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Resource Efficiency and the Role of Renewable Energy in Miskolc: The City's Journey Towards Becoming a Smart City

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Abstract: Miskolc, which is the focus of our investigation, is the fourth most populous city in Hungary and the center of one of the most underdeveloped NUTS2 (basic territorial category for the regional policy of the European Union) regions in the European Union. The socialist heavy industry played a decisive role in the development of the city, the decline of which also left deep traces in the city. In its current position, the city tries to manage its available resources as efficiently as possible, and the city management is open to the use of modern urban development tools. This is supported by the fact that Miskolc was the first Hungarian city to join the Green Cities for Sustainable Europe movement in 2011, and then in 2015, it joined the Triangulum project of the EU Smart Cities and Communities program as a follower city. In the process of becoming a smart city, the dimensions of environmental sustainability and energy efficiency were given a prominent role, which should not be surprising considering the traditions of the city. Within this, we must first mention the construction of the geothermal central heating system, with which the city really took significant steps in this field. The main goal of the study is to develop a new smart local concept closely linked to regional development and the key energy sector, through which the local adaptation of the defining elements of the internationally defined smart city in several forms for the city of Miskolc will be presented. In our study, we review how the results achieved by Miskolc so far and the development plans for the future fit in with the smart energy developments of smart cities. Before exploring the processes in Miskolc, we will deal in more detail with the possibilities inherent in district heating and geothermal energy utilization and Hungary's capabilities.

Keywords: smart city; local energy systems; renewable energy; geothermal energy; district heating system; local and regional resources

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1. Introduction

Miskolc is the fourth most populous city in Hungary, the seat of the Miskolc district, moreover the capital of Borsod-Abaúj-Zemplén county and the center of the Northern Hungary region. The city is situated in the eastern part of the Bükk Mountains, in the valley of the river Sajó and its tributaries, at the meeting point of various natural and economic features, and has been an important center of goods and passenger traffic for centuries. Despite its dominant socio-economic role, the city has been steadily losing population, which is now less than 150,000 people. The negative demographic trends naturally have repercussions on other spheres of the municipality, which from time to time justify a renewal of the urban development toolbox. Miskolc has set itself the goal of becoming a smart city in the 2014–2020 development period [1,2].

The main goal of the study is to present a new smart local concept as a case study, focusing on the specific characteristics of the city under study. Our approach is closely linked to regional development, urban development, and the key energy sector, through

which the local adaptation of the defining elements of the internationally defined smart city in several forms for the city of Miskolc will be presented. In the course of our research, we considered it important to review the relevant literature on the energy aspect of the smart city concept. In order to continue the study of the topic, we have tried to review the literature that focuses on the generation of thermal energy and, within this, on the use of geothermal energy, as is the case in Miskolc today. Following the literature review, the current situation of renewable energy use in Hungary is presented. Within renewable energy sources, geothermal energy has significant potential and can contribute to the smart city objectives of other Hungarian cities. The main aim of the research was to present a good practice in Hungary, and the literature review and analyses were carried out accordingly. In this study, we touch on the main pillars that are decisive for the city's energy sector from both the economic and the urban development points of view, and we present the developments that the city has already achieved in relation to energy developments, keeping in mind the role of resource efficiency and renewable energy in Miskolc. Miskolci Hőszolgáltató (MIHŐ (the company responsible for the examined district heating service)) Ltd. (Miskolc, Hungary) has set itself the future goal of environmentally friendly energy, so it is important to emphasize that the developments carried out so far under the auspices of Miskolci Hőszolgáltató Ltd. promote the connection between the energy sector and smart urban development. Based on all this, the aim of the study is not a technical field-based approach.

Based on Sikos Tomay and Szendi's economic and environmental sustainability analysis, Miskolc was classified among cities with cyclical development and average characteristics. In terms of livability, the cities in the cluster are around average or below average compared to the other cities studied in Hungary. In Miskolc, which used to be a stronghold of heavy industry, unemployment increased significantly (by 19.5% of the long-term rate) following the decline of metallurgy [3]. Today, the situation has become more favorable, but the process of restructuring and renewal still presents many challenges for urban development specialists.

The city has won EU funding under the URBACT program (for more than 20 years, the program has been encouraging integrated and sustainable urban transformation throughout Europe), which allows municipalities to become "smarter" as quickly and efficiently as possible. In Hungary, URBACT helps settlements to develop integrated actions for the sake of sustainable change, which is also decisive in the case of Miskolc in terms of settlement policy priorities. The URBACT Program, which has been in operation since 2002 and is the first regional cooperation program in Europe, supports the exchange of experience and learning for the sake of sustainable urban development. The members of the European city networks created in response to the call of the program develop their action plan focusing on a jointly chosen problem area with the involvement of local social actors. In terms of the smart pillars, the energy sector's focus on the future towards renewable energies, the receptiveness of smart people, and the digital transition in the various decision-making processes should be emphasized. The program supports urban network projects with various measures and capacity-building activities, such as the expert group, the summer university, the e-university, seminars, the URBACT toolbox (Knowledge Hub), and a series of different methodological tools, which can also be used during some tenders and during the planning process. In relation to smart people, it is important to emphasize the testing and demonstration of city festivals, joint city development actions, real situations, and the training sessions for politicians and city developers. The city needs to organize its development plans into an action plan, which includes the methods and technologies that can be used to achieve them, as well as the areas where it wants to be "smarter". This could be environmental improvement, enhancing the quality of life and attractiveness of the city, or economic or governance-related development. It is important that this is done with the involvement of the people who live there [4]. The SmartImpact project is looking at five main themes: organizational development within city administrations, procurement and financing of innovative solutions, activation of the local

renewable ecosystem, supporting regulations and incentives, and data integration. The county seat has launched initiatives in all six smart components: "smart economy, smart governance, smart mobility, smart environment, smart living conditions, smart people" [5]. The most prominent are environment and mobility. Related to these themes, projects such as geothermal energy, smart grids and metering systems, development of a sensor-based flood protection system, installation of smart poles to protect air quality, creation of parks, installation of solar panels, development of a public area fault reporting application, a green transport system, intelligent traffic management, introduction of electronic ticketing, and construction of electric charging stations were identified [6,7].

Geothermal energy accounts for a significant share of renewable energy consumption. The city is continuously striving to increase the share of renewable energy in the utility systems supplying the population, with 51.3% of district heating consumed in 2022 coming from renewable energy [8]. We focused our research on this sector, where Miskolc has already made significant progress towards becoming a smart city. Although the focus of our research was the utilization of geothermal energy in district heating, we carried out our empirical research in a complex approach, taking into account the mutual influence of different sectors and developments.

1.1. Smart Energy as a Key Factor for Smart Cities

Occupying only 3% of the Earth's surface, cities use 75% of natural resources, and the spatial distribution of the world's population shows a further increasing concentration. Territorial inequalities in access to natural resources continue to grow, which raises more and more sustainability issues [9]. At the same time, efforts to increase resource efficiency in cities can be particularly effective in achieving low-carbon economy goals, not to mention addressing local challenges. Improving resource efficiency at the urban scale is therefore an important part of smart city initiatives [10]. A smart city is rightly expected to match energy supply and demand based on smart technology solutions [11]. From the point of view of smart cities, the most powerful measures are considered to be those that directly affect at least these three sectors—energy, transport, and information and communication technology [12]. Research carried out in Graz (Austria) in 2016 has concluded that about 2/3 of the ecological effects of a medium-sized smart city are due to different forms of energy supply, within which the role of heat supply for households stands out [13]. In many cases, sustainability is not the main goal of the local implementation of smart city projects; however, the smart objectives in most cases increase ambition in the direction of energy sustainability. Sustainability measures in smart cities are rarely driven by advanced technology, even though innovations are central to smart cities. Furthermore, there is a very significant sustainability potential in the integration between sectors, the measurement of which also raises challenges [14]. An effective sustainable energy management system can be implemented using all possible forms of renewable resources, and it also requires the use of intelligent systems, IoT systems, and the introduction of green technologies. The essence of an intelligent system is the embedding of modern technologies into functions already used by the world [15]. To make the energy use of cities more sustainable, the new renewable energy and energy saving technology solutions provide countless opportunities, but it is very important to treat these developments as part of a complex system. Developments are always implemented to ensure a better quality of life for citizens while addressing urban energy challenges related to climate change, lack of energy resources, or inadequate and deteriorating energy infrastructure [16]. Spatial research has not only shown how different strategies are used in urban areas and in the countryside but also that the application of extremely diverse solutions within a city can lead to results due to the different characteristics of the city structure [17,18].

Since the early 2000s, the concept of the "smart energy city" has been increasingly addressed in the relevant literature as a sector-specific version of the smart cities concept. The first research projects focused on buildings and smart grids and then extended to the city level and several urban sectors [19,20]. Smart cities are built from the energy saving

systems of smart homes, in which the diversity of building types and related infrastructures poses a serious challenge [21]. At the same time, energy management at the city level can have many positive effects on the efficient management of energy consumption at the household level [22,23].

Energy solutions for smart cities can be focused on three main areas. As a first step, the issue of energy efficiency cannot be avoided, followed by energy sustainability, the main topic of which is the utilization of renewable energy sources. The third, more complex topic is energy and urban planning, including the consideration of smart networks, smart homes/buildings, intelligent urban and energy planning, and electric vehicles [24].

