



SWOT analysis of renewable energy sector in Mazowieckie Voivodeship (Poland): current progress, prospects and policy implications

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Abstract

Renewable energy (RE) plays an increasingly important role in the economy of almost every country in the world. In order to examine the state of renewable energy (RE) in Mazowieckie Voivodeship (Poland), a literature review was carried out, anonymous surveys were conducted, a SWOT (Strengths, Weaknesses, Opportunities, Threats) and TOWS analysis were carried out and the potential of RE in Mazowieckie voivodship was estimated. The total capacity of all installations is equal to 712 MW. In recent months, number of prosumers have increased to 11,742 in the Voivodeship, and the capacity of their installations is estimated at 66 MW. Simplification of legal regulations and educating society is strongly recommended. Respondents in the survey and SWOT analysis on the future of the energy sector in Mazowieckie Voivodeship show that solar energy (35.5% of respondents) and wind energy (24.5% of respondents) have the greatest chances for the development. Development of the RE sector in the Voivodeship means new jobs, both in this sector and around it. Significant RE potential together with large project financing possibilities may cause Mazowieckie Voivodeship to be a leader in RE production in Poland. It is this Voivodeship (with its capital Warsaw) that can serve as an example of the energy transformation towards 100% RE.

Keywords Renewable energy · Mazowieckie Voivodeship · SWOT analysis · Surveys

1 Introduction

Energy is one of the most important factors determining the development of civilization, because each management process must be powered by energy. The uninterrupted supply of energy is essential for the functioning of the modern economy, households and, consequently, the quality of life (Corral-Verdugo et al., 2020). At the same time, its production from fossil raw materials is the largest source of emissions of pollutants and greenhouse gases—GHG

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(Greenhouse Gases), mainly CO₂, which leads to climate change (Foguesatto et al., 2020; Irman & Shrestha, 2020).

The development of renewable energy (RE) sources is associated not only with the development of technology and reduction of GHG emissions (Piwowar & Dzikuć, 2019), but also contributes to creation of new jobs, called green jobs (Rutkowska-Podołowska et al., 2016). Clean energy is most often based on the energy potential, which is why it is also generated and consumed in the close distances (Yadav et al., 2020). This offers opportunities for direct or indirect benefits to the consumers themselves, as new jobs are created and the outflow of funds to fossil fuel countries is eliminated (Paska & Surma, 2014).

The Polish energy sector is currently facing serious challenges. High demand for energy, inadequate level of development of fuel and energy production and transport infrastructure, considerable dependence on external supplies of natural gas and almost full dependence on external supplies of crude oil, and obligations in the field of environmental protection, including climate protection, necessitate taking decisive measures to prevent deterioration of fuel and energy consumers' situation (Brodny et al., 2020a; Michalak & Dziugiewicz, 2018).

A fair transformation, the construction of a parallel, zero-emission energy system and good air quality are the three main elements of the draft of Poland's Energy Policy until 2040 (Poland's energy policy until 2040 (project), Warsaw 2020). An additional target provides a 30% reduction in energy poverty, and the creation of 300 thousand new jobs, thanks to the development of RE, including offshore wind, nuclear and electromobility, through appropriate prioritization in energy policy. Poland is a country in which RE sector has been developing for over 20 years. The wind energy (aeroenergy), combustion and co-firing of solid biomass have been developing the fastest. However, there has been an increasing interest in geothermal energy, heat pumps, solar collectors and photovoltaics (PV) panels recently. Each month, the number of energy prosumers increases (The Energy Regulatory Authority, 2018).

The aim of the article is to present the current state, potential and development prospects of the RE in the Mazowieckie Voivodeship (Province). There is no such article in the literature, and due to the energy transformation of the Voivodeship and Poland, it should be presented to a wider audience. The article presents the SWOT (Strengths, Weaknesses, Opportunities, Threats) and TOWS analysis and a survey on the future of RE in the largest Voivodeship in Poland—Mazowieckie Voivodeship. It should be emphasized, that country capital, Warsaw, is located there. It is worth adding that Mazowieckie Voivodeship is one of the most dynamically developing regions in Poland, situated at the crossroads connecting Eastern and Western Europe. This region, with Warsaw in particular, is developing very dynamically. Mazowieckie Voivodeship generates 20% of total Polish income. Mazowieckie Voivodeship should be an example how to switch to RE in a sustainable way.

The article is a continuation of RE research in various regions of Poland; so far, the analysis of RE has been presented for Kujawsko-Pomorskie (Igliński et al., 2010), Zachodniopomorskie (Igliński et al., 2013), Wielkopolskie (Igliński, Buczkowski, et al., 2015), Pomorskie (Igliński, Piechota, et al., 2015) and Łódzkie (Igliński et al., 2016) Voivodeships.

2 Short description of the Mazowieckie Voivodeship

Poland is administratively divided into 16 Voivodeships (Provinces). Each voivodeship has a capital city and a local government, and thus has a local policy, including an energy strategy. Mazowieckie Voivodeship is the largest Polish Voivodeship. With the area of 35.6 thousand km², it constitutes 11.4% of the country area (Fig. 1). In terms of

population, it also occupies the first place—the Voivodeship population is 5.1 million people, which represents 13.4% of the Polish population (Statistical Yearbook of the Regions of Poland, 2017).

In terms of altitude, the vast area of the Voivodeship belongs to lowland areas. The plains are cut by river valleys and valley depressions (sometimes with dunes) filled with sandy sediments of river accumulation (Mazovia, 2018; Statistical Yearbook of the Regions of Poland, 2017).

Mazowieckie Voivodeship climate is spatially diverse and has a transitional character, from maritime to continental one. Greater influence of the continental climate is noted in the eastern part of the Province which is characterized by lower temperatures in winter period, higher temperature amplitudes and shorter growing season. Mazowieckie Voivodeship is located in the part of the country characterized by the average and low annual rainfall (totals). In central and western part of the Voivodeship the lowest precipitation occurs, in the range 450–500 mm, in northern and southern fringe areas, annual precipitation totals around 550–600 mm. In the summer and autumn, the west winds dominate, in spring winds from the north, whereas in the winter—south-eastern winds. The average wind direction distribution in the Voivodeship is shown in Fig. 2 (Mazovia, 2018; Statistical Yearbook of the Regions of Poland, 2017).

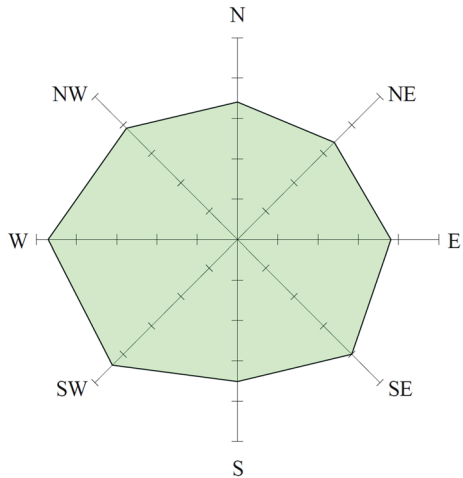
In Mazowieckie Voivodeship, light brown, podzolic and rusty soils prevail. According to the bonitation value, the arable soils of weak and medium quality predominate, with the advantage of the IVa and IVb bonitation classes, which cover over three-quarters of the province area. Agricultural land constitutes 69.6% of the province area. Forests, coppices and bushes cover only 23% of the province area, with almost the lowest rate in the country (Mazovia, 2018; Statistical Yearbook of the Regions of Poland, 2017).

Mazowieckie Voivodeship area is located in the Vistula River basin and includes the central course of the Vistula, together with central and estuary sections of its largest tributaries. In the Province area, the Vistula River receives the waters of the largest right-bank tributary—the Narew River—and the left-hand tributaries—the Pilica and Bzura Rivers. River network in the province is well developed, the total length of

Fig. 1 Mazowieckie Voivodeship location in Poland (own elaboration)



Fig. 2 Average distribution of wind directions in Mazowieckie Voivodeship (own elaboration based on (Statistical Yearbook of the Regions of Poland, 2017))



watercourses, including ditches, exceeds 15 thousand km (Mazovia, 2018; Statistical Yearbook of the Regions of Poland, 2017).

The total capacity of all RE installations in Poland exceeds 9500 MW, however the installation spacing is un even throughout the country. The largest total power is installed in Pomorskie Voivodeship (1600 MW), and the smallest one in Opolskie Voivodeship (174 MW). In terms of RE installations capacity, Mazowieckie Voivodeship is ranked 5th in Poland (712 MW) (Fig. 3) (The Energy Regulatory Authority, 2018).

3 Literature overview

In the current literature, there are quite a few publications devoted to the study of renewable energy in Poland. There are even fewer articles on SWOT/TOWS survey and analysis.

Pietrzak et al. (2021) described the current state and prospects for the development of RE in Poland based on sociometric surveys conducted among RE experts in groups on social networks. It was found that the sun, wind and biomass energy have the greatest chances for development. However, the author did not carry out a SWOT/TOWS analysis.

Paska and Surma (2014) presented activities for the development of renewable energy, as well as the current status and prospects for the use of renewable energy sources in Poland and the EU. However, the authors did not carry out a SWOT/TOWS analysis.

Marks-Bielska et al. (2019a) show the potential of straw in the Braniewski powiat in the Warmińsko-Mazurskie Voivodeship. In the Braniewo powiat, the average annual amount of straw to be used for energy purposes is over 40 thousand tons of straw, which corresponds to about 60 TJ of energy (over 24 thousand tons of hard coal). Additionally, a survey was conducted among farmers from the district. Based on the survey, it is known that some farmers are interested in biomass, including energy crops. There is also no SWOT/TOWS analysis in this study.

