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The Potential and Development of the Geothermal Energy Market in Poland and the Baltic States—Selected Aspects

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Abstract: The problem of rising energy prices stems from the weakening of economies operating in the realities of the COVID-19 coronavirus pandemic, as well as from the rising cost of CO_2 emission allowances in connection with the European Union's environmental policy. The outbreak of war in Ukraine has deepened the energy crisis in European countries, which, to a significant extent, benefit from hydrocarbon resources imported from Russia. This problem is particularly acute in countries that are heavily dependent on conventional forms of energy production (e.g., Poland). In light of the problems observed, the need to develop a market for renewable energy has become more urgent than ever. Although this problem affects a number of countries, the authors of the study decided that it is particularly important in the region of the countries neighbouring the line of the ongoing armed conflict in Ukraine, i.e., Poland and the Baltic States (Lithuania, Latvia and Estonia). The choice of the research area was determined by direct proximity to the examined countries, as well as the generally comparable social and economic conditions of Poland, Lithuania, Latvia and Estonia, which creates the basis for factual comparisons and conclusions. The main objective of the study was to assess the directions of the development of the geothermal energy market in Poland against the background of the Baltic States in the current economic conditions, together with an attempt to determine the most justified direction of geothermal energy development in Poland—with the strongest impact on increasing the share of RES in the energy system and limiting the increase in electricity prices in this country. Identification of solutions practiced in the geothermal energy market in Lithuania, Latvia and Estonia for comparative purposes (Poland region) was helpful in this respect. The subject of this study was oriented towards the diagnosis of the state of the geothermal energy market in the surveyed countries to determine the general directions of its development. Particular attention was paid to the study of needs and preferences in this field on the Polish market concerning individual users, which constitutes the basis of the research. The instruments required for carrying out the research work in the outlined scope were basically drawn from the area of economic analysis and evaluation of phenomena (multifaceted analysis including critical analysis of the literature, comparative analysis of research results, situational analysis of geothermal market), in comparison with the results of our own research (questionnaire survey) carried out on the Polish energy market (individual customers). The research revealed the strong position of Poland in the field of the development of deep and shallow geothermal energy in the area of the countries accepted for the study. The determinant of the above is the abundance in this country of easily accessible heat deposits of the Earth. In general, the actions taken by the surveyed countries in the field of geothermal development are of a similar nature (shallow geothermal heat pumps are the most developed), while, in the field of deep geothermal energy, an interesting observation is the orientation towards solutions based on the energy of crystalline rocks in Lithuania and Estonia, determined by the availability of such deposits in this region. Surveys indicate the growing awareness of the validity of efforts to extract energy from the earth. However, this problem still represents a major challenge (e.g., deep geothermal energy in Estonia), so indicating the role of geothermal energy in the energy market—especially in the area of the countries accepted for the survey—is an important and relevant topic.

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1. Introduction

The energy crisis is growing. The outbreak of war in Ukraine, together with a set of economic consequences resulting from actions taken in the world towards the aggressor, has reinforced the problem of supplying the energy market with fossil fuels, which, to a very significant extent, supply the European energy market. This problem particularly concerns countries whose energy market is based primarily on conventional production, including, in particular, a significant proportion supplied by raw materials hitherto obtained through imports from Russia, strengthening the risk over the years [1]. The supply policy practised for several years has been shaken. As a consequence of the disruption to the stability of fuel supplies, there has been a solid increase in fuel prices. The remodelling of the sources of supply in energy-bearing raw materials requires capital-intensive investment efforts in connection with the provision of new channels for their acquisition.

The problem of rising energy prices is not a new one. An increase in energy consumption bills has been observed in response to the rising cost of CO_2 emission allowances in connection with the European Union's environmental policy, which is particularly relevant for countries strongly dependent on traditional energy production formulas (e.g., Poland). The reality of rising electricity prices further weakens the financial situation of a number of companies and households that have already suffered from the COVID-19 coronavirus pandemic [2] and are struggling with the effects of the economic crisis observed in a number of areas in Europe and the world. The above indicates the importance and scale of the impact of force majeure factors on the energy stability of a number of economies.

