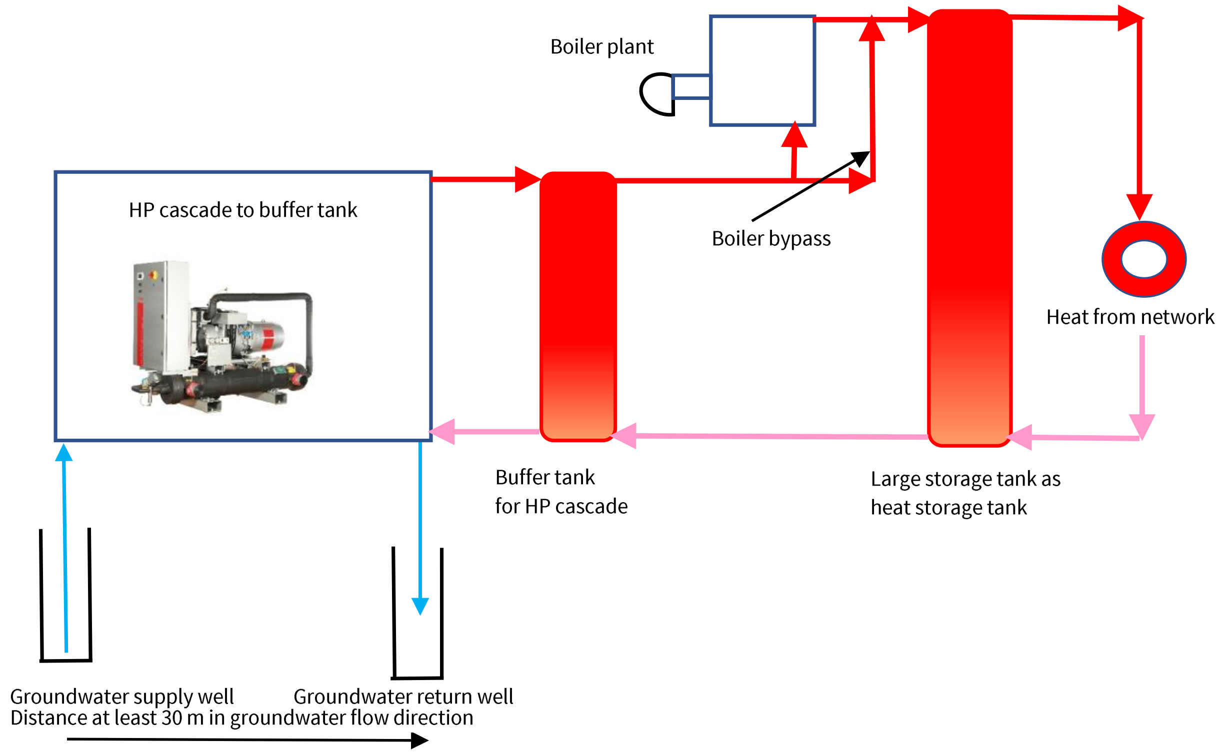


Figure 4: Block diagram, exemplary for both heat pump stations

4.1.Heat sources

Large-scale heat pumps can use various heat sources to absorb heat energy and bring it to a higher temperature. Some of these sources are described in greater detail in the following.

4.1.1. Groundwater

Large-scale heat pumps can use groundwater as a heat source. The cold groundwater is removed, the heat energy contained in it is extracted via a heat exchanger and the cooled water is then fed back into the subsoil.

Groundwater would be an optimal source energy for the heat pump stations in Hajnówka. The Hajnówka city utilities have not yet been able to make a final statement on the availability of water up to now. According to the current state of knowledge, the groundwater resources should be sufficient (see Section 3.13). However, drilling of test boreholes is recommended for the purposes of ensuring this. During the detailed design, a check of whether this amount of groundwater can, or is permitted to, be removed and whether the required groundwater return wells are designed accordingly.

If groundwater is not present or cannot be utilised in a sufficient amount, then the alternative would be air–water heat pumps. Due to the lower air temperatures in the six winter months, however, lower coefficients of performance, or seasonal coefficients of performance, are yielded than with use of groundwater at a constant temperature of 10 degrees Celsius.

4.1.2. Wastewater

Large-scale heat pumps can also utilise the heat energy from wastewater or wastewater treatment plants. The hot wastewater is routed through a heat exchanger and the contained heat is thereby extracted. The cooled wastewater is then returned to the sewer or wastewater treatment plant. This is conceivable for one of the heat pumps in the first station. A heat pump planned to be supplied with wastewater energy requires approx. 104 m³ per hour from the heat exchanger, which would still have to be installed. Unfortunately, despite having a sufficient heat output[12], the wastewater treatment plant is not a suitable energy source: the wastewater treatment plant does not have a connection to the heating network and is too far from the boiler houses and the heating network for economical operation. The plant is at the southern edge of the urban area. Establishing a connection to the heating network would be too complex and expensive.

Untreated wastewater from the interceptor is also a possible heat source, as the interceptor passes right by the Mazury / Mala street boiler house. The main pumping station for wastewater is approximately 300 m away. The interceptor has a diameter of DN 1000.

The first data obtained for wastewater flows from the short observation period thus far are presented in the appendix.

The data for the months of August to December 2022 were not yet available at the time of elaboration of this concept. For the heat recovery, the corresponding heat exchangers should be installed in the sewer to extract the heat energy from the wastewater. According to the city utilities, rehabilitation of this interceptor is planned for the near future. The rehabilitation could take place at nearly the same time as the installation of the sewer heat exchanger. However, the rehabilitation must be completed before the sewer heat exchanger can be installed. Otherwise, the inside bottom of the sewer pipe would no longer be able to be rehabilitated because the sewer heat exchanger would be resting or mounted on it.

The minimum average volume per day is 3,000 m³. This corresponds to an hourly water flow of 125 m³/h. Cooling by 3.4 degrees Celsius yields an output of 500 kW, which would be available as a minimum constant source energy.

The exact wastewater temperature in the interceptor is currently not known. Experience has shown that temperatures between 13 degrees Celsius and 15 degrees Celsius can be assumed in sewers.

4.1.3. Other sources

Other theoretically possible sources are:

- **Surface water**:
  Rivers, lakes or ponds can serve as heat sources for large-scale heat pumps. The surface water is routed through a heat exchanger and the contained heat is thereby extracted. The cooled water is then returned to the body of water. This is not possible in the urban area.

- **Ground**:
  Geothermal energy can be extracted from the ground. Ground probes or geothermal heat collectors are installed in the ground for this. They extract the natural heat from the ground and convey it to the heat pump. The geological surveys performed up to now suggest that such a heat source is not present (see Section 3).

- **Industrial processes:**
  Large-scale heat pumps can utilise the heat energy from some industrial processes. This can be waste heat sources such as cooling systems, exhaust gases or production processes in which heat

[12] Water flow for first stabilisation pond: 2,000 m³/day divided by 24 h = 83.3 m³/h times delta T = 4 degrees Celsius yields 387 kW; for second pond: 6,000 m³/day divided by 24 h = 250 m³/h times delta T = 4 degrees Celsius yields 1,162 kW.

is released. No sufficient source of waste heat could be found in the city. There is industrial waste heat in the city. However, this path will not be pursued further in this study so that no dependency[13] on a private company arises.

4.2.Heat pump stations

Whereas a heat pump should use untreated wastewater (see Section 4.1.2), the remaining pumps should use groundwater as the source.

According to the Hajnówka city utilities, the output requirement for heat pump station 1 is 5.76 MW and 4.9 MW for the two sectors to be supplied. This corresponds to a total output of 10.66 MW. The HP station provides about 52 per cent of the required heating output and can supply the network alone down to a temperature of about –2 degrees Celsius. This heat pump station 1 at the Mala boiler house could be equipped with eight large-scale heat pumps[14], with two each connected in parallel in a cascade (on the sink side = heating network). The source energy for the seven heat pumps is groundwater. Wastewater energy is provided to the eighth heat pump via a sewer heat exchanger in the interceptor (see above). A stratified buffer tank with a capacity of at least 110 m³ should be used for the heat pump cascade. Further, two thermal energy storage tanks, each with a capacity of 150 m³, are recommended to use surplus wind or PV electricity for heat generation and store the heat energy[15].

Five large-scale heat pumps, likewise connected in a cascade, should be used in heat pump station 2 (Podlasie boiler house). The exclusive source energy for the five heat pumps is groundwater. The stratified buffer tanks for the heat pump cascade should have a capacity of at least 70 m³. One thermal energy storage tank in the network with a capacity of 150 m³ is recommended. The storage tanks can be smaller than in Station 1 because fewer heat pumps are installed.

The average COP is 3.1[16]. The statistical tolerance is 10 per cent. Based on empirical values, about 15 per cent must additionally be subtracted from the COP value for operation[17] of the pumps. The electricity requirements for operation of the heat pumps with the associated infrastructure were forecast based on archived weather data and the so-called average seasonal coefficient of performance (SCOP) as a function of the outside temperatures. This coefficient describes the ratio between the electricity required and the amount of heat energy generated.

