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Transformation of the Polish Heating Sector Based on an Example of Select Heat Energy Companies Supplying Energy to Local Government Units

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Abstract: The aim of this study was to identify changes in the Polish heating sector and assess modernization investments in the field of energy transformation. This research covered 30 municipalities in Poland that applied for the II National Competition for Local Government Units for the Most Energy Innovative Local Government. In terms of changes, the analysis covered the years 2002–2021 and in the investment assessment, data from 2021 were used, as well as plans and strategies of enterprises and local governments. To assess planned investments in district heating companies, an original method of assessing social needs and the ability and readiness of enterprises to modernize the infrastructure in the field of heating was developed. It considers the emissivity factor of a heating plant and the assessment of investments by experts according to nine criteria. The method was used to assess changes in the district heating system in 30 municipalities in Poland. The shaping of the energy strategy in Poland is influenced by the climate and energy policy of the European Union (EU), which assumes that by 2040, households and industries will be heated with system heat or low-emission energy sources. Poland is the second-largest district heating market in the European Union, but heat production in the country is dependent on coal, which is why this sector requires transformation in the coming years. Research shows that thermal energy companies modernizing their installations more often use low-emission technologies than zero-emission ones. The main objectives of investments in energy production are the decarbonization of the heating system and a reduction in greenhouse gas emissions, as well as social needs in the field of connecting houses and flats to the system networks.

Keywords: heating; heating sector; local government; heat companies; heat energy

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1. Introduction

More than half of the energy demand is used for heating and cooling. The world's heating industry is largely based on fossil fuels such as coal, natural gas and oil. In Europe, more than 70% of this energy comes from fossil fuels. In households, this figure is as high as 80%. Statistics show that there are 22 million old, substandard heating appliances and several thousand large fossil fuel appliances in households in the European Union [1]. Dependence on traditional energy sources contributes to greenhouse gas emissions and ultimately to global warming, climate change and health problems. These problems contribute to the need to accelerate actions for the energy transition. They concern most countries in the world, even those countries where these activities are most advanced, i.e., in Europe and, in particular, in the countries of the European Union. Of course, the level of

change is not equal in all countries, and high costs and restrictions on access to modern technologies slow down these processes. Therefore, it is important to know the need for transformation, challenges, initiatives and progress, as well as the role of innovation and modern technologies of "green heat" considering sustainable development.

The energy transition processes in the field of heating have been undertaken by Poland, which has the second-largest district heating market in Europe after Germany.

About 42% of more than 13.6 million households are connected to the district heating network. The district heating network is therefore used by about 16.1 million inhabitants of the country [2]. The total amount of thermal capacity installed at licensed heat producers in 2021 was 54,109.6 MW [3]. Unfortunately, heat production in Poland is dependent on coal, whose share in 2021 accounted for 69.5% of consumable fuels, which was the highest rate in Europe. Until recently, this was not a problem, but the tightening standards for gas emissions (SOx—acid gases, NOx—acid gases) and particulate matter with a size of less than 2.5 μm (PM2.5) and particulate matter with a diameter of 2.5 to 10 μm (PM10—2.5), as well as the growing cost of purchasing CO_2 emission allowances, mean that this type of fuel is an increasing source of costs. In addition, it is estimated that as many as 80% of the heating and boiler plants in Poland do not meet the requirements of the Energy Efficiency Act, and many of them do not meet the increasingly higher standards of greenhouse gas and dust emissions [4]. Some of these heating and boiler plants (80%) heat about 3.5 million buildings, which are equipped with outdated heat sources in which low-quality coal, and sometimes waste, is burned. Even more worrying is the fact that individual households have renewed the burning of lignite. The ban on the use of this fuel was frozen for 2 years due to the lack of hard coal on the market and its high prices caused by the dependence on supplies of this raw material from Russia. This contributes to the so-called low emission, i.e., the emission of PM dust and carcinogenic benzopyrene from chimneys with an outlet below 40 m in height. Due to such pessimistic data, the development of modern technologies based mainly on renewable energy sources, and above all, the modernization of heating plants, is inevitable in Poland. Global warming and climate change, as well as social and political pressures, mean that these actions must be accelerated. The aim is to increase the share of low-carbon sources, including the use of renewable energy sources (such as solar, wind, geothermal or biomass). One of the innovative solutions is to base the energy generation market on hydrogen technologies. This will allow the industry to achieve climate neutrality in Poland and globally in the future [5]. Research also shows the possibility of using heat pumps in buildings to carry out the energy transition process and decarbonize the country [6].

Analyzing the global situation, it can be seen that many countries have focused on innovation, and the strategies adopted focus on:

- Transition to electricity: Many world leaders, including those in European countries, are actively working on decarbonizing their economies by investing in modern technologies and renewable energy sources.
- Digitalization and smart grids: Technologies such as the smart grid, which ensure better management and distribution of energy, are becoming more common in the world.
- The use of nuclear energy: Investments in this technology contribute to reducing the release of CO_2 emissions [7].

The European Union, including Poland, strives to introduce strict rules in its sustainable development strategies. The key elements of the above-mentioned district heating strategy include the efficient use of energy, the development of cogeneration, increasing the share of renewable energy sources (RESs) and a reduction in greenhouse gas emissions, as well as the implementation of energy-saving technologies in buildings [8]. As a result, the energy sector, including heating, is being transformed by promoting low-emission technologies and reducing the use of fossil fuels in favor of renewable energy sources. The deployment of smart district heating and electricity grids and their integration into sustainable smart energy systems is of paramount importance in this process [9–13].

The EU's climate policy assumes that by 2040, households and industries will be heated with district heating or low-emission energy sources. This obliges companies to significantly reduce greenhouse gas emissions, as well as to improve energy security and increase competitiveness and energy efficiency of the economy. Such activities contribute to an improvement in the living conditions of urban and rural residents, including ensuring the protection of citizens against drastic increases in fees for the use of heat. This is also the goal set by the government in the "Energy Policy Polish until 2040" [14].

Activities in the field of energy transition, including heating, are significant for the local and international community due to climate change, energy security, regional air quality and economic and political dynamics in the European Union. Poland relies heavily on coal, one of the fossil fuels with the highest carbon emissions, for heating and electricity generation. This dependency is of serious concern to the international community due to the sector's huge share of greenhouse gas emissions, which contribute to climate change. Therefore, international stakeholders are closely watching the efforts of Poland and Polish local governments to transition to cleaner energy sources [15].

Energy security is also crucial for any country, and Poland's district heating sector is an integral part of it, especially given the geopolitical tensions in Europe and the efforts of various countries to reduce their dependence on Russian gas. Diversification of energy sources, including the use of renewable energy in heating, can increase the energy security of Poland, and thus the entire EU region [16].

The burning of coal and other fossil fuels for heating is a major source of air pollution. This has a serious impact on public health and the environment. It is an issue that transcends national borders and affects neighboring countries, making it a matter of international concern [17].

Poland is an EU Member State, and its internal energy policy, including the heating sector, is relevant to the bloc's broader goals, such as energy transition, economic cohesion and regional development. The EU's ambitious greenhouse gas emission reduction targets require joint action by all Member States, making the Polish energy sector a key area of focus [18].

Therefore, the scale of investment and modernization needs is enormous. As noted by Skowroński, from the National Energy Conservation Agency [19], over the next 10 years, the value of expenditures on investments in the heating sector may amount to about PLN 100 billion. In the case of large companies (capital groups), this modernization is already in advanced stages. Medium and small district heating companies, below 50 MW, which account for almost 50% of this sector, have more difficulties. In this case, it will be necessary to increase financial outlays, as well as improve legal, logistic and organizational aspects, so that heat energy companies can carry out activities in the field of heating transformation and use RESs and municipal waste thermal treatment installations in district heating. In addition, these entities should be helped in their efforts to heat power plants, modernize and expand the heat distribution system and popularize the idea of heat storage and smart grids. This is also important because for several months, as a result of dynamic changes in the energy market, part of the Polish heating sector has found itself at a critical moment because basic energy raw materials are reaching record prices.

Some heat companies, especially those run by smaller local governments, in small towns, signal the possibility of bankruptcy, and other heating plants are looking for loans for the purchase of fuel (coal, gas, etc.). This is also accompanied by increases in the prices of CO_2 emission allowances. This makes the implementation of investments in energy transformation much more difficult. In many district heating systems, natural gas was supposed to be the "bridge" fuel. Given the rapid increases in the exchange prices of this fuel (even by several hundred percent), it will be much more difficult to carry out investment and modernization in such a way that after their completion and commissioning of the units, it will be possible to calculate heat prices that will maintain minimal profitability, and, at the same time, will not cause payment gridlocks or resignation of consumers from heat supplies. In this situation, it will be important to use external

financial sources for the implementation of the investment. This will make it possible to become independent of the costs associated with the purchase of CO_2 emission allowances.

The strategic importance of district heating and the recent dynamic changes in this sector have become an inspiration to undertake research on the state of change in the Polish heating sector. The existing literature [20–22] highlights the key role of local government in countries that have successfully developed district heating. In Poland, there is a fairly large research gap in the area of transformation in the heating sector. The lack of analyses applies in particular to the activities of local governments in the energy transition processes. Available studies focus mainly on regional examples or on the use of technologies and their relevance to the transition.

Research on the role of local government in the energy transition in the Lower Silesia Voivodeship was carried out by a research team led by Struś. The main objective of this research was to determine if local authorities are taking action to achieve the region's energy transition [23].

Kata and her team [24] conducted research on local government investments in south-eastern Poland in the field of energy transition. As part of the analyses, the authors noted a research gap in this area, pointing to numerous publications on renewable energy sources [25,26] or presenting an analysis of social attitudes and bottom-up initiatives [27].

Part of the research on the role of local government includes the determination of various factors in the processes of energy transition. Wójcik-Jurkiewicz and her team [28] undertook research to identify the factors determining decarbonization processes in Poland. Their study also presents directions enabling the diffusion of knowledge on decarbonization to develop a sustainable energy strategy for Poland. Regarding the topic of local governments, the focus was on the role of municipalities in the field of subsidies granted for investments in renewable energy sources, including the decommissioning of solid fuel stoves.

Hałaj et al. [29] conducted research on the modernization of the district heating system that will enable the production of sustainable urban energy. The authors conducted research on the use of available renewable energy sources in order to integrate them into the city's existing district heating system and increase the flexibility of the system and its decentralization. Their main focus was on the technical sphere and the efficiency of the energy obtained using this technology. Other analyses focused on the role of the district heating company in the economy without considering local governments.

Most of the available literature presents the results of research on a narrow subject, e.g., the analysis of the energy potential of biomass in individual municipalities, considering specific local conditions. One study aimed to investigate the energy potential of solid biomass in the Opolskie Voivodeship, a region located in the south of Polish. Duczkowska and others pointed out that even in such a narrow scope, there is a lack of studies [30].

Other studies include energy transition in urban areas. Svazas et al. attempted to determine the conditions for quantitative and qualitative data collection to assess the degree of energy transition in regional areas [31]. Another subject of the analysis was the global–local development of heat demand as part of the energy transition [32,33]. This literature review shows that the issue of the role of local governments in the transformation of the heating sector in Poland and other European or global countries has not been fully recognized.