The very complicated situation in the energy market reinforces the need to take action to limit progressive increases in energy prices and to mitigate their negative effects. One such action is an orientation towards obtaining energy from renewable sources [3], which is to be determined by energy policies adopted at the level of individual countries, which outline space and define conditions for taking challenges and initiatives in connection with the development of renewable energy sources. One such direction is obtaining energy from inside the Earth (geothermal energy), which inspired the authors to take up this issue within the framework of this study.

The issue of renewable energy sources is an important topic, especially in relation to countries where energy prices have risen significantly recently and where, due to a strong dependence on the conventional formula of production using a raw material restricted by the aggressor in the war in Ukraine, the risk of further increases is the highest (e.g., Poland). Hence, the authors found it justified to analyse the directions of geothermal energy development on the Polish market against the background of the neighbouring countries (Baltic States), as well as those located in the vicinity of the line of the ongoing armed conflict in Ukraine (Lithuania, Latvia and Estonia). With reference to the outlined group of countries, the authors decided to explore the issue of acquiring green energy from inside the Earth as the direction of actions aimed at strengthening the participation of RES in the energy systems of these countries, limiting the progressive increase in electricity prices and reducing the negative impact of these changes on the environment. The choice of the research area is furthermore supported by their similar socio-economic conditions, which enables factual comparisons and the formulation of substantive conclusions.

The basic aim of the study was the evaluation of the directions of geothermal energy market development in Poland in comparison to the Baltic States in the current economic conditions, together with an attempt to determine the most justified direction of geothermal energy development in Poland—with the strongest impact on increasing the share of RES in the energy system and limiting electricity price increases in this country. In order to enrich the research in this field, solutions specific to the geothermal energy market in Lithuania, Latvia and Estonia were identified for comparative purposes (Poland region).

Partial objectives of the study include an outline of the essence of the process of obtaining heat from the ground, a review of the basic types of solutions used in this area, together with the analysis of the potential for geothermal energy development in the Polish market in comparison to the Baltic States.

The authors are aware that studies of a similar character are the subject of interest of researchers. However, it should be stressed that the available literature is poor in the analysis of geothermal conditions and development of geothermal energy for the systems of the countries adopted for the study. Here, the literature basically focuses on general analyses in the scale of Europe and the world. Bearing the above in mind, the authors decided that the considerations in the subject of the adopted research will contribute to filling the observed research gap, responding to the information demand in the undertaken subject and the explored scope. The diversified level of drawing from RES solutions at the level of countries accepted for the study will enrich our understanding of the system of challenges connected with the problem of geothermal energy development at the level of the particular subjects of the study. Moreover, it is worth mentioning that the structure of countries adopted for the analysis is justified by the relatively good availability of data enabling the research (Eurostat analytics, industry reports, etc.).

This study adopts the following structural layout: Section 1 is the introduction, and Section 2 presents the literature review on the issue of geothermal energy market development in the world. Section 3 discusses the results of research on the analysis of geothermal conditions and the degree of development of deep and shallow geothermal energy in Poland and the Baltic States—supported by the analysis of development trends, together with recommendations defined in relation to the research results. The content of Section 4 comprises the discussion and conclusions.

2. Geothermal Energy in the World—Literature Review

The lever for economic development is the efficiency of the energy sphere, which is confirmed by numerous considerations presented in the literature on the development of economies [4–8]. In light of the sustained high demand for energy, in the realities of the aggravating energy crisis and rising prices on the global energy market, the orientation towards its acquisition from renewable sources should constitute the foundation of the energy market development in the contemporary world [9]. This is supported by the fact that the trend of limiting the extraction of fossil fuels has been intensified for years—in connection with the tightening of the policy for the protection of non-renewable natural resources and also due to the increased awareness in the field of environmental protection of the negative impact of discharges and emissions accompanying the production of energy by conventional means [10]. Environmental restrictions and related rights to greenhouse gas emissions (mainly CO_2) [11] are correlated with significant financial burdens, determining the cost of energy production in the conventional mode, ultimately burdening the consumers of energy produced in this way. The pro-environmental policy of the world's economies—often associated with a change in energy acquisition policy [12,13]—and the increase in consumer awareness and behaviour [14] causes the global energy market to draw more and more heavily on renewable energy sources [15], at the expense of supporting segments of economies engaged in the extraction and processing of energy-bearing fossil resources in countries dependent on the classical energy industry [16]. These actions are absolutely justified and particularly necessary in areas where the basic production capacity is based on non-renewable sources of energy supply (e.g., Poland).