Igliński et al. (2016) describes wind energy in detail. SWOT analysis is presented, but only for wind energy. Gnatowska and Moryń-Kucharczyk were also mainly involved in wind energy (Gnatowska & Moryń-Kucharczyk, 2019). An economic analysis was carried

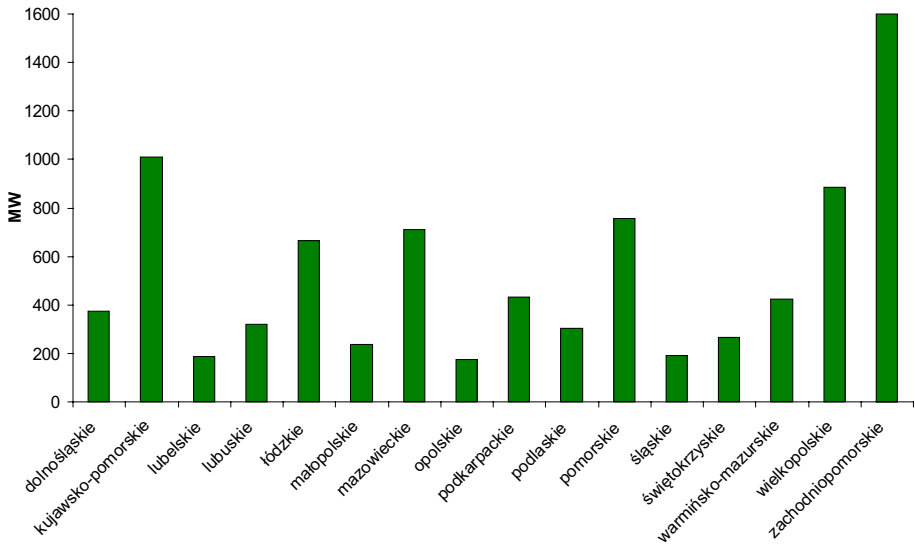


Fig. 3 RE installations power in individual voivodeships in Poland (own elaboration based on (The Energy Regulatory Authority, 2018))

out on wind farms in Poland in accordance with the Act on RE sources. It was emphasized that “green” energy still needs government support.

Brodny et al. (2020b) writes that there are no studies forecasting energy production from RE in Poland, therefore such an analysis was carried out using artificial neural networks by 2025. The results may be helpful in implementing energy and economic policy in Poland.

Adamczyk i Graczyk (2020a) emphasize that the air quality in Poland is bad. One of the methods of reducing this high level of air pollution is the intensification of the development of renewable energy sources by introducing effective mechanisms of supporting investors for new, user-friendly and environment-friendly energy. The article presents the model of the support system (green certificates) for RE production in force in Poland.

Łączak et al. (2018) presents the current state and development prospects of the Lubuskie Voivodeship. No surveys and SWOT analysis were conducted. The total capacity of RES installations to be built by 2023 will be nearly 2.5 GW. Therefore, in the coming years, the installed capacity of RE installations will increase 13 times in the Lubuskie Voivodeship.

4 Materials and methods

The first stage of the research was to conduct a sociometric research on the RE among the inhabitants of the Mazowieckie Voivodeship. The questionnaire was placed on groups devoted to energy on the social networking site with a request that only residents of the Mazowieckie voivodship fill it in (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

Information obtained from the Marshal’s Office in Warsaw (Mazovia, 2018), data available on the Map of RE Sources in Poland (The Energy Regulatory Authority, 2018) and information available on the Internet was used to prepare a description of the current state

and development prospects of the RE in Mazowieckie Voivodeship. Maps were prepared showing the current state of the RE in the Voivodship. The development prospects for each type of RE in the Voivodship were described.

Based on the available literature, the current state and development prospects for each type of RE in the world were presented.

The SWOT and TOWS analysis was carried out on the basis of the conducted surveys, information obtained directly from employees of the RE sector, legal regulations and available literature.

Strategic planning is currently an extended tool for regional development and territorial structuring. Cities, regions and provinces have carried out their strategic plans on the basis of participation processes, which have driven the later development of their territories (Chen et al., 2014). A SWOT analysis is a structured planning method used to evaluate the strengths, weaknesses, opportunities and threats involved in a project or in a business venture. The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit (Fig. 4):

- *Strengths* characteristics of the business or project that give it an advantage over others,
- *Weaknesses* characteristics that place the business or project at a disadvantage relative to others,
- *Opportunities* elements that the project could exploit to its advantage,
- *Threats* elements in the environment that could cause trouble for the business or project (Chen et al., 2014; Igliński, Buczkowski, et al., 2015).

The TOWS analysis is a reversal of the SWOT, and in practice it is the beginning of the research from activities resulting from the environment, ending with internal strengths and weaknesses.

5 A vision of the development of RE in the Mazowieckie Voivodeship: surveys

Respondents believe that primarily helioenergy (35.5% of respondents) (Fig. 5), followed by aeroenergy (24.5%), bioenergy (18.3), geoenergy (12.7%) and hydroenergy (9%) has the greatest chance for development in Mazowieckie Voivodeship (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

To the question “What should be done to make the RE sector in Mazowieckie Voivodeship grow faster?” 2/3 of respondents replied that the law in Poland should be changed—the rules should be simplified so that there would be less bureaucracy (Świątkiewicz-Mośny & Wagner, 2012). Currently, the investor is struggling with many documents, permits—and a

Fig. 4 Scheme of SWOT analysis (own elaboration)



significant part of them can be liquidated or reduced. The law should be investor-friendly. The act on RE resources is being constantly changed, which leads to chaos on the RE market in Poland and in Mazowieckie Voivodeship. Several respondents also wrote that they are eager to increase their investments in RE, but are still waiting for regulations “normalization” (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

81% of respondents believe that it is necessary to educate Mazowieckie Voivodeship society on RE. For many Poles, RE is still something new and unknown, so they approach it with respect or reluctance. In energy education, primary schools or even kindergartens play an important role. Educating these pupils, very often means getting the message across to the parents. Respondents also emphasize that the existing RE installations in Mazowieckie Voivodeship should also play an important role in educating the public. Seeing with one’s own eyes how an agricultural biogas plant works will decrease the reluctance towards this type of facilities (Ocetkiewicz et al., 2017).

79% of respondents believe that more financial incentives or tax remissions should be introduced for RE investors in Mazowieckie Voivodeship (Standar et al., 2021). The respondents emphasize that it is not just about introducing very high subsidies, but rather about clear accounting principles, market access, and trouble free connection to the power grid. Investment capacities should be popularized, including the possibility of deduction of amounts invested in RE sources from the PIT tax by the investor (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

Participant of the study almost unanimously (92% of respondents) believe that the development of RE will positively affect the reduction of harmful substances to the environment. Polish society generally accepts the construction of a low-emission economy, although they are afraid that this will significantly increase the costs of energy and consumer goods (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

The vast majority of respondents (86% of them) believe that the development of RE will positively affect new jobs in Mazowieckie Voivodeship. Respondents emphasize that the development of RE technologies means new, well-paid jobs. Importantly, further jobs

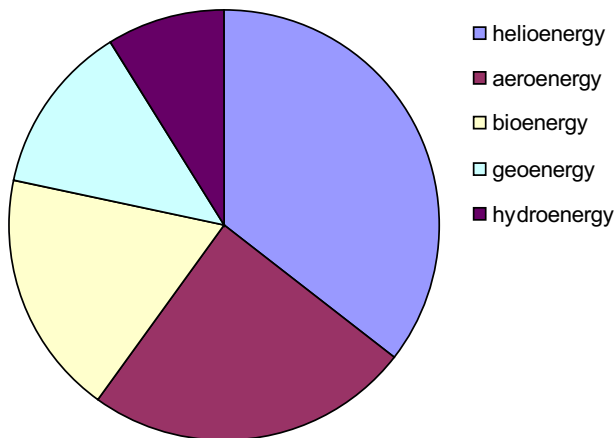


Fig. 5 Types of RE that have the greatest development opportunities in Mazowieckie Voivodeship (questionnaire survey)

are also created around the RE sector. It is estimated that there are 2–3 places associated with this sector per 1 employee in the RE sector: mainly industry, but also construction, services, etc. Participants of the study believe that the development of the RE industry is a great opportunity for both the economy of the region and for Poland (Rutkowska-Podołowska et al., 2016). When we create a law that is favorable (or at least not interfering) to low-energy construction, prosumers, energy cooperatives, intelligent networks and other future technologies; then new companies will be established, providing well-paid jobs, gaining roots, growing up and starting to supply their products and provide services to international market.

Several people have pointed out that smart energy networks should be developed. Smart network is a solution that enables the implementation of an important mechanism related to energy security, which is demand management. The supply of energy with the use of intelligent network is associated with the flow of information allowing both continuous monitoring of demand and the control of this demand through impacts on energy receivers. This will allow flexible demand shaping and adjustment of supply (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

Respondents believe that Mazowieckie Voivodeship has a good chance of becoming a leader in the production of RE. The presence of the capital city—Warsaw implies the largest financial resources in Poland for the development of a low-emission economy based on the RE sector. Beneficiaries may apply for a significant co-financing/loan/loan from EU funds, Voivodeship funds or funds from a given borough. It is in Warsaw or in its vicinity that companies which produce RE installations should be established. Schools and universities also have the opportunity to train employees in the RE sector. Finally, the RE potential of the Voivodeship allows for fairly even development of RE in the Province (Survey—a vision of the development of renewable energy in the Mazowieckie Voivodeship, 2018).