The current study has a chance to partially fill this gap in the scientific literature.

The aim of this study was to identify changes in the Polish heating sector and the progress of the energy transition in this sector. An additional objective of this study was to determine the impact of the transformation on local government units. For the purposes of achieving the main objective, five research questions were also formulated:

1. What is the current situation of the Polish heating sector in relation to the assumptions of the EU climate and energy policy?
2. What are the most important directions of changes in Poland's energy policy in the area of heating?

3. What is the role of Poland's local governments in the transformation of the heating sector?
4. What investments and tasks are undertaken by local government heat energy companies as part of the energy transition?
5. What is the impact of the transformation on the local community?

This study mainly covered enterprises and municipalities at the beginning of the transition. Therefore, an original method of assessing the capacity and readiness of entities and local governments to modernize infrastructure in the field of heating was developed. This method was called "Aspiring Innovator of the Year in the field of heating" because this research was part of the third competition for the Most Innovative Local Government in Poland, described in more detail in the methodology. Thanks to this, the authors had the opportunity to verify the developed method and the organizers of the competition could develop a ranking list. The added value of this study is that the results, as well as the developed conclusions, will allow municipal authorities and entrepreneurs from the heating sector to benefit from the experience of other local governments in the design and implementation of energy innovations in the field of heating. In addition, because of our own research, it is possible to verify previous studies, as well as to show the dynamics of changes in the heat market, especially in the face of the so-called "energy crisis" caused by the armed conflict in Eastern Europe. At the end of this study, a case study of selected plans for the development and modernization of heat energy companies is presented, which, according to the developed methodology, were considered to be the most aspiring to implement innovations.

To achieve the stated goal and research assumptions, the following structure was introduced in this article. The first part presents theoretical considerations and statistical analyses of the Polish heating sector. The condition of the Polish heating sector is presented, considering the assumptions of the EU climate and energy policy. An analysis of costs and revenues in the industry was made, and attention was paid to the impact of the activities of these enterprises on the environment. It then describes the method of selecting the "Aspiring Innovator of the Year in the field of heating" and how to interpret the results achieved. The case study is used to describe the best assumptions of local government heat energy companies in the context of modernization and implementation of innovations in heating infrastructure, which are aimed at implementing the assumptions of the EU climate and energy policy. Then, this article concludes with a discussion of the results of this research. The conducted research and analyses allowed us to develop conclusions on improving the heating sector in local government units.

2. Materials and Methods

This article uses research methods adapted to the implementation of the objectives set out in the Introduction, as well as the research questions. Several research methods were adopted for individual research questions. To study the current situation of the Polish heating sector in relation to the assumptions of the EU climate and energy policy and the direction of changes in the Polish heating sector, an analysis of documents and a review of the literature was carried out. The analyses used documents on climate and energy policy, including reports, white papers, strategy documents, etc. A review of the source and the industry literature on the Polish district heating system, its structure, energy sources, emissions and other applications was carried out.

In the context of the third research question, an analysis of the literature on the subject was carried out, which made it possible to show the role of Polish local governments in the transformation of the heating sector. In addition, a comparative analysis was carried out to identify gaps, challenges and opportunities in the context of greater involvement of local government units in the energy transition. Theoretical issues, including a review of previous research, were developed because of studies of the literature on the subject and the Polish-described heating sector, considering the assumptions of the EU climate and energy policy. Using mass statistics in tabular and graphical layouts, an analysis of the condition of

heat energy companies in Poland was carried out. The analyses consider the assumptions of the new institutional economy and ecological economics. New institutional economics is supported by the fact that the scope of research is similar to the problems of the company and its relations with the environment [34]. In turn, the main assumption of ecological economics is to solve specific problems facing society, in particular, problems related to sustainable development [35]. Economics is an interdisciplinary science that is heavily influenced by physics, climate science, biology and other natural sciences. Ecological economics, on the other hand, is strongly oriented toward empirically testing hypotheses and theories. It is also rooted in a moderately falsified understanding of science [36].

Because of theoretical considerations in the field of economics, the authors decided to examine the modernization of heating infrastructure in the implementation of climate and energy policy. This made it possible to answer the fourth question about investments and tasks undertaken by thermal energy companies. To this end, qualitative and quantitative research was carried out while developing an original research method based on multi-criteria analysis. This method was prepared to meet the needs of the organization of the Third National Competition for Local Government Units for the Most Innovative Energy Local Government in Poland, in which empirical research was carried out on the condition of Polish heat energy companies and their readiness to modernize their infrastructure. The competition was organized by the Ignacy Łukasiewicz Energy Policy Institute based in Jasionka near Rzeszów (Poland) in cooperation with the Industrial Development Agency S.A. (Poland) and the Industrial Development Agency S.A. (Poland), Bank Gospodarstwa Krajowego and Polska Grupa Energetyczna Obrót S.A. The aim of the competition, and in particular, its second category (Aspiring Innovator of the Year in the Field of Heating) coincided with the objective of this research, which was to increase the awareness of the public and local authorities about the importance of energy in environmental protection and, above all, the intensification of activities in the field of modernizing heating plants. The aim of this competition was also to motivate local governments to accelerate the modernization of the Polish energy sector and improve air quality [37]. Thirty municipalities entered the competition, which have been included in this research.

The activities carried out under the competition allowed us to verify the developed, proprietary method of selecting a heat energy company that is ready to implement the assumptions of the heat policy in the near future. The method was developed in cooperation with industry experts from the Industrial Development Agency S.A. It consists of two parts. The first part concerned the emissivity coefficient of a heating plant, where the highest indicator rewarded indicated the urgent need to modernize such an installation. In this regard, the following formula was developed:

$$E\,hp = \frac{(Ei)}{(Ei\ max)} \times 10$$

where:

E_{hp}—heating plant benchmark ($\frac{\mathrm{MgCO_2}}{MWh}$);

E_i—CO_2 emission factor for heat produced in a heating plant ($\frac{\mathrm{MgCO_2}}{MWh}$);

$E_{i\ max}$—the highest CO_2 emission factor for heat produced in a heating plant among those participating in this study ($\frac{\mathrm{MgCO_2}}{MWh}$).

As part of the second part of this study, which consisted of a subjective assessment of the planned modernization of the heating installation in the municipalities, scored criteria were developed. Local government entities presented a description of the concept of modernizing heat sources (excluding the heating network), considering technical conditions, estimated investment costs, social need, readiness for the implementation of modern technologies (m.in. RES, sustainable water management), the real deadline for the implementation of the investment and compliance with strategic documents such as the European Green Deal, the local heat supply plan, etc. On this basis, a panel of experts composed of four representatives of the heating industry (one representative of the organizer

and the competition partners) conducted an assessment in which points were awarded based on the specific criteria presented in Table 1. The selection of criteria was aimed at a multifaceted assessment of the investment. Each criterion was assessed on a scale of 0–10 points. The maximum number of points for the subjective assessment of the modernization concept was 90 points.

Table 1. Criteria for the assessment of the planned modernization of a heat company.

Lp.	Specification	Point Weight
1.	The social need for investment.	0–10 p.
2.	Current state of progress in the preparation for the investment.	0–10 p.
3.	Estimated total value of the planned investment/scale of investment/(PLN).	0–10 p.
4.	Guaranteed deadline for the settlement of the tender for the contractor of the investment.	0–10 p.
5.	Impact of the investment on the environment/reduction in CO_2 emissions.	0–10 p.
6.	Innovation and versatility of the applied technical solutions (heat pumps, hydrogen, heat accumulators, etc.) as well as the versatility and scalability of the proposed solutions.	0–10 p.
7.	Achieving the status of an energy-efficient system after the implementation of the scope of modernization.	0–10 p.
8.	Compliance of the investment with the European Green Deal policy and with applicable local strategy papers/plans, including the local plan for the supply of heat, electricity and gaseous fuels.	0–10 p.
9.	Compliance of the investment with the assumptions of the 3W Idea Water–Hydrogen–Carbon (considering aspects of sustainable water management in the design and implementation of the investment; applying carbon nanotechnologies in the designed solutions; ensuring the possibility of powering the designed installation with green hydrogen fuel).	0–10 p.
	Maximum	90 p.

Source: own research.

As part of the assessment, a given entity could obtain a maximum of 100 points (90 points assessment of experts + 10 points for the benchmark). The results of this research allowed for ranking local governments of heat energy companies, which are, in the near future, ready to implement the assumptions of the climate and energy policy in the area of heating. The greatest social need is also included in this area.

In terms of research, case studies were also analyzed. They covered seven select heat energy companies from all over Poland that obtained the highest score among those that participated the Competition (Table 2). The use of the case study method made it possible to verify the results of the quantitative study, as well as to test the effectiveness of the applied methodology in identifying the innovative readiness of selected enterprises.

Table 2. Local government thermal energy companies analyzed in this research.

Lp.	Municipality	Province	Type of Municipality
1.	A	Wielkopolskie	urban
2.	B	Podkarpackie	urban
3.	C	Pomorskie	urban
4.	D	Mazowieckie	urban
5.	E	Małopolskie	urban
6.	F	Mazowieckie	urban
7.	G	Świętokrzyskie	urban

Source: own research.

The source of data for the analysis was information provided by municipal governments on specially prepared forms. The case studies were supplemented with materials from municipal offices available on local websites. Due to the lack of consent to the publication of detailed data provided in the forms, the names of municipalities and enterprises were anonymized.

Based on the presented methods, as well as analyses and qualitative research, including a hidden interview and a panel of experts with representatives of local governments and heat energy companies, recommendations and conclusions were drawn up. These allowed us to answer the last research question on the impact of transformation on the local community.

The time range of theoretical analyses of changes in the Polish heating industry covered the years 2002–2021. In turn, our empirical research used data from 2021 and plans and strategies of enterprises and local governments for the next few years.

3. The Polish Heating Sector in Relation to the Assumptions of the EU Climate and Energy Policy

The Polish heating sector plays a key role not only in the national but also in the European context. Its current solutions and future challenges have an impact on shaping the energy policy of the entire continent.

Polish district heating has a rich tradition that dates back to the beginning of the 20th century. In the times of the Polish People's Republic, the development of the heating industry was related to the exploitation of hard coal and lignite, which made it one of the main producers of heat in Europe [38]. Currently, in the context of challenges and pressures to reduce CO_2 emissions, Poland is trying to modernize the sector, resulting in the diversification of energy sources.

Poland is an important element in the European heating system. Polish companies, such as the Polish Oil and Gas Company and the Polish Energy Group, participate in many European projects, focusing on the development of innovative technologies and maintaining the highest standards of district heating [39]. In addition, Poland is one of the largest CO_2 emitters in Europe, which affects the prices of CO_2 emission allowances.

3.1. The Polish Energy Policy within the Framework of European Union Regulations

The EU's climate and energy policy is the basis for the formulation of the Polish energy strategy, which strives to achieve climate neutrality by 2050. In addition, it shapes the regulatory mechanisms that will achieve the assumed effects in the next thirty years. In 2009, the European Union established a set of laws setting out three main targets for combating climate change by 2050 (known as the "3 × 20%" target), with each country adapting the law to its own realities. In this regard, Poland has taken the following actions:

- Increasing energy efficiency by saving 13.6 Mt from primary energy consumption in the coming years compared with the 2007 fuel and energy demand forecast;
- Increasing the final consumption of energy from renewable energy sources to 15%;
- Contributing to the EU's 20% reduction in greenhouse gas emissions (compared with 1990).