In practice, it is often seen that the realization of ambitious objectives runs into serious obstacles. Based on a precise assessment of resources, the short-term goal cannot be a complete transition. Even the fact that individual cities have made spectacular progress in certain segments related to the concept should be evaluated positively. In most cases, the assessment of renewable energy sources is positive, but their spread is also influenced by the characteristics of the previously built systems, the market competition against fossil energy carriers, and the peculiarities of the support policy [25]. The complexity of the problem to be solved requires an integrated approach to operational planning [26]. Developments have led to success on a wide range of technological bases, while smart solutions have also increased the efficiency of other investments. The composition of the really successful developments has effectively followed local conditions and needs, and it is only by taking these into account that good practices can be replicated [27]. Smart cities from an energetic point of view always have several paths ahead of them, and, accordingly, several scenarios can be formulated with a comparative analysis of possible developments, based on efficiency aspects [28].

Of course, the complex urban energy models do not only focus on one popular sector but also cover the issues of electricity, heat energy, and energy used in transport [29]. In the planning process, professionals pay close attention to each of the following five areas of intervention: generation, storage, infrastructure, facilities, and transport. It is important to highlight that the five main energy-related activities are interrelated as illustrated in Figure 1 and are generally known as areas of intervention [30,31].

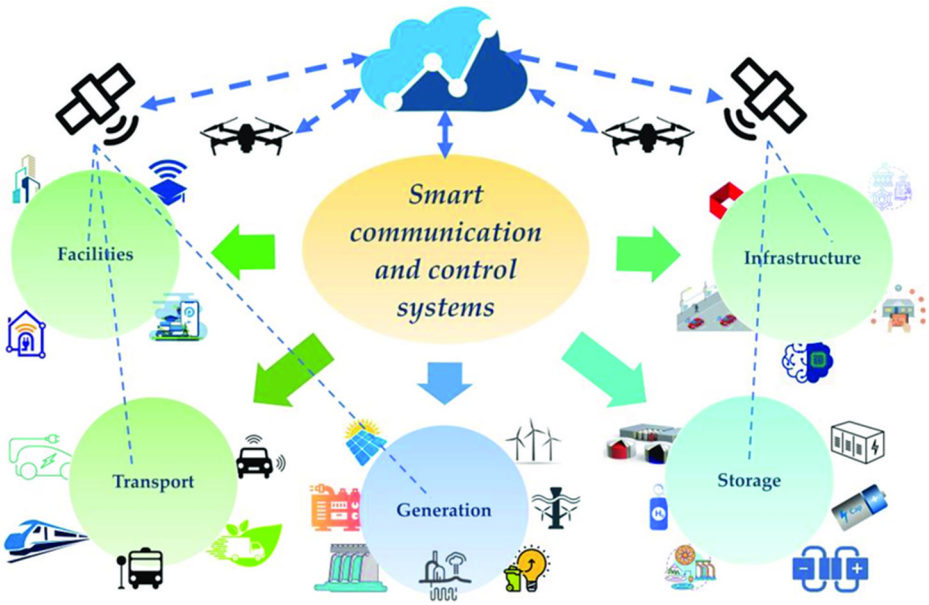


Figure 1. Smart city energy model components. Source: Refs. [30,31].

During the energy transition of smart cities, not only the local but also the regional characteristics of different scales must be taken into account. It is necessary to examine the compatibility of the local renewable energy strategy with the surrounding national

and global energy systems to know the plans for the utilization of resources and the development of industry and transport [32].

A research study that systematically explored and analyzed the success of smart energy city projects examined the main obstacles in 43 cities of the European Union. The researchers used a multidimensional approach, in which they took into account the frequency of the obstacles, the degree of their impact, and the cause-and-effect relationships between the obstacles based on their origin and scale. The research results highlighted the lack of long-term political support and cooperation as the main obstacles, as well as the insufficient amount of financial support and the fragmentation of project-level responsibility [33]. In 2019, South Korean researchers introduced the Smart Energy Transition Index, which measured the contribution of the smart city component to the energy transition in a complex approach. Based on the Index, the examined South Korean cities were classified into three groups. Cities in the first wave of smart cities focused on smart transportation and security services. In the second wave, comprehensive city services came to the fore, while members of the third group did not meet the smart city requirements. During the complex evaluation, the smart cities of the second wave achieved a higher score than the cities of the first wave, and the difference was even greater with non-smart cities [34].

We consider it very important to get to know the opinion of the population regarding the concept of smart cities and the evaluation of the energy developments made for this purpose. (We asked about this in the context of a civil forum). A questionnaire survey conducted earlier in Sopron in western Hungary showed that far fewer people were aware of the concept of a smart city (24.9%) than those who supported the energy rationalization efforts associated with it (91.7%) [35]. A survey in Žilina (Slovakia) reached a very similar result, according to which the population did not necessarily know the exact concept of a smart city but supported green solutions, including the use of renewable energy sources [36].

Patkós et al. in their study found that in Hungary, the guidelines of the central government prevail when determining energy development guidelines, and grassroots initiatives are not given enough space. Local interests, specialties, and resources often remain latent, which could come to the fore with a more thoughtful use of EU financial support resources [37]. Collaborations and community support in this sector can also make a meaningful contribution to the well-being of the local population [38]. However, we must also note that the change in central regulation can create unfavorable conditions for previously successfully implemented energy developments, which thus become unsustainable from a financial point of view [39].

A study based on a review of previously realized research has shown that the energy system of smart cities is an extremely complex system, the exploration and transformation of which requires careful preparation from a sustainability point of view. A smart city system model should take into account city functions (current and planned), infrastructure, characteristics of local communities (needs, preferences, etc.), selection process, input elements, output elements, and the wider (economic, ecological and social) environment [40]. Smart cities are often mentioned without criticism as a sustainable method of urban development. Computing and information technology create the conditions for the interconnection of more and more people and things, which only further increases the complexity of urban systems. At the same time, the increase in the complexity of societies, based on previous experience, causes an increase in energy consumption, contrary to the original objective. A critical study sought to answer whether excessive complexity leads to a decrease in energy efficiency and the development of unmanageable urban systems [41].

1.2. Providing Heating and Hot Water for the Smart City Communities

Electricity generation, which can be directly linked to the electrification of local transport, is often at the center of the analysis of the renewable energy production capacity of individual municipalities [42]. One example of this is the rapid spread of solar panels in Hungary, which presents system operators with many new tasks. At the same time, solar

collectors, which are effective in supplying hot water and can be used locally, have not gained such popularity in the country [43]. Based on the features of Miskolc, which is the focus of our investigation, and the results achieved so far in the transition, we will continue the literature review focusing on the thermal energy sector. Newer generations of district heating, intelligent heating networks, can play a significant role as part of the implementation of comprehensive sustainable energy systems [44]. Additionally, we must not forget that half of the final energy consumption of the European Union is spent on heating and cooling, so thermal energy is the largest energy end-user sector [45].

In the 2010s, the replacement of natural gas-based district heating services with biomass arose in many cities [46]. The study on Riga, which describes the first experiences of becoming a smart city, focuses on the steps taken in the field of district heating. The examined joint-stock company from Riga was the largest heat production, distribution, and sales company in Latvia and also in the Baltic States. Heat was produced in 43 heat sources, including five district heating plants (DHPs) and 38 automated gas-fired boiler houses (BH). The first significant developments were realized with the support of the Cohesion Fund of the European Union and were aimed at the reconstruction of the district heating main pipeline in order to reduce heat loss. This was followed by the purchase of higher efficiency boilers. Then the utilization rate of renewable energy sources came to the fore compared to natural gas, which also met the national energy policy objectives. Considering the availability of resources, they decided to use wood chips in a cogeneration power plant. The "Heat meters automatic remote reading system" project proved to be a reliable solution for controlling and accounting for the consumed heat, which at that time was installed on 8000 individual heating units [12].

Cicea et al. looked for good examples of how modern forms of energy utilization of biomass can contribute to the goals of smart cities. The study registered the solutions used both in the field of heat and electricity production and in transport. In Stockholm (Sweden), around 190,000 households were served by a combined heat and electricity power plant with an output of 130 MW of electricity and 280 MW of heat. Helsinki (Finland) aims to replace coal-fired heating with biomass by 2024. Tallinn (Estonia) has a cogeneration power plant with a thermal output of 67 MW and an electrical output of 21.4 MW, which provides 20% of the city's heat needs. Kaunas' (Lithuania) district heating system provides heating for 118,000 people using three biomass (wood chips, sawdust, forestry waste) boilers with a total output of 70 MW. In Vilnius, also in Lithuania, 40% of heat production was covered by biomass. In Łódź and Poznań in Poland, biomass was also used to help reduce CO_2 emissions in combined electricity and heat production. With more than 900,000 inhabitants, Gothenburg is the second largest city in Sweden, where more than 80% of households are connected to the central heat production system, which uses solid biomass, incinerated waste, and biogas as fuel. In Vienna (Austria), the city's main source of energy is waste incinerators, which provide central heating for more than 270,000 people. Overall, we can state that several of Europe's most modern cities rely significantly on biomass-fired solutions for their heat supply [47]. Of course, good examples of the utilization of wood chips in district heating systems can also be found in Hungary, which are also not unique but form a complex system, such as, e.g., in Kaposvár [48].

Increasing the share of district heating can be an important way to improve energy efficiency in energy systems where there is a need for heating. It enables the integration of intermittent energy sources, such as wind energy and photovoltaic energy, into the heating sector, playing a role in solving overproduction problems. According to model calculations, significant savings can be achieved by connecting and integrating systems, which is true for resources, costs, and CO_2 emissions [49].

Among the renewable energy sources, even taking into account larger systems and urban district heating systems, the utilization of biomass often took on a more significant role, and later its combination with geothermal energy arose. In addition to creating a competitive situation, the utilization of two different energy carriers and their associ-

ated technologies also enabled the utilization of synergies, contributing to climate policy goals [50,51].