6 Hydroenergy in Mazowieckie Voivodeship

As it has already been mentioned, the entire Mazowieckie Voivodeship is located in the central Vistula River basin and covers 21.2% of the basin district in the country. The province area is in the lowland, and the absolute altitudes rarely exceed 200 m above sea level. The hydrographic network is characterized by a large number of watercourses with small flows, some of which periodically dry in the summer season. Only the Vistula with its largest tributaries are characterized by greater flows. In recent years, the average flow is equal to 560 m³/s (Mazowieckie & Voivodeship, 2006).

Currently, there are 24 hydropower plants in Mazowieckie Voivodeship with a total capacity of 21.183 MW (Fig. 6) (The Energy Regulatory Authority, 2018).

6.1 Prospects for hydropower development

In general, Mazowieckie Voivodeship has several rivers with significant flows, such as: the Narew, Bug, Pilica, Bzura, Wkra, Omulew, Orzyc, Radomka, Skrwa, Prawa, Hżanka. However, they possess only moderate potential for hydroenergetic management, because river valleys are usually flat, which makes it impossible to obtain favorable slopes. The terrain conditions most often create slopes of 1.5–2.5 m. Only studies carried out in the 1980s have made it possible to estimate the chances of using existing dams and planned reservoirs and barrages for the needs of small hydropower. Obviously, in the Province there

is a much larger number of places that can be used to generate energy, for example former mill backwater/dam. For energy management it is recommended to first use dams existing on the following rivers: the Skrwa Prawa, Wkra, Jeziorka, Radomka, Okrzejka and Iżanka (Mazowieckie & Voivodeship, 2006).

In “Small Water Retention Program for Mazowieckie Voivodeship” (2006) the construction, reconstruction and modernization of approximately 500 facilities is planned. The development of retention reservoirs under the small retention program will facilitate the development of hydroelectric power in the Province.

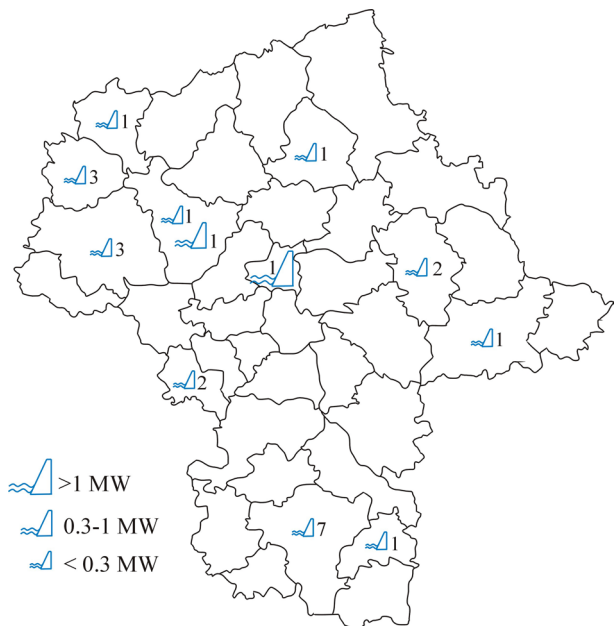
6.2 Hydroenergy development in the world

Until recently, RE in the world was produced practically only in hydropower plants. Despite the annual increase in power by 3–4%, the share of hydropower in the global mix of RE drops every year (Shaktawat & Vadera, 2021). This is due to the rapid development of other types of RE in the world, including wind and solar energy (Renewable Energy Policy Network for the 21st Century, 2020). In 2019, 15.9 GW of hydropower capacity was installed worldwide. The world’s total hydropower capacity is 1,150 GW. The largest increase in this capacity took place in Brazil (4.9 GW in 2019), and China is the leader in terms of total hydropower capacity—it already has over 320 GW.

Wang et al. (2008) explained the functioning of a small hydropower (SHP) system using outlet-water energy of a reservoir in southern Taiwan. The rated capacity of this SHP system is 8.75 MW and the generated power is delivered to the 69-kV. The paper presents some details of the finished SHP system including engineering, electricity prices, capital cost, revenue of power generation, etc.

In this paper (Scheffli et al., 2019), authors provide the first regional quantification for the share of Alpine hydropower production that directly relies on the waters released by

Fig. 6 Hydropower plants locations in Mazowieckie Voivodeship (own elaboration based on (The Energy Regulatory Authority, 2018))



glacier mass loss, i.e. on the depletion of long-term ice storage that cannot be replenished by precipitation in the coming decades. Based on the Switzerland case (which produces over 50% of its electricity from hydropower), we show that since 1980, 3.0%–4.0% (1.0–1.4 TWh·yr⁻¹) of the countryscale hydropower production has been directly provided by the net glacier mass loss and that this share is likely to reduce substantially by 2040–2060. For the period 2070–2090, a production reduction of about 1.0 TWh·yr⁻¹ is anticipated.

6.3 Hydroenergy SWOT analysis

Hydroenergy SWOT analysis for Mazowieckie Voivodeship is presented in Table 1.

6.3.1 Strengths

It must be said that hydroenergy is a well-mastered technology, since many hydropower plants have been operating in Mazowieckie Voivodeship for several dozen years (Mazovia, 2018). Moreover, in contrast to, wind turbines, hydroenergy plants allow to produce electricity in a stable and predictable manner.

Among the strengths there is a fact that small hydropower plants are a part of water regulation system, they improve soil moisture and groundwater level (Majumder et al., 2020). Therefore, they cocreate a small water retention thanks to numerous accumulations and retention reservoirs (Mazowieckie & Voivodeship, 2008; Timilsina et al., 2018).

In Mazowieckie Voivodeship there are over 2000 existing dams on which SHP can be built (Mazowieckie & Voivodeship, 2006)). In the Province, SHP should be erected on the existing dams with the capacity of::

- 1620 dams on which you can place a SHP with a power below 5 kW,
- 115 dams on which you can place a SHP with a power 5–10 kW,
- 143 dams on which you can place a SHP with a power 10–20 kW,
- 108 dams on which you can place a SHP with a power 20–50 kW,
- 52 dams on which you can place a SHP with a power 50–100 kW,
- 12 dams on which you can place a SHP with a power 100–500 kW,
- 2 dams on which you can place a SHP with a power above 500 kW (Fig. 7) (www.kzgw.gov.pl/index.php/pl).

Table 1 Hydroenergy SWOT analysis for Mazowieckie Voivodeship (own elaboration)

Strengths	Weaknesses
Well-mastered technology	Often the need to dam the river
Stable energy production	Resistance of ecological groups (large hydropower plants)
Increasing of surface and groundwater retention	Impact on the fish population
SHPs can be built in many places	
Opportunities	Threats
Possibility of using water reservoirs for tourist and recreational purposes	Unclear regulations
Fishery development	Not much interest show by the investors
New directions for the SHP development	Progressive climate changes

The total theoretical capacity of SHP at all dams is 32.7 MW.

6.3.2 Weaknesses

The weaknesses are related to the fact that construction of large reservoir power plants involves the need of partitioning the river. This is connected with flooding of a large area, which in turn implies social protests, protests of ecological groups and the need for resettlement.

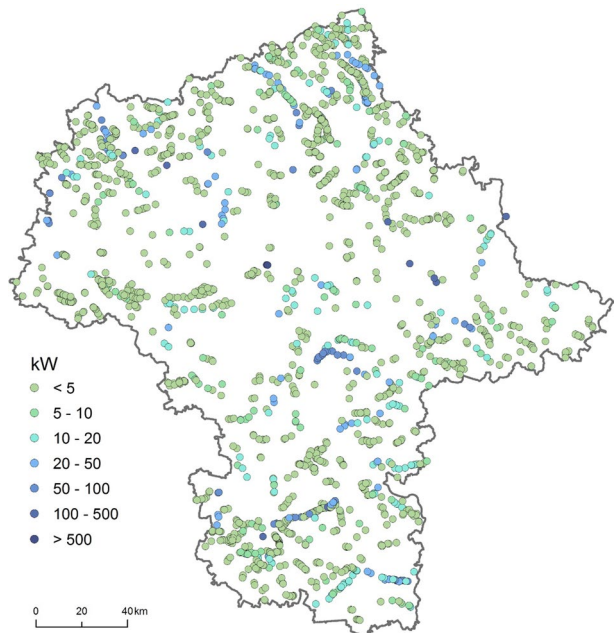
Weirs, dams and barrages cause physiochemical and biological processes in water, which in turn affect the living conditions for the fish in the dammed part of the river. The lands of Salmonidae fish change into the areas of carp fish. Such river species as brown trout, grayling, barbell, common nase, chub, dace, asp or ide give way, and are replaced by typical fish for free-flowing or standing waters—e.g. bream, roach, silver bream, perch and other fish (Mazowieckie & Voivodeship, 2008).

6.3.3 Opportunities

The construction of tanks at a hydroenergy plant should involve making it available to the local community for tourism and recreation purposes. The tank should be designed to be suitable for water sports and fishing.

Use of waste water is a chance for the hydroelectric power plant development. Power plants of this type are qualified as SHPs operating in the flow. The greatest opportunities for using utility water are found in cooling systems of thermal power plants or in sewage treatment plants. What is important, the flow of utility water stream is slightly dependent on weather conditions (Mazowieckie & Voivodeship, 2008).

Fig. 7 The location of the existing dams and the power of hydroelectric power plants in the Mazowieckie Voivodeship (own elaboration based on (National Water Management Authority)



6.3.4 Threats

The development of hydroenergy in the Voivodship will continue to be hampered by numerous unclear and fast changing law. As a result investors are extremely cautious towards building new hydroelectric power plants.

Another threat is the ongoing climate change. It is characterized by long rainless periods, which have a huge impact on hydroelectric power plant operation and electricity production. Pelting rains and strong winds may in turn destroy the infrastructure of a hydroelectric power plant (Timilsina et al., 2018).