Table 5: Heat pump stations 1 and 2 compilation.

		Required 10,660 kW			Required 7,000 kW			Total HP 1 + HP 2 + boilers
Total	**HP station 1**	Boiler output	***Total 1***	**HP station 2**	Boiler output	***Total 2***	**HP 1 + HP 2**	
Heating output Qh	**5,564.0** kW	**5,087.2**	**10,651.2**	**3,503.0** kW	**3,488.4**	**6,991.4**	**9,067.0** kW	**17,642.6**
Electric power consumption N	**1,802.0** kW			**1,131.0** kW			**2,933.0** kW	
Cooling output Qc[18]	**3,762.0** kW			**2,372.0** kW			**6,134.0** kW	
COP heating	**3.1**			**3.1**			**3.1**	

[13] Changes in the company's production processes or mode of operation can affect the availability and quality of the waste heat. It is important to take this into account in the planning and when concluding agreements with the company.

[14] Of type Ochsner WP IWWHS 740 ER7c2.

[15] A stratified buffer tank is a special type of thermal energy storage tank that is used to release heat from a heat source and on demand. Unlike a conventional buffer tank, which simply stores the heat energy and later releases it, a stratified buffer tank can store the heat energy in layers and release it from these layers.

A stratified buffer tank is made up of multiple layers with different temperatures. The layers are separated from each other in each case by a stratification device such as a tee fitting or a spreader plate. The hotter heat source feeds the hot water into the uppermost layer of the stratified buffer tank, where it accumulates and cools until it reaches the temperature of the layer beneath it. As soon as the upper layer has cooled, the heat source is switched on to reheat the water in the uppermost layer and repeat the process.

[16] In heat pump station 1 at 3.09.

[17] Auxiliary units, feed pumps for the well, circulating pumps for the HP cascades, etc.

[18] The cooling output determines the ability of the heat pump to supply the desired cooling output and lower the temperature of the cooled medium to the desired value.

The two heat pump stations cover somewhat more than 50 per cent of the required heating output for the heating network and perform about 90 per cent of the annual heating work.

The electric power at the operating point is nearly 3,000 kW. With the 15 per cent required for operation, the required electric power is approximately 3,500 kW.

At lower outside temperatures, boiler plants, e.g. a biomass boiler, would have to make the additionally required heating output available. The heat pump station can, in principle, also supply feed temperatures of over 80 degrees Celsius (to maximum 90 degrees Celsius). However, the efficiency value then decreases.

These considerations show that, in purely technical terms, it is possible to decarbonise the heating network for the city to a great extent and supply it with heat pumps.

5. Coverage of electricity requirements of heat pumps by renewable energies

The optimal electricity requirements coverage for the project in Hajnówka is generation of energy from internal renewable sources with simultaneous use of the energy by the consumers (heat pumps and others) assigned to this municipality.

The energy consumption profile of the plants and heat pumps does not completely match the energy generation profile from photovoltaic systems, so wind sources should also be used. Within the framework of the generated energy accounting and balancing, the energy from the public electricity grid must also be used.

Although balance sheet-based self-sufficiency (i.e. generation of the same amount of energy as that demanded) is possible with renewable energy technologies on the scale of the annual profile, it is not possible to balance generation and demand completely on the scale of daily and hourly balances. Deviations must be compensated for via the public electricity grid through the sale of surplus amounts and purchase of amounts to cover deficits. In order for the green energy to be retained, the energy taken from the grid will be energy with a guarantee of origin, i.e. energy from other renewable sources, e.g. from biogas plants.

Renewable energy plants do not require any significant control by the operator in the operational phase, and ongoing maintenance is limited to cyclical (usually annual) technical inspections.

For design of the renewable plants and estimation of the simultaneous coverage of the electricity requirements by the renewable plants to supply the heat pumps, an hourly profile of the electricity requirements of the heat pumps is needed. In order to generate this hourly profile of the electricity consumption, it is first necessary to determine the hourly heating output demand of the network.

As the basis for the analysis of the use of renewable energies and estimation of the costs for provision of energy for the heat pump system described above, the trends that are currently shaping the energy market are presented. As a result of the rising costs of fossil fuels (intensified by the Russian war of aggression on Ukraine), an increase in energy prices can be observed in Poland.

These changes are being accompanied – with varying degrees of success – by legislation, with ad hoc controls such as subsidies to counter rising prices and with new charges that increase costs for consumers while emissions-intensive plants are retained. Given this situation, building internal power plants is a good solution for lowering electricity costs and mitigating the risks associated with rising electricity prices.

Within the framework of this concept, an energy balance for electricity for the city of Hajnówka and an energy balance for the use of heat pumps in the city's heating network were drawn up. The data were made available by the city. The plant output for generation of sufficient energy for coverage of requirements was calculated on this basis. The impact of diverging energy generation and consumption profiles on the examined units was shown to necessitate the use of various generation technologies and the purchase of amounts to cover deficits or the sale of surplus amounts to the electricity grid.

5.1.Determination of electricity requirements

It should be stressed that the electricity requirements for the heat pumps are estimates and the actual values may differ from the assumed values during physical operation of the heat pump generation sources. This depends on the factors that affect operation of the heat pumps, namely the heating energy demand on the consumer side, which is mainly affected by low outside temperatures.

As the project idea is to cover as much of the energy requirements for heat pump operation as possible from renewable sources, the requirements should be broken down into daily and hourly values. Through the superimposition of requirements profiles on electricity generation profiles, energy surpluses and deficits can be determined. Based on the electricity balance, an attempt can be made to select the generation technologies in such a way that close to 100 per cent self-sufficiency, i.e. a balance between generation and consumption, is achieved.

With the provided data regarding generation of heat energy fed into the district heating network as a basis, the energy requirements of the heat pumps were determined using a COP factor.

The electricity requirements were determined through correlation of the heating demand with the outside temperature. The heating demand data as a function of temperature supplied by PEC Hajnówka were used as a benchmark for the heating demand. Because PEC installed a measurement system in June 2022, the data supplied only cover half of the statistical annual heating cycle. These data were supplemented with historical meteorological data from the Institute of Meteorology and Water Management. The electricity consumption was then extrapolated. As mentioned in the previous section, a COP of 3.1 for heat pump station 1 and a COP of 3.09 for heat pump station 2 were used for the calculations (see Section 4.2).

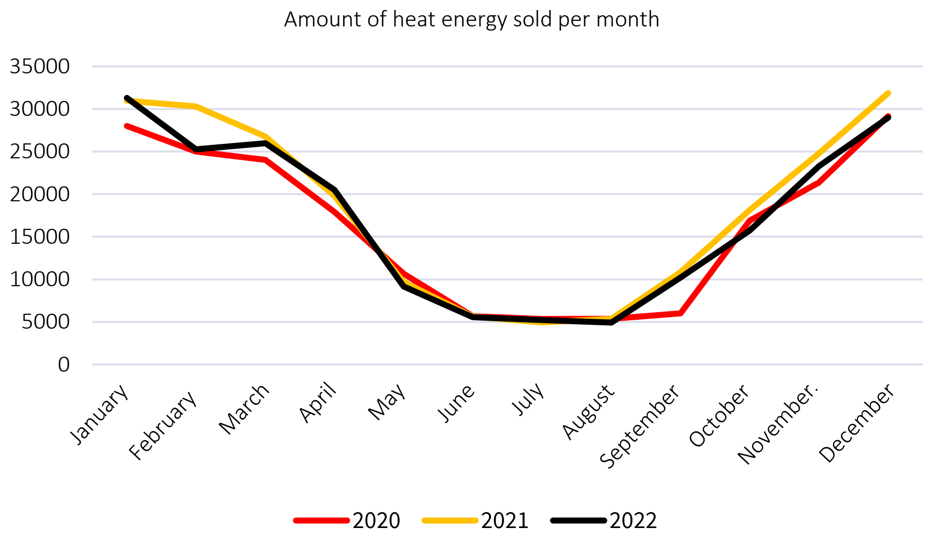


Diagram 8: Amount of heat energy sold per year by month

The district heat sold in recent years is shown by month and location in the graph above. The data table can be found in the appendix. The diagram shows that the sold heat energy has not changed much over the last three years. In 2021 the winter was somewhat harsher, which meant more heating.
In addition to the output requirement of 3 megawatts for each of the heat pump stations, around 500 kilowatts for operation of auxiliary units and pumps are needed. The expected electricity demand is summarised by hour and by month for the sectors in the tables below. Two groups were formed, one comprising sector one and two and the other comprising sectors three and four, as each group should be heated by a heat pump station.