1.3. Utilization of Geothermal Energy in Smart Cities

The role of geothermal energy in smart electricity and thermal energy networks is enhanced by the fact that it can also provide heating, cooling, and electricity. The geological characteristics of individual regions can be quite different; however, cities with a less favorable location should not give up on the utilization of geothermal energy, which is provided by the development of new technologies. The Smart Thermal Grid model also enables the application of shallow geothermal technologies in the next generation of district heating. Dumas formulated the following characteristics as criteria for smart thermal grids of smart cities: flexible, adapting; intelligent; integrated; efficient; competitive; sizable; securing energy supply [45].

An analysis of the economic aspects of geothermal energy in Poland found that the cost of geothermal energy in district heating was higher than that of coal alone and that it was cheaper than systems based on biomass, natural gas, or fuel oil [52]. However, complex prognoses that also take into account the role of biomass and renewable urban waste did not necessarily establish the primary role of geothermal energy in district heating. In some cases, it is only planned for the longer term (e.g., Helsinki), and in others, it is not planned at all (e.g., Warsaw) among the most important development projects [53].

In the Netherlands, previous unsuccessful experiences rejected the use of geothermal energy in the district heating sector. However, technological development and the more limited availability of natural gas reserves have now made it possible to overcome the previously experienced obstacles. Based on the tests conducted in Rotterdam, geothermal sources may not be able to cover the entire thermal energy demand; however, if they provide the base load demand, which is 40% of the maximum heat demand, it can cover 70% of the annual consumption. In order to further reduce natural gas consumption, combining the geothermal system with biomass and solar energy has also been proposed. However, the construction of the new systems still requires extensive preparatory work due to the different infrastructural features, strict regulations, and the involvement of potential beneficiaries [54].

1.4. The Role of Geothermal Energy Among Renewable Energy Sources and in the Hungarian Energy Mix

Increasing the role of renewable energy sources is also an important objective in Hungary based on environmental protection aspects, but this is further enhanced by the dependence on imports of fossil energy sources from Russia, which was brought into the center of attention by the war in Ukraine [55]. At the same time, energy consumption in Hungary has increased in recent years, in contrast to the experience of the previous decades, also thanks to the re-industrialization efforts of the Hungarian government. For this reason, it is a fundamental task to increase energy intensity and involve renewable energy sources more than before [56]. The new market system has put municipalities and the public in a new position, although it has undoubtedly put businesses in the most difficult situation, as they have to pay market prices for energy rather than subsidized prices [57].

The table below shows the most common renewable energy sources in Hungary. The first column shows the ways in which energy is extracted or produced, followed by their potential uses. The most common applications are electricity generation and heating (Table 1). The most widespread use is geothermal energy. Wind energy is the most important source of electricity generation in the EU Member States, followed by solar energy and biomass, and finally geothermal energy. In Hungary, the share of renewables in electricity generation is dominated by solar energy, followed by biomass, wind, and finally geothermal energy [58]. In heat generation, biomass and geothermal are the most important [59].

Table 1. Method of extracting or producing renewable energy, use, proportion in energy production, amount of energy or heat produced (source: own edited, based on data of Hungarian Energy and Public Utility Regulatory Authority, Hungarian Central Statistical Office, Eurostat, and MET Hungary Pvt Ltd).

Renewable Energy Source	Solar Energy	Geothermal Energy	Biomass	Wind Energy
Way of extracting or producing energy	Solar panel, Solar collector	Geothermal well, Heat pump	Boiler, During a chemical process	Wind turbine
Possibilities of energy use	Production of electricity, Heating and cooling, Production of hot water	Production of electricity, Heating and cooling, Food-drying, Heating of liquids (ex. production of hot water), Bathing, Production of biogas, Breeding of aquatic animal species, Food preservation	Production of electricity, Heating, forage, Industrial raw material	Production of electricity
Energy use in Miskolc	Supplementing and supplying electric energy, heating-cooling and hot water needs of family houses. Supplementing and supplying electric energy to public institutions and businesses, heating-cooling.	Cooling and heating of family houses with a heat pump. Heating of housing estates and hot water supply using a geothermal well. Ensuring the water needs of wellness and beach baths. Heating of greenhouses.	Heating of housing estates.	-
Share of electricity produced from renewable energy sources in EU-27 [%], (2022)	18.2	0.2	6.9	37.5
Share of electricity produced from renewable energy sources in Hungary [%], (2022)	61.8	0.1	22.1	8.0
Use of primary renewable energy sources by energy source in Hungary [PJ], (2022)	17.7	6.9	88.6	2.2
Electricity production in Hungary [GWh], (2022)	4732	4	1693	610
Heat production in Hungary [TJ], (2022)	0	3133	3898	0

In the two decades between 2000 and 2020, the amount of energy produced from renewable energy sources in Hungary tripled. By 2022, 66% of the renewable energy produced was biomass. In 2020, biomass energy provided 3.96% of electricity generation and a significant share of the 17.7% of renewable energy used for heating and cooling.

Projections assume further growth as a result of the European Union's REPowerEU strategy to increase renewable energy use to reduce Russia's dependence on gas [60].

The average heat flux of the Pannonian basin, which defines the geology of Hungary, is approximately 90 mW/m^2, which means a heat flux of 8.37 GW of heat output over 93 026 km^2 of surface area [61]. The total annual amount of geothermal heat delivered by the heat flux is 264 PJ. Of the country's total primary energy use (1154.8 PJ), geothermal energy accounted for only 6.6 PJ in 2021. The theoretical potential for further utilization is thus huge, but developments are slowed down by financial and technical limitations.

One important element of greater use of renewable energy capacity may be that the country exploits its abundant and still relatively untapped geothermal reservoirs. Compared to Europe, their temperature and geological position are also more favorable, an Earth's crust thermal gradient nearly double the global average. Geothermal energy can be an effective tool for developing a more independent energy supply in Hungary, capable of meeting the 435 PJ heating and cooling demand in a long term. At the same time, the right choice of location is critical in reducing risks, which may be related to availability, quantity, suitability, sustainability, and potential uses. In 2020, the Hungarian Energy and Utilities Regulatory Office drew up a plan to promote the increased use of geothermal energy [62,63].

Technologies for the direct use of geothermal energy go back to significant traditions. The relevant literature also highlights Hungary, where greenhouses for growing vegetables are widespread. However, there is only one example of geothermal power plants that will provide electricity for more than 60 million people globally by 2020, due to the lower-temperature hot water sources [64].

Electricity production based on geothermal energy is very risky in Hungary within the current technological conditions and legal framework. From the point of view of the national grid as a whole, its role cannot be compared to the importance of solar panels and wind farms [65]. However, the forms of heat utilization of geothermal origin are extremely diverse. The number one users of the produced geothermal heat are Hungarian spas with a share of nearly 40%, followed by the heating of greenhouses with a share of about 30%. In the remaining 30% are additional sectors such as agricultural drying, industrial heat production, and fish breeding. The share of district heating is 17%, to which is added geothermal heat pumping (4.6%) and individual space heating (3.6%) [66].

Hódmezővásárhely (county town) is in one of the most favorable positions for the utilization of geothermal energy, as the thermal gradient established by geophysical measurements in the area is 4 °C/100 m. Accordingly, utilization took place earlier (in 1954) and on a wider scale (with 10 production wells). The district heating system produces 1.6 million cubic meters of thermal water and 126 TJ of heat per year, which supplies 2725 apartments and 130 public buildings. The structure of the geothermal network is complex due to the variety of wells with different temperatures and pressures. The city's heating system is based on the cooperation of two heating plants. These first provide the demand for domestic hot water, and then the heating water is heated to the required 90 °C flow temperature through heat exchangers. In the next step, the cooled thermal water meets the heat demand of the hospital area, and then finally it is used to supply water to the swimming pools [67].

Achieving the goals of the European Union's energy policy for 2030 presupposes that a large amount of new geothermal capacity must be integrated into the system in Hungary in the coming years. The increase in the role of the district heating sector is predicted by the fact that the forecasts link 40% of the construction of new capacities to this sector. Another 30% can be achieved by installing heat pumps. The plans also include a review of the current forms of utilization and a greater consideration of consumer needs, through which the utilization of geothermal energy can overcome these challenges and become more effective [68].

2. Materials and Methods

To prepare our study, we used both primary and secondary research methods. Our applied research project was carried out using the methodological elements of the disciplines related to urban development (both engineering and social sciences). During primary research, we collect data in order to solve a specific problem using different forms of research (quantitative or qualitative). In our research, several individual interviews were held with experts involved in the topic of resource efficiency, while a focus group interview was held with civilians living in the city interested in the topic. The interview is one of the popular methods of data collection, especially in the fields of social sciences, but its preparation requires thorough preparation and great care. Before formulating the interview questions, it is necessary to define the purpose of the interview, that is, what we want to assess and whether we want to use a quantitative or qualitative research method. During the interview, we looked for the answer to how the participants think about the resource efficiency of Miskolc and how typical the utilization of renewable energy sources is in the settlement. In terms of the methodology of the study, it focuses on the collection of qualitative, i.e., quality data, highlighting individual opinions, thus giving a more comprehensive picture of the views formed on resource efficiency and the utilization of renewable energies. During secondary research, data that were previously collected to solve another problem are used. In our research, we used the publicly available databases of the Hungarian Energy and Utilities Regulatory Office, the Central Statistical Office, and the Miskolci Hőszolgáltató (MIHŐ) Ltd. for our calculations and graphic representations.