6.3.5 Recommendations

Our recommendations are:

- simplification of regulations,
- construction of SHP on already existing dams,
- construction of fish passes and barriers.

7 Wind energy in Mazowieckie Voivodeship

Wind energy has been developing in Poland and in Mazowieckie Voivodeship very quickly until mid-2016 (Gnatowska & Moryń-Kucharczyk, 2019). So called a “distance Act” (Act, 2016) was then introduced, which practically stopped the further development of this RE sector.

Currently, there are 85 wind farms (single turbines or farms) in Mazowieckie Voivodeship with a total capacity of 680.52 MW (Fig. 8) (The Energy Regulatory Authority, 2018).

7.1 Wind energy development perspectives

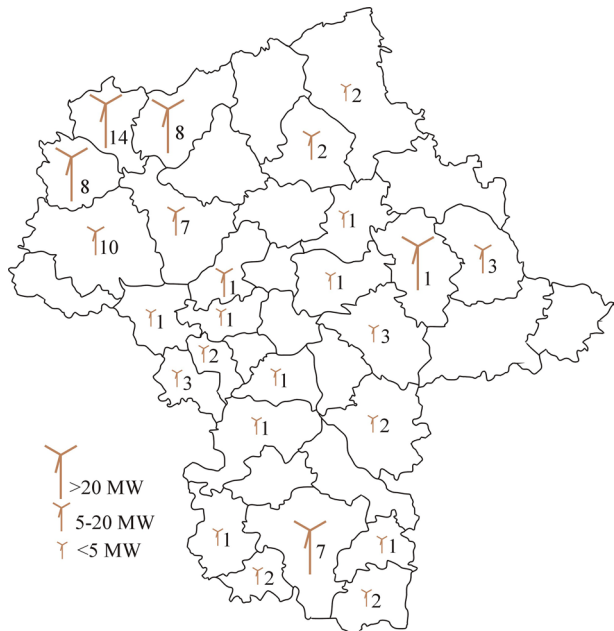
For the Province, no detailed map of wind resources has been devised so far. In general, the most beneficial area is the western and central part of the Voivodeship, counties: Płock, Ciechanów, Płoński, Grójec, Mława, Garwolin. In many cases, apart from the abovementioned areas, local terrain conditions may also facilitate investing in wind energy. It should be noted that agricultural land under the wind turbine towers can still be used for cultivation (Mazovi, 2018).

The distance Act (Act, 2016) has practically cramped the development of wind power industry in Mazowieckie Voivodeship. Further development of wind energy will possible once the regulations are relaxed.

7.2 Wind energy development in the world

Wind energy plays an increasingly important role in the global economy. In the years 1995–2019, the capacity of existing wind farms increased more than 100 times, reaching 651 GW in 2019. The increase compared to 2018 is over 51 GW. More than half

Fig. 8 Location of wind installations in Mazowieckie Voivodeship (own elaboration based on (The Energy Regulatory Authority, 2018))



(27.5 GW) of new capacity has been installed in China (Renewable Energy Policy Network for the 21st Century, 2020).

Villacreses et al. considered (2017) different selection criteria which include meteorological parameters (wind speed, air density), relief (slope), location (distances to substations, road network, urban areas, transmission lines, charging ports) and environmental parameters (vegetation coverage). The results of revealed that the site with the highest overall performance index is the Andean region of Ecuador, with an area of more than 617.5 km².

Sliz-Szkliniarz and Vogt have calculated the wind energy potential in the Kujawsko-Pomorskie Voivodeship in Poland (Sliz-Szkliniarz & Vogt, 2011). The application of a GIS-based approach showed that the Province could be used for wind energy production, since the major technical potential remains untapped. By excluding the infrastructural and ecological related barriers, almost 7500 km² of the area remains available for wind sitting (research before “distance Act” implementation) (Act, 2016).

7.3 Wind energy SWOT analysis

Wind energy SWOT analysis for Mazowieckie Voivodeship is presented in Table 2.

7.3.1 Strengths

The strengths of wind power industry include the fact that the Mazowieckie Voivodeship has good wind conditions in the prevailing area, in particular the western and central part of the Voivodeship.

Wind energy producers in the province have extensive experience—some wind farms have been working for over 20 years. Wind power industry is very popular among investors (despite the “distance Act”). The contributing factors include: significant investment profit, following other farm owners and the desire to protect the environment. Investors generate profits from electricity and green certificates sale (Adamczyk & Graczyk, 2020b). Wind turbines launched by the end of June 2016 can expect the financial support in form of green certificates, and after that date they can participate in the auction system.

7.3.2 Weaknesses

The “distance Act” introduced in 2016 (Act, 2016) has practically hindered the development of aeroenergy in Poland. This is due to the fact that there is almost no area available for new turbines (Sokołowski, 2017).

The weaknesses also include the fact that an investor interested in aeroenergy in Poland must show the great patience and self-motivation. Obstacles they face are connected with a long and complex investment process, the success of which depends not only on the competences and determination of the investor, but also on the favorable local authorities, local government and environmental organizations.

Investors wishing to develop aeroenergy in the Mazowieckie Voivodeship have more and more problems with connecting the installation to the power grid. This is related to the poor condition of the power grid in the Province (especially in the eastern part), as well as with too many hitherto issued permits to clump in, many of which are only “virtual” (exciting only as an administrative permission) (Sokołowski, 2017).

The weaknesses include the negative impact of wind turbines on humans and on fauna, in particular on birds and bats. Very close proximity of wind turbines, and in particular the noise and infrasound emitted, can trigger a set of symptoms that begin with the set up moment. They are sometimes referred to as “wind turbine syndrome” (Colby et al., 2009). Wind farms as high devices (often over 100 m), with a contrasting color to the sky and the surface of the earth, which are in addition moving, affect the landscape.

Table 2 Wind energy SWOT analysis for Mazowieckie Voivodeship (own elaboration)

Strengths	Weaknesses
Good wind conditions in the major part of the region	Distance Act
Well-mastered technology	Complicated and long-term procedures
Great interest by investors	Problems with new wind turbines terminals
Financial support, including green certificates and auctions	Potential danger for humans and fauna
	Landscape interference
Opportunities	Threats
Technological progress increasing the efficiency of wind installations	No transition period between the certificate System and the stock exchange system
Improvement of energy security through diversification and decentralization of electricity production	Lack of a clear energy policy

7.3.3 Opportunities

The aeroenergetics opportunities include the fact that research all over the world is under way on new types of turbines, or on improving the existing ones. The development of wind energy is also a great impulse for economic progress (World Wind Energy Association, 2017).

The development of RE, including aeroenergy, helps to improve energy security through the diversification and decentralization of electricity production. In Poland, electricity is produced in several very large power plants. In the event of failure of one of them, even several hundred thousand houses may be deprived of electricity. Due to sudden atmospheric phenomena, resulting from climate change, blackout appears in Poland more and more often. Failure of several wind farms (or another RE source) would not disturb the operation of the power system.

7.3.4 Threats

Lack of a transitional period between the system of certificates and the auction system is a threat to the development of aeroenergetics in Mazowieckie Voivodeship. Investors do not start construction before they win the auction.

Recent months brought new information on the vision of the energy sector future in Poland, including nuclear power plant or new coal (or gas) power plant in Ostrołęka. The lack of clear long-term plans for energy future in Poland has a negative impact on every sector, including the aeroenergetics sector.

7.3.5 Recommendations

Our recommendations are:

- regulations simplification,
- changing “the distance Act”,
- setting turbines in places where they do not threaten fauna and do not significantly interfere with the landscape,
- educating society on aeroenergetics.

8 PV in Mazowieckie Voivodeship

The majority of the Mazowieckie Voivodeship area is characterized by an annual total radiation of 3700–3800 MJ/m². Only in the western part the average total radiation annual exceeds 3800 MJ/m². In Warsaw region, due to industrial air pollution (smog), these values are lower. The total solar radiation energy in the region per year is 985 kWh/m², however in the eastern part it is on average 1081 kWh/m². The largest amount of solar energy can be received between April and October (Website IMGW, 2018).

There are 30 professional PV plants which operate in the region and are connected to the power grid with a total capacity of 1.825 MW (Fig. 9) (The Energy Regulatory Authority, 2018). It is also estimated that there are several times more off-grid solar installations.

In recent months, there has been a rapid development of PV prosumers in the Voivodeship. A total of 11,742 people from the Voivodeship benefited from the “My Current” program (2020). The total capacity of civic energy exceeds 66 MW.

8.1 PV development prospects

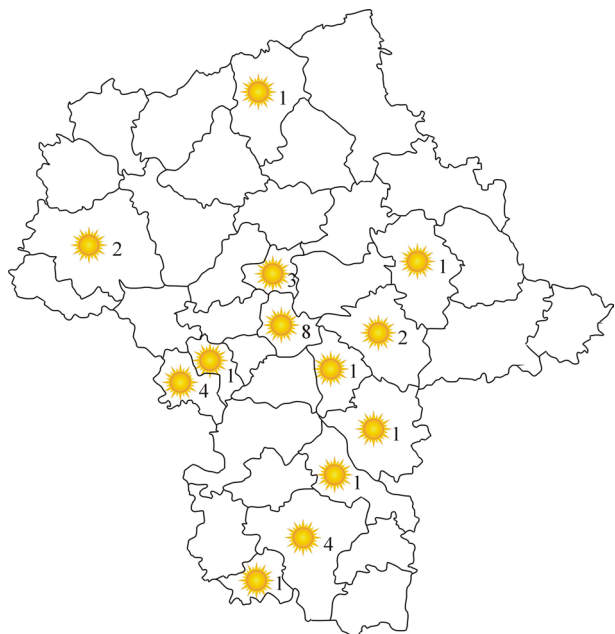
Mazowieckie Voivodeship has good conditions for further development of both solar collectors and PV panels. Every month the interest of individual investors in PV is growing. Interestingly, most of them would like to use produced electricity only for their own needs (Mazovia, 2018).