The next step in the analysis process was development of three different electricity demand profiles for the city of Hajnówka. The analysis was carried out on the basis of data made available by the local government unit. Apart from supply of the heat pumps, electricity supply of the city is also examined. Although supply of the heat pump and the public and municipal facilities would already fulfil the task, the potential of renewable energies for supplying other parts of the city is also examined. Analysis was carried out for three profiles:

Profile 1: electricity consumption for heat pumps, public facilities, municipal facilities and street lighting
Profile 2: profile 1 extended by electricity demand from local companies
Profile 3: profile 2 extended by electricity consumption by private households.

Tables containing the data presented in the graphs can be found in the appendix.

Table 6: Energy consumption structure for profile I.

Recipient	**Energy demand for profile 1 [kWh]**	**Energy demand for profile 2 [kWh]**	**Energy demand for profile 3 [kWh]**
Tariff G	-	-	15,257,244
Tariff C	1,577,303	9,084,443	9,084,443
Tariff B	3,579,921	21,612,008	21,612,008
Lighting	376,265	376,265	376,265
Heat pumps	16,175,362	16,175,362	16,175,362
TOTAL	**21,708,850.74**	**47,248,077.84**	62,505,321.84

Source: Authors' compilation based on PGE Dystrybucja S.A.

The energy demand more than doubles from profile 1 to profile 2 if companies with tariffs B and C are also to be supplied. Profile 3 contains the most consumers, for which reason the electricity demand, at nearly 62,505 megawatt-hours, is also the highest. The energy demand here increases again by nearly 15,000 kilowatt-hours because the private households should also be supplied with renewable energies. The monthly energy demands for the three profiles are shown in the diagram on the next page.

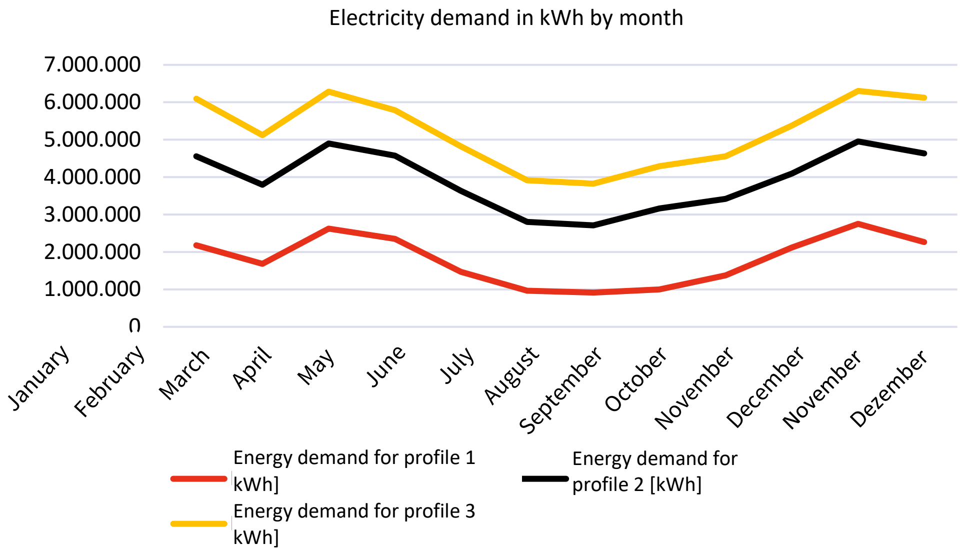


Diagram 9: Annual electricity demands of the three profiles broken down into months.
Source: Authors' compilation based on PGE Dystrybucja S.A.

The highest energy demand occurs in the months of November, December and March. These are also the months with the highest heating demand. This hardly changes between profiles. The energy demand increases overall because more consumers are included in each successive profile. The graphs run in parallel with a nearly 2.00 MWh spacing between them.

5.2. Determination of output required from renewable energies to cover electricity demand

Following the presentation of the electricity demands of all three profiles, coverage of these demands will be addressed in this section. In the consideration of the possibility of covering the electricity demand from renewable sources, the possibility of building plants was analysed. With the potential study 'Energy, clean air and climate protection plan for Hajnówka County and its municipalities Part 2 Energy, GHG and pollutant balance – potential analyses' from the framework project 'Resource-efficient regional development in Podlaskie' of the EuroNatur Foundation (EFV 2018) as a reference, the potential for installing renewable energy sources in the region of the city and municipality of Hajnówka is presented in the table below. At the time of preparation of this analysis, an H10 distance regulation for wind turbines still applied in Poland.

Table 7: Electricity generation potential in the municipality of Hajnówka.

Type of installation	Power [MWe]	Area [m^2/ha]
Building-mounted photovoltaic systems	1.88	
Ground-mounted photovoltaic systems	68.0	81.6
Small-scale wind turbines	0.16	
Wind turbines*	78.0	

*Distance criterion: 1 km from residential buildings. Source: EFV 2018.

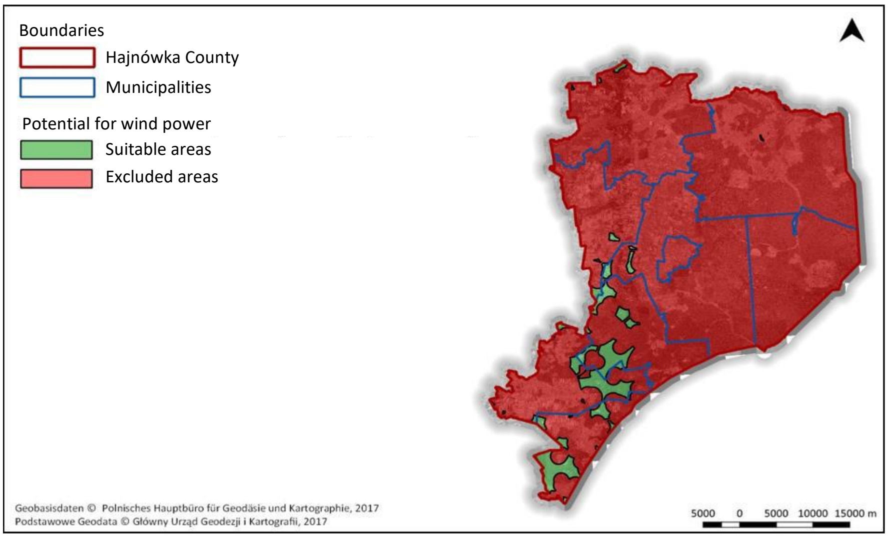


Figure 5: Potential locations for wind turbines, distance to residential zone 1,000 m.
Source: EFV 2018

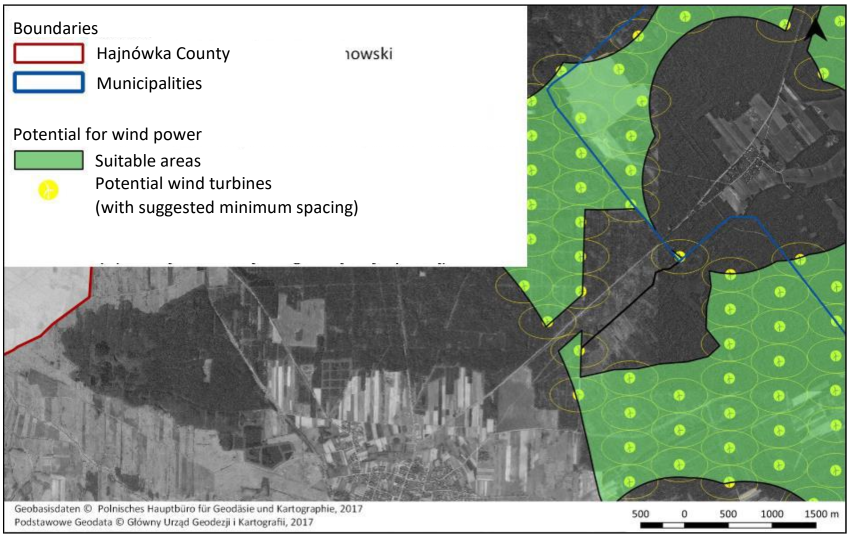


Figure 6: Installation density of wind turbines, distance to residential zone 1,000 m.
Source: EFV 2018

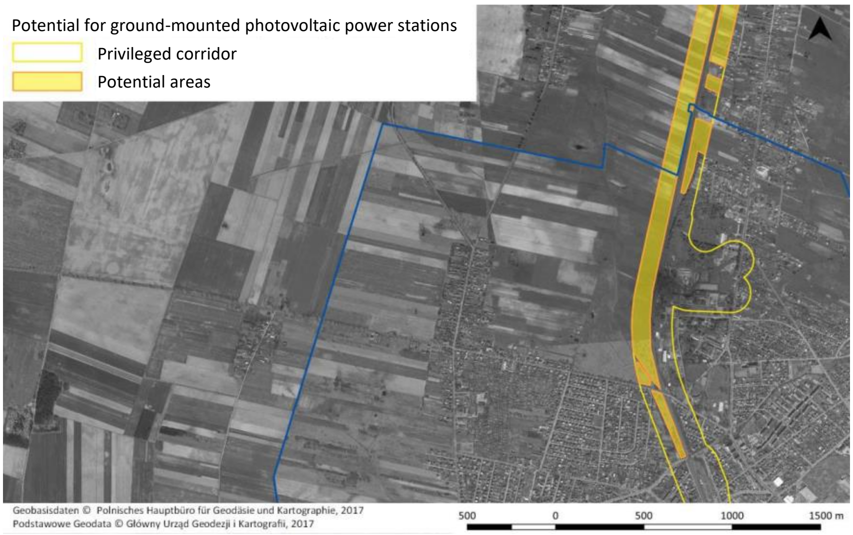


Figure 7: Possible locations for PV systems.
Source: EFV 2018

The figures and the data tables show that the existing potential is sufficient for balancing the electricity demand with photovoltaic and wind energy sources. In total, 433 wind turbines could theoretically be erected; they would generate eleven times as much electricity as is consumed (EFV 2018). If just the suitable areas (green) at a distance of 1,000 metres to a built-up area, approximately 24 wind turbines with a total power of approx. 72 MW could be installed. Based on the existing wind forecasts, the wind turbines should be able to generate a total of about 157,200 MWhel. This already amounts to some 92 per cent of the total annual electricity consumption in 2018 (EFV 2018) of approx. 169,634 MWhel of electricity.