In 2014, the European Council maintained the direction of combating climate change and approved four 2030 targets for the entire EU, which, after revision in 2018 and 2020, aimed at the following:

- Reducing greenhouse gas (GHG) emissions by at least 55% (compared with 1990);
- A minimum share of 32% of renewable energy sources in the gross final energy balance;
- Increasing energy efficiency by 32.5%;
- Finalizing the completion and modernization of the EU's internal energy market.

In 2019, the European Commission presented a communication on the European Green Deal, which aims to achieve climate neutrality by 2050 [40]. The European regulatory framework relating to the energy sector, including district heating systems, is contained in two documents: the "Fit for 55" package [41] and the RED II directive, dealing with renewable energy sources. The package of regulatory changes concerns, i.e., modifications to emissions trading (EU ETS) [42], the RES Directive [43] and energy efficiency [44] or changes in CO_2 emission standards for cars (cars and vans) [45].

Poland supported the goal of climate neutrality. However, Polish realities were taken into account, and socio-economic aspects were also considered. The framework for the

country's energy transformation is set by the Polish Energy Policy until 2040 (EP2040). It takes into account all the provisions and guidelines of the Paris Agreement, which was adopted in December 2015 during the 21st Annual Paris Agreement at the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21). Its main premise is the need to carry out the transition in a fair and solidarity-based manner. The basic directions of Polish energy policy include:

- Increasing energy efficiency;
- Increasing the security of fuel and energy supplies;
- Diversifying the structure of electricity generation with the implementation of nuclear energy;
- Increasing the use of renewable energy sources, in particular, biofuels;
- Developing and introducing new competitive fuel and energy markets;
- Reducing the negative impact of energy on the environment.

The adopted guidelines for energy policy are interdependent. Measures to improve energy efficiency limit the increase in demand for fuels and energy, thus contributing to improving energy security. As a consequence, there is a reduction in dependence on imports, and measures are being implemented to reduce the impact of energy on the environment by reducing greenhouse gas emissions. Very similar effects occur in the development of the use of renewable energy sources, including the use of biofuels, as well as the use of clean coal technologies or the implementation of nuclear energy. The energy policy adopted in Poland assumes major changes in the heating sector with the implementation of investments in infrastructure and new technologies. This is because about 80% of the fuels in district heating are fossil fuels. In addition, outdated infrastructure is also a major obstacle. The modernization of heating and construction will therefore require large financial outlays.

Currently, the situation in the heating sector is quite difficult because the dynamically growing prices of fuels (coal and natural gas) are accompanied by significant increases in the prices of CO_2 emission allowances. In this situation, it is much more difficult to implement investments in the energy transformation. In large district heating systems, the "bridge" fuel was to be natural gas. However, with the current increase in the exchange prices of this fuel by up to several hundred percent, it will be much more difficult to implement investments in a way that, after their completion and commissioning of the units, will allow for calculating heat prices that will maintain minimal profitability, and, at the same time, will not cause customers to resign from heat supplies or payment gridlocks. Thus, the possibilities and skills of obtaining external funds for the implementation of investments aimed primarily at becoming independent of the costs associated with the purchase of CO_2 emission allowances [46] will be important.

In 2020, heating companies began the process of adapting heating sources to the European Union directives and are currently implementing activities in the field of transformation of heating, RES sources and municipal waste thermal treatment installations. By 2029, expenditures on these investments are expected to amount to approximately PLN 5.4 billion. However, this is only a small part of the resources needed, and changes are very slow. According to the Energy Regulatory Office, meeting the challenges of the EU's decarbonization policy will require investment outlays in the next decade for projects related to energy transformation of PLN 53 to 101 billion. Assuming an even distribution of these expenditures over a period of 10 years among all licensed heating companies, they would have to increase each year in the range of PLN 5.3 billion to PLN 10.1 billion (in addition to the expenditures already incurred or already planned to be incurred), which constitutes an additional 35 to 67% of the total annual revenues from heating activities (excluding turnover, i.e., heat sales).

Due to the high costs, the transformation of heating in Poland will take place with the use of both national and EU funds indicated in the Polish Energy Policy until 2040, i.e., Cohesion Policy, Recovery and Resilience Facility, Just Transition Fund, React EU and other instruments, such as priority programs of the NFEP&WM and Common Agricultural Policy funds. An important source of support for the transformation of the energy system

in Poland is new instruments, such as the Modernization Fund or national special purpose funds, which are supplied with funds from the sale of CO2 emission allowances (i.e., the Energy Transition Fund) [47].

In the context of the impact of the European Union policy on the heating sector, from the perspective until 2025 and 2030, the Polish District Heating Chamber of Commerce has defined the following proposed directions of technological changes:

- Production of energy from emission-free sources;
- Electrification of the heating sector;
- Use of waste for energy production;
- Development of decentralized production of energy from renewable sources;
- Energy storage;
- Promotion of action on sustainable and more efficient technologies and innovative solutions;
- Closer integration of the electricity and heating sectors;
- Development of modern, low-temperature heating systems;
- Adaptation of infrastructure with smart and cyber-secure digital solutions;
- Improvement in energy infrastructure, making it more resilient to climate change [48].

To sum up, the Polish heating sector is constantly adapting to the assumptions of the European climate and energy policy. The European Union's strategy aims for climate neutrality by 2050, which results in the need for deep reduction, distribution and consumption of energy, including heat.

There are five most important areas to focus on:

1. Decarbonization: Poland's district heating sector is largely dominated by fossil fuels, primarily hard coal and lignite. The European Green Deal [40] imposes a need for individual countries to decarbonize. The challenge for Poland is to implement effective ways to replace coal with other, greener energy sources.
2. Renewable Energy Sources (RESs): According to EU assumptions, the basic principle of operation is the transition to RESs. The Polish district heating sector needs to control the share of electricity from wireless sources, which requires investment in new technologies such as heat pumps or biomass [43].
3. Energy efficiency: The European Union exerts a lot of pressure on energy. The Polish heating sector must work to reduce energy losses in its distribution and use. In this regard, it is necessary to modernize infrastructure, including distribution networks [44].
4. System integration: In a specific context, energy system integration is also an important aspect. The Polish district heating sector should seek to be connected with other energy segments, including the electricity sector, which can lead to greater stability and efficiency in the energy system as a whole [49].
5. Financing: Poland can benefit from various EU programs, including the Just Transition Fund, which aims to cover the least advanced countries with the energy transition [50].

The Polish heating sector has a great influence on shaping energy policy in Europe. This is linked to environmental challenges and social needs. Thanks to this strategy, Poland can become a leader in innovation and development regulation on the European continent.

3.2. Changes in the Polish Heating Sector in the Years 2002–2021

At the end of 2021, there were 393 companies operating in Poland that held licenses for generation, transmission and distribution as well as heat trading [3]. Since 2002, this number has more than halved. In the initial period, this was caused by changes in the Energy Law Act and organizational and ownership transformations in heating [4]. Currently, these changes result from consolidation processes in the heat market. In the years 2002–2021, the structure of legal forms of heating companies in the country also changed. In 2021, the share of enterprises conducting business activity in the form of limited liability companies

accounted for 77.9%, and activity in the form of joint-stock companies accounted for 18.2%. The proportion of other companies was only 3.9% (Figure 1).

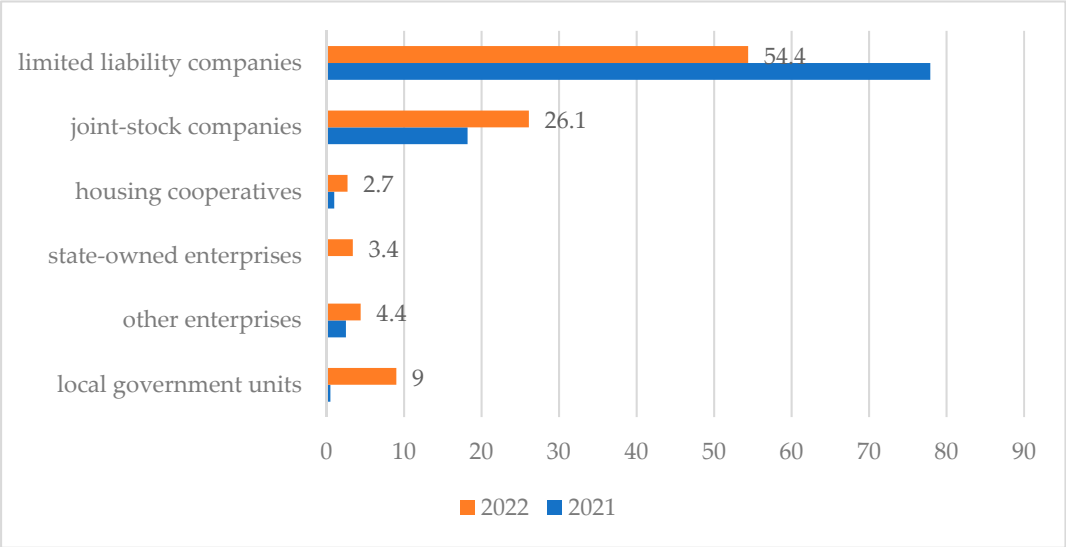

Figure 1. Change in the structure of legal forms of district heating companies in Poland in the years 2002–2021. Source: Thermal energy in figures 2021. Energy Regulatory Office. Warsaw 2022 [3].

Along with the consolidation of companies in the heating sector, the concentration of district heating networks is increasing. In 2002, there were 23.81 networks per company, and in 2021, this figure increased nearly 3 times to 61.22 km. In 2021, heating companies had networks with a total length of 22,223 thousand km, which is longer by less than 5000 km compared with 2002.

District heating companies are, in most cases, vertically integrated and deal with both heat generation and its distribution, as well as trading. In 2021, out of all enterprises, 350 dealt with heat generation, 353 with heat transmission and distribution and 107 with turnover. Out of 378 companies generating heat, 133 also produced heat in cogeneration (35.1%). Including the heat recovered in technological processes, they generated 390.6 thousand TJ of heat. After satisfying the companies' own heating needs (139.3 thousand TJ) and considering losses during transmission to connected customers (35.3 thousand TJ), 250.4 thousand TJ of the generated heat finally went to the network.

Companies generating heat were diverse in terms of installed capacities, but small ones, i.e., up to 50 MW of installed capacity, dominated among them. Their share was 44.7% of manufacturing companies (Figure 2). Only ten companies had a capacity above 1000 MW, but their combined capacity accounted for more than one-third of the capacity achievable by all heating companies.

The economic situation of district heating companies changed in the following years. In 2021—for the third time since 2013—the revenues generated by these enterprises were lower than the costs of conducting activities related to supplying heat to consumers. Thus, the profitability ratio of district heating companies was negative and amounted to approximately − 5.78%. In particular, the high costs of purchasing CO_2 emission allowances contributed to this situation. An additional factor contributing to the decline in profitability was the pandemic and the resulting collapse of the economy, in particular the fuel market (especially gas).