Currently operating solar power plants have been built during the last 2–3 years, and many new projects are at various levels of investment stages. It is anticipated that more and more solar plants with the capacity of 1–2 MW will be created in Mazowieckie Voivodeship (Current & Program, 2020). There are plans to use the building roofs or closed landfills for their construction.

8.2 PV development in the world

Solar energy, especially PV, is the fastest growing industry in the world. In 2019 alone, a 12% increase was achieved—115 GW of new capacity was installed. The total PV power is 627 GW, which means a 15-fold increase over the last 10 years. The highest total power can be found in China (over 200 GW), followed by the USA (almost 80 GW), Japan (over 60 GW) and Germany (50 GW) (Renewable Energy Policy Network for the 21st Century, 2020).

Fig. 9 Location of professional PV plants connected to the power grid in Mazowieckie Voivodeship (in 2018) [own elaboration based on (The Energy Regulatory Authority, 2018)]



Yushchenko et al. (2018) present estimates of the geographical and technical potentials for solar electricity generation in rural areas of West Africa. According to their estimates deployment of large-scale grid-connected solar power systems in the best suitable areas has a technical potential of about 700–1800 TWh/year (or 2–5 MWh/year per capita) in the case of CSP, and 900–3200 TWh/year (or 3–9 MWh/year per capita) in the case of PV. Off-grid PV technical potential is about 81 TWh/year in best suitable areas.

The performance from 18 months of 86.4 kW smart PV solar panels integrated in a building in Sadeem Building at Awali Town (middle of a desert area) in the kingdom of Bahrain is reported in the article (Alnaser, 2018). The PV system covers an area of 59 m² (36 PV panels) and was installed on a roof tilted by 25° and facing 225° (45° west of south). The panels are cleaned by sweet water every 2 months and it requires around 500 dm³ of water for the an panels installed on the roof each cycle (i.e. 14 dm³/panel).

Okoye and Oranekwu-Okoye (2018) presented an economic model to assess the cost–benefit of off-grid PV system. The developed method is demonstrated on a case study of rural Gusau, Nigeria. The results show that the feasibility of the proposed system is highly location dependent. Overall, conclusion is drawn that PV technology is eligible for project financing as it can repay its loan within the stipulated time considering the current infrastructure and energy policies in Nigeria.

The study (Karjalainen & Ahvenniemi, 2019) focuses on solar PV adoption in Finland, where the adoption of solar systems is still at a low level. Twenty-eight semi-structured interviews were conducted to obtain an understanding of the experiences of Finnish pioneer households. The results show that the adopters have overcome the barriers to adoption with the help of trustworthy information and advice from experts and from other adopters. The adopters are very satisfied with their PV plants even though economic profitability is not particularly good. The adopters actively monitor their energy production and are highly engaged in domestic energy matters. Many have enlarged their solar PV system or plan to do so, or are highly interested in upgrading their energy system with an electric car or advanced home automation.

8.3 PV SWOT analysis

PV SWOT analysis in Mazowieckie Voivodeship is gathered in Table 3.

8.3.1 Strengths

Of all types of RE, it is solar energy that enjoys the greatest social support in Poland. Research of the Public Opinion Research Center “Poles on energy sources, energy policy and the state of the environment” (Center for Public Opinion Research, 2016). showed that among all RE Poles definitely prefer solar installations (73%).

The strengths of PV include the fact that the installation of PV panels together with the energy storage provides electricity in places where access to the power grid is difficult. Moreover, PV installations are characterized by low operating costs.

It is becoming more and more popular to combine a solar installation with other RE installations, e.g. heat pumps. PV installation provides electricity for a heat pump, which in turn feeds the central heating and hot water storage (Current & Program, 2020).

Table 3 PV SWOT analysis in Mazowieckie Voivodeship (own elaboration)

Strengths	Weaknesses
High social acceptance It can be used in places not connected to the power grid Low operating costs of the installation Can be connected to other installations, e.g. heat pumps	High costs of PV installations Long return period for the purchase of the installation Disproportions in the amount of solar energy available in the spring–summer and autumn–winter seasons
Opportunities	Threats
Fast technological progress that increases efficiency and reduces the cost of solar installations Development of perovskites	Little support for micro and small energy sources

8.3.2 Weaknesses

Solar installations are still quite expensive, therefore, without co-financing, not many individuals decide to have them. The price of a solar system is about 18.5 thousand PLN per panels with a capacity of 3 kW and approx. 28.5 thousand PLN per panels with a capacity of 5 kW. High price of a solar installation means a long investment return period (Yushchenko et al., 2018).

The weaknesses include the fact that Polish climate conditions cause large disproportions in the amount of solar energy available during the year. Most of the total annual sun exposure is limited to six months of the spring and summer season, from the beginning of April till the end of September, with the solar operation time extended to 16 h a day in the summer, and shortened to 8 h a day in winter.

8.3.3 Opportunities

There are many research centers around the world working on improving existing materials or developing new materials used in solar installations. Perovskites may revolutionize PV soon. A perovskite is any material with the same type of crystal structure as calcium titanium oxide (CaTiO_3), known as the *perovskite structure*, or $^{\text{XII}}\text{A}^{2+}\text{VI}^{\text{B}^{4+}}\text{X}^{2-}_3$ with the oxygen in the edge centers. There are many advantages of these minerals, and the most important are: high absorption capacity, flexibility, transparency and lightness. PV cells based on perovskites can be used to cover a variety of materials—from thin PET films, through tiles and walls, to clothes and electronics. In this way, the above-mentioned could become a mini-technology factory producing clean energy (Manser et al., 2016; Yin et al., 2014).

Since 1977, the PV price, per unit of electric power, has in nominal terms, dropped around 250 times—from 76 dollars to 36 cents per watt; it is worth emphasizing here that the actual drop in this price was even greater, as in the last 30 years the value of money, including American dollar, has dropped significantly (<http://www.greentechmedia.com/articles/read/solar-pv-module-costs-to-fall-to-36-cents-per-watt>).

The opportunities are connected with the fact that the price drop in PV cells has been accompanied in the last three decades by a several-fold increase in their efficiency, which is

currently of 10–30% (depending on the type), and in the case of the most efficient ones, it approaches 50% (www.nrel.gov).

8.3.4 Threats

Small support for micro and small energy sources of private individuals is a threat. While public utility institutions can expect the co-financing, in case of individual clients, support is small (Pietrzak et al., 2021).

8.3.5 Recommendations

Our recommendations are:

- greater financial support for PV micro installations,
- energy batteries development,
- new PV materials development, including perovskites.

9 Bioenergy in Mazowieckie Voivodeship

Wood, straw, liquid biofuels and biogas are used for energy purposes in Mazowieckie Voivodeship. Currently, there is no liquid biofuel plant in the Province (Mazovia, 2018).

9.1 Solid biomass

In Mazowieckie Voivodeship, wood for energy purposes is used as: firewood, wood chips, shavings, sawdust, bark, briquettes and pellets. For energy production purposes, waste wood from forests or wood industry is most commonly used. Straw is also becoming more and more important as a raw material. Biomass can be incinerated or pyrolyzed/gasified (Arodudu et al., 2020; Fahmy et al., 2020).

First of all, wood, and to a lesser extent, straw has been used in Mazowieckie Voivodeship for heating in individual houses for centuries. In recent years, biomass is also increasingly used in large boiler plants or heat and power plants (Fig. 10).

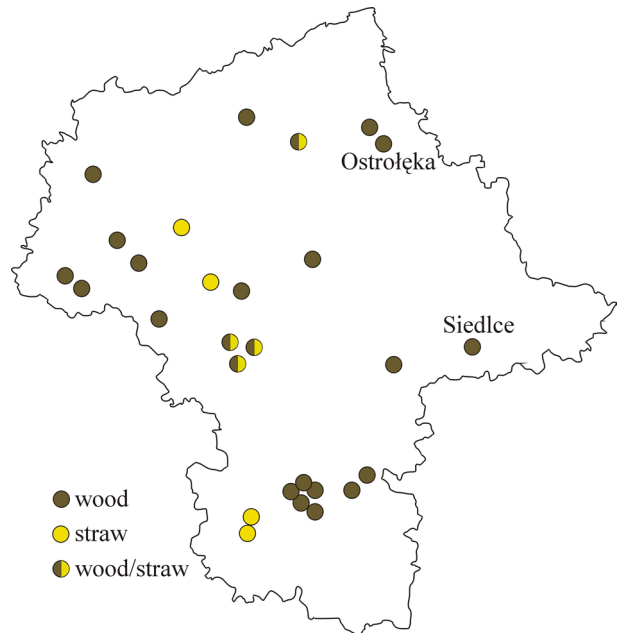
In the mid-1990s, the “Ostrołęka Heat and Power Plant” (Fig. 10) faced a challenge on how to use energetically large amounts of wood bark from the neighboring cellulose and paper plant. The problem was solved by the use of “fluidal waste incineration” that was not known in Poland in that time. For this purpose, a steam boiler was modernized, started in 1997 and has been working until now. In 2006, the installation for the co-combustion of hard coal and biomass in power boilers at “Elektrownia Ostrołęka B” was completed (Mazovia, 2018).

“Thermal Power Enterprise” in Siedlce (Fig. 10) uses biomass (chips) in the co-firing process for the needs of the heating network. Annual heat production from biomass is at the level of 11.5 thousand GJ (Mazovia, 2018).