Areas in a 110 m corridor along existing supraregional traffic routes and railway lines (brownfield), rezoned areas (e.g. rock quarries, former dumps, areas previously used by the military) and areas outside of forested regions are especially indicated as possible locations for photovoltaic systems (EFV 2018).

Investment costs per MW of installed output are much lower for renewable energies than for fossil fuel technologies (FOES 2021). The obvious disadvantage is the lack of regulation ability, but with knowledge of the usual energy generation profiles, it can be assumed with a high probability that 1 MW from a photovoltaic system can generate about 1,000–1,050 MWh of energy (Joint Research Centre 2022) and 1 MW of wind power about 2,000–2,500 MWh (EFV 2018) annually.

A comparison between the different profiles and target groups is summarised below.

Table 8: Profile balance summary.

Position	Units	Profile I	Profile II	Profile III
Ground-mounted photovoltaic power stations	kW	3,900.00	5,100.00	5,350.00
Wind power station capacity	kW	8,200.00	19,500.00	26,400.00
Production from PV systems	kWh/year	3,997,500.00	5,227,500.00	5,483,750.00
Wind production	kWh/year	17,712,000.00	42,120,000.00	57,024,000.00
Energy generation	kWh/year	21,709,500.00	47,347,500.00	62,507,750.00
Electricity consumption	kWh/year	21,708,850.74	47,248,077.84	62,505,321.84
Self-consumption	%	60.84%	64.46%	63.92%
Self-sufficiency rate	%	100.00%	100.21%	100.00%

Source: Authors' own calculations.

Analysis of the possibility of covering the electricity demand with renewable energy sources showed that this is a technically feasible goal for all three profiles. At the same time, the installed capacity to be built for reaching 100 per cent annual balance sheet-based self-sufficiency does not exceed the local generation potential from the cited potential analysis (EFV 2018).

In view of the fact that the city of Hajnówka primarily wants to meet its own electricity generation needs, Profile I was taken as a basis for the economic analysis.

6. Feasibility Study

In addition to the technical level, the economic level is, of course, very important and shall be examined in this chapter.

6.1. Investment costs

Investment costs are used for illustration and as a guide - but it cannot be said that they are the final costs. When estimating investment costs, efforts focus on the costs related to the implementation of the investment already in the planning phase. The pre-investment process applies to administrative activities such as:

- Soil investigation (recommended measure to determine the stability of the soil for photovoltaic and wind energy plants,
- Conducting the environmental procedure and obtaining an environmental decision,
- Processing the application for connection conditions and payment of the connection fee,
- Procedure for public consultation in the event that an amendment to the ICZM is required,
- Procedure for amending the local spatial development plan.

These costs are not conditional on a specific production technology and are independent of the final concept that is implemented.

Investment costs have increased significantly, in particular in the period between 2022 and 2023, due to the economic situation in Poland and throughout Europe. A market survey is recommended before making a final decision. By contrast, the final price is significantly influenced by the fact that part of the assembly work and some components are purchased in the local currency - the basic components of the power generation units are converted according to the current exchange rate of the euro and the US dollar. Investment costs are used for illustration and as a guide - but it cannot be said that they are the final costs. In the case of local government units, in particular, it can take approximately 36 months from the time of the decision to the physical realisation of the investment, which is determined not only by the preparation of the investment in the pre-investment phase (i.e. environmental decision, development plan, connection conditions), but also by the procurement of external funds and the duration of the tendering procedures.

The following values per MW of installed capacity were assumed for the investment costs. The price also includes the construction of a transformer station as infrastructure for feeding into the electricity grid:

Table 9: Investment costs of renewable energy in PLN and EUR, own presentation.

	Costs per MW in PLN	Costs per MW in EUR	Total in PLN	Total in EUR
PV costs	3,500,000.00	776,650.00	13,650,000	3,031,665
Wind energy plants	5,700,000.00	1,264,830.00	46,740,000	10,380,954

Just under PLN 50 million or 14 million euros need be calculated for the renewable energy plants. The investment cost of the large-scale heat pumps and a storage system need to be added to this, see the following table.

Table 10: Investment costs of the heat pumps in euros, with two possible subsidy rates. (30 and 70%). Own presentation.

		Investment in the case of subsidy			Capital service with subsidy €/a	
	Capital costs	30 %	70 %	Useful life	30 %	70 %
Heat pump	5,869,450	4,108,615	1,760,835	20 years	263,556	112,953
Hydraulics + storage	2,197,600	1,538,320	659,280	30 years	73,497	31,499
Groundwater	1,230,000	861,000	369,000	30 years	41,137	17,630
Capital costs buildings	2,100,000	1,470,000	630,000	50 years	51,829	22,213
Total investment EWP	**11,397,050**					
Depreciation gas boiler	1,050,000	1,050,000	1,050,000	20 years	67,354	67,354
Total capital-linked costs in €/a					**497,374**	**251,648**

In total, therefore, investment costs in the order of PLN 112 million or EUR 25 million are to be expected.

6.2. Cost of energy production

With regard to the investment costs, the operating costs and the operating costs during an operating period of 25 years were compiled to determine the price of energy production per unit of energy. With regard to the calculation, it is assumed that no loans would be necessary. For the sake simplicity, capital costs are assumed to be constant price values for PV and wind energy, as listed in the following tables.

Table 11*:* Operation and maintenance costs for 1 MW PV and for 1 MW wind energy.

Item	Costs PV [net PLN/year].	Costs PV [Net PLN/ 25 years].	Wind costs [net PLN/year].	Wind costs [Net PLN/ 25 years].
insurance*	21,000.00	525,000.00	34,200.00	855,000.00
Inspection	10,000.00	250,000.00	30,000.00	750,000.00
Lawn mowing	5,000.00	125,000.00	-	-
Module washing	4,000.00	100,000.00	-	-
Repair costs	41,280.00	1,032,000.00	54,720.00	1,094,400.00
Energy for own consumption**	2,050.00	51,250.00	4,320.00	108,000.00
TOTAL PV	**83,330.00**	**1,876,850.00**	**123,240.00**	**2,807,400.00**

* Insurance in the sum of 0.6% of the investment value.
** Energy consumption for own use 0.2% per year x 1000 PLN/MWh, Source: own preparation.

No lease fees were included because the power plants will be located in urban areas where the municipality of Hajnówka is the owner.

The generation costs for 1 MWh of electricity from renewable energy sources were determined based on the calculated operating cost estimate for a 25-year operation of a photovoltaic and wind power plant. The investment costs were added to the operating costs during a period of 25 years and this figure was divided by the amount of energy generated during this period. The electricity generation costs per MWh shown in the following table were determined in this manner.

Table 12*:* Cost of generating 1 MWh from each PV and wind energy during 25 years in PLN.

Item	1 MWh from PV	1 MWh from wind energy
Net investment pln	3,500,000.00	5,700,000.00
Operating costs /25 years/	1,876,850.00	2,807,400.00
Generated energy /25 years/	24,036 MWh	50,625 MWh
Cost of generating 1 MWh	**PLN 223.70**	**PLN 167.96**

Source: own preparation.

According to this, the generation of one MWh costs PLN 224 or approximately 49 euros from photovoltaics and PLN 167.96 or 37 euros from wind energy and is, therefore, significantly below the average prices on the Polish electricity exchange (Globalpetrolprices.com 2022). For comparison in Germany, the maximum value for onshore wind and ground-mounted photovoltaic tenders for the 2023 bidding dates was 73.5 euros and 73.7 euros/329 PLN per MWh, respectively[19] (German Federal Network Agency 2023a and 2023b).

6.3. Future heat price

A future heat price can be calculated based on investment costs and expected running costs.