There are many directions for obtaining energy from renewable sources. Energy can be obtained from the Earth's interior, from waves, currents, tides, biomass [17], wind [9], solar radiation [18] or from the Earth's heat.

The share of geothermal energy in the structure of renewable sources in the studied areas is insignificant, reaching 2.48% in Poland (geothermal and heat pumps), with the share of RES in the Polish energy mix at 18%, where coal is the leader (70%), and gas takes a share of 10% in the structure of energy sources in this country [19]. Although, at the moment,

the energy obtained from the Earth's heat is not able to replace the energy produced from hydrocarbons imported from Russia, it is worth exploring this alternative to fossil fuels in order to promote this direction of RES development, seeing in it the potential to change the unfavourable constellation of energy supply sources, improving the energy efficiency of the energy system of the studied economies, as well as increasing the energy security of entities and stabilising their operation. The importance of this theme is strengthened by the crisis in the fuel market and the continuous increase in energy prices. On the other hand, growing social awareness and formal and legal obligations in the sphere of environmental protection make traditional methods of obtaining energy unacceptable in the long term.

Geothermal energy, which is the subject of this study, is the thermal energy of the ground, water and rocks located below the Earth's surface, obtained through drilling. The main energy of the Earth is located in the Earth's core, oscillating within 6600 °C, one fifth of which is the effect of gravitational contraction due to the formation of the planet, and the remaining part is the effect of power supply due to the decay of radioactive isotopes in the Earth's mantle, as well as internal friction due to the occurrence of tidal forces and changes in the speed of rotation of the globe [20]. Part of the energy from the Earth's core penetrates into its crust, which can lead to the formation of energy accumulations (heat spots, lava caps) [21], but the natural process is its penetration to the surface, with the power oscillating within 46 TW [22] (with the heat flux at the average level of approximately 0.063 W/m^2), which, when juxtaposed with the size of the globe, gives grounds to classify these energy deposits into the category of inexhaustible, although slowly renewable [23].

The source of thermal energy is the Earth's heat energy accumulated in rocks, waters or water vapour filling the fractures of rocks, occurring at depths ranging from several tens to several thousands of metres, the exploitation of which is carried out by means of boreholes [24], enabling the acquisition of geothermal energy from deep and shallow aquifers. The depth of resource exploration provides a basis for distinguishing shallow geothermics—up to 100 m depth of borehole—and deep geothermics exceeding the indicated threshold, whereas the temperature of the geothermal source provides a basis for classifying low-temperature geothermics—up to 150 °C—or high-temperature geothermics (above 150 °C) [24]. The type of technology and capital intensity of the geothermal energy gaining enterprise is determined by the quality of deposits—their technical availability, temperature, degree of salinity of water, etc. A necessary condition for the determination of an appropriate (optimal in the input–effect relation) technology for acquiring geothermal energy is the assessment of the level of availability of geothermal deposits together with the assessment of their technical potential for application in a given system [25].

In a general approach, the potential of access to heat from the Earth's interior—regardless of weather conditions—makes this source of energy supply popular in urban, suburban and rural areas in almost all corners of the world. The attractiveness and popularisation of the solution is enhanced by the multivariate approach to acquiring geothermal energy from local energy sources of the Earth (e.g., geothermal wells, borehole heat exchangers (BHE), etc.), as well as the widespread discussion about the relatively low operating costs of the installations, after the—in principle, significant—outlays incurred for their construction.