9.2 Biogas

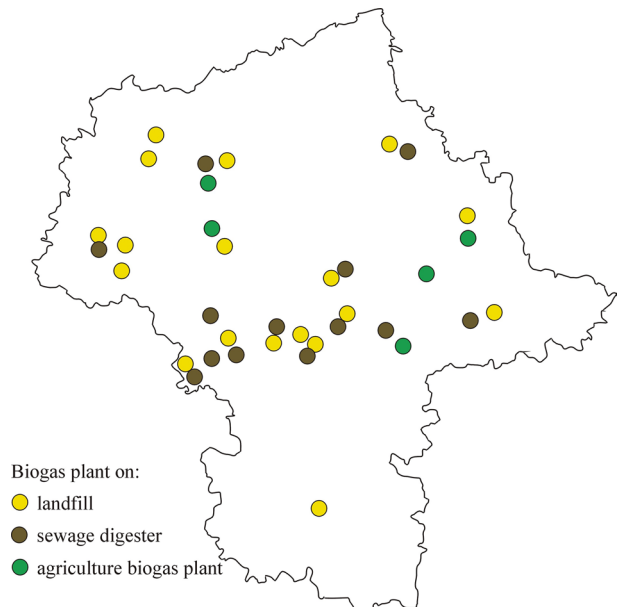
In Mazowieckie Voivodeship, biogas plants were first established in landfills, followed by sewage treatment plants and agricultural biogas plants (Fig. 11) (Abbas et al., 2020;

Fig. 10 Location of major installations using solid biomass for energy purposes in Mazowieckie Voivodeship (own elaboration based on [The Energy Regulatory Authority, 2018; Mazovia, 2018])



The Energy Regulatory Authority, 2018). The total capacity of biogas plants in landfills is 11,857 MW, biogas plants in sewage treatment plants 10.815 MW, and agricultural biogas plants 6.819 MW (The Energy Regulatory Authority, 2018).

Fig. 11 Biogas plants location in Mazowieckie Voivodeship (own elaboration based on (The Energy Regulatory Authority, 2018))



9.3 Bioenergy development prospects

Wood resources for energy purposes in Mazowieckie Voivodeship are estimated at around 370,000 m³ per year. The energy potential has been calculated at around 2.3 million GJ. The largest timber resources are in: Ostrołęka, Przasnysz, Ostrów, and Wyszaków the counties (Mazovia, 2018).

Wood from orchards for energy purposes can be obtained from the annual spring trees trimming and old orchards elimination. Wood resources were estimated at about 197,000 GJ per year, and the largest one is Grójec county (over 50% of total resources). In turn, the total resources of waste wood from roads, including national and provincial roads, were calculated at around 268,000 GJ/year (Mazovia, 2018).

The total surplus of straw that can be used for energy purposes is estimated at around 500–600 thousand tones. The largest straw surplus in terms of energy potential (over 200,000 GJ per year) occurs in the western counties of Mazowieckie Voivodeship (Marks-Bielska et al., 2019b; Mazovia, 2018).

Assuming that the whole waste ground and fallow land were utilised for the cultivation of energy crops, the theoretical energy potential would be around 35 million GJ/year (on the understanding that there are 280 thousand hectares of arable land, with heat value of 11 MJ/kg and 30% humidity).

The technical potential of biogas in Mazowieckie Voivodeship is about 138 million m³, where about 7 million m³ comes from the production of cattle manure, 8 million m³ of pigs and over 120 million m³ of poultry. The largest potential for the use of agricultural biogas, due to the high concentration of animal husbandry, occurs in the western counties of Mazowieckie Voivodeship (Mazovia, 2018).

The combustion of biomass in power boilers in order to produce heat was used in individual houses so far. In connection with the development of the market of local producers of electricity and increasingly convenient legal regulations in this respect, it may be expected that in the near future the production of electricity and heat in small and medium cogeneration units based on steam boilers and turbines will develop (Mazovia, 2018).

9.4 Bioenergy development in the world

The capacity of bioenergy plants in the world increased by about 6% in 2019, from 131 to 139 GW. The largest number of biomass power plants is in operation in China, Brazil, India, Germany, the UK, Sweden and Japan (Malek et al., 2020; Renewable Energy Policy Network for the 21st Century, 2020). In Europe, the consumption of biomethane in transport increased by 20% in 2018 to 8.2 PJ. Sweden remains the largest consumer of biomethane in the region, using almost 60% of the total, followed by Germany, Norway and the UK, where fuel consumption quadrupled to 0.6 PJ in 2018 (Renewable Energy Policy Network for the 21st Century, 2020).

Authors (Zyadin et al., 2018) used GIS applications, secondary data from official sources, and data from a field survey with 210 farmers to produce land use and GIS maps for surplus forest and agricultural biomass. The survey-based data was collected by developing a questionnaire and approaching farmers in the selected voivodeships (Kujawsko-Pomorskie and Śląskie, Poland). Field surveys with the farmers were carried out between July and August 2015. The survey was carried out at random directly at the farmer's house. The questionnaire was completed by 110 farmers from the Kujawsko-Pomorskie

Voivodeship (representing 0.085% of the farmers in the Voivodeship) and 100 farmers from the Śląskie Voivodeship (representing 0.084% of the farmers in the Voivodeship). Surplus residues from all crops in Śląskie Voivodeship and in Kujawsko-Pomorskie Voivodeship were estimated at 0.60 Mg/ha over a 12-month period.

Sliz-Szkliniarz and Vogt have calculated biogas potential in the Kujawsko-Pomorskie Voivodeship in Poland (Sliz-Szkliniarz & Vogt, 2012). The potential for biogas production that could meet the demand for 368 GWh of electricity and 442 GWh of heat or 98 Mm³ of methane (5% of the target) based on assumed biogas feedstock mix.

9.5 Bioenergy SWOT analysis

Bioenergy SWOT analysis for Mazowieckie Voivodeship is presented in Table 4.

9.5.1 Strengths

Strengths include the fact that Mazowieckie Voivodeship has a high potential of agricultural biomass, which can be burned or co-combusted, utilised through methane fermentation. A significant amount of biomass energy available is located in the eastern part of the Voivodeship, where there are frequent breaks in electricity supply (Mazovia, 2018).

The combustion of biomass, mainly wood, has been known for thousands of years, it is a well-mastered and quite simple technology. In turn, biogas plants in the Province have been in operation for over 20 years (The Energy Regulatory Authority, 2018).

One of the strengths of biogas energy is also the fact that it is a technology that deodorises and neutralizes waste (Herbes et al., 2018; Rolewicz-Kalińska et al., 2016). Biogas plants allow to manage organic matter waste in a controlled manner (Bauer et al., 2018).

9.5.2 Weaknesses

Low and variable prices of green certificates have a negative impact on the financial liquidity of biomass and biogas installations in Mazowieckie Voivodeship (together with other RE installations).

In recent years, there has been a seesaw of prices in biomass, and unfortunately many farmers believe that this will continue in the future. This is one of the main reasons why agricultural production of biomass for energy purposes is not expanding.

Table 4 Bioenergy SWOT analysis for Mazowieckie Voivodeship (own elaboration)

Strengths	Weaknesses
Well-developed agriculture and considerable potential of straw and biogas	Low and variable prices of green certificates Variable biomass prices
Technology well known and fairly simple to implement In the case of biogas, the technology of deodorising and neutralizing waste	IN the case of biogas, the problem of heat management
Opportunities	Threats
Possibility of managing waste biomass streams Possibility of utilising unused land New jobs in the energy and heating sector	Difficulties in ensuring the stability of biomass supplies No support for heat production

The weaknesses also include the point that some of the already working biogas plants have a problem with the management of heat, especially in the summer period (Mazovia, 2018).

9.5.3 Opportunities

Mazowieckie Voivodeship has a well-developed agriculture and food industries that generate significant amounts of biomass waste (Mazovia, 2018). The management of biomass waste streams is an opportunity for further development of bioenergy in the region.

Another opportunity is the fact that the management of fallows and wastelands for agricultural purposes—biomass production will generate new jobs in agricultural areas, i.e. with the highest unemployment. Today, money for the purchase of fuels and electricity flows out of the village in a wide stream, impoverishing it. The development of RE based on biomass will make the villagers beneficiaries—they will supply waste to the power plant/boiler room, and energy crops will be grown on their fields.

9.5.4 Threats

Late frosts or dry summers (like in 2015 year in Poland) affect significant decrease in biomass yields for energy purposes. Insufficient amount of contracted biomass means that power plants and combined heat and power plants are forced to look for additional fuel sources or reduce the amount of biomass burned.

Investors are struggling with the problem of ensuring uninterrupted supply of basic substrates. The continuity of biomass supplies requires the development of a logistic network, which generates additional costs and adversely affects the economy of the enterprise. It is already at the stage of choosing the location for the bioelectric plant, where this problem should be considered a priority—the facility must be located near the raw material (Mazovia, 2018).

9.5.5 Recommendations

Our recommendations are:

- long-term farmer—biomass installation contracts,
- fixed price of the contracted biomass,
- economic use of heat.

10 Geothermal energy in Mazowieckie Voivodeship

Most of the Mazowieckie Voivodeship area is located in the Polish Lowlands, in the geothermal district of Grudziądz-Warsaw. This district is characterized by an area of approximately 70,000 km² with geothermal water with a usual temperature below 100 °C occurring in Triassic deposits and in Cretaceous and Jurassic waters, with a total stocks of 3,100 km³ (Fig. 12) (Bujakowski & Tomaszewska, 2014; Szewczyk & Gientka, 2009).