6.3.1. Electricity price assumptions

A current grid electricity price of PLN 1 or EUR 0.20 per KWh for private customers was assumed (wysokienapiecie.pl 2022). A discounted grid electricity price of PLN 0.81 or EUR 18 per kWh (€180/MWh) from the grid was assumed as the actual value for heat pump electricity, because they fall into a more favourable consumption class due to their consumption profile and power consumption.

[19] Wind: 7.35 cents per KWh, PV: 7.37 cents per KWh.

Table 13*: Assumptions for electricity price determination. Own assumptions.*

	PLN/EUR per kWh
Grid electricity price	PLN 1/ EUR 0.20
Grid electricity price for heat pumps	PLN 0.81/ EUR 0.18
Own power supply for heat pumps	PLN 388/ EUR 86
Distribution fee	PLN 207/ EUR 46

For the electricity supply of the heat pumps from the renewable energy plants (self-supply with wind + PV) an average price of just under PLN 388/EUR 86 per MWh was assumed (2/3 wind, 1/3 PV). Furthermore, the distribution fee was taken as a base value with an average of PLN 207.47 or EUR 46 per MWh.

Cost of a potential (bio)gas boiler to cover the remaining 10 percent of the annual heating work were drawn from empirical values. The cost of a heat storage tank, on the other hand, were not taken into account [20] However, it can be assumed that a heat storage tank has a positive effect on economic efficiency.

6.3.2. Scenarios

Two basic scenarios were selected, in which the heating system continues to run on coal. Since the development of the hard coal price is very difficult to estimate, two scenarios with different prices were calculated.

One scenario was calculated with a coal price of PLN 676 /EUR 150/tonne of hard coal. This corresponds to the price before the start of the Russian war of aggression in Ukraine. A coal price of PLN 1,221 /EUR 272 per tonne was selected as a comparison scenario. This corresponds to the high price of 2022[21]. The scenarios with continued coal use were contrasted with two scenarios with large heat pumps using electricity from new RE plants.[22] The scenarios differ in that in the second one use of additional heat storage was analysed. [23]

Table 14*: Overview of key data selected baseline scenarios with coal.*

Scenario	Coal price per tonne
Coal scenario 1	PLN 1,221/ EUR 272
Coal scenario 2	PLN 676/ EUR 150

Table 15*: Overview of key data for selected scenarios with heat pumps*

Scenario	Gas price per MWh	Subsidy level
Heat pumps	PLN 405/ EUR 90	70 %
Heat pumps + storage	PLN 405/ EUR 90	70 %

Source: own preparation.

For both variants with heat pumps, a new gas boiler was calculated to provide the missing 10 percent heating capacity on very cold days. There, PLN 405/EUR 90 per MWh were taken as values.

It is assumed that a share of 70 percent of the investment costs for the heat pumps can be financed via public subsidies[24].

[20] A detailed economic analysis with storage tanks should be taken into account in an implementation plan. This could not be done in this feasibility study due to a lack of data.
[21] Figure received from municipal utilities.
[22] Whereby the operating and investment costs of the RE plants with electricity generation are depreciated during 25 years.
[23] With a planned useful life of 30 years
[24] Direct subsidies or concessionary loans are conceivable.

6.3.3. Comparison of operating and consumption costs (without CO2 costs)

The following diagram shows the annual operating and consumption costs[25] of the scenarios listed in the previous table. The Europe-wide emissions trading for heat and mobility (ER 2023), which will apply to the heating sector from 2027, is not included in the calculations.

Consumption-based costs in heating systems are costs that are directly linked to the consumption of heating energy. The more efficient a system is, the lower the consumption costs.
A more detailed list of costs can be found in the Appendix. These costs form the basis for determining the future heat price.

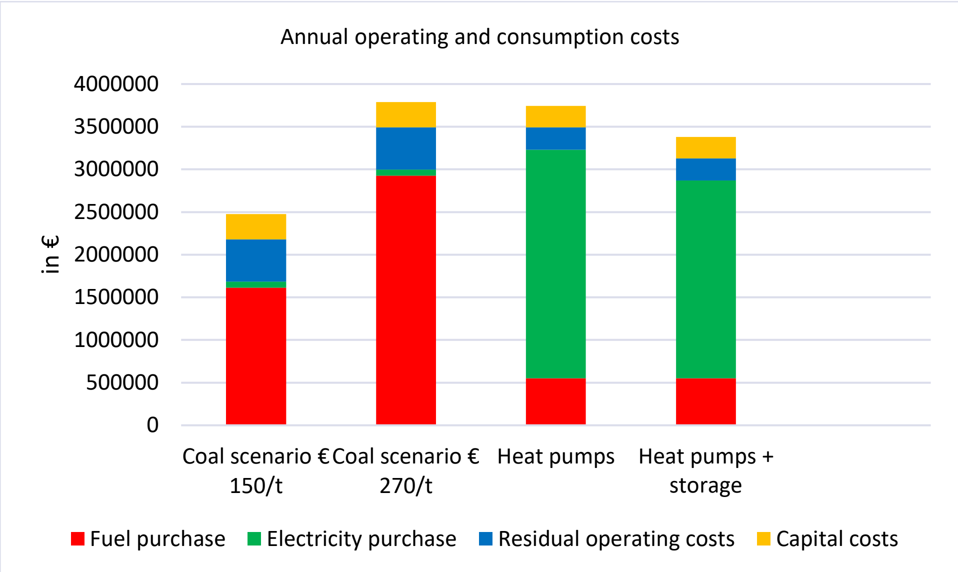


Diagram 10: Compilation of the annual operating and consumption costs in euros according to the current framework conditions for scenarios (existing heating network with two different coal prices + heat pump scenarios without and with heat storage). Own presentation.

It can be seen that at coal prices from before the war in Ukraine, the current system has the lowest operating and consumption costs of all scenarios. At the same time, it becomes clear that high coal prices, as in 2022, raise the costs to the same or above the level of the heat pump systems. This shows the high price sensitivity of the existing heating system.

By contrast, the prices of electricity purchased from own renewable energy plants can be predicted well. Once the systems have been installed, the pure generation price of a kilowatt hour is effectively constant for the entire operating period.

Changes in the purchase of electricity from the public grid may apply. The highest possible self-consumption is therefore a good hedge against such changes (see Chapter 2). The heat storage systems additionally strengthen this effect because they further increase self-consumption and reduce the amount of electricity drawn from the grid. The dimensioning of the storage facilities and their financing would need to be examined in detail in an implementation plan. However, it is already clear that the additional investment costs can be more than compensated for by the significantly lower operating costs during the operating period.

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[25] Without CO2 costs

An average grid fee of the last two years was used for the analysis. It is quite conceivable that the grid fees for new energy communities will be reduced. The Polish state considers the establishment of energy communities a good way to develop rural areas and promotes energy communities and plans further support. Since this process has not yet been completed and only a few energy communities have been founded, a conservative calculation was made here with a grid fee that is probably too high.

6.3.4. Comparison of heat prices for the scenarios (with CO2 price)

The future EU emissions trading for the heating sector from 2027 must also be included in the analysis to evaluate the long-term heat prices and, therefore, the economic viability of the different scenarios. By 2050, the heating sector is to be climate neutral in accordance with the EU climate targets. By way of various regulations, the CO2 price is capped at 45 euros/tonne up until 2030 (ER 2023).

Due to the high CO2 emissions in the heating sector and the ambitious reduction path of 5.1 percent annually (5.30 percent from 2028), it can be assumed that the maximum price will be reached right at the beginning and will not be undercut thereafter. Moreover, it is to be assumed that CO2 prices will rise after 2030.

Therefore, the heating costs are calculated with three different CO2 prices in each case for the comparison of the scenarios: EUR 45/tonne as a lower limit, EUR 100/tonne as a probable value after 2030 and EUR 200/tonne as a value that covers the actual environmental costs of CO2 emissions (Abrell et al 2022).

The figures were assumed to be constant for the entire operating period. Although this does not reflect fluctuations over time, it is sufficient for a reliable evaluation of the scenarios.

Table 16 and Diagram 11 show that the relations between the scenarios shift significantly.

Table 16: Effects of a C02 price on annual costs

Variants	Annual costs	Total annual costs with a C02 price of			Heat costs in €/MWh		
CO_2 price scenario		**€ 45**	**€ 100**	**€ 200**	**€ 45**	**€ 100**	**€ 200**
Actual situation							
Coal boiler € 272 /t	3,822,047	5,137,506	6,745,289	9,668,530	93	123	176
Coal boiler 150 €/t	2,509,449	3,824,908	5,432,691	8,355,932	70	99	152
Heat pumps							
Heat pumps	3,743,817	4,049,524	4,423,167	5,102,516	74	80	93
Heat pumps + storage	3,381,545	3,596,432	3,859,071	4,336,598	65	70	79

Own estimates. More detailed in the Annex.