Currently, geothermal energy resources are used by 88 countries in the world, with geothermal capacity oscillating around 107,627 MW in 2020, which constitutes approximately 52% growth over a five-year period [26]. Directions for the direct use of geothermal energy on a global scale include [27]:

(a) District heating: shallow geothermal (heat pumps) and deep geothermal, with an 83.81% (90,315 MW) share of the total installed capacity and an annual heat production of 762,960 TJ (with nearly 79% share of shallow geothermal in this process);
(b) balneotherapy and recreation, with a share of 11.38% (12,253 MW) of the total installed capacity;
(c) greenhouse heating, with a share of 2.28% (2459 MW) of the total installed capacity;
(d) aquaculture, with a 0.88% (950 MW) share of the total installed capacity;

(e) industrial use, with 0.79% (852 MW) of the total installed capacity;
(f) use in road infrastructure maintenance (de-icing), with a 0.40% share (435 MW) of the total installed capacity;
(g) other, with a share of 0.09% (106 MW) of the total installed capacity.

Heat pump technology is leading the way in utilising the Earth's heat resources for utility purposes and is strengthening its position in the heating market [28]. It is most strongly used in European markets, where the leaders in drawing from shallow geothermal deposits include Sweden, Germany, France, Finland and Austria, with Poland ranked eighth in terms of the number of completed installations (60,000) and fifth in terms of sales growth (year-on-year dynamics in 2019/2020 at around 15%) [26]. Heat pump technology is seen as a lever for the implementation of plans to achieve carbon neutrality in the period up to 2050.

The European market is also leading the way in district heating, in the use of geothermal for cooling buildings and in the use of geothermal heat in industry, services and agriculture, where geothermal heating has been developed in 34 European countries, including 25 countries with district heating systems (GEODH), with a total installed capacity of 5.5 GW [26].

A growing field of application of geothermal energy in the world is the production of electricity, which is carried out in 29 countries, with an installed capacity in 2020 of 15,950 MWe and an annual energy production of approximately 95.1 TWh (which represents approximately 30% growth of this market in a three-year period), where the leaders in this market include [29]:

(a) globally, the United States of America, Indonesia, Philippines, Turkey, Kenya, Mexico and New Zealand (with a minimum installed capacity of 1000 MW);
(b) in European dimension, Turkey, Italy, Iceland, France and Germany (with an installed capacity of 3300 MW, including 1000 MW in EU countries).

In this context, it is worth pointing out the countries that have started producing electricity in geothermal power plants, i.e., Chile, Honduras, Croatia, Hungary and Belgium [30].

An observed development direction for tapping geothermal resources is [29]:

(a) an increase in electricity generation using binary plant technology (using an additional refrigerant circuit at a reduced evaporation/condensation temperature), in order to increase the efficiency of drawing on the Earth's heat resources;
(b) stepping up the development of district heating, particularly heat pump installations;
(c) development and optimisation of district heating systems (GEODH) and Enhanced/Engineered Geothermal Systems (EGS) technologies;
(d) increasing the use of the Earth's energy in aquaculture, balneotherapy, recreation or agriculture;
(e) orientation towards geothermal water treatment and extraction of metals, minerals and other elements, such as SiO_2, Na, K, Li, Ca, Mg and REE elements (yttrium, cerium, lanthanum, neodymium, etc.).

The main advantages of geothermal energy, which are the mainstay of this energy source on the RES market, include its indifference to the environment, assuming that the installation operates correctly, and the relative lack of significant impacts on landscape changes associated with the construction of the installation—compared to wind farms or photovoltaic farms, which have a strong presence in the landscape.

Counterbalancing the many advantages of geothermal may be its disadvantages, which include [23]:

(a) the relatively limited accessibility of deposits of the Earth's energy resources, due to their local structure, which determines the technology for tapping the resource;
(b) the risk of environmental pollution, as a result of the penetration of harmful substances into the environment, in the event of defects in the installation;

(c) the problem of the risk of migration of terrestrial energy deposits in connection with the exploitation of the source;
(d) the problem of the cooling of the spring and its exploration site due to overexploitation of the deposit.

The strong demand for energy from renewable sources makes geothermal energy a currently strongly developed aspect of the energy supply in the field of RES, as confirmed by the above literature review. This review is an introduction to further research, focused on the analysis of the geothermal energy market in Poland against the background of the Baltic States, in accordance with the purpose of this study, presented in the Introduction.

3. Materials and Methods

The research process required maintaining the principles of comprehensibility and relevance of the themes explored, in order to ensure adequate information quality, for the correct assessment and interpretation of the phenomena.