In the area of Grudziądz-Warsaw Sub-Zone, several projects for using geothermal water for energy purposes have been designed. The only project carried out so far is the investment in Mszczonów. “Geothermal Plant in Mszczonów” was established as the third one

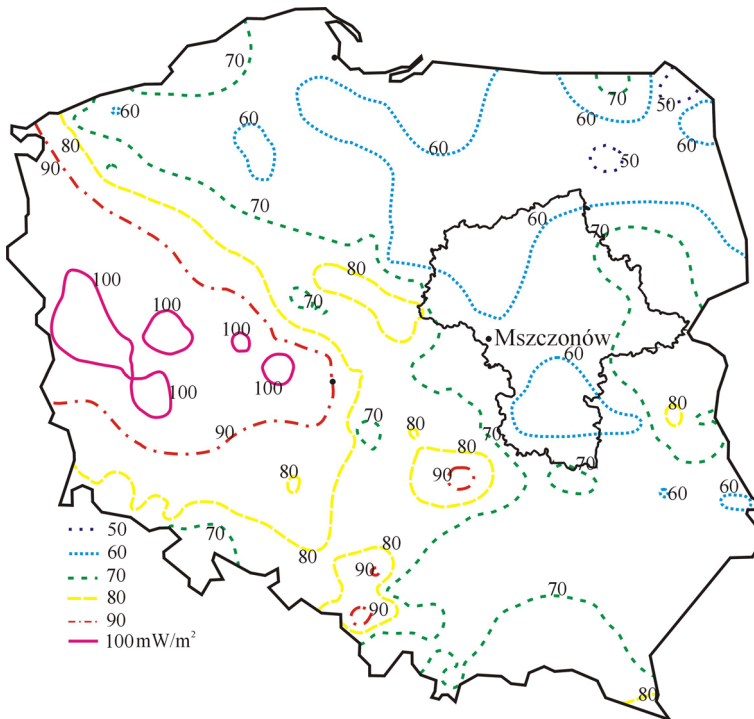


Fig. 12 The map of the terrestrial heat stream density for the Mazowieckie Voivodeship in comparison to the whole of Poland (own elaboration based on (Szewczyk & Gientka, 2009))

in Poland. Geothermal water extracted there since 2000 has been used for heating and recreational purposes, and what is unique on a European scale—for the drinking purposes. Geothermal heating plant located in Mszczonów replaced three obsolete municipal coal-fired boiler houses, which emitted 15 tones of nitrogen compounds, 60 tones of sulfur compounds, 9700 tones of carbon dioxide and 145 tones of dust every year. The total power of this heating plant is about 7.5 MW, where about 2.7 MW comes from an absorption heat pump using geothermal water. Heat production equals to about 55 TJ/year, while in the heating season about 40% of the heat supplied to consumers comes from geothermal water. Geothermal water cooled in the heating section, when it is passed through the iron removal unit, is directed to the municipal water supply network as high quality potable water (Balcer, 2007; Gaudard et al., 2019).

The number of heat pumps installed in Mazowieckie Voivodeship is very difficult to determine—it is estimated that there are at least several thousand of them. It is an increasingly popular way of heating not only for individuals, but also public institutions buildings, such as schools, churches and hospitals. For example, the “Municipal Wastewater Treatment Plant Żyrardów” uses heat pumps for heat recovery from wastewater (Balcer, 2007).

10.1 Geothermal energy and heat pumps development perspectives

The most favorable conditions for the use of geothermal energy are found in the western and southern counties of Mazowieckie Voivodeship. The construction of geothermal

systems can be profitable in larger towns, where it is possible to receive heat in a constant, large amount. This prefers, in the first place, agglomerations, with a high density of buildings, and a well-developed heating system (Website Balcer, 2007; Mazovia, 2018).

It is anticipated that heat pumps will become a standard heating method in newly built homes soon. Collective use centers can apply for external funds/support relatively easier, so the further development is also expected here.

10.2 Geothermal development in the world

In 2019, approximately 700 MW of new geoenergy capacity was added to the world, of which 32% was in Turkey, 25% in Indonesia and 22% in Kenya. The USA remained the world leader in installed geothermal capacity, with a total capacity of nearly 2.5 GW, followed by Indonesia (nearly 2.2 GW) and the Philippines (1.9 GW) (Renewable Energy Policy Network for the 21st Century, 2020).

Gaudard et al. (2019), estimate the potentials for heat extraction and disposal for the main lakes and rivers of Switzerland based on acceptable temperature changes in the waterbodies, and compare them to regional demands. In most cases, the potentials considerably exceed the demand, and minor impacts on the thermal regime of the waterbodies are expected. There are, however, critical situations: rivers crossing densely-populated areas, where demand often exceeds the potential, and heat disposal in summer into lowland rivers and shallow lakes, where temperatures may exceed ecological criteria. To assess the impacts of a realistic thermal use, authors model the temperature effects in two lakes: Upper Lake Constance, a large lake with relatively low population density, and Lower Lake Zurich, a smaller lake with high regional demand. The estimated mean temperature alterations are -0.05 to $+0.02$ °C for Lake Constance, and -0.60 to $+0.22$ °C for Lake Zurich. The analysis demonstrates that waterbodies provide real alternatives for heat/cold production in many regions of the world.

The paper (Klijajić et al., 2020) examines the integration of local geothermal potential in the northern part of the Republic of Serbia and assesses the implications of using geothermal heat pump technology in a district heating system. The main benefit of the geothermal heat pump system is the reduction of the inlet primary energy by at least 30% by avoiding the use of almost a 22 million cubic meters of natural gas per year. This also results in a competitive energy cost of 23 EUR/MWh, an investment with internal rate of return of up to 38%, and a discounted payback period of 4.9 years.

10.3 Geoenergetics and heat pumps SWOT analysis

Geoenergetics and heat pumps SWOT analysis in Mazowieckie Voivodeship is presented in Table 5.

10.3.1 Strengths

Well-designed geothermal installation or heat pump works almost without failure.

Strengths include the fact that heat pumps, like solar installations, are very popular among Poles. It can even be stated that having a heat pump has become fashionable.

Table 5 Geoenergetics and heat pumps SWOT analysis in Mazowieckie Voivodeship (own elaboration)

Strengths		Weaknesses	
Low failure rate Very high social acceptance		High investment costs LONG costs return period	
Opportunities		Threats	
Development of balneology and swimming pools Development of a low-emission economy		Lack of effective promotional policy towards geothermal energy Limited experience of some installation companies	

10.3.2 Weaknesses

The most important weakness of heat pumps is their high investment costs; the cost of a heat pump is usually 30–40 thousand PLN. High investment costs imply a long return period.

10.3.3 Opportunities

The construction of a geothermal plant should be associated with the development of balneology, as geothermal waters generally have appropriate chemical composition for medicinal purposes. Geothermal hot water and/or geothermal heat should be used for recreational purposes in thermal baths, as is the case of Mszczonów, where since 2008 there has been a “Thermal Swimming Pool Complex” (Website Termy, 2018).

The production of geothermal heat practically does not contribute to the emission of harmful chemical compounds. Geothermal heat plants construction and heat pumps installation will contribute to the development of low-emission economy in Mazowieckie Voivodeship.

10.3.4 Threats

It should be stated that in the case of geoenergy there is still a lack of effective promotion policy in both Mazowieckie Voivodeship and throughout Poland. Central and local authorities should introduce more programs supporting the further development of “deep” and “shallow” geothermal energy (Mazovia, 2018).

Another threat is the fact that there are companies on the market that install heat pumps in a less specialized way, which entails high failure rates of the installation.

10.3.5 Recommendations

Our recommendations are:

- financial support for individual investors,
- effective policy promoting geothermal energy and heat pumps,

- public education on geothermal energy and heat pumps.

11 TOWS analysis of the RE in the Mazowieckie Voivodeship

11.1 SO situation—aggressive maxi-maxi strategy

The situation of the RE sector, inside which strengths prevail, and in the environment—opportunities. It is a maxi-maxi strategy: strong expansion and diversified development. In the Mazowieckie Voivodeship, PV and bioenergy are in the situation of SO. These sectors of the RE have the greatest opportunities and possibilities of rapid development.

11.2 WO situation—mini-maxi strategy

Here we are dealing with the RE sector which has an advantage of weaknesses, but is favored by the system of external conditions. Its strategy should be to take advantage of these opportunities while reducing or improving weaknesses within the sector. In the Mazowieckie Voivodeship, the situation of WO is aeroenergy and geoenergy. As of today, the biggest weakness of aeroenergy is the “distance Act”, which almost stopped the development of this technology in Poland. Even in this difficult situation, aeroenergy should develop based on its strengths and opportunities. In turn, in the case of geoenergy, the greatest weakness is the high cost of the installation. Therefore, it is necessary to focus on the development of balneotherapy and thermal baths, which would allow to obtain external funds for financing the investment.

11.3 ST situation—maxi-mini strategy

The source of RE development difficulties for this sector is the unfavorable system of external conditions (predominance of threats). You can oppose it with great internal potential and try to overcome the threats using your strengths to the maximum. In the Mazowieckie Voivodeship, hydropower is in the situation of ST. The biggest threat is the low interest of investors. This RE sector must emphasize its strengths more: stable energy production, water retention and the fact that SHP can be placed in many places in the Voivodeship.

11.4 WT situation—mini-mini strategy

In such a situation, the RE sector is deprived of development opportunities. It operates in an unfavorable environment and has little potential for change. It does not have significant strengths that could counteract the threats. In the pessimistic version, the mini-mini strategy comes down to liquidation, in the optimistic version—to is trying to survive. In the case of Mazowieckie Voivodeship, no RE sector is in the situation of WT.