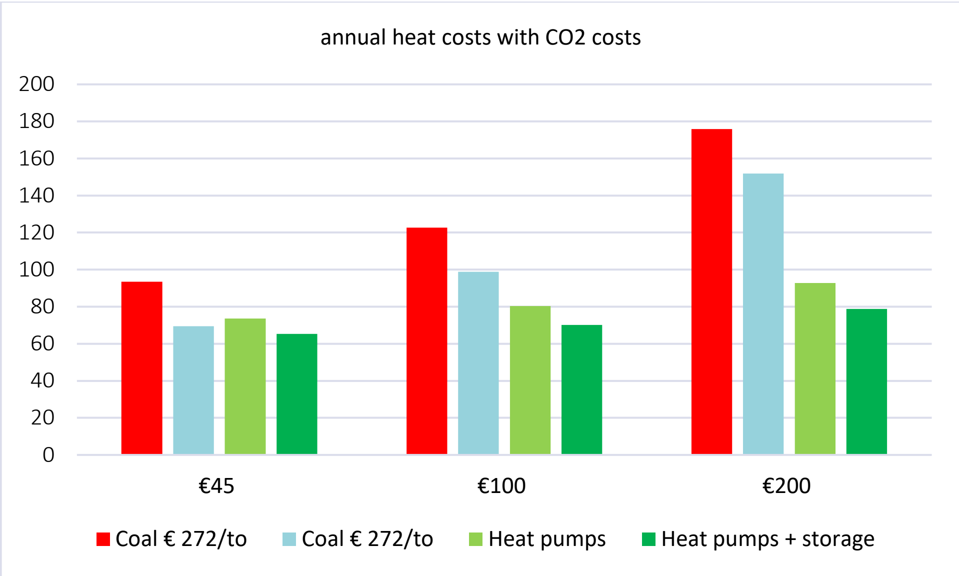

Diagram 11: Representation of the heat costs (€/MWh) of the four scenarios (coal scenario 1 + 2, heat pumps and heat pumps + storage in dependence of CO_2 certificate prices (EUR 45, EUR 100 and EUR 200/t).v Own representation.

Already at a CO2 price of EUR 45/t[26], the heat pump systems have the same price level as the existing heating system at the lower coal price. The heat pump system with storage is even lower. At the higher coal price as in 2022, the differences are significant at EUR 15 and EUR 28 respectively[27].

In the case of rising CO2 prices, the heating costs (due to the remaining fossil-covered residual heat demand of 10 percent) for the heat pump systems also increase, but only moderately. If a biomass boiler were used, the heating costs would not be affected by the CO2 price. In comparison, the heating costs for the existing system would almost double. The increase in both price scenarios is more than PLN 360 or EUR 80/MWh.

Political market interventions would be necessary if the heat prices for consumers and/or companies are nevertheless to remain constant in the existing system or not increase to the same extent. The then incumbent Polish government would have to cap the price by taking over the difference via subsidies. Otherwise, the price of fossil-based heat will increase accordingly for the end consumer.

In a comparison of heat pump systems, the higher self-consumption share due to the additional heat storage shows even less sensitivity to higher CO2 prices. The increase in heating costs is only PLN 63/EUR 14/MWh compared to PLN 85/EUR 19/MWh for the system without additional heat storage.

This illustrates two things:
On the one hand, it shows how sensitively the heat costs react to changing fuel costs. On the other, it shows the high level of cost stability that a changeover to an own power supply with renewable energies entails and contributes to the security of supply of the region.

7. CO2 reduction

In addition to a cheaper and above all reliable heating price for the citizens of Hajnówka and the companies, the reduction of climate-damaging emissions is also a subject of this study.

[26] PLN 202
[27] PLN 68 or PLN 126.

One kilowatt hour of electricity in Poland currently causes an average of 569 grams of CO_2. Heat production with pulverised lignite and fluidised bed coal causes an average of 97.5 tonnes of CO2 per terajoule. One terajoule is equivalent to 277.78 megawatt hours and consequently 350.997 grams of carbon dioxide are produced per kilowatt hour (Federal Environment Agency 2022).

The following table shows that even if the heat pumps are completely supplied with electricity from the public grid, the CO2 balance improves.

Table 17: Co_2-savings with grid electricity and with new RE plants

	Actual situation	Heat pumps with grid electricity	Heat pumps with RES	Heat pumps with RES and storage	
Coal	28,834	-		-	to /year
Gas	-	1,228	1,228	1,228	to /year
Electricity grid	398	12,293	4,917	2,704	to /year
Electricity EE	-	-	648	843	to /year
Total CO^2	29,232	13,521	6,793	4,775	to /year
Reduction in %		54 %	77 %	84 %	to /year

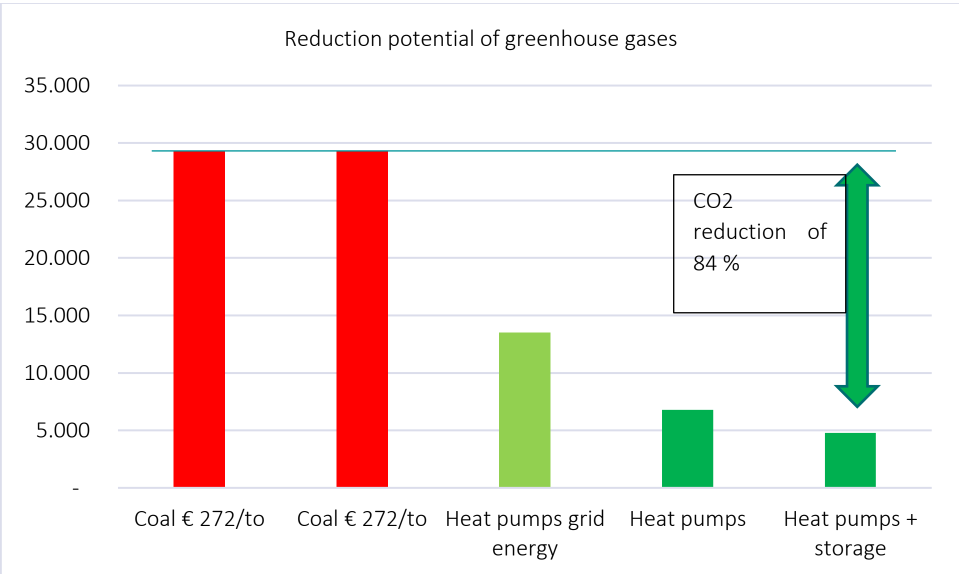

Diagram 12: Compilation of the reduction in emissions when the heating network is converted to heat pumps.

A conversion to heat pumps alone would result in a CO2 reduction of 54% with the current electricity mix. Since it can be assumed that the electricity mix in Poland will become steadily lower in CO2 in the future due to the expansion of renewable energies, this calculation would improve even further in the coming years. However, if 60 per cent of the energy supply comes from renewable sources, as proposed in this study, and if a storage system is used to increase the share of self-generated electricity, CO2 emissions will be reduced by 84 per cent[28].

8. Impact on the region

High and unstable fuel purchase prices put a strain on the budgets of households and municipal companies supplying system heat, in particular in economically underdeveloped regions.
The price dynamics in 2022 were exceptional.

[28] 4,775 tonnes of CO_2 instead of 29,323 tonnes of CO_2.

According to the Polish Industrial Development Agency, the PSCMI2 coal index (for district heating companies) in August 2022 was PLN 1338.35/t (PLN 54.75/GJ), up 194 per cent from July. The average monthly price of such coal at ARA ports in August was about PLN 1776/t (Energia 2022).

The increased cost of purchasing coal for heat and power generation leads to a significant increase in operating costs, i.e. many district heating companies operate on the edge of profitability. The cost of generating heat from fossil fuels is highly influenced by the EU's strengthened climate targets, including the withdrawal of free CO2 allowances and the inclusion of the building and transport sectors in the emissions trading scheme.

Carbon allowance prices will affect poorer households belonging to the first income quintile. The least prosperous EU Member States will also be more affected by the increase in emission allowance prices. In the case of Poland, the cost increase for households is likely to be much higher than in the EU27 (Cire 2021). At the PGE Energia Ciepła heat provider in western Poland, CO2 emission costs already accounted for 38 per cent of the total cost of heat production in 2022. At PEC Biała Podlaska it was 38.9 percent and at MPEC Olsztyn – 30 percent. The increase in fuel prices and CO2 emission charges increased the cost of heat generation at MPEC Olsztyn by 100 percent in 2022 (Portalsamorzadowy 2022).

Reducing the import of energy sources and replacing them with energy from local sources, i.e. wind, solar, biomass, will significantly reduce the capital outflow from the region and increase the purchasing power of residents.

The described economic effect depends on the ownership structure of the RES plants. Research by the University of Kassel (2016) shows that the regional benefits of wind energy are eight times higher if the plant is owned by local actors and not by external investors. Participatory financing, which gives residents the opportunity to participate in the construction and operation of the plant, is a decisive factor for the acceptance of the investment.