The center of our study is Miskolc, and the primary data collection was concentrated exclusively on this city; however, in the foundational secondary research phase, we considered it absolutely important to evaluate local experiences according to international and Hungarian trends. Cities in more developed countries with more favorable financial situations are also ahead of their Hungarian counterparts in the introduction of innovative technological solutions. These may not always provide long-term solutions due to the changing energy policy situation, but the accumulated experience can provide useful knowledge for the catching-up regions of Central and Eastern Europe. A good example of this is the delayed mass installation of solar panels in Hungary, helped of course by the fact that the technology has become cheaper in the meantime. Knowing the trends in Hungary is also important because the priorities for the development of the energy sector have also changed significantly in recent years and decades. At the beginning, the technological conditions were best suited to the increased use of biomass, but then the focus shifted to other resources. The installation of wind power plants preceded solar panels in time, but fluctuating production limited the development of additional capacity [58]. Support for the use of geothermal energy has been available in the past, but the Hungarian government intends to significantly increase it in the future [69].

2.1. Analysis of Statistical Data Series Relevant to the Topic

During the secondary research, in addition to the document analysis, we performed calculations using the public data of the Hungarian Energy and Public Utility Regulatory Authority, the Hungarian Central Statistical Office, and the local MIHŐ Miskolci Hőszolgáltató Ltd.

In the study, we justify the use of data from 2006, 2014, and 2022 with the availability of the data, on the one hand, in accordance with Regulation 7/2006, effective from 29.11.2019. (V.24.) TNM decree no. 7, according to its annex, indicates that the following formulas and values are used, on the other hand, based on the time series available on the MIHŐ website. It is most appropriate to select the time interval of 2014 and 2022 from the point of view of the topic.

First, from a slightly broader perspective, we examined the evolution of energy demand in Hungary in the sectoral distribution. Following this, we narrowed our further analyses to thermal energy production, within which we addressed the question also investigated by other researchers [70]: how can the dominant use of natural gas be re-

placed by renewable energy sources? Based on the reviewed literature, district heating services, especially their newer technologies, create favorable conditions for households and public institutions to base their heat energy needs on more efficient or renewable energy sources [44,50–54,61]. After that, we specifically focused on what conditions Miskolc has among Hungary's big cities and, in light of this, what results it has achieved in the field of greening the district heating service. When taking into account the positive effects, we analyzed natural gas savings and the reduction of CO_2 emissions.

The service company can produce part of the thermal energy that ensures the operation of the 10 district heating systems of the Miskolc district heating service using its own equipment. In the boilers, natural gas, wood chips, and biogas are burned, and in the case of the latter, it is also possible to use a gas engine. In terms of making district heating greener, the most significant geothermal energy is procured from companies established for this purpose (Figure 2). In addition, there are other large and small energy service companies in the city that use natural gas with the help of gas turbines, boilers, or gas engines.

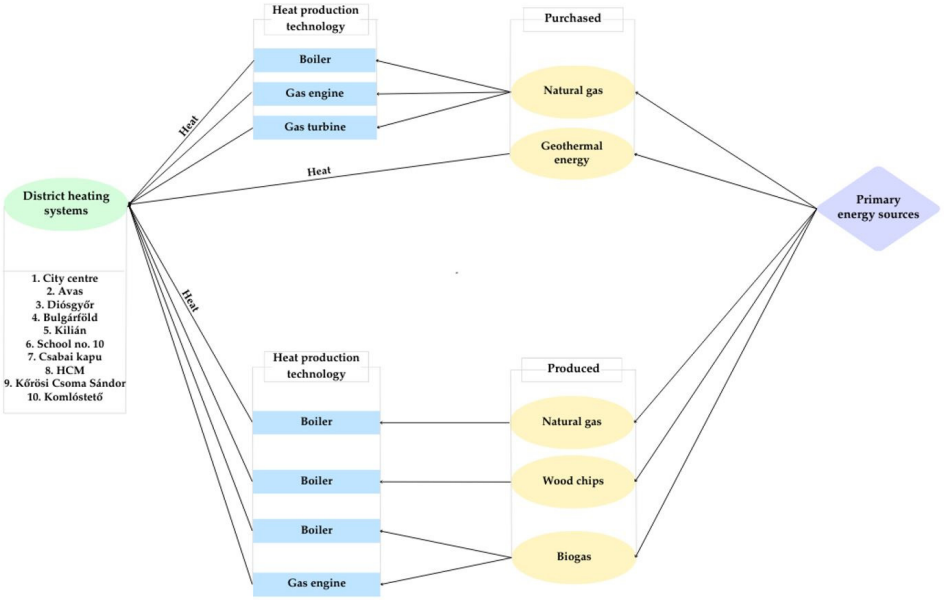


Figure 2. Resource and technological background of the Miskolc district heating system (source: own editing based on information provided by MIHŐ Ltd.).

2.2. The Method of Calculating the Energy Conversion Factor and the Share of Renewable Energy Sources in the District Heating Service

From the point of view of making the district heating system smarter, we considered it important to examine the efficiency of energy conversion and the share of use of renewable energy sources. Increasing both values can also be an important objective of future developments. Looking at the entire district heating system, the energy conversion factor is 0.4869, and the use of renewable energy sources as a whole reached a share of 0.5441.

2.2.1. Original Primary Energy Conversion Factor ($e_{\text{district heating}}$)

$$e_{district\ heating} = \frac{1}{1-h} \times \left(e_{electr} \times a_{electr} + \sum_{i=1}^{14} e_i \times a_i \right)$$
$$e_{district\ heating} = 0.4869 \quad (1)$$

h: (specific) Heat loss from the network (kWh/kWh) per heat delivered to the district heating network in the district heating system under study.

e_{electr}: Primary energy conversion factor (kWh/kWh) of electricity used for heat production and circulation.

a_{electr}: The ratio of the electricity used by the heat generator for the production and circulation of the district heat as a percentage of the amount of heat released to the district heating network in the given district heating system (kWh/kWh).

e_i: The primary energy conversion factor (kWh/kWh) of the i-th heat generation technology used in the heat generators of the district heating system (i = 1…14).

a_i: The ratio of the district heat produced with the i-th heat-generating technology in relation to the total amount of heat released to the district heating network in the given district heating system (kWh/kWh), (i = 1…14) (Table 2).

Table 2. Values used in the calculation of the primary energy conversion factor (own editing based on information provided by MIHŐ Ltd.).

Purchased/ Produced	**Purchased**				**Produced**			
Primary Energy Source	**Natural Gas**			**Geo-Thermal**	**Natural Gas**	**Wood Chips**	**Biogas**	
Technology	Boiler	Gas engine	Gas turbine			Boiler		Gas engine
e_i:	1.12	0.55	0.54	0	1.12	0.6	0.6	0.432
α_i:	0.1095	0.0053	0.2850	0.5840	0.0163	0.0000	0.0000	0.0000
h:	0.15							
e_{electr}:	2.5							
α_{electr}:	0.006							

- e_i: According to point 1.9 of Annex 7 to TNM Decree 7/2006 (24 May 2006)
- h: According to point 1.6 of Annex 7 to TNM Decree 7/2006 (24 May 2006)
- e_{electr}: According to point 1.8 of Annex 7 to TNM Decree 7/2006 (24 May 2006)
- α_{electr}: According to point 1.10 of Annex 7 to TNM Decree 7/2006 (24 May 2006)

2.2.2. Share of Renewable Energy in District Heating ($e_{SUS,\ district\ heating}$):

$$e_{SUS,\ district\ heating} = \frac{\sum a_i \times e_{SUS,i} + a_{electr} \times e_{SUS,electr}}{1 + a_{electr}}$$
$$e_{SUS,\ district\ heating} = 0.5441 \quad (2)$$

a_i: The ratio of the district heat produced with the i-th heat-generating technology in relation to the total amount of heat released to the district heating network in the given district heating system (kWh/kWh), (i = 1…14).

$e_{SUS,i}$: The share of renewable energy sources used in the i-th heat generation technology.

a_{electr}: The ratio of the electricity used by the heat generator for the production and circulation of the district heat as a percentage of the amount of heat released to the district heating network in the given district heating system (kWh/kWh).

$e_{SUS,electr}$: The renewable share of electricity used for the production and circulation of district heat (Table 3).

Table 3. Values used in the calculation of the share of renewable energy in district heating (own editing based on information provided by MIHŐ Ltd.).

Purchased/ Produced	**Purchased**				**Produced**			
Primary Energy Source	**Natural Gas**			**Geo-Thermal**	**Natural Gas**	**Wood Chips**	**Biogas**	
Technology	Boiler	Gas engine	Gas turbine			Boiler		Gas engine
α_i:	0.1095	0.0053	0.2850	0.5840	0.0163	0.0000	0.0000	0.0000
$e_{SUS,i}$:	0	0	0	1	0	1	1	1
α_{electr}:	0.006							
$e_{SUS,electr}$:	0.1							

- α_{electr}: According to point 1.10 of Annex 7 to TNM Decree 7/2006 (24 May 2006)
- $e_{SUS,electr}$: According to point 2.4 of Annex 7 to TNM Decree 7/2006 (24 May 2006)

2.3. Stakeholder Interviews and Civil Forum

During our primary research, we wanted to obtain relevant information from the group of experts and decision-makers as well as the population of the city. During the interview of the stakeholders, we asked several of the current and former members of the representative body of the Miskolc municipality, the managing director of MIHŐ Ltd., and the dean of the Faculty of Earth and Environmental Sciences of the University of Miskolc.

With the help of social media, we announced and then held a public and civil forum at the beginning of March 2024, in which fourteen people from those interested in the city's resource efficiency and the utilization of renewable energy sources participated. During the conversations, we tried to find out how they think about resource efficiency and renewable energy sources and their necessity. We asked them what comes to mind when they hear these definitions and how they imagine efficient resource management in a city. From then on, we were also curious as to whether they knew how resources are managed in the case of the city of Miskolc and what renewable energy sources are used to support the city's needs. Furthermore, we asked the participants about which renewable sources they would use to support or replace the resource needs of Miskolc and whether the coronavirus epidemic and the Russian-Ukrainian war had an impact on the utilization of renewable energy sources. The questions of the focus group interview conducted in the framework of the civil forum are as follows:

1. What do you think of the term resource efficiency?
2. In your opinion, what are the main characteristics of a city's resource-efficient management?
3. What is the first thing that comes to mind when you hear the term renewable energy sources?
4. Do they know what renewable energy sources Miskolc uses to support its resource efficiency?
5. In your opinion, did the coronavirus epidemic and the Ukrainian-Russian war affect the use of renewable energy sources in Miskolc?
6. Do you think the city plans to support its resource needs with additional renewable energy? (If so, what solutions would you recommend?)
7. Is it considered feasible to extend the district heat and hot water service from geothermal or other renewable sources to the entire city, including the residential areas?

3. Results

3.1. The Transformation of Energy Production and Consumption in Hungary, with Particular Regard to Thermal Energy

Hungary is making significant efforts to increase energy efficiency and spread renewable energy sources. Success in this regard varies in individual sectors and activities. Some general and sector-specific development trends in the country have further increased the country's energy consumption in recent years (by 12.7% over the eight years examined). Comparing the data from 2014 and 2022, the amount of energy used in transport increased the most (by about a third), and its share increased from 24.7% to 29.5%. This increase raises many sustainability issues, but the increase in motorization undoubtedly had a direct impact on the population's standard of living. Although to a lesser extent, residential use also increased despite the spread of energy-saving equipment, which is due to the fact that the Hungarian population is also using electrical equipment for more and more purposes. Compared to the other sectors, this resulted in a decrease of 2.2 percentage points. Previous studies have shown that the increase in incomes in Hungary goes hand in hand with the increase in both electricity and natural gas consumption [71,72]. According to the data of the 2022 Census, 27.6% of Hungarian apartments had air conditioning equipment, which is not such a high percentage in international comparison, so a further increase in this

regard is expected. The energy consumption of Hungarian households for this purpose increased more than fourfold between 2014 and 2022, while the use of electricity for heating purposes also increased significantly. Thanks to the Hungarian government's deliberate industrialization and reindustrialization efforts, the energy used in industry also increased above average (Figure 3). Trade and public services represent the sector in which significant energy savings were achieved in absolute terms (−10.9% and −2.8 percentage points).

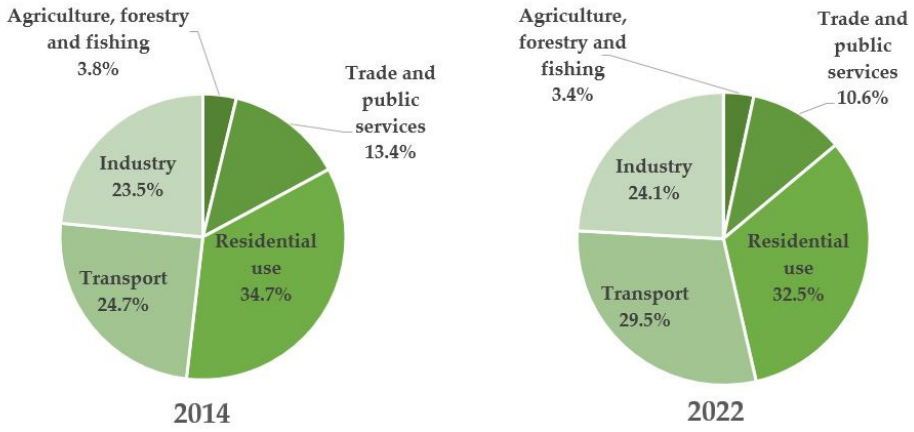


Figure 3. Share of the main sectors (%) in final energy use in Hungary in 2014 and 2022 (source: our own edited figure based on data of Hungarian Energy and Public Utility Regulatory Authority, 2024).

Natural gas plays a decisive role in thermal energy production in Hungary, which, in addition to being a fossil energy carrier (admittedly less polluting), is highly dependent on imports, which became an even more pronounced problem due to the Russian-Ukrainian war [55]. Persistent trends and newly occurring changes not only present new tasks to the specialists responsible for energy supply but also influence the way of thinking of the population about which energy source should be used with which level of technology. However, decisions related to energy supply are also influenced by the fact that the Hungarian state tries to keep prices low with officially determined prices for residential and public institution users, while on the other hand, tender resources are available for developments that help achieve energy policy goals.

The role of natural gas decreased by 4.5 percentage points in the period between 2014 and 2022, but it still accounts for two-thirds of production (Figure 4). The decline in the role of coal and petroleum derivatives was relatively more spectacular. This decline was offset by the increased utilization of renewable energy sources in all categories included in the statistics, but the most decisive role was given to geothermal energy (increasing from 2.4% to 6.7%). It should be noted that thanks to the spread of technologies that utilize renewable energy sources, which are primarily suitable for the production of electricity, the use of electricity also played a greater role in heating (heat pumps, heating air conditioners, panel heaters). The district heating service of cities can play an important role in energy sources that are geographically concentrated and can be used efficiently primarily on a larger scale.

District heating providers sell about 80% of the thermal energy (for heating and hot water use) to the public. The district heating service accounted for only 7.9% of the final household heat energy consumption of the entire population in 2022. This ratio was 8.2% for heating and 15.6% for domestic hot water. Heating accounted for 75.3% of the energy used and hot water for 24.7% in 2022. The share of hot water service within the total residential thermal energy consumption was the lowest in 2017 (23.4%) and the highest in 2020 (26.4%). During the examined period, the amount of energy used did not change significantly; only minor fluctuations were experienced. In the case of heating, the different weather of each year was noticeable (Figure 5). The colder winter half-years resulted in higher energy consumption for heating purposes. The year 2022 resulted in a spectacular decline for both data sets, as the Russian-Ukrainian war made the supply of natural gas to district heating systems more uncertain.

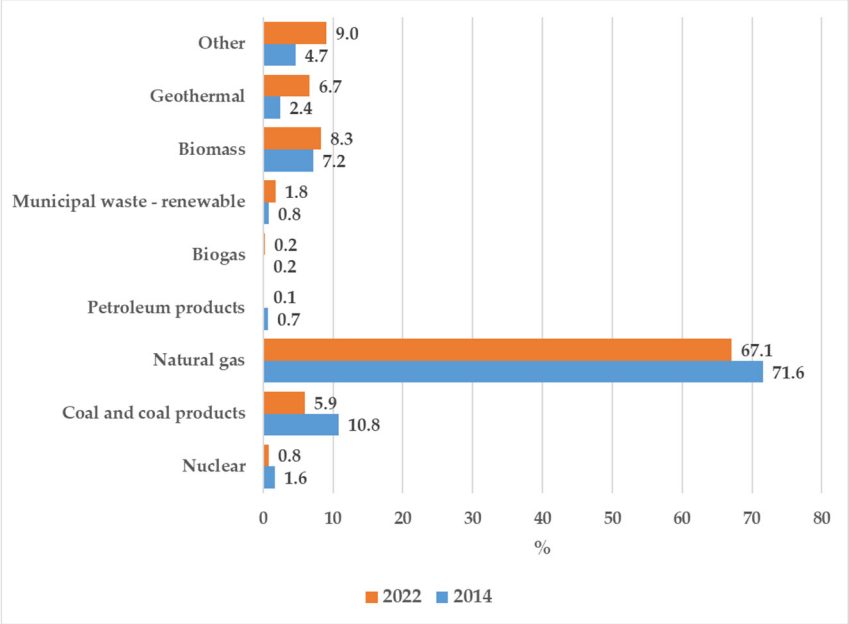


Figure 4. The share (%) of each energy carrier in Hungary's thermal energy production (source: our own edited figure based on data of Hungarian Energy and Public Utility Regulatory Authority, 2024).

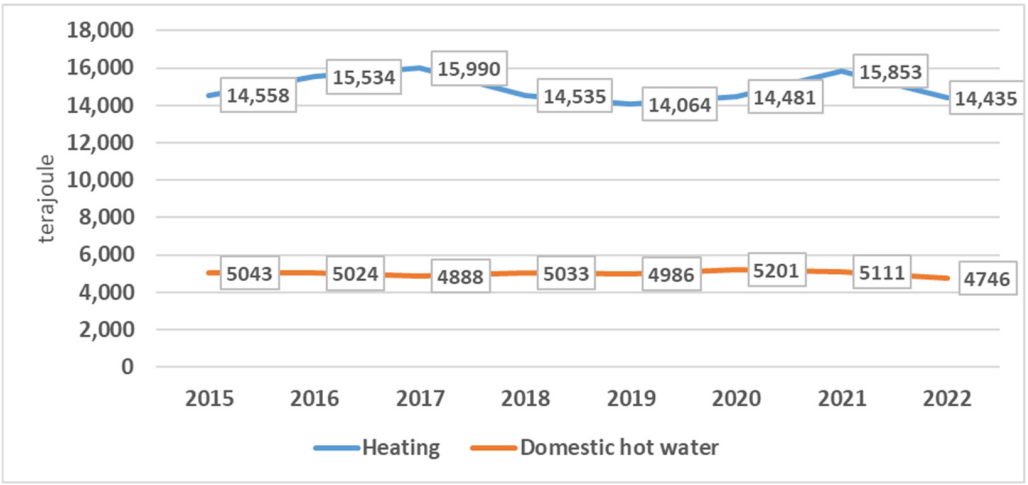


Figure 5. District heat use in Hungarian households for heating and domestic hot water, 2015–2022 (source: our own edited figure based on data of Hungarian Energy and Public Utility Regulatory Authority, 2024).

At the time of our investigation, district heating systems were operating in 95 settlements in Hungary (Figure 6), and the number of apartments with district heating was more than 674 thousand. The proportion of apartments heated by district heating is 15.57% on a national average. District heating systems are typically present in larger cities due to economies of scale, but they have also been developed in small towns with a population of less than ten thousand people, while they are absent from two county seats (Békéscsaba and Zalaegerszeg). A particularly good opportunity for the construction of the district heating system opened up in those towns that host a thermal power plant or a heavy industry center. A district heating system was also built in three villages: in Almásfüzitő, this was justified by the industrial role, while in Pornóapáti, a biomass-based community heating plant was built, and in Cserkeszőlő, famous for its spa, geothermal energy is utilized.



Figure 6. Settlements with district heating services in Hungary in categories according to the amount of energy used, 2022 (source: Hungarian Energy and Public Utility Regulatory Authority—Data of the Hungarian District Heating Sector 2022).

Miskolc, which is the focus of our investigation, has one of the most favorable characteristics from the point of view of contributing to the greening of thermal energy use and the improvement of the population's quality of life through the development of the district heating service. The number of apartments connected to the network is the third highest in the country, which means nearly 40% of the total housing stock. Based on the amount of heat supplied, it took second place after the capital in 2022 (Table 4). The cities that were the main beneficiaries of socialist urban development before 1990 have the highest ratio. The city policy at the time prioritized the further development of the infrastructure of central and industrial cities.

Table 4. The most significant Hungarian cities based on the number of apartments connected to district heating, 2022 (own edited, based on data of Hungarian Energy and Public Utility Regulatory Authority and Hungarian Central Statistical Office).

Ranking & City Name	Number of Apartments Connected to District Heating	Proportion (%) of Apartments Connected to District Heating	Amount of Heat Energy Supplied (GJ)
1. Budapest	240,777	25.0	7,503,213
2. Debrecen	31,928	31.9	841,739
3. Miskolc	31,547	39.9	962,229
4. Pécs	31,309	42.2	774,833
5. Szeged	27,647	31.3	764,173
6. Győr	26,081	40.7	703,721
7. Tatabánya	22,662	72.1	720,604
8. Székesfehérvár	21,877	45.3	517,798
9. Dunaújváros	19,088	82.8	495,485
10. Nyíregyháza	16,629	31.0	424,839

More efficient use of primary energy and increasing the proportion of renewable energy sources are, of course, also important aspects in terms of evaluating district heating systems. Environmentally friendly district heating systems that perform well in accordance with these goals can receive an eco-label, which has been awarded to two heating districts

in Miskolc. A total of 26 district heating systems nationally had this title in 2022. In terms of specific carbon dioxide emissions, those district heating systems where it is possible to utilize renewable energy sources are in a more favorable position. In terms of importance, after geothermal energy and biomass, the renewable part of organic waste in Hungary can be highlighted; biogas and solar energy play a very minor role. In a comparison of geothermal energy and biomass, taking into account the limitations of the available supplies and the needs of other utilization methods, geothermal energy currently has a greater development potential (Figure 7). Biomass can play a greater role in mobilizing local resources in sparsely populated rural areas [73]. However, the sector's long-term vision expects that by 2050, both types will be able to provide about a third of the energy source for district heating.

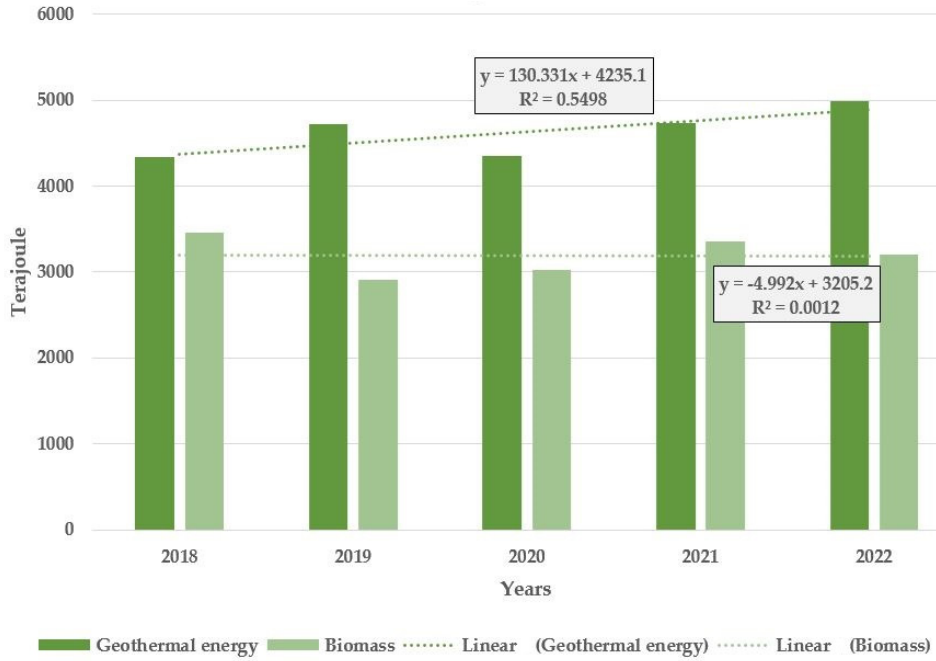


Figure 7. Use of geothermal energy and biomass in district heating in Hungary, 2018–2022 (own edited, based on data of Hungarian Energy and Public Utility Regulatory Authority).

3.2. Use of Geothermal Energy in the Miskolc District Heating Service

The heat production and heat service activities of MIHŐ Ltd. cover the administrative area of Miskolc. As a part of its core business, it provides district heating and domestic hot water services to nearly 32 thousand residential and additionally to nearly 1000 other commercial users. The proportion of residential properties connected to the district heating system is high, at 42%. As a supporter of livable and environmentally conscious modernization, in 2010, Miskolc, jointly with the Mályi village (located 12 km from the city), began drilling the first geothermal well and building the associated system in order to use the heat energy extracted from it to reduce heat production from other sources. The project therefore extended beyond the administrative boundaries of the city and required the cooperation of the agglomeration settlement. The development was focused on the Avas district of Miskolc, dominated by apartment blocks, where it was possible to reduce natural gas consumption and greenhouse gas emissions in a concentrated way in terms of territorial and infrastructural networks, thus contributing to the creation of a cleaner and more livable urban environment [74]. In the first phase, in May 2013, 12,167 apartments were heated in a more environmentally friendly way with the extracted 105 °C hot water, and in the second phase, the center of Miskolc was included in the system, which increased the number of apartments heated and supplied with hot water using geothermal energy to 14,559. Already in 2013, a 7000-square-meter agricultural foil tent was built, the heating of which was ensured by this system, contributing to the supply of the city with horticultural

products and providing job opportunities in the city, which was struggling with a high unemployment rate at the time. Later, the heat supply of several important industrial plants in the city was solved by connecting them to this network [75].

In 2020, the rate of renewable energy use was 68.28% in the Avas district and 60.31% in the city center. The common goal of the city and the heat provider is to combine the smaller heating districts that currently operate with natural gas and connect them to the downtown heating district with geothermal energy. This will allow greater utilization of renewable energy capacities, as well as the modernization of heat generation and district heat supply systems, the third generation (low temperature) district heating service, and the construction of its technology. However, the latter also presupposes the energetic modernization of the housing stock in an outdated technical condition.

There are seven thermal wells in Miskolc, of which three are currently out of operation, while the aforementioned housing estates are supplied from outside the city's administrative areas. However, the use of thermal waters does not only serve energy purposes, as Miskolc is also a spa town with unique features thanks to the Miskolctapolca cave spa. In addition to supplying water to the pools, the spring located in the spa area also serves as a backup drinking water base. The second bath in the city is the Selyemrét Bath, whose thermal wells provide the facility's entire heat and hot water supply in addition to the bath water supply. The purpose of water production from the Fonoda street thermal well is to heat and supply drinking water to the central office building of MIVÍZ Ltd. (the company providing water supply to Miskolc and part of its agglomeration).

3.3. Findings from the Focus Group Interview

During the focus group interview, we clarified with the help of nine guiding questions what the participants mean by resource efficiency, how they imagine the resource-efficient management of a city, what comes to mind about renewable energy sources, and in the case of the city of Miskolc, what renewable energy sources contribute to efficiency. After that, they could make suggestions for further developments and formulate what they think about the future of green energy in Hungary and Miskolc as a whole.

For most of the participants, the term resource efficiency meant the use of natural and financial assets, as well as human resources, in a way that contributes to development and sustainability and generates benefits in an acceptable way for others. The participants mostly associated the term with the words sustainability, solar energy, raw material, potential, development, openness, innovation, environmental awareness, modern technologies. We also generated a word cloud from the emerging words for better transparency (Figure 8).



Figure 8. Associations of focus group interview participants regarding resource efficiency (source: our own edited figure).

The word cloud diagram is most often used as an illustration in scientific works in connection with various scientific fields [76]. Their popularity shows an ever-increasing trend, which is why we decided on this illustration, in which the size and color of the words have different meanings. The size of the most frequently spoken words in a focus group discussion is decisive [77]. In our opinion, the reader's understanding is served by displaying the associations of the participants in the focus group interviews regarding resource efficiency. Our goal in the study was to use Figure 8 to display a graphic element based on which the reader can get information about what the interviewees mean by resource efficiency, how they imagine the resource-efficient management of a city, and what comes to mind about renewable energy sources. It is clear that the most frequently used words are sustainability, energy, and energy awareness. In the case of a word cloud display, the differences in colors make visualization easier. The word cloud display indirectly contributes to the developed local smart concept, and the displayed words highlight potential areas for improvement.

They all had the same opinion about resource-efficient management in a city. In order for this type of management to be realized, the city administration must think in a systematic way and connect the various processes and resources. Efforts must be made to use local resources, including solar, wind, and hydropower—the latter two have not been exploited in the study area due to geographical constraints. A recent Hungarian survey showed that these are the most popular renewable energy sources among the population, in that order (solar energy—81%, wind energy—77%, hydro energy—65%) [78]. After solar panels, wind turbines, and solar collectors, among the devices that use renewable energy, many more people associate hydropower plants than geothermal wells or biomass boilers, whose role in reality is much greater compared to the frequency of mention [79]. These can all contribute to reducing energy dependency, supporting the local economy, and educating the population about resource-efficient lifestyles through awareness-raising programs. This can be helped by the development of a smart city strategy, in which the city management connects the economic, social, and physical infrastructure in a complementary manner, thereby increasing sustainability and livability.

In relation to resource efficiency, we were curious to know the first thoughts that come to the participants when they hear the term renewable energy sources. Here, the opinions ranged in a very wide range. Some people thought of the residential and institutional use of solar energy, while others thought of mitigating the environmental impact, climate protection, or not having to worry about running out of supplies. There were those who emphasized the potential inherent in it and that, unfortunately, they find that renewable energy sources do not replace the use of fossil energy carriers but supplement the energy demand. The pessimistic approach was supported by information from the literature [40] and partially by our own research results; however, a significant amount of natural gas was indeed replaced by the utilization of geothermal energy.

Clarifying what kind of image comes to mind when hearing these expressions, we focused on Miskolc in the rest of the interview. As a first step, we collected the renewable energy sources with which the city supports its energy needs. These include the geothermal energy used in district heating, heat supply based on biomass and landfill gas, the utilization of biogas from the sewage plant, and the photovoltaic solar park with a capacity of 1 MW.

Then we also discussed whether, according to the knowledge of the participants, the city management plans to strengthen the use of renewable sources, to which we received a unanimous positive response. The interviewees said that the main goal is to use geothermal energy on a larger scale, so they also want to enable the use of geothermal energy for the companies of the Northern Industrial Estate, as well as to expand the size of the area provided so far by connecting heat districts in district heating. In addition, the city administration wants to increase the utilization of solar energy and biomass and to explore what other renewable energy utilization is still possible.

When asked if they see potential in extending district heating provided by geothermal energy to single-family areas, we received the answer that it would be technically possible,

but given the current energy prices and regulatory environment, it would not be economical. The managing director of MIHŐ Ltd. stated that instead of extending district heating to areas with single-family homes, a reasonable solution would be to create residential energy community systems in these areas using solar panels, solar collectors, and heat pumps. Between 2014 and 2022, solar panel capacities in Hungary increased from 27 MW to 7670 MW, which changed the opinion of experts and the general public about the use of electricity for heating and hot water purposes [80]. Based on the EurObserv'ER database, solar collector capacities in Hungary are increasing, but at a slow pace. Compared with the data of the similar-sized and neighboring Austria, the capacities there (4,460,000 m^2) currently exceed those of Hungary (426,000 m^2) by more than ten times. However, based on surveys, the technology has been known among the Hungarian population for decades [81]. Based on the EurObserv'ER database as well, it can also be stated that the spread of heat pumps in Hungary started late; however, it has accelerated in recent years, and their number increased from 9210 to 28,632 in the four years between 2017–2021. Thus, we also identify significant development potential in this sector.

After the discussion of energy prices, we asked the participants whether they think the coronavirus epidemic and the Ukrainian-Russian war have influenced the use of renewable energy sources in the city of Miskolc. All of the participants agreed that they definitely had indirect effects, among which is the increase in the installation of solar panels and heat pump systems among the population and local government institutions after the energy price explosion. They also said that the city is trying to reduce its energy dependence, which is why the demand from the municipality for the use of renewable energy sources has increased.

At the end of the interview, we asked the participants to share their thoughts on the future of green energy in Hungary and Miskolc. They all agreed that the energy strategy of the country and the settlements should be based on green energy, but this requires rethinking and restructuring the current regulatory and support system, which will better enable the realization of these developments. In the case of Miskolc, solar energy has significant unexploited utilization possibilities, such as installing solar panels on the roof surfaces of family houses, housing estates, industrial and commercial units, wreck sites, and other paved areas. Based on international examples, this would create a good opportunity to integrate solar panels into the current energy networks [82,83], with the help of district heating systems as well in case of peak performance. However, this requires the modernization of the energy network, the creation of energy communities, and the implementation of facilities suitable for energy storage.

In the city, wind and hydropower are less usable due to the geographical conditions and are not desirable from the point of view of nature conservation and landscape. Geothermal energy already covers nearly 50% of the city's district heating, but the goal is to use it as much as possible, and several investments have already been prepared for this purpose. The raw material for biomass is currently provided by the Bükk forests (a significant part is a national park), which the city does not intend to use on a large scale. This idea can be paralleled by the fact that the villages and small towns located in the neighborhood of Miskolc are also counting on the use of wood chips for district heating, which can be a more sustainable solution on a smaller scale [84]. Among their long-term plans is the modelling of the city's biomass flow and the implementation of conscious biomass management accordingly. The production of biogas is currently only realized by the utilization of sewage sludge from the sewage plant, which they intend to increase in the future by involving the utilization of other organic materials.

3.4. The Experiences of the Public Forum and Analysis of Transferred Data

After discussing the concepts of resource efficiency and renewable energy sources, we asked those who appeared at the public forum—similar to the focus group interview—what renewable energy sources they think are used to support the city's energy needs in Miskolc, and we asked for their opinion on what solutions they would recommend. Only six of

the participants knew what renewable resources the city uses, which, even with the small number of attendees, suggests that the public's information in this regard is incomplete, considering that people who are interested in the topic appeared at the forum. We would like to confirm here that the results of the public forum are not representative.

After revealing the range of renewable energy sources actually utilized, we asked the participants which sources they would recommend to the city administration to expand or implement based on the information obtained. Almost all the participants, twelve people, thought that more solar panels should be placed on the city's buildings, thus contributing to their energy needs. Public institutions, industrial buildings, and larger supermarket chains were highlighted. Ten believed that it would be feasible to install wind turbines in industrial areas, based on the example of Felsőzsolca. (An 1800 kWp wind turbine was installed in a settlement in the neighborhood of Miskolc in 2006, but with more favorable wind conditions than Miskolc.) Half of those gathered saw potential in the further expansion of geothermal energy (Figure 9); they would see it feasible to supply district heating with geothermal energy in the Diósgyőr district (the total number of apartments exceeds 70,000) in addition to Avas and the city center. Only three of the participants thought that it would be appropriate for the city to expand the biomass heating plant.

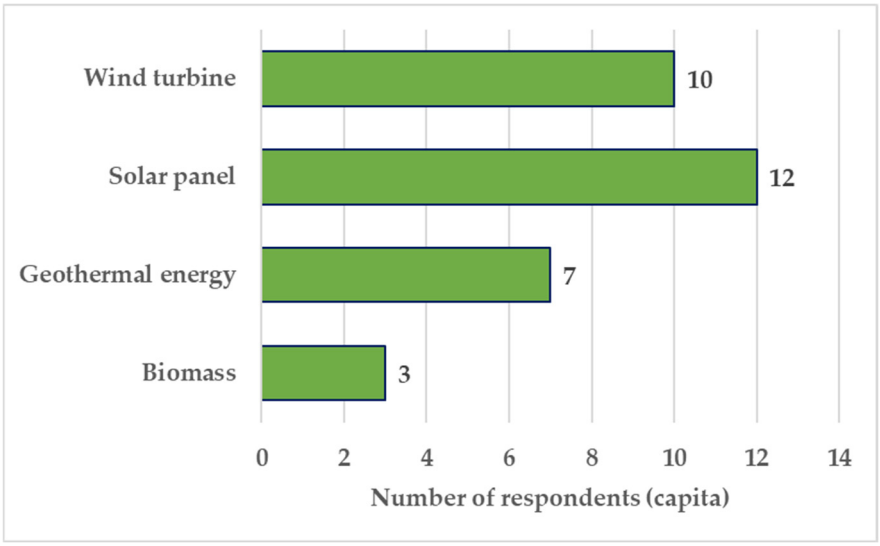


Figure 9. The extension proposal of the civil forum related to the utilization of renewable energy sources in the city (source: our own edited figure).

Based on the data series published by MIHŐ Ltd., we can present the changes in the district heating service between 2014 and 2022. It can be read from Table 5 that the role of renewable energy sources continued to increase for the city as a whole, which is due to the increased utilization of geothermal energy.

The share of biomass utilization based on wood chips within the total primary energy consumption even decreased to a small extent. In this regard, the use of biogas is specifically considered peripheral, which also results from the fact that it originates from landfill gas, the volume of which decreases over time. The position of the district heating company is fundamentally influenced by the fact that it does not produce about 85% of the energy itself, but at the same time, the modernization efforts of the energy policy cannot avoid these actors either. For this reason, a significant change was also observed between the types of heat production of fossil origin; the role of gas engines and gas boilers decreased, while the share of the combined cycle power plant increased from almost zero to more than 18%.

Table 5. Sources of primary energy used in the Miskolc district heating service in 2014 and 2022 (source: own editing based on data provided by MIHŐ Ltd.).

Source of Heat Production	Type of Heat Generation	2014	2022
Renewable	Geothermal energy (purchased)	45.808%	51.873%
	Biomass boiler (purchased, 2014/own, 2022)	2.908%	2.674%
	Biogas boiler (own)	0.004%	0.134%
	Biogas engine (own)	0.396%	0.000%
Fossil	Gas boiler (own)	12.126%	11.843%
	Gas boiler (purchased)	24.968%	11.531%
	Gas engine power plant (purchased)	13.669%	3.290%
	Combined cycle gas turbine power plant (purchased)	0.122%	18.656%
Total		100.000%	100.000%

We also considered it important to explore how the use of different energy sources is distributed between district heating systems and what infrastructural limitations there may be for further developments. In Table 6, six of the ten districts are described, as the other four have an energy consumption of less than 1000 MWh per year and can be specifically linked to the company's own gas boilers. The issue of energy rationalization and renewable energy sources cannot be pushed forward efficiently through these small players. Developments based on geothermal energy were realized in the two district heating systems, which cover 83.8% of the total energy demand. In the third and fourth largest districts (Diósgyőr, Bulgárföld), no transition took place, so our respondents' suggestion that these housing estates could be the targets for the utilization of geothermal energy is justified. The energy supply of the Kilian district is mainly provided by a biomass boiler with a nominal output of 3 MW, which is supplemented by natural gas.

Table 6. The amount of heat primary energy (MWh) fed into the six major district heating systems of MIHŐ Ltd. and the proportion and source of renewables in 2022 (source: own editing based on data provided by MIHŐ Ltd.).

Name of District Heating System	Amount of Primary Energy (MWh)	Primary Energy Conversion Factor ($e_{district\ heating}$)	Share of Renewable Energy (%)	The Source of Renewable Energy
Avas area	165,610	0.3634	65.09	geothermal
Downtown area	165,462	0.3678	58.11	geothermal
Diósgyőr Heating plant	31,542	1.0864	0.08	-
Bulgárföld Heating plant	14,628	1.3500	0.11	-
Kilián-South Boiler House	12,741	0.8427	82.13	wood chips
Boiler house of the cement factory in Hejőcsaba	3227	1.3500	16.29	biogas

The MIHŐ Ltd. used a total of 426,694 MWh of energy in 2022, which consisted of purchased derived heat (83%), natural gas (15%), and electricity (2%). The former two are related to the company's main activity, while the latter is necessary for the operation of buildings and machines. Energy consumption results in carbon dioxide emissions, 79% of

which come from the use of natural gas and 21% from the use of electricity. The relatively high value of the latter suggests increasing the role of renewable energy sources in this sector in the region as well.

4. Discussion

In addition to rationalizing energy use and increasing the utilization of renewable energy sources, the energy sector is an important part of the implementation of the smart city concept [85]. Due to the geographical concentration of end users, large cities can also be a priority target of energy policy subsidies, contributing significantly to the achievement of climate policy objectives [86]. We cannot forget that the human resources necessary for development are also available in these cities. At the same time, smart developments are not only about the introduction of innovative technologies, but especially about individual cities finding the steps that best suit their circumstances in the right order [16,33]. Of course, every city wants to implement improvements in all components of the smart city energy model according to the needs of its residents. However, the characteristics of individual cities do not allow them to advance at the same speed in all sectors [15,87]. After the initial successes, professional and careful work of an increasingly high standard is usually required to achieve further goals. The basis of the whole is precise engineering work; however, from the point of view of urban planning, it is necessary to include the developments in a complex system, taking into account local, regional, and national needs [88].

Based on the characteristics of the target area of our investigation, we put the district heating service and within it the utilization of geothermal energy into the focus of the study. In general, these solutions cannot be considered novel; however, with the help of technological development and the change in the role of fossil energy carriers, they open up new possibilities for greening the energy supply of smart cities. In addition, they are usually not the most spectacular developments, so in surveys on the knowledge of renewable energy sources among the population, they are mentioned with a much lower number of mentions than solar panels or wind farms [78,79]. The new type of developments can be effective on a smaller scale and using geothermal energy at a lower temperature [64]. From the relevant literature, we can learn about many good solutions for urban heat utilization of geothermal energy, biomass, and renewable municipal waste. However, with the exception of the cities with the most favorable conditions, a combination of these will be necessary, supplemented by additional forms of decentralized solutions. It would be advisable to use the remaining fossil fraction as efficiently as possible. Additionally, with the gradual reduction of resources, the demand for finding smart solutions and working out their details increases [89].

The characteristics of a significant part of Hungary are more favorable than the European or global average with regard to the utilization of geothermal energy [68]. However, balneology and agricultural purposes have played a greater role in the focus of utilization until recent years [90]. It is also important to note that there are several unused or partially used hot water wells in the study area. Long-term, sustainable utilization is possible by taking into account and coordinating the interests of potential actors, that is, by maximizing the awareness of resource management. The exact identification of resources can also enable the larger-scale utilization cited as an example, but elsewhere, several smaller investments may be a suitable choice, for which almost a hundred other cities in Hungary provide potential.

The uniqueness of the topic choice is that it examines a large city in a disadvantaged region of Hungary. Most of the articles on a similar topic focus on cities that are at the forefront of smart city expectations and renewable energy utilization. Miskolc tries to use its natural resources to its advantage in a sustainable way, despite the less favorable conditions from a social and economic point of view. In addition to the increased utilization of resources, the developments require an even more well-thought-out strategy for the implementation of further steps, for which the elements of the smart city concept can provide useful ideas. The construction of the geothermal district heating systems represented

a significant step forward in the life of the city. A similar scale of development was not realized later, and some of the renewable energy utilization capacities built earlier are currently unused.

The coal mines once made it possible for the city to develop into the country's dominant heavy industry center, and then, due to the recession after 1990, it became a depressed area. Nowadays, the city's catch-up is becoming more and more spectacular, so the need for modernization, the adoption of the latest technologies, and environmentally friendly urban development is rightfully arising. The current city administration can do this based on the heritage of the industrial city. The favorable geological conditions and the densely populated residential areas made it possible to quickly and efficiently green the heating systems. Further developments can be implemented on a smaller scale, precisely following the unique characteristics of Hungary's energy policy in Europe.

We have previously described that the immediate vicinity of the city is not suitable for the development of significant wind and hydropower capacity, even if the population would support it. The use of hydropower would be more important in the case of the pumped storage power plants currently being planned in Hungary. One potential site for such investments is near Miskolc. The use of solar energy is a supported and rapidly developing sector in the country and in Miskolc, but unlike in other cities [91,92], it has not yet emerged as a significant player in district heating systems. Within Hungary, Miskolc and its region have assumed a decisive role in spreading the use of biomass for energy purposes. However, based on local and regional conditions and public opinion, the primary goal may be to maintain the previously achieved results in this sector. This can be achieved by utilizing a higher proportion of organic waste and using more modern technologies. It would be advisable to extend the use of geothermal energy to housing estates currently supplied with natural gas. In decentralized garden cities, it is advisable to encourage the spread of new solar panel and heat pump technologies.

The relevant literature describes several case studies where 100% renewable energy has already been targeted [32,93,94]. Nowadays, some professional fields no longer aim for net zero emissions but rather aim to achieve climate-positive effects [95]. Considering the current situation of Miskolc, this objective can only be formulated in the long term. Thanks to its specific characteristics, Miskolc has achieved significant results in the utilization of renewable energy sources in certain areas of energy supply. The current situation fundamentally affects the future competitiveness of further renewable energy investments.

5. Conclusions

Several stages in the history of Miskolc, which are the focus of this study, justify increasing the efficiency of resource management. The decline of the heavy industry of the former industrial city was followed by the various symptoms of the crisis. As a regional center, the city's management considers it an important task to put settlement development on new foundations and adopt innovative solutions. For Miskolc, the central element of this activity is the process of becoming a smart city, in which, taking into account the characteristics and traditions, the issue of energy has a prominent role. The city has projects in all components of the energy sector; however, based on their volume and success, we must highlight the transition of a significant part of the district heating service to geothermal energy. The slogan of the company responsible for the district heating service is as follows: "Environmentally friendly energy for our future". The utilization of geothermal energy is accompanied by the utilization of solid biomass and biogas on a smaller scale, without exceeding the amount of available resources.

The city's residents and leaders are committed to sustainable solutions based on renewable energy, which is why the engineers and economists of the companies responsible for energy supply are constantly investigating the possibilities of expanding the current systems for this purpose. The positive examples seen in other cities or localities cannot always be followed in other parts of the city and require extremely fine coordination of the available systems. The connection of the systems can also be realized with similar

properties; however, cooperation with the residential service provider and industrial companies has also come up as an idea. In a strange way, the spectacular developments based on geothermal energy were effectively implemented with the densely populated residential area due to the industrial city's past. However, this also required the discovery of a thermal well with adequate capacity 12 km from the city. They are still working on the expansion of the current geothermal district heating system, but taking into account the structure of the city, especially in the garden city zones, residential energy communities and smaller-scale investments (e.g., solar panels, heat pumps) may play a more decisive role in the future. The city's natural, infrastructural, economic, and social features, the technological development and the availability of these technologies, and Hungary's energy policy will determine the unique combination of geothermal energy, solar energy, and biomass utilization in the city, in addition to reducing the role of fossil energy resources.

Based on the example of Miskolc, it can be seen that cities at a similar level of development can also achieve significant results in terms of the energy objectives of the smart city concept. However, developments are not being implemented evenly in the different energy sectors. The introduction of new technologies imposes significant financial burdens on the city; based on this, the priority order of development goals must be established. As a final conclusion, it can be stated that the utilization of geothermal energy can also be a priority in other cities with similar geological conditions. It is recommended that further renewable energy investments be planned accordingly.

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