12 Future perspectives of RE development in the Mazowieckie Voivodeship and Poland

In the Mazowieckie Voivodeship, an energy mix should be developed, mainly based on bioenergy, aeroenergy and helioenergy. The mix of different RE will ensure the energy self-sufficiency of the Mazowieckie Voivodeship. The conducted SWOT analysis allows a rather optimistic view of the further development of RE sources in the Mazowieckie Voivodeship. Solid biomass, wind and PV energy will be used for electricity production, solid biomass and heat pumps for heat production. The Mazowieckie Voivodeship should further develop the RE mix. Heat and power plants should be built in areas rich in waste biomass, wind farms in areas with high winds, etc. Only the sustainable development of the RE will allow the energy transformation of the Mazowieckie Voivodeship. In 2021 or 2022, the first biomethane plant in the Mazowieckie Voivodeship is to be opened. Biomethane is to be used as automotive fuel and/or as gas injected into the gas grid.

The SHP potential in Mazowieckie voivodship calculated on the basis of stacking amounts to 32.7 MW. Building dams as part of “Small Retention” may increase the hydro-power potential in the Province. Aeroenergy is currently developing very poorly in the Mazowieckie Voivodeship (as well as in the whole of Poland) due to the “distance Act”. It must be liberalized. In recent months, prosumer PV has been developing very quickly in the Province. Further rapid development of pro-consumer PV in the Voivodship is expected, which results from the decline in prices of PV panels, increased efficiency and more and more incentives, such as the “My Current” Program (Current & Program, 2020). “My Current” program allows to obtain a subsidy for the construction of PV micro installations (from 2 to 10 kW) in the form of a subsidy of up to 50% of eligible costs, but not more than PLN 5 thousand per project. It is a prosumer energy sector, PV installations are most often installed on the roofs of the investor’s buildings (Stadniczeńko, 2020). Bioenergy has a very good chance for development—the Voivodeship has a great potential of forest and agricultural waste. Solid biomass will be incinerated/co-incinerated in combined heat and power plants, and biogas will be produced from “wet” waste. The inhabitants of the Province are more and more willing to choose heat pumps as the main/additional source of heat.

PEG (Polish Energy Group), the largest energy company in Poland, headquartered in Warsaw, published a new strategy in autumn 2020 (www.gkpge.pl/biuro-prasowe/komunikatyprasowe/korporacyjne/strategia-grupy-pge-neutralnosc-klimatyczna-w-2050-roku). The company presented the Group’s transformation plan and the way to decarbonise production, and announced the goal of achieving climate neutrality by 2050. Firstly, to the end of 2030, PGE Group intends to build 2.5 GW of new capacity in offshore wind farms, 3 GW in PV and expand the portfolio of onshore wind farms by at least 1 GW. Recognizing the interest of customers, PGE Group will prepare for them the opportunity to participate in the energy transformation for them. Large-scale projects will be accompanied by a complementary storage program of at least 0.8 GW, which will support the safe and flexible operation of the power system (www.gkpge.pl/biuro-prasowe/komunikatyprasowe/korporacyjne/strategia-grupy-pge-neutralnosc-klimatyczna-w-2050-roku).

The development of domestic RE installations, their assembly and conservation works are a huge impulse for the economic development of the Mazowieckie Voivodeship. And we should start with the fact that the development of RE sources means new, relatively well-paid jobs in rural regions with relatively high unemployment. A power plant/RE installation means not only jobs, but also great financial benefits, as it pays

various types of taxes, VAT, transfers money to the Labor Fund and the Guaranteed Employee Benefits Fund, tax on natural persons and legal persons, as well as various maintenance fees; supports local culture. The commune and the State Treasury gain.

Sustainable use of RE resources in the Mazowieckie Voivodeship will radically reduce the emission of harmful compounds, including dust responsible for smog (Dzikuć & Adamczyk, 2015). RE also generates less waste than conventional fuels. Improving air quality will have a positive effect on the health of the inhabitants as well as attract more tourists.

The development of RE is conducive to a decentralized society, powered by a network of smaller and safer power plants and strengthening local communities. Much of the energy production (biogas, biomass, the Sun, etc.) will be transferred to agricultural land, with economic benefits. The development of RE sources means that rural residents will be the beneficiaries—they will supply waste to biogas plants, for example, solar farms will work on their premises. They will find work in new plants producing energy from RE. Farmers' income will be diversified. Own energy production will also improve the quality of rural infrastructure and the quality of life. The development of the RE mix will allow the Voivodeship and Poland to gradually transform towards 100% RE. This is expected to happen in 2050 at the latest.

It should also be noted here that the increase in electricity obtained from RE sources, in addition to the lower negative impact on the natural environment compared to conventional energy sources, may translate into improvement of the country's energy security. Thus, the actual increase in the share of electricity from RE in consumption may contribute to the gradual implementation of sustainable development idea (Gue et al., 2020) in the socio-economic life of the Voivodeship. In recent months, prosumer PV has been developing very quickly in the Mazowieckie Voivodeship. Further rapid development of pro-consumer PV in the Province is expected, which results from the decline in prices of PV panels, increased efficiency and more and more incentives, such as the "My Current" Program (Current & Program, 2020).

The EU climate and energy policy, including its long-term vision of striving for EU climate neutrality by 2050 and regulatory mechanisms stimulating the achievement of effects in the coming decades, have a significant impact on shaping the national energy strategy (Sovacool et al., 2021). Achieving the EU's 2020 and 2030 climate and energy targets is key to a low-carbon energy transition. According to the Polish Energy Policy until 2040 (Ministry of Climate & Environment, 2020), the transformation of the Polish energy sector is to be based on three pillars:

1. The First Pillar—transformation of coal regions, reducing energy poverty and new industries related to the RE and nuclear energy.
2. Second Pillar—offshore wind energy, nuclear energy as well as local and community energy.
3. Third Pillar—transformation of heating, electrification of transport and passive constructions (Ministry of Climate & Environment, 2020).

Poland's Energy Policy (Ministry of Climate & Environment, 2020) provides a departure from burning coal in households by 2030 in cities and by 2040 in rural areas. In 2040, more than half of the installed capacity will be zero-emission sources. The implementation of offshore wind energy into the Polish power system and the commissioning

of a nuclear power plant will play a special role in this process. There will be two strategic new areas and industries that will be built in Poland.

13 Policy and Managerial Implications

The conducted research indicates that in order to develop the RE in the Mazowieckie Voivodeship (as well as in Poland), bureaucracy should be reduced. Currently, the RE investor in Poland has to prepare a lot of documents, permits, and often an environmental impact assessment. It is time-consuming and capital-intensive. Therefore, the number of necessary documents should be reduced to a minimum, and those that remain as much as possible simplify. A sensible solution is to delegate a person/persons in each commune who will help RE investors in preparing the necessary documentation.

The “Distance Act” regulation must be changed as soon as possible—this is probably the most stringent regulation for building turbines/wind farms on land. The rules on offshore wind energy need to be simplified.

Knowledge about the RE in the Mazowieckie Voivodeship (as well as in the whole of Poland) is still at a fairly low level. This needs to be changed by introducing the basics of RE at every level of education. It is worth preparing educational films about RE, doing workshops, organizing conferences and study trips at the RE facilities. Adults, including politicians, should also be educated. The increase in knowledge in the society should result in greater support for the RE and a decrease in protests against the construction of the RE installations.

The Mazowieckie Voivodeship (as well as the whole of Poland) is struggling with the problem of poor air quality, and with smog during the heating season. The development of RE installations (geothermal energy, heat pumps, biomass) can improve air quality, so the amount of subsidies, loans, low-interest loans or tax exemptions for investors who are switching to low- or zero-emission heat sources should be increased.

The energy transformation of the Voivodeship, just like the whole of Poland, requires cooperation with conventional energy companies. Adequate support programs for renewable energy workers should be provided so that they can change industries and start a new job. Also companies producing mining equipment should be able to change the structure of production and the possibility of producing, for example, components for wind energy.

Legal provisions should allow for the sustainable development of the energy mix. Only the energy mix will ensure energy security in the Voivodeship and Poland.

14 Conclusions

It should be summarized that RE in the Mazowieckie Voivodeship is developing well. At present, biomass and wind energy dominate. The Voivodeship has a significant potential for RE. The SWOT analysis carried out allows us to be optimistic about the further development of the RE in this region. Moreover, the possibility of financing RE investments may contribute to the fact that the Voivodeship will be the RE leader in Poland. The most important advantages of using RE include:

- economic development of the region,
- activation of the local community,

- using local raw materials surplus for energy purposes,
- the possibility of managing fallows, wastes and introducing an additional source of income for farmers by growing energy crops, increasing industrial crops,
- reduction of pollutant emissions,
- change of fuel in large boiler rooms or elimination of individual carbon sources, causing so-called low emission,
- lowering of the energy obtaining costs—renewable sources are characterized by lower variable costs,
- promoting the region as ecologically clean—it is particularly significant in regions where development of recreational and leisure functions is expected,
- increase of the region energy security.

Further development of the RE sector in Mazowieckie Voivodeship is strongly dependent on legal provisions that should be simplified and investor-friendly.

The transition from the coal power sector to the non-emission one is a long lasting process, which requires a good political and economic strategy as well as ensuring an appropriate legal basis, funding sources and operating resources. It is very important not to focus on one selected RE technology, but to establish a balanced structure of RE sources.

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Declaration

Ethical approval The authors of this manuscript submit that we have read the ethical responsibility of authors submitting to the Journal and confirm that there are no foreseen ethical implications for this manuscript. The manuscript has not been submitted to any other journal for concurrent consideration for publication. Informed consent was obtained from all individuals who were involved in this study, and all necessary ethical procedures for data collection were followed. We therefore agree to the ethical implication that any ethical misconduct may result.

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