Already the individual prosumer, who is both producer and consumer of the energy consumed on site, often without feeding it into the grid, contributes to strengthening regional purchasing power (this also applies to the group prosumer, which operates according to similar principles). In the case of a prosumer cooperative, which operates in a community of producers and consumers, the economic success is usually significantly higher, in particular if surplus electricity is used to generate heat or for mobility purposes.

A significant advantage of an energy community, operated for example as a cooperative or as an organisation with another legal form, is the possibility of energy exchange between the members of the community (energy sharing). In the Directive of the European Parliament and of the Council 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources, Article 22(2), B Renewable Energy Directive II), explicitly grants the "Renewable energy community" ("Renewable Energy Communities") the right to share the renewable energy produced by the generating units owned by this energy community. In that respect it is irrelevant whether the generation and storage facilities required for this are privately owned by individual members of the community or owned by the community as a whole, as long as the managers (operators) of the facilities act on the basis of instructions from the renewable energy prosumers within the meaning of Article 21, 5 Renewable Energy Directive II.

Put in perspective, the goal of the municipalities should not only be the generation of electricity. Converting electricity into heat, electricity into gas or electricity into mobility is also a sensible option, which should balance out the imbalance in energy generation over time and at the same time stimulate regional economic activity. The networking and digitalisation of generation units, storage facilities and consumers enables the intelligent control of energy generation and consumption within a community and the creation of a virtual power plant.

Such a prosumer group is still a pipe dream, however, because there are only a few examples of organisations that operate as a whole (e.g. with the management of surplus energy for electro-mobility) according to the scheme described. But there are already examples of prosumer “Communities” that meet a basic requirement: Consumers join together to supply themselves with energy, as long as this makes economic sense and is technically possible.

In Poland, too, the legal construction of energy cooperatives and energy clusters provides a framework that creates the space for energy communities to operate. Technical and economic progress to date and forecasts for the future suggest that the idea of prosumer communities will spread rapidly and the energy management developed in them will become the norm. Prosumer communities will initiate new local and regional economic relationships that will strengthen local economies and create new, valuable jobs. However, their goal will not be to make profits, but to provide energy to community members at the best possible price.

8.1.Improving air quality

The biggest threat to air quality in Hajnówka are emissions (Hajnówka 2022) associated with the combustion of solid and liquid fuels, the products of which are dust (PM2.5, PM10), gases (carbon dioxide - CO_2, carbon monoxide - CO, sulphur dioxide - SO_2, nitrogen oxides - NO_x, polycyclic aromatic hydrocarbons such as. e.g. bezno(a)pyrene, and heavy metals (lead - Pb, arsenic - As, nickel - Ni, cadmium - Cd).

Air quality modelling in the Podlaskie Voivodeship report (Główny Inspektorat Ochrony Środowiska 2021) shows that in 2021 in Hajnówka the concentration of benzo(a)pyrene in PM10 fine dust exceeds the values of the “Target value for the average annual concentration for the protection of health” and ranges from 1.5 ng/m^3 to about 5 ng/m^3. The maximum PM10 concentration from the daily average concentrations indicates elevated values of this indicator, which ranged between 35.5 $\mu g/m^3$ and 45 $\mu g/m^3$.

An end to coal combustion in Hajnówka's heating system will significantly improve air quality and, therefore, the health of the city’s residents.

8.2.Hajnówka as a pioneer

The promotional activities and the numerous projects conducted by the district and city authorities in cooperation with foreign partners contribute to a positive image of the Bialowieza Forest by protecting the climate and ensuring energy independence and quality of life for the inhabitants. Hajnówka is taking a pioneering role in the energy transition by way of the model solution of heat generation from renewable energy sources using the existing municipal central heating network. It is also the first step towards creating energy communities.

Given the significant potential of Hajnówka County's forest and agricultural ecosystems to sequester carbon dioxide emitted by the economy, Hajnówka could become one of the first net-zero emitting cities in Poland.

8.3.Impact on local regional labour market

Impact The project is not expected to have a significant impact on the labour market. Some increase in employment might result from the increased connection of heat consumers to the grid and the related need for expansion. The project is unlikely to have an impact on the regional RES market, which is developing independently and is mainly designed in response to the voivodeships’ national support schemes.

However, an increase in RES competence and power-to-X technology of PEC Hajnówka’s employees is very likely. The company could quickly become a national pioneer of the energy transition, following the example of Stadtwerke Wunsiedel (SWW Wunsiedel GmbH) in Germany, which has been inspiring local communities to take new paths towards sustainability and climate neutrality for years[29]. An increased number of visits and study tours could have a positive impact on the local labour market in the hospitality sector, among others.

9. Conclusion and recommendations for potential implementation

The local heating network of the town of Hajnówka is a good example for many other local heating networks of small towns in rural Poland.

The conducted analysis shows that converting the heating network of the town of Hajnówka to a power to heat system will bring many benefits to all stakeholders in the medium and long term.

It can be assumed that the long-term costs will be significantly lower than for continued operation with coal. Especially after the start of EU emissions trading for heat and mobility in 2027, a switch to an electricity-based heating system with its own renewable electricity generation has clear economic advantages. A "Simple" implementation with heat pumps would keep costs stable in the medium and long term and save over 22,000 tonnes of CO2 emissions annually. If a heat storage system were added to the system, the heating costs would be further reduced and stabilised, and the CO2 reduction would increase to 25,000 tonnes per year.

In addition, the air quality would improve considerably, the economic situation of the municipal utilities would stabilise and the regional added value would increase if the citizen participation is properly designed.

All those involved in the project would very much welcome it if the Powiat, the city of Hajnówka and the municipal utilities were to pursue and implement this feasibility study. This would make an important contribution to the energy independence, economic development and financial stability of the region.

Notes on possible detailed and implementation planning

Some of the assumptions still need to be checked, verified or clarified in the implementation planning.
These include:

- Exact wastewater temperature
- Availability of groundwater
- Space required and available for the heat pump cascades, buffer storage and large heat storage tank
- Control concept and integration in the central control technology,
- Detailed market investigation into price developments for the main components and services (due to the dynamic price development in Poland and Europe in recent months)
- Review of use of a biomass boiler instead of a gas boiler.
- Installation of heat storage tanks.

The implementation planning, or detailed planning, is to be drawn up following consultation with the other project participants and the responsible decision-makers in the town of Hajnówka, after the present concept has been endorsed and is to be taken forward.

[29] Other examples of EE villages are: Feldheim in Brandenburg, Schönau in the southern Black Forest (EWS), Wolfhagen in Hesse, Steinfurt administrative district in Lower Saxony, Energievision Franken (Bavaria).

As part of the detailed planning, a review should also be conducted as to whether the entire electricity demand of the Hajnówka region can be covered by wind and PV plants, at least on a balance sheet basis. The heating sector will have the greatest electricity demand following a conversion to heat pumps. The additional planning and financing costs for further renewable energy plants and their land requirements are manageable. The available land is sufficient in any case (see Chapter 5.2.)

Providing impetus for other municipalities

It is also desirable that other municipalities are motivated by this study to convert their district heating to a Power-To-Heat system. Experience gained from this study should be included in feasibility studies for other municipalities. Active communication with the municipal representatives at an early stage and the active involvement of the local public utilities has proven to be essential. The local municipal utilities are a key player in this process: They have all the necessary data or can collect such data. They are responsible for the implementation of the measures. They can keep heating costs stable for their customers by way of the climate-friendly conversion of their heating network and, therefore, honour their public service mission. And they secure their own long-term economic stability.

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II.Appendix

Table 18: Average flow from the wastewater pumping station to the urban wastewater treatment plant in m³ per month.

Month 2021	1	2	3	4	5	6	7	8	9	10	11	12	2021
Volume in m³	60.00	65.41	83.47	72.86	83.49	75.41	104.85	106.75	80.01	72.99	66.08	74.87	94618

Month 2022	1	2	3	4	5	6	7	8	9	10	11	12	2022
Volume in m³	86,066	87,098	77,852	85,744	77,013	74,428	98,234						586435

Data collection from August 2022. Section 4.2.

Table 19: Heat pump stations 1 and 2 detailed compilation. Section 4.2.

		Required 10,660 kW			Required 7,000 kW				Total HP 1 + HP 2 + boilers
Total	HP station 1	Boiler output	*Total 1*	HP station 2	Boiler output	*Total 2*	HP 1 + HP 2		
Heating output Qh	**5,564.0** kW	**5,087.2**	**10,651.2**	**3,503.0** kW	**3,488.4**	**6,991.4**	**9,067.0**	kW	**17,642.6**
Electric power consumption N	**1,802.0** kW			**1,131.0** kW			**2,933.0**	kW	
Cooling output Qc	**3,762.0** kW			**2,372.0** kW			**6,134.0**	kW	
COP heating	**3.1**			**3.1**			**3.1**		
Evaporator									
Inlet	**10.0** °C			**10.0** °C			**10.0**	°C	
Outlet	**6.0** °C			**6.0** °C			**6.0**	°C	
Volume	**808.8** m³/h			**510.0** m³/h			**1,318.8**	m³/h	
Condenser									
Inlet	**50.0** °C	**80.0**	**50.0**	**50.0** °C	80.0	**55.0**	**50.0**	°C	
Outlet	**80.0** °C	**105.0**	**105.0**	**80.0** °C	105.0	**105.0**	**80.0**	°C	
Volume	**159.5** m³/h	**175.0**	**166.5**	**100.4** m³/h	120.0	**120.3**	**159.5 / 100.4**	m³/h	

Table 20: Sold heat energy from district heating network in 2020. Section 5.1.