The first stage of the research is conceptual in nature. The analytical and empirical dimension of the research at its further stage is to provide a reliable view of the most important aspects of geothermal development in Poland against the background of the Baltic countries, in order to answer the questions articulated in the Introduction.

The analysis of the state of the geothermal market in Poland and the Baltic States was based on data drawn from energy market industry reports in Poland, Lithuania, Latvia and Estonia. Statistical materials, prepared at the levels of the countries adopted for the study, with broad reference to the European Union energy market, were used for the study. At the same time, it is necessary to point out the methodological limitations, which result from the system of differences in the means of determining certain parameters, which constitute the analytical input material for the conducted findings (e.g., source material in the form of reports), narrowing the spectrum of possible studies. The paper also uses the results of our own research on the subject of shallow geothermal market development on the Polish energy market (heat pumps), with reference to the background and conditions of investment decisions in connection with their construction. In order to fully explore the subject of the research, the paper uses the techniques of systematisation and decomposition of phenomena. The work applied the laws of comparative analysis, as well as applying methods of situational analysis and instruments used in the sphere of the planning and prediction of phenomena. The structure of the study adopted the following layout:

1. Analysis of the world literature in the field of geothermal energy, with identification of contemporary challenges and trends in geothermal development, using simple methods;
2. Causal analysis in the sphere of the geothermal conditions of the countries adopted for the study Poland, Lithuania, Latvia and Estonia, and socio-economic aspects of market development in the outlined area;
3. Situational analysis of the geothermal market in Poland and the Baltic States, with reference to specialist studies and industry reports;
4. Comparative analysis of geothermal market development in Poland and the Baltic States, including
    - analysis of installed capacity;
    - analysis of geothermal installations put into service;
    - analysis of the sales volume of heat pumps;
5. Analysis of geothermal market development opportunities in Poland—including our own research results (survey of heat pump users);
6. Conclusions and recommendations.

The research referred to a wide range of current literature on the geothermal energy market, as well as industry reports presenting the latest development trends in the energy sector, in order to relate them to the problems of the research.

The literature on geothermal energy raises many issues, providing numerous research results presented in international studies, reports, analyses, statistical lists or forecasts. The authors note, however, that they mostly concern the perspective of global energy transformation and present generalised (at the scale of a continent or the world) results of the considerations. With this in mind, the authors have attempted to generate findings in the sphere of fundamental issues related to the undertaken problems, in order to start from the global experience in the research process and consequently move on to the countries adopted for the study—Poland, Lithuania, Latvia and Estonia—for the purpose of the substantive verification of the theses set out in the research process. To assess the energy transformation process in Poland, a critical analysis of the current situation on the RES market was made, and the results of a survey among users of geothermal installations in the country are presented. Such an orientation of the research with the adopted configuration of countries provides up-to-date, niche information which is to serve as an information supply in the sphere of challenges in connection with the development of geothermal energy in the studied region, as well as to provide input data for further research of the explored issues. Despite the limitations in terms of the area (scope of the study) and comparison (arrangement of available data), the collected material enables the formulation of conclusions in relation to answering the questions posed in the Introduction

The main goal of the authors is to increase knowledge in the field of environmentally friendly energy technologies and to update it in order to model solutions with the highest degree of applicability in the realities of the economies of Poland, Lithuania, Latvia and Estonia. The main goal is to provide information to the modelling process of the integrated vision for energy development of the region, using RES technologies—with a special focus on geothermal energy. This is to be achieved, in particular, by the quantitative data obtained in this study, which can create the basis for the assumptions of future development.

This article is part of a series of research conducted by the authors in the field of RES in Poland and the Baltic States. Therefore, in order to ensure the comparability of the explored aspects, the authors implement the cognitive process according to the concept outlined above. It should be noted that the issues will be developed in the framework of subsequent studies.

4. Results

4.1. Geothermal Conditions of Poland and the Baltic States—Deep Geothermal

The geothermal conditions in Poland can be regarded as favourable due to the existence of geothermal provinces and districts in approximately 80% of the country's area (provinces: Central European, Sub-Carpathian, Carpathian; districts: Baltic, Pomeranian, pre-Sudetic-Świętokrzyski, Lublin), with water temperature in the range of 20–100 °C (with local heat spots with