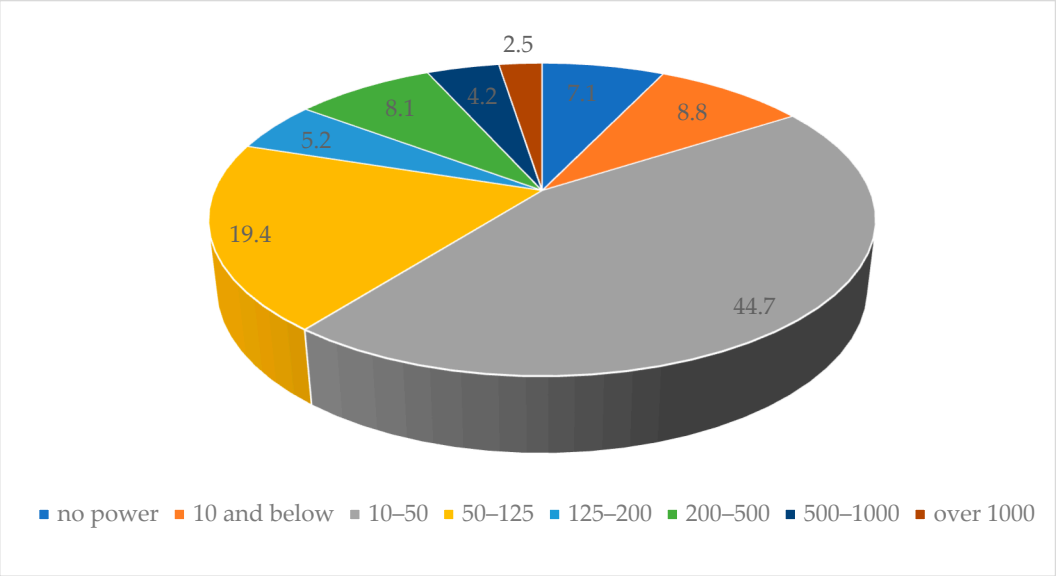

Figure 2. Structure of district heating companies in Poland in 2021 by installed capacity in MW. Source: Thermal energy in figures 2021. Energy Regulatory Office. Warsaw 2022 [3].

The structure of consumed fuels in the heating sector was dominated by coal fuels, whose share accounted for 81.7% in 2002 and 68.9% in 2020 (Figure 3). The diversification of fuels used to produce heat is very slow. Since 2002, the share of coal fuels has decreased by 12.8 percentage points. At the same time, there was an increase in the share of gaseous fuels by 6.9 percentage points and RESs by 7.2 percentage points. The share of other fuels, including biomass, biogas, municipal solid waste, non-renewable industrial waste and sewage sludge, is also increasing. Due to the dominant share of fossil fuels, the transformation of domestic heating is currently one of the greatest challenges for the Polish administration and heating companies.

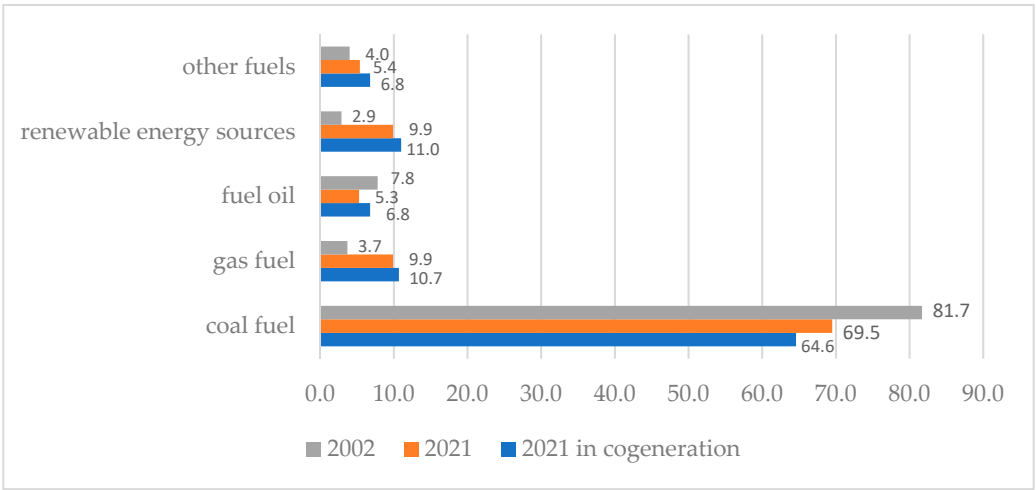

Figure 3. Structure of fuels used for heat production in heat companies. Source: Thermal energy in figures 2021. Energy Regulatory Office. Warsaw 2022 [3].

The report of the Energy Regulatory Office from 2022 shows that currently, 80% of small heating systems (with a capacity of 1 to 100 MWt) in Poland are inefficient, i.e., do not meet the requirements of the EU Energy Efficiency Directive [51]. One of the ways to achieve the status of an efficient district heating system is to switch to combined heat and power (CHP), i.e., the simultaneous production of heat and electricity. In traditional power

plants, heat is a by-product, and in combined heat and power plants, it is used for utility purposes. Companies producing heat in cogeneration account for one-third of the licensed heating companies in the country, but they are responsible for the production of two-thirds of the district heating [52].

In 2021, total sales of heat by licensed district heating companies (including resale to other companies) amounted to 385,598.57 TJ and was higher than the volume from 2020 by 40,885.97 TJ (an increase of 11.86%). Sales of purchased heat, which are part of total sales, amounted to 919.9 TJ5 (an increase of 2.7%).

The average price of heat sold by all licensed heat-generating companies in 2021 was PLN 47.65/GJ (an increase of 7.49% compared with 2020). On the one hand, the average price of heat sold from licensed sources generating heat without cogeneration amounted to PLN 53.31/GJ (an increase of 2.78%). On the other hand, the average price of heat sold from licensed sources generating heat in cogeneration amounted to 45.27 PLN/GJ (an increase of 9.56%).

The level of heat prices is closely related to the type of fuel used to produce it. In 2021, compared with the previous year, a decrease in unit costs of fuels used in heat production, such as hard coal, lignite and heavy fuel oil (mazut, asphalt) (Table 3), was recorded. For other fuels, there was a significant increase in unit costs, especially gaseous fuels. During this period, the unit cost of high-methane natural gas (GZ-50) increased by two times, while nitrogen-rich natural gas increased by 78%.

Table 3. Changes in unit costs of fuels used in heat production in the years 2002–2021.

Specification		Unit Cost of Fuels			Change	
		2019 r.	2020 r.	2021 r.	2020/2019	2021/2021
					(%)	
hard coal	PLN/t	306.91	302.91	296.07	−1.30	−2.26
lignite		49.74	52.95	49.90	6.45	−5.76
light fuel oil		2883.62	2369.61	2972.97	−17.83	25.46
heavy fuel oil		1152.78	876.40	749.27	−23.98	−14.51
high methane natural gas	PLN/m^3	1.05	0.87	1.74	−17.14	100.00
nitrided natural gas		0.57	0.50	0.89	−12.28	78.00
biomass	PLN/GJ	16.27	16.26	10.07	−0.06	4.98
other fuels		14.83	12.37	17.37	−16.59	40.42

Source: Report: Thermal energy in figures 2021. Energy Regulatory Office. Warsaw 2022 [3].

3.3. Direction of Changes in the Field of Thermal Energy in Poland

The transformation of the heating sector is currently one of the most important topics [53,54], mainly due to the changing standards of greenhouse gas emissions (sulfur dioxide, nitrogen oxides) and dust [55]. The cost of purchasing CO_2 emission allowances is also increasing (almost a fourfold increase in 2020–2021), which was reflected in the financial results of heating companies.

Unfortunately, the district heating sector is underinvested and modern [56], and modifications in the system regulation are used to save costs for companies, passing the costs on to heat consumers [57].

The "Energy Policy Polish until 2040", announced in 2021 [52] indicates that the development of cogeneration (simultaneous production of electricity and heat) is the most efficient way of using fuel energy. Electricity generation in high-efficiency cogeneration will be supported, and in the longer term, district heating should be generated because of low-emission sources.

However, until 2020, there was little diversification of fuels for heat production. Coal fuels still dominate in Poland [54], and their share in heat sources is decreasing very slowly. For example, their share amounted to 68.9% in 2020; 71% in 2019 and 72.5% in 2018. Over the last 20 years, the share of coal fuels decreased by 12.8%, and the share of renewable

energy sources (RESs) increased by 7.2% [47]. During this period, CO2 emissions also decreased by around 20%.

All this affects the need to carry out many changes in the Polish heating sector. Above all, this sector needs a heating strategy, which will be combined with bold actions to change the current situation.

The Polish Energy Policy until 2040 (PEP 2040) [52] sets out the following guidelines for heating:

- Covering the heat needs of all households by 2040 with system heat and with zero-emission or low-emission individual sources.
- An increase in installed photovoltaic capacity, by about 5–7 GW in 2030 and about 10–16 GW in 2040, which will enable the transition to heat generation from electricity of self-producers and prosumers.
- Natural gas is a bridge fuel in the energy transition. It is planned that in 2030, it will be possible to transport a mixture containing about 10% of decarbonized gases through gas networks, which will enable low-emission heat generation in cogeneration. The use of decarbonized fuels will help energy companies build efficient district heating systems.
- Thanks to the use of heat pumps, electric heating and solar collectors, it will be possible to move away from burning coal in households (by 2030, this will happen in cities, and by 2040, this will happen in the countryside).

The Polish Energy Policy until 2040 indicates the most advantageous innovative solutions in the field of heating [52], i.e., include:

- Heat storage technologies, regardless of demand peaks, will contribute to optimizing the operation of sources generating heat and electricity in cogeneration, and this will contribute to increasing the operational security of the entire power system;
- Investments in electricity storage will contribute to the rapid development of sources based on solar and wind energy, which in turn will eliminate instability and dependence on natural conditions;
- The development of hydrogen technologies and, in particular, the acquisition of "green hydrogen" will contribute to the creation of local and regional hydrogen clusters based on local hydrogen production, also integrating renewable energy production systems.

The aim of the Polish Energy Policy until 2040 is also to reduce the impact of energy on the environment by implementing the following specific objectives [52]:

- Individual coverage of heat needs using sources with the lowest possible emissions (electric heating, heat pumps, natural gas—primarily decarbonized gas) and moving away from coal;
- Assume that around 1.5 million new households will be connected to the district heating network by 2030;
- In 2030, at least 85% of heating or cooling systems, where the contracted capacity exceeds 5 MW, should meet the criteria of an energy-efficient heating system (currently it is about 10%);
- Assume that within ten years, there will be an increase in heat production from RES by at least 1.1 p.p. per year, which will result in an expected share of renewable sources in the entire heating sector at the level of 28.4% in 2030.

According to Rubczyński, to achieve the goal of climate-neutral heating in Poland, the following actions should be taken [57]:

1. Develop an ambitious heating strategy [58] that will make it possible to clean up the heating sector and define strategic objectives for the sector, thus contributing to improving the quality of the environment, reducing the health costs of society and making Poland independent of fossil fuel imports.
2. Increase the share of waste and RES energy—the share of energy from RES in district heating is small because it has never been properly supported. A proper support policy could increase the number of projects aimed at the use of waste and renew-

able energy. Solar farms, PV installations, heat pumps and energy accumulators should become a natural option in domestic heating. The importance of this area was pointed out, i.e., by the authors of the article entitled RES Market Development and Public Awareness of the Economic and Environmental Dimension of the Energy Transformation in Poland and Lithuania [59].

3. Determine the role of gas in heating. According to Forum Energy's analysis, in 2050, the demand for electricity in Poland will increase to 300 TWh. To provide this energy fully from domestic sources, the installed capacity in the system must amount to about 170 GWe (Figure 3). Such large capacities in the National Energy System (PPS) will provide little green gas, and yet, green gas will be used in industry, transportation and energy. Currently, domestic natural gas consumption is about 240 TWh and may increase to 360 TWh within a decade. So, questions arise about the amount of green gases (hydrogen, biomethane) Poland needs in the future.
4. Define the role of biomass, which, together with biodegradable waste, can constitute a noticeable stream of primary energy in district heating systems. However, institutional aid and clearer policies are needed. An example of such use of biomass is presented in the article entitled "Relationship between Renewable Biogas Energy Sources and Financial Health of Food Business Operators" [60].
5. Support the development of high-efficiency cogeneration (with appropriate policy), which will fill the generation gap, fill power deficits in the system and improve the security of the National Power System. Energy production in high-efficiency cogeneration in 2020 amounted to 20.3 TWh, i.e., it has not changed for 40 years.
6. Support the development of heat electrification with the integration of the heat and energy sectors (use of electricity to produce heat, i.e., through heat pumps).
7. Change the business model of district heating because the current one (more sales—more profit) does not support an increase in energy efficiency or an increase in the share of renewable energy. It is necessary to change the model to a qualitative one, which will allow for creating conditions in which heating companies will earn on the energy savings achieved. This makes it possible to operate within the ESCO (Energy Saving Company) or EPC (Energy Performance Company) model.
8. Develop thermal insulation for buildings—currently, only 5% of buildings in Poland achieve a technologically available energy standard. The low rate of thermal insulation causes a higher demand for energy, which in turn increases fuel imports and has a negative impact on the natural environment.
9. Create the right industrial policy and develop sectoral strategies and the resulting economic objectives. The technologies to be supported and developed should also be defined. Setting long-term goals will allow for thoroughly preparing staff and other necessary resources.

Achieving the complex goals of heating transformation will require coordination of work carried out by energy companies, building owners and local authorities. In the current situation, this will not be easy, as the municipal authorities are responsible for the supply of utilities and energy, but the tools to carry out these tasks are in the hands of third parties. Only 20% of municipalities in Poland have energy plans made in accordance with the requirements of PEP 2040, although, according to the energy law, a municipality is obliged to plan and organize energy supply in its area. Only recent years have seen greater interest for local governments in energy planning, but mainly in larger cities. Planning is to serve the proper organization of the energy supply, and the right organization is one that responds to the needs of consumers and gives sustainable local development in the long term, i.e., reduces the impact of energy supply on the environment. Systematic and reliable energy planning requires an inventory of resources. A coherent vision of a city and a company is an important component of the functioning of district heating in the future. Changes in heating, accelerating the process of thermal insulation of buildings, improving air quality in cities and reducing the impact on the climate require an increased role of local

authorities. Equipped with appropriate legislative tools, they should become a planning center for the energy transition at the local level.

4. The Role of Local Governments in the Transformation of the Heating Sector in Poland

4.1. Tasks of Local Governments in the Field of Fuel and Energy Management

Local governments play an important role in the transformation of the heating sector because they are closest to the residents and know their needs best. Even in the 20th century, the heating sector in Poland was centrally managed. The introduction of local government reform in the 1990s [61] contributed to the decentralization of the management of this sector. As a result, the local society has a great influence on the direction and pace of the transformation of the heating sector in Poland. They bear the main burden of greenhouse gas reduction activities in Poland, which was defined by the Center for Climate and Energy Analysis in the document titled Poland net-zero 2050. The developed criteria show that to achieve climate neutrality in the country by 2050, it will be insufficient to reduce the use of fossil fuels and develop the use of renewable energy sources and nuclear energy. It will require, i.e., the implementation of modern emission-free technologies, the implementation of solutions using hydrogen as an energy carrier, the electrification of industry and heating, the expansion of electromobility and structural changes in the agricultural sector. The next challenge will be the transition to a low-carbon and ultimately climate-neutral economy. Therefore, the role of municipalities will be to actively act in the implementation of low-emission economy projects, cooperate with entrepreneurs, conduct promotional and educational activities and effectively raise funds [62].

The aforementioned document, Poland net-zero 2050, defines potential transformation directions in the area of three scenarios that should contribute to the implementation of climate policy objectives (Table 4) [63]:

- A baseline scenario (BAS) assuming a 60% reduction in greenhouse gas emissions in 2050 compared with 1990 emissions, excluding the land use and forestry sector;
- A reference scenario (REF) aiming at a greenhouse gas emission reduction target of around 80% in 2050 compared with 1990 emissions, excluding the land use and forestry sector;
- A neutrality scenario (NEU) assuming approximately 90% reduction in greenhouse gas emissions in 2050 compared with 1990 emissions and net-zero emissions, including carbon sequestration and the land use and forestry sector.

Table 4. Level of reduction and greenhouse gas emissions in economic sectors in Poland.

Detailing		Poland 2030			Poland 2050		
		BAS	REF	NEU	BAS	REF	NEU
emission reductions (%)	together (vs. 1990)	42	42	53	60	80	90
	EU ETS (vs. 2005)	48	48	60	69	83	93
	non-ETS (vs. 2005)	7	7	18	31	62	73
energy and heating							
emissions (Mt Co_2ekw.)		87	87	54	16	−11	−20
industry, construction, services, and household							
emissions (Mt Co_2ekw.)		121	123	103	109	92	71
transport							
emissions (Mt Co_2ekw.)		55	53	52	46	23	16
agriculture							
emissions (Mt Co_2ekw.)		26	26	22	20	10	8

Source: "Poland net-zero 2050—Road map of achieving the Community's climate policy goals for Poland". IOŚ-PIB, KOBiZE, 2021 [63].

Striving for climate neutrality by 2050 means large reductions in CO_2 emissions in the electricity and heat generation sector. Energy and district heating are sectors in which drastic reductions are possible from a technical point of view but involve large financial outlays. They will therefore have to bear most of the burden of national reductions, as other sectors such as construction, industry, transport and agriculture have technological constraints that prevent a complete reduction in greenhouse gases.

The structure of legal forms of heat energy companies shows that only two heating plants belong to the local government. However, in the last two decades, most local governments have transformed their heating plants into various companies, which have a significant impact on the management and development process. Thanks to many tasks, including the implementation of municipal management, municipalities and districts have the greatest potential for the integration of measures for distributed energy production, energy efficiency and air protection. Local authorities are also responsible for preparing development plans for supplying documents, communes or cities with fuels and energy. These plans form the basis for the energy development of local communities. They should not only guarantee stable supplies of fuels and energy carriers, but also engage residents to actively participate in the energy economy with the greatest benefit for them. In addition, local governments that will apply for support from European funds allocated for low-emission development in the financial prospect 2021–2027 will be obliged to create a Low-Emission Economy Plan, which will consist of three parts: an analytical part, a strategic part and the action plan itself with a schedule. This plan will be a document describing the development strategy of a city or commune. The document will define the directions of development in the field of investment and non-investment activities regarding fuel and energy management, spatial development, public transport and waste management. It will be based on the Sustainable Energy and Climate Action Plans (SECAP) implemented under the Covenant of Mayors [64]. Such a document should include the following elements:

- Submission of SECAP, approved by the city or municipality council within 2 years after the Covenant of Mayors initiative, which sets out the measures and policies that the city or municipality will implement to achieve the objectives set;
- Regular biennial monitoring reports on progress in the implementation of the action plan;
- The development of a Risk and Vulnerability Assessment (RVA) for threats arising from climate change, which measures the level of risk by analyzing potential climate risks and assessing vulnerability in the territory of the signatory;
- The development of the Baseline Emission Inventory (BEI), which determines the amount of CO_2 emitted in the territory of the signatory [65].

In terms of other activities, local authorities in the field of energy transformation will have to perform tasks related to the thermal modernization of buildings, modernization of individual heating sources, modernization of street lighting, development of sustainable district heating, support for the development of distributed RESs and implementation of the circular economy, as well as increasing investments in electromobility and alternative fuels.

Thermo-modernization of buildings, including public buildings, improves the living conditions of residents and employees, reduces energy bills and increases energy security. It is one of the cheapest means of reducing gases. Although these investments are expensive, in the long term, the costs incurred for modernization pay for themselves in the form of lower energy bills [66]. Similarly, the modernization of individual heating sources brings many benefits. Emissions from individual heating sources are the main cause of poor air conditions in Poland and, as a consequence, the occurrence of smog in cities and municipalities. The role of municipalities in this area may be to obtain loans to cover the costs of modernization of the poorest households. In the longer term, they can support these farms in terms of increased heating costs through social programs [67].

The development of sustainable district heating is important because about 80% of all district heating systems in Poland do not have the status of efficient systems. An efficient system is one that makes significant use of renewable sources and cogeneration,

e.g., 50% of the energy comes from renewable sources, 50% of the energy comes from waste heat or 75% of the heat comes from cogeneration [68]. Local governments should play an important role in this respect, as they have the majority of small- and medium-sized district heating systems on their boards. It is the authorities of municipalities and cities who are faced with the task of creating heat supply plans aimed at transforming all district heating systems into efficient systems. Local authorities can also act as coordinators and popularizers of knowledge in the field of supporting the development of distributed renewable energy installations. Less and less expensive RES technologies are conducive to residents investing in smaller installations, thus contributing to the idea of civic energy [67]. To these activities should be added the task of implementing the Smart City idea, under which local governments can introduce modern solutions in the field of digitization and information exchange in the urban space in the field of energy.

The participation of local governments in education and the implementation of social activities is important. Municipalities play a key role in educating communities about the benefits of grid power supply, as well as investments in individual RES installations. Local governments organize meetings, workshops and information campaigns that are important for residents [69].

It is also important to work with a private selector. Many local governments have established partnerships with private companies that provide modern technological solutions and know-how in the management and use of district heating infrastructure. Public-private partnerships often rely on external capital financing of investments [70].

The transformation of the heating sector also requires changes in spatial planning. Local governments have the opportunity to shape energy infrastructure to ensure the development of sustainable energy sources and energy infrastructure for modern heating supply [71].

To sum up, it should be stated that the involvement of local government units in the transformation of the heating industry is crucial due to the goal of Poland and other European countries regarding climate neutrality. An analysis of the role of local governments in the transformation allows us to identify two main gaps in this area. The first is the lack of awareness of the employees of local government units in terms of the need for changes. Many entities in this area may not have full knowledge of the technologies used in the processes of heating modernization [72]. In addition, despite increasing progress in available measurement methods, there is still a deficit in data on emissions, energy consumption and energy use at a level that hampers the implementation of effective strategies [73].

Local governments face additional challenges related to financing, innovation and social resistance. Large investments are needed for access to energy sources and infrastructure, which can be particularly difficult for smaller municipalities [74]. In terms of technical aspects, it is important to quickly adapt to changing technological standards and legal regulations at the national and EU level [75]. Similar to any change, the transformation may also encounter social resistance, which will be related to the production or supply of heat [76].

Local governments have various options in terms of access to capital to finance transformation, continuous development of technology and partnership initiatives. Significant funds for the modernization of heat sources and district heating systems are available within the European Union, such as the Just Transition Fund or the Recovery Plan for Europe, which can accelerate the transformation of the heating sector [77]. On the other hand, advances in renewable energy technology offer local governments the opportunity to diversify heat sources, energy security and dependence on imported fuels [78]. It is also critical to cooperate with other local governments, the private sector or research institutions that can help in transforming, identifying and using best practices [79].

4.2. Development Plans and Strategies of Select Local Government Heat Energy Companies

4.2.1. Characteristics of the Examined District Heating Companies

Our research carried out in 2022 on selected local government heat energy companies in Poland was aimed at recognizing the current situation of these entities, as well as defining plans for the modernization of heat sources for the needs of energy transformation.

The survey involved 30 municipalities in which heat energy companies operate, i.e., about 10% of the local heating plants. Seven municipalities and enterprises were selected for the analysis which, in the opinion of experts, were the most representative. At the same time, these entities agreed to a detailed presentation of the results, with the proviso that their names would be encoded in the form of letters (Table 5). The average installed capacity in these companies in 2021 was 40.52 MW. The smallest heating plant had a capacity of 10.02 MW, while the largest produced 98 MW of heat. The average demand for heat in the summer was at the level of 8914.96 MWh/year. In the smallest heating plant, 1250 MWh/year was produced in the summer, and in the largest company, 14,320.00 MWh/year was produced per year, but this result did not apply to the heating plant with the highest capacity. The average demand in the heating period (winter) was 70,358.28 MW/H, which was about 8 times higher than in the summer. The lowest demand in the surveyed group of enterprises was at the level of 22,280.30 MWh/year.

Table 5. Basic parameters of the surveyed heat energy companies.

TEC	Installed Thermal Power (MW)	Heat Source Used			Heat Demand (MWh/Year)		Number of Heat Recipients (Pcs. Buildings)	Percent Buildings	Annual Greenhouse Gas Emissions (Mg)	Emission Index ($MgCO_2$/MWh)
		Hard Coal (Mg)	Natural Gas (m^3)	Biomass (Mg)	Summer period	Winter				
A	38.50	12,000.00	-	6000.00	14,320.00	70,830.00	382.00	-	24,000.00	0.28
B	98.00	20,401.83	1,122,155.00	81,747.08	11,212.43	82,077.29	298.00	3.87	32,993.00	0.34
C	32.20	3331.00	-	26,543.00	7344.00	137,376.00	392.00	-	10,488.20	0.75
D	49.22	2107.00	-	37,935.75	6649.00	61,560.00	257.00	3.00	4272.00	0.05
E	10.02	5813.00	-	-	1250.00	22,280.30	162.00	25.00	12,207.90	0.52
F	18.90	8433.00	10,485,998.00	-	17,154.00	60,287.00	362.00	50.00	38,332.00	0.24
G	36.78	9282.20	1,029,988.00	-	4475.26	58,096.69	228.00	80.00	21,515.09	0.50

Source: own research.

On average, the surveyed companies supply about 23% of residential and public buildings. In one of the surveyed municipalities, heat is supplied to only 3% of buildings located in its area. The situation is extremely different in a municipality where heat is supplied from the local heating plant to 80% of buildings. Annual greenhouse gas emissions from the tested heating plants ranged from 4272.00 $MgCO_2$/year to 38,332 $MgCO_2$/year and averaged 20,544.03 $MgCO_2$/year. Each of the heating plants used hard coal as fuel. In turn, 42% of the heating plants also used gas for heat production, and 57% used biomass.

Using the developed methodology, in the first stage, the level of the emission factor was assessed based on the CO_2 emission factor for heat produced in the heating plant in ($MgCO_2$/MWh). The data show that local government heating plants emit an average of 0.38 $MgCO_2$/MWh. The lowest emission ratio in the surveyed companies was 0.053, and the highest was 2.679. This indicator is important because it indicates the ecological condition of heating, and in the context of the conducted research, allows for determining the need to modernize installations resulting in emission reduction.

4.2.2. Modernization of Heat Undertakings

As part of this research, at the beginning, the emission index of the heating plant was determined based on the emissivity coefficient, and then the need for intensification of heating plant modernization activities was assessed using nine criteria (Table 1). Table 6 presents detailed assessments of individual criteria that allowed for the assessment of heating companies in terms of modernization needs. The surveyed companies could score a maximum of 100 points. Criteria 1 to 9 were assessed subjectively based on information obtained by the companies. In turn, the benchmark is based on the emissivity factor calculated in $MgCO_2$/MWh. Some of this information was used to develop case studies.

Table 6. Assessment of the needs for modernization of heat energy companies based on the author's method.

Community	Evaluation Criterion										Total Points	Spot
	1	2	3	4	5	6	7	8	9	Emission Index		
A	4.33	6.67	7	6.67	7.67	5	7.67	8.33	2.67	3.76	59.76	2
B	4.67	4.33	4	5.67	3.67	5	4.67	5	2	4.56	43.56	6
C	5.67	4.33	3	5.33	3.33	3	4.33	4.33	1.67	10	45	5
D	3.33	7	7.67	7.67	6	4.67	4	6	2	0.71	49.04	3
E	7.67	4.67	5	5	6.67	6.67	7.33	8.33	1.67	6.97	59.97	1
F	6	3	4	4.67	4.33	6.33	3.33	6.33	1.67	3.25	42.91	7
G	6.33	4.67	3	5.33	3.67	4.33	5	5.67	1.67	6.71	46.38	4

Source: own research.

Our research shows that the highest emissivity index was characterized by a company from municipality C, in which the emissivity factor was 0.745 $MgCO_2$/MWh. The lowest emissivity was characterized by the CHP plant in Krosno (0.05 $MgCO_2$/MWh).

According to experts, the greatest social need to perform PEC modernization exists in municipality E. In turn, the smallest social need to carry out the investment occurs in municipality D. Considering this criterion, there is a noticeable correlation with the benchmark. Therefore, it can be concluded that the experts were guided by this indicator when assessing this criterion.

The current state of preparation for the investment was also significant for the experts. In this respect, the level of preparation of documentation needed to apply for funds for investments was considered. In this case, it was considered that the most advanced municipality is municipality D. However, other local governments obtained a similar number of points below 5 points, which indicates that each municipality is similarly advanced in the modernization process and is "halfway" to the start of the investment.

In the case of the third criterion, the experts assessed the estimated total value of the planned investment. In this case, it was found that in municipalities A and D, the planned investments were of the largest scale. Another criterion concerning the guaranteed date of tender for the contractor of the investment was closely connected with the state of progress of preparing for the investment. This criterion was linked to the possibility of external financing. In this case, the most points were scored by local government D.

A significant assessment criterion was the impact of the investment on the environment and, above all, a reduction in CO_2 emissions. Experts concluded that the greatest impact on decarbonization is planned after the completion of the investment in municipality A. In turn, the investment from municipality G will contribute to a small reduction in CO_2 emissions.

The sixth criterion assessed the innovativeness and versatility of the technical solutions used (heat pumps, hydrogen, heat accumulators, etc.) as well as the versatility and scalability of the proposed solutions. In this case, it was found that the most innovative solutions were proposed by local governments E and F. In municipalities G and F, more traditional technologies are planned.

In the opinion of experts, the planned investment from municipalities A and E will contribute most to achieving the status of an energy-efficient system. In these local governments, the modernization of heating plants will be most consistent with the European Green Deal policy and with the applicable local strategic documents (e.g., plans, including the local plan for the supply of heat, electricity and gaseous fuels).

Finally, the experts assessed the compliance of investments with the assumptions of the 3 W Water–Hydrogen–Carbon Idea, i.e., considering aspects of sustainable water management when designing and implementing the investment. In this respect, the use of carbon nanotechnologies in the designed solutions and ensuring the possibility of powering the designed installation with green hydrogen fuel was considered. A fairly low score of

around 2 points indicates that local governments, despite the desire to modernize heating plants, did not adapt them to the assumptions of the 3W Idea. It is encouraging, however, that the scope of the investment itself was developed in line with the European Green Deal policy. However, as experts emphasize, municipalities participating in the research will be able to count on advisory support in adapting planned investments to current EU recommendations.

The evaluations of individual criteria allowed for the development of a ranking list, which indicated the need to modernize the heating plant primarily in municipality, and then in municipalities A, D and G.

4.2.3. Case Studies

According to experts, the seven most representative municipalities and entities participating in the research were selected for the presentation of the survey results. According to the results of the adopted assessments, investments planned in these municipalities for district heating companies achieved the highest score. In this way, a ranking list for the most energy-innovative local governments was created.

Municipality A

Municipality A, together with the thermal energy company (PEC), is located in the Greater Poland Voivodeship. It is a small town with about 20,000 people. There is a PEC in the city, in which 100% of shares belong to the local government. The plant has a concession for heat production as well as a concession for the transmission and distribution of heat. The activities of the enterprise include primarily:

- Producing, transmitting and selling heat (licensed activity);
- Operating, maintaining and repairing heating equipment managed by the Company;
- Programming and coordinating district heating in the city;
- Conducting repairs, modernizing and investing services in the field of heating;
- Carrying out investments and modernizing heating equipment.

Currently, the heating plant has four WR5 boilers fired with hard coal and a biomass boiler (wood chips) type KIV H/18/R/H 4000 with a capacity of 3.5 MW. The efficiency of the boilers ranges from 84% to 87%. All boilers are equipped with deducting devices to meet the current requirements of environmental protection regulations. The annual consumption of fine coal is about 12,000 Mg and of wood chips is 6000 Mg. The demand for heat in the summer is about 14,320 MWh, and in the winter, the demand is 70,830 MWH. The data for 2021 show that the emission index of the heating plant is at the level of 0.28 $MgCO_2$/MWh, and the annual greenhouse gas emission is 24,000 Mg. To improve the emission indicators, the company planned to build a geothermal heating plant with a connection to the existing district heating system of the city. The first work has already been carried out, which consisted of drilling wells, as well as building filters. After the commissioning of the heating plant, CO_2 emissions are expected to be reduced by about 20,000 Mg, i.e., by about 80%. At the same time, the company's energy efficiency is expected to exceed 80% [80].

Municipality B

Municipality B is located in the south of the Malopolska Region and has over 80,000 inhabitants. This municipality operates a municipal heating plant, which is a limited liability company. A heating plant is an operator of a network system with two basic elements: sources, i.e., a system producing heat, and a district heating network. Over 93% of heat energy is produced with coal technology in three sources. The company has pro-ecological gas and oil heating devices, and some units are additionally supported with solar collectors. The network is about 50 km long and is systematically modernized. The heating plant currently operates two boiler rooms. In the first boiler room, two water boilers with an efficiency of about 85% and a biomass boiler with an efficiency of about 93% are installed. In the second boiler room, five boilers with an efficiency of about

85% are installed. The total nominal power in fuel of all boilers in operation is 93.3 MW. In addition, the plant has a boiler room equipped with four coal-fired boilers with a capacity of 3.5 MW each. The total efficiency of the boiler room is about 80%.

The company also has two gas boiler houses. The first of them, with a capacity of about 1.4 MW has an efficiency of about 95%. The second one, with a capacity of 2 MW, is supported with solar collectors with an area of 100 m^2. The total capacity of the operated heat sources is 98 MW. The annual fuel consumption of fine coal is 20,401 Mg/year, of natural gas is 1,122,155 m^3/year and of biomass is 81,747 Mg/year. The annual demand for heat in the summer is 11,212 MWh/year, and in the winter, it is 82,077 MWh/year. The annual greenhouse gas emissions are 32,993 $MgCO_2$/year, while the benchmark is 0.34 $MgCO_2$/MWh.

The company plans to increase the share of renewable energy sources in heat production in the near future. In addition, it intends to continue activities in the field of modernizing the transmission network, which will contribute to minimizing heat losses and losses of network water. This will reduce fuel consumption as well as reduce the pollution generated. After completing the intended investments, the company will achieve the status of an energy-efficient system, and above all, it will have 16 MW of power from cogeneration and RESs. Heat storage will also be an important investment, which will allow the use of excess heat energy after hours and days when the demand is lower. Heat storage facilities provide flexibility in the operation of heat sources and heating networks, which allows full use of renewable energy sources, such as biomass. Thanks to the use of energy storage, there would be no need to run coal sources during peak demand. Thermal energy storage allows for stabilizing the operation of the heating network and enables a much smoother change in network operating parameters, as well as a faster response during rapid temperature drops. The estimated parameters of the heat storage are 3000 m^3 and peak power at the level of 103 MWh [81].

Municipality C

Municipality C is located in the Mazowieckie Voivodeship and is inhabited by over 20,000 people. There is a company in the city that has one heat source and about 20 km of heating and distribution networks, as well as 108 single and dual-function nodes. The enterprise is equipped with:

(a) Two water boilers with a total installed thermal input of 22.0 MW:
- One water boiler with a capacity of 7 MW for coal fuel.
- One water boiler with a capacity of 15.0 MW for coal fuel with 20% biomass admixture.

(b) One steam boiler with a capacity of 10.2 MW for biomass of wood origin. The total rated power of the 3 boilers is 32.2 MW.

In 2021, 3331 Mg of coal and 26,543 Mg of biomass in the form of wood chips were used for heat production. The demand for heat in the summer amounted to 7344 MWh and, in the winter, the demand amounted to 137,376 MWh. Annually, the heating plant emits 7039.5 $MgCO_2$ of greenhouse gases from coal combustion and 34,484.7 $MgCO_2$ from biomass combustion. The emissivity index was 0.745 $MgCO_2$. Currently, there are plans to build electrostatic precipitation at the level of boiler deducting, thanks to which exhaust emissions will be reduced. The second important investment is the installation of a photovoltaic installation with a total capacity of 0.515 MWe [82].

Municipality D

Municipality D is located in the southern part of the Podkarpackie Voivodeship. It is a city inhabited by about 50,000 people. For the needs of residents, there is a heating company in the form of a municipal company that supplies heat to users. The local government unanimously states that they are among the best in Poland. The plant's activity is based on the cogeneration operation of an ORC installation with a thermal capacity of 5.35 MW and

electricity capacity of 1.4 MW, a biomass boiler with a capacity of 7.0 MW built in 2020 and four boilers, with coal fine being used as a peak and reserve fuel. Biomass plants produce 90% of the thermal energy. The length of the district heating network is more than 35 km, of which about 80% is pre-insulated. In 2021, 37,935 Mg of biomass in the form of wood chips and 2107 Mg in the form of hard coal were used. The demand for heat in the summer amounted to 6649 MWh, and, in the winter, the demand amounted to 61 560 MWh. Annual greenhouse gas emissions amounted to 4272 $MgCO_2$, and the emission index was at the level of 0.053 $MgCO_2$/MWh.

Currently, the local government, together with the thermal energy company, is building a power unit for residues from municipal waste sorting. Its purpose is to use residues from sorting municipal waste for the production of heat for the needs of the municipal heating network and electricity for the needs of the plant and other municipal entities. In addition, together with several other local governments, the company implements a mechanical and thermal waste treatment installation [83].

Municipality E

The local government heat energy company is located in a small town of about 10,000 inhabitants, in the north of the Pomeranian Voivodeship. There is a company that has a boiler room consisting of five grate coal–water boilers powered with coal with an efficiency from 70 to 80 * and power from 1.1 MW to 3.5 MW. The plant also has a peak boiler room with four boilers with a capacity of 0.53 MW each. For the needs of the heating plant, 5813 MG of hard coal is burned annually. The demand for heat in the summer is at the level of 1250 MWh and the demand in the winter is 22,280 MWh. Annual greenhouse gas emissions in 2021 amounted to 12,207.9 $MgCO_2$, while the emission index was at the level of 0.519 $MgCO_2$/MWh.

The main investment plan of the company in municipality E is the construction of a biomass installation with a thermal capacity of 2 MWt. In addition, the plant plans a photovoltaic installation with a capacity of 0.4 MWe. There are also to purchase a cogeneration unit with an electrical capacity of 0.999 MWe and a thermal capacity of 1.2 MWt. Further plans of the local government are air heat pumps with a capacity of 1 MWt and two gas boilers with a capacity of 3 MWt and 2MWt. The main objective of the investment is to reduce the high level of emissions and encourage residents to connect to the district heating network [84].

Municipality F

Municipality F is located in the Mazowieckie Voivodeship, which is inhabited by over 40 thousand people. For the needs of residents, there is a company supplying heat through pre-insulated networks. The heating plant focused on the development of an intelligent heating network, expanding the remote control and visualization of heat substations and automatic control of technological processes and hydraulic circuits in heat sources. By the end of 2020, a modern and ecological installation using gas cogeneration technology was to be built. Currently, the installed thermal capacity is 6.7 MWt, and the electrical capacity is 6.6 MWe. The heating plant is equipped with four grate boilers, fired with hard coal, whose consumption in 2021 amounted to 8433 Mg. In turn, the gas boilers used 10,485,998 m^3 of natural gas in the same year. The demand for heat in the summer amounted to 17,154 MWh, and the demand in the winter was 60,287 MWh. The plant emitted 38,332 Mg of greenhouse gases in 2021, of which 45% were a result of burning hard coal. The emissivity index was 0.242 $MgCO_2$/MWh.

The local government of municipality F plans to invest in two RES units. Both are to have 2.0 MW of thermal power each. They will consist of solar water heating systems, photovoltaic systems for energy generation for RESs and heat pumps. The investment results from the social needs of the implementation of ecological heat sources for the district heating system, a reduction in the company's energy consumption for primary fuels, the

decarbonization of the district heating system and the implementation of new and modern technologies for generating units and reducing greenhouse gas emissions [85].

Municipality G

Municipality G is an urban commune located in Świętokrzyskie Voivodeship, where over 22 thousand inhabitants live. The thermal energy company operating in this municipality deals with the production of steam, hot water and air for air conditioning systems. In addition, it generates heat and electricity. It covers about 60% of residents' heat demand. The plant uses over 10 km of its own networks and 3 km of non-company assets. The installed thermal capacity of the enterprise is 36,784 MW. Heat is generated in one coal-fired boiler, one coal–gas boiler and eight gas boilers. In 2021, 1,029,988 m^3 of natural gas and 9282.2 Mg of fine coal were used for heat production. The demand for heat in the summer amounted to 4475.26 MWh, and the demand in the winter was 58,096.69 MWh. The annual greenhouse gas emission index was 21,515.094 $MgCO_2$, while the emission index was at the level of 0.4 $MgCO_2$/MWh.

The municipal government plans to modernize the coal–gas boiler room by building two biomass boilers with a capacity of 1 MWt each. Thanks to this investment, air quality in the municipality will improve, and the costs of heat production will remain at an acceptable level. Ash production will also decrease, and CO_2 emissions will be reduced by 300 Mg/year [86].

4.2.4. Impact of the Energy Transition in the Heating Sector on the Local Community

As part of this research, a qualitative analysis of ongoing and planned investments and modernization was carried out by a panel of experts. On its basis, it was concluded that the energy transition in the heating sector has a very large impact on the local community and includes a change in ecology, economy, public health and quality of life and the adaptation of policy and management to the expectations of society.

Reducing emissions and improving air quality play an important role in the local community. The energy transition, often associated with a reduction in fossil fuels, contributes to a reduction in emissions of greenhouse gases and other substances (e.g., PM2.5 dust, nitrogen oxides and sulfur oxides). Improving air quality also has a direct impact on the health of residents, reducing the risk of respiratory and cardiovascular diseases. Similar conclusions were drawn by authors studying the impact of PM2.5 on mortality [87]. Modernization processes in the heating industry have economic aspects and are related to employment. The energy transition, with investments in new technologies, is associated with the creation of new jobs. Innovations in energy and heating and low-cost, renewable energy sources can be used to reduce energy costs for households, which is particularly important in energy-poor communities [88]. On the other hand, projects related to the energy transition often result in the involvement and support of the community, which leads to greater environmental awareness and can initiate local actions for the undertaken development [89]. Transformation decisions, which are initiated by local authorities, may result in the introduction of changes in energy and environmental policies, as well as having an impact on spatial planning [90].

5. Discussion

Across Europe, national governments are increasingly turning to local governments for leadership in the development of local aspects of the energy system. Local governments' actions range from encouraging the use of energy efficiency measures in buildings to strategically coordinating the deployment of new low-carbon technologies such as photovoltaics, solar energy and district heating [90,91].

Over the last two decades, most European local governments (including Polish ones) have focused on striving to modernize their heat generation systems and, at the same time, reduce greenhouse gas emissions. In this context, the modernization of municipal heating plants has become an element in the strategy of most local governments. The

modernization of heating infrastructure is aimed at helping to reduce CO_2 emissions and improving the quality of life of residents. Analyzing the surveyed local governments, it can be concluded that the main reason for the need to modernize municipal heating plants is the age of the heating infrastructure, as well as the source of their power supply. Many district heating systems are outdated, resulting in heat and energy losses. For the average resident, this means that they pay high heating bills and greenhouse gas emissions remain at unacceptable levels.

The modernization of the Polish heating system is crucial for several reasons, including, above all, environmental protection, the use of renewable energy sources and a reduction in greenhouse gas emissions. Modernizing district heating systems, particularly by moving away from coal to more sustainable energy sources, contributes to reducing greenhouse gas emissions. This is in line with the objective of the European Union to become climate-neutral [40]. This is confirmed by the results of research conducted by Polish local governments. Representatives of the authorities and heat energy companies indicate that this is one of the most important arguments contributing to decision-making related to the transformation.

To improve air quality, it is important to reduce the combustion of gases and other fossil fuels that are emitted in heating plants. Work on investments in local heating plants contributes to activities related to environmental protection [92]. The surveyed local governments are very aware of this issue. Most of them have even invested in measuring devices that, in the future, after the completion of the investment, will indicate how much the air quality has improved. This will indicate the effects of investments.

Modern heating technologies have an impact on improving energy efficiency, which translates into minimizing costs for residents and heating plants. In this respect, all the surveyed local governments are counting on an improvement in efficiency, referring to the indications of the Energy Regulatory Office [93].

Compliance with European Union law is also an important argument. Poland, as a member of the European Union, must align its emissions and development regulations with EU law. Modernization in the heating sector must be carried out in accordance with the guidelines contained in national and EU documents. The basic document for local governments in this respect is the study entitled "Climate action" [94].

As the world moves toward a sustainable future, the search for alternative, renewable and clean energy sources has intensified. In the thermal energy sector, the focus is shifting from fossil fuels, which have long been the dominant source, to alternative technologies that can efficiently harvest thermal energy while minimizing environmental impact.

As the global community strives to reduce greenhouse gas emissions and combat climate change, the exploration and adoption of alternative thermal energy production technologies is becoming a necessity. From harnessing the earth's natural thermal energy to converting ocean temperature differences into energy, these technologies represent a shift toward a sustainable energy future. By fostering innovation and investing in R&D, the full potential of alternative heat sources can be unlocked, paving the way for a greener and cleaner planet.

(a) Using the experience of other local governments, as well as putting into practice the results of research and, above all, innovations, it is possible to implement modern technologies. The modernization of heating systems is related to the introduction of modern technologies, such as cogeneration, heat pumps, solar collectors or biomass. These excellent solutions are based on results and analysis.
(b) Create tailor-made infrastructure: In cities that are growing, district heating networks need to be modernized so that additional heat demand is met. Flexibility and scalability of the infrastructure are crucial to the success of participation.
(c) Decouple from fossil fuels: Part of the share of heat in the calculation shall be considered in the transfer of energy sources from fossil fuels to renewable energy sources. Thanks to this, it is possible to have an impact on the natural environment and energy security in the region.

It is also important that the modernization of municipal heating plants brings many benefits for both residents and the whole society:

(a) Reduction in greenhouse gas emissions: Reducing fossil fuel consumption and the impact of hydropower sources on greenhouse gas emitting supports objectives related to the fight against climate change.
(b) Improvement in air quality: Modernization of a heating plant reduces impacts on the air, which translates into an improvement in the quality of life of residents, as well as the use of treatments associated with subsequent polluted air.
(c) Financial savings for residents: Modern district heating systems improve energy use, which increases heating costs for residents.
(d) Improvement in development and economy: Modernization of heating plants supports the operation of energy sources and technologies, which contributes to economic growth and job creation.

According to many authors, the right solution for the energy transition is a flexible combination of the electricity and heating sectors into smart energy systems. This can contribute to both the integration of renewable energy and decarbonization [11,12,30,95]. In the near future, in terms of heat supply, 4GDH and 5GDH systems, i.e., low-temperature district heating networks that are integrated with sustainable energy systems using renewable energy sources and heat storage, will dominate [11–13,96,97]. The 4GDH and 5GDH systems, with low network losses, will allow for an effective supply of heat and cold from heating systems to low-energy buildings. An important feature of these will be the use of low-temperature renewable heat sources, which will be integrated with the operation of intelligent energy systems [98].

Faced with the necessity of energy transition, Poland should learn from other countries in the world. Such actions should be:

- International cooperation: Poland can be connected within an international network, both within the European Union and with other countries, to gain access to energy sources.
- Investment in R&D: Investments in R&D can be used to develop new technologies.
- Education and public awareness: Raising public awareness of the benefits of producing energy from clean and alternative sources.
- The role of local governments: Stimulating the actions of local authorities to accelerate the energy transition.

In conclusion, it should be noted that the modernization of municipal and municipal heating plants in Polish and European local governments is the result of applying a strategy for effective development and combating climate change. Introducing modern technology and infrastructure to meet the needs and switching to a renewable energy source can be useful in improving efficiency and adding and improving the quality of life of users. Assistance in modernization to enable economic and technological development will bring long-term progress to regions in Poland and Europe.

6. Conclusions

Polish heating plants are the most dependent on coal in Europe. Each of them has coal-fired boilers, and together, they burn about 14.5 million tons of this raw material. Even the heating plant in municipality D, which mainly burns biomass, has coal-fired boilers, which are treated as peak and reserve. Also, in the case of municipality G, which plans to modernize the coal and gas boiler, it wants to leave the coal boiler as a reserve or use during peak periods. In the coming years, the heating sector in Poland will have to switch to low- and zero-emission technologies.

Poland is the second-largest district heating market in the European Union. The total length of the heating network in Poland is 21,701 km, which is used by 16 million Poles. Unfortunately, as many as 83% of systems in the country do not meet the requirements of an efficient heating system, i.e., at least 50% of the energy is from renewable sources or

waste heat or 75% of the heat is from cogeneration or 50% of the energy and heat systems are used to produce heat or cold [47,68].

European regulatory documents relating to the energy sector, including heating systems, confirm that in Poland, most companies do not meet the guidelines contained in two basic documents: the "Fit for 55" package and the RED II directive, dealing with renewable energy sources. The "Fit for 55" package for Poland assumes activities aimed mainly at decarbonizing district heating. This can be achieved, i.e., with the development of district heating. Local governments will play an important role in this case. Rural cities and municipalities are responsible for the development of these systems. The task of local authorities will be to encourage residents to join the system networks. Therefore, all actions should be taken that will contribute to accelerating investments in modern thermal systems. One such activity was to organize research for an aspiring innovator in the field of district heating combined with a competition. As a result, an original method for selecting municipalities in which thermal energy companies operate, which shows an urgent need to modernize their installations and, above all, reduce emission indicators, was developed. The results of this research made it possible to develop a ranking of municipalities requiring the modernization of heating plants [41].

It should be emphasized that the developed method used in the presented research was carried out for the first time, and it can be said that this was a focus study. Of all the analyzed municipalities, seven local governments agreed to the publication of partial indicators and modernization plans, with the proviso that the names of the entity and the municipality would not be given.

The obtained results allowed us to develop the following conclusions:

(a) All heating plants operating in the analyzed municipalities use coal-fired boilers for heat production.
(b) The most popular fuel used in heating plants in the country is wood chips.
(c) Thermal energy companies, when modernizing their installations, more often use low-emission technologies than zero-emission ones.
(d) The main objective of investments in energy production is the decarbonization of the heating system and the implementation of modern technologies in generating units, as well as a reduction in greenhouse gas emissions.
(e) An additional goal of modernization is social needs in the field of connecting to system networks.
(f) A less popular investment among local governments is the construction of a thermal installation for the utilization of municipal waste used for the production of system heat.
(g) Local governments adapt the type of installation to the availability of fuel, e.g., in the fruit growing region, there are plans to develop biomass boilers in which trees removed by fruit growers will be burned.
(h) The use of and improvement in the efficiency of the technology are expected to eliminate emissions of CO_2, NO_x and other harmful substances. Switching to a higher green grade of fuels, such as biomass or natural gas, can help control climate impacts.
(i) The modernization of heating infrastructure allows for increasing the use of energy sources, which in turn reduces heat losses and reduces production costs.
(j) Investments in the modernization of heating plants will contribute to an improvement in the country's energy security.

The analysis of the source text, strategic documents and our research conducted here allowed us to formulate answers to the research questions posed in the introduction.

Question 1. What is the current situation of the Polish heating sector in relation to the assumptions of the EU climate and energy policy? The Polish heating sector is facing issues related to the implementation of climate and energy policy assumptions. The European Union is moving toward decarbonizing its economy and reducing greenhouse gas emissions, which requires a profound transformation in the way heat is generated and distributed. Poland, as a country largely based on coal, must accelerate activities related

to the transformation of the heating supply in this area by investing in renewable energy sources and modern technologies, such as district heating or heat pumps.

Question 2. What are the most important directions of changes in Poland's energy policy in the area of heating? In recent years, Poland's energy policy has addressed the following issues:

- Decarbonization of the economy: Poland, like many other countries, is striving to reduce CO_2 emissions, which includes reducing energy production from hard coal and lignite.
- Development of renewable energy: Poland is increasing energy in the Polish energy mix from sources such as wind, solar or biomass.
- Infrastructure improvements: Investments in modern technologies and increasing energy capacity contribute to maximizing the needs of the community.
- Diversification of supply sources: To reduce dependency on a single supplier, Poland aims to diversify its gas supply and pipelines, which includes investing in LNG terminals or gas interconnection with neighboring countries.

Question 3. What is the role of Polish local governments in the transformation of the heating sector? The role of Polish local governments in the energy economy is crucial. Local governments take independent actions as well as cooperate with individual heating companies in the field of investments in modern technologies that reduce emissions and ensure comprehensive heat supply. Local authorities promote and support the development of various energy sources for heating, such as wind power, solar energy, biomass or geothermal. They also have an impact on individual users, encouraging them to connect to network installations built by municipalities.

Question 4. What investments and tasks are undertaken by local government heat energy companies as part of the energy transition?

Studies have indicated that the majority of local government thermal energy companies use coal-fired boilers as well as biomass boilers to produce heat. To adapt to the directions of Polish policy, as well as to achieve climate neutrality, local authorities and heat generation companies are taking the following measures:

- Increasing the share of renewable energy sources in heat production (solar energy—photovoltaic installations and geothermal energy);
- Increasing the use of biomass-fired boilers;
- Modernizing heating networks to reduce heat losses during the transmission of energy to end users;
- Constructing heat storage facilities that ensure the flexibility of heat sources and the heating network, which ultimately helps to make full use of renewable energy sources;
- Constructing electrostatic precipitations at the boiler level, which reduces flue gas emissions;
- Constructing power units for residues from municipal waste sorting;
- Constructing cogeneration units and gas boilers;
- Constructing solar water heating systems;
- Investing in heat pumps.

These investments will contribute to improving energy efficiency and the development of the use of renewable energy sources including biofuels, thus reducing the impact of the energy sector on the environment and increasing the security of the energy supply. Unfortunately, the above-mentioned actions of local governments and their investments are insufficient, as the process of achieving climate neutrality is slow.

Therefore, when analyzing the activities carried out by other local governments, the following activities should be recommended to Polish municipalities:

- Increasing the development of high-efficiency cogeneration, i.e., the simultaneous production of heat and electricity;
- Implementation of activities to support the development of heat electrification with the integration of the heat and energy sectors (heat pumps);

- Resumption of thermal modernization programs for public and residential buildings;
- Increasing the awareness of employees of local government units in the field of heating transformation;
- Improving the education of the local society and raising awareness of the production of energy from clean and alternative sources;
- Establishing cooperation within the framework of an international partnership of cities and municipalities to exchange experience in the field of good practices in the energy transition.

Question 5. What is the impact of the transformation on the local community? The energy transition has an impact on the local community by:

- Job creation: New technologies and investments often lead to new jobs in district heating, such as renewable energy or infrastructure upgrades.
- Impact reduction: Reducing emissions from energy sources such as coal contributes to improved air quality, which directly affects the health of residents.
- Changing landscape: Installations such as wind farms or photovoltaic panels can interfere with the local landscape, which is not always welcomed by the community.
- Increased environmental awareness: Transformation is often linked to environmental education, which can result in community involvement in environmental protection activities.
- Fluctuations in energy prices: In the event of a rapid transition, energy prices may fluctuate, which will have a direct impact on residents' household budgets. Ultimately, however, there will be a reduction in energy prices as a result of using cheaper energy sources.

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