	Group	Subgroup	Location	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Energy units				[GJ]											
2020	I	1	Masuren	8,030	6,940	7,201	5,486	3,411	2,227	2,020	1,847	2,184	4,866	5,893	8 822
		2	Batorego	7,875	7,102	6,622	4,905	2,834	1,331	1,191	1,279	1,373	4,560	5,922	7 943
		Group total		**15 905**	**14,042**	**13,823**	**10,391**	**6,245**	**3,558**	**3,211**	**3,126**	**3,557**	**9,426**	**11,815**	**16,765**
	II	3	Armii Krajowej	9,210	8,361	7,760	5,626	3,112	1,462	1,566	1,587	1,767	5,727	7,240	9 420
		4	Podlasie	2,894	2,605	2,427	1,885	1,308	631	569	637	666	1,727	2,304	2 981
		Group total		**12 104**	**10,966**	**10,187**	**7,511**	**4,420**	**2,093**	**2,135**	**2,224**	**2,433**	**7,454**	**9,544**	**12,401**
		Year total		**28 009**	**25,008**	**24,010**	**17,902**	**10,665**	**5,651**	**5,346**	**5,350**	**5,990**	**16,880**	**21,359**	**29,166**

Source: PEC Hajnówka.

Table 21: Sold heat energy from district heating network in 2021. Section 5.1.

	Group	Subgroup	Location	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII

Energy units				[GJ]											
2021	I	1	Masuren	8,598	9,097	8,280	5,945	3,139	2,113	1,902	1,826	3,233	5,453	7,062	8 822
		2	Batorego	8,650	8,093	6,929	5,224	2,412	1,313	1,142	1,320	2,784	4,751	6,715	7 943
		Group total		**15 905**	**17,248**	**17,190**	**15,209**	**11,169**	**5,551**	**3,426**	**3,044**	**3,146**	**6,017**	**10,204**	**13,777**
	II	3	Armii Krajowej	10,382	10,033	8,818	6,524	2,996	1,528	1,296	1,572	3,619	6,045	8,397	10 479
		4	Podlasie	3,333	3,092	2,733	2,081	1,129	676	599	665	1,230	1,897	2,599	3 355
		Group total		**12 104**	**13,715**	**13,125**	**11,551**	**8,605**	**4,125**	**2,204**	**1,895**	**2,237**	**4,849**	**7,942**	**10,996**
		Year total		**30 963**	**30,315**	**26,760**	**19,774**	**9,676**	**5,630**	**4,939**	**5,383**	**10,866**	**18,146**	**24,773**	**31,867**

Source: PEC Hajnówka.

Table 22: Sold heat energy from district heating network in 2022. Section 5.1.

	Group	Subgroup	Location	I	II	III	IV	V	VI	VII.	VIII	IX	X	XI	XII
Energy units				[GJ]											
2022	I	1	Masuren	9,360	7,459	7,715	5,963	3,264	2,005	1,806	1,907	3,080	4,431	6,721	7 903
		2	Batorego	8,470	6,863	6,953	5,505	2,182	1,309	1,268	1,170	2,523	4,182	6,273	8 030
		Group total		**15 905**	**17,830**	**14,322**	**14,668**	**11,468**	**5,446**	**3,314**	**3,074**	**3,077**	**5,603**	**8,613**	**12,994**
	II	3	Armii Krajowej	10,226	8,320	8,603	6,884	2,697	1,541	1,477	1,272	3,417	5,452	7,840	9 858
		4	Podlasie	3,247	2,608	2,703	2,144	1,023	683	656	573	1,208	1,651	2,437	3 207
		Group total		**12 104**	**13,473**	**10,928**	**11,306**	**9,028**	**3,720**	**2,224**	**2,133**	**1,845**	**4,625**	**7,103**	**10,277**
		Year total		**31 303**	**25,250**	**25,974**	**20,496**	**9,166**	**5,538**	**5,207**	**4,922**	**10,228**	**15,716**	**23,271**	**28,998**

Source: PEC Hajnówka.

Table 23: Profiles I to III – Electricity demand.

Month	Energy demand for profile 1 [kWh]	Energy demand for profile 2 [kWh]	Energy demand for profile 3 [kWh]
January	2,179,093	4,554,010	6,094,825
February	1,687,591	3,798,183	5,117,620
March	2,627,507	4,899,478	6,287,880
April	2,348,189	4,577,925	5,786,959
May	1,473,756	3,633,250	4,822,896
June	967,012	2,805,976	3,915,051
July	915,109	2,711,482	3,825,624
August	998,732	3,165,370	4,294,996
September	1,375,358	3,421,410	4,552,749
October	2,119,985	4,095,653	5,377,428
November	2,751,656	4,953,580	6,303,575
December	2,264,862	4,631,760	6,125,720
TOTAL	**21,708,851**	**47,248,078**	62,505,322

Source: Authors' compilation based on PGE Dystrybucja S.A. Section 5.1.

Table 24: Assumptions for investment and energy costs for heat pumps and gas boilers

Cost item		Unit
Gas - oil price (estimated)	90	€/MWh
Boiler efficiency (estimated)	90	%
Electricity demand heat pumps (OPS)	18,786	MWh/a

Electricity demand for auxiliary drives EWP (OPS)	2,818	MWh/a
Total electricity demand heat pumps (OPS)	21,604	MWh/a
Network losses (OPS)	12	%
Boiler investment costs (estimated)	80,000	€/MW
Investment costs rest (estimated)	25,000	€/MW
Gas boiler output	10.00	MW
Fuel costs gas boiler (calculated)	100.0	€/MWh
Total investment heat pump (OPS)	11,397,050	€

Table 25: Consumption and operational costs (electricity and fuel costs) of the different scenarios.

Scenario: **Coal price of € 272 per tonne.**			Annual costs in EUR
Coal consumption boiler	10,759 to/a	€ 272/to	2,926,448
Electricity demand coal-fired boiler	700 MWh/a	€ 100/MWh	70,000
Operating costs			528,978
Total			**3,525,426**
Scenario: Heat pumps			
Boiler gas consumption	6,111 MWh/a	€ 90/MWh	550,000
Electricity demand EWP from solar	12,962 MWh/a	€ 65/MWh	1,125,650
Electricity demand EWP from grid	8,642 MWh/a	€ 180/MWh	1,555,481
Operating costs			261,038
Capital-related costs			251,648
Total:			**3,743,817**
Scenario: Heat pumps + energy storage			
Boiler gas consumption	6,111	90	550,000
Electricity demand EWP from solar	16,851	65	1,463,344
Electricity demand EWP from grid	4,753	180	855,514
Operating costs			261,038
Capital-related costs			251,648
Total:			**3,381,545**

Own presentation. See next table for a detailed list of operationally linked costs.

Table 26: Operational costs of the current status and forecast when the heat pumps are installed.

Operational costs of the coal boilers	EUR		€/a
Boiler operation	16.7	25,000	418,478
Boiler maintenance	2,550,000	3 %	76,500
Maintenance of conveying and ash removal	1,360,000	2.5 %	34,000
Total operating costs			**528,978**

Operational costs heat pumps			
Maintenance of gas boilers	1,050,000	1 %	10,500
Personnel engineer		40,000	160,000
Maintenance contract	13	2,574	33,462
Maintenance hydraulics	2,197,600	1 %	21,976
Groundwater maintenance	1,230,000	2 %	24,600
Building maintenance	2,100,000	0.5 %	10,500
Total operating costs			**261,038**

Table 27: Impact of a Co2 price on annual costs. Own forecasts.

Variants	**Annual costs**	**CO_2 price**			**Total annual costs**			**Heat costs in €/MWh**		
CO_2 price scenario		**€ 45**	**€ 100**	**€ 200**	**€ 45**	**€ 100**	**€ 200**	**€ 45**	**€ 100**	**€ 200**
Actual situation										
Coal boiler 272 €/t	3,822,047	1,315,459	2,924,712	5,849,423	5,137,506	6,746,759	9,671,470	93	123	176
Coal boiler 150 €/t	2,509,449	1,315,459	2,924,712	5,849,423	3,824,908	5,434,161	8,358,872	70	99	152
Heat pumps										
Own electricity use, 70%	3,460,719	305,707	697,497	1,394,994	3,766,427	4,158,216	4,855,713	68	76	88
With storage	3,013,519	214,887	487,507	975,014	3,228,405	3,501,026	3,988,533	59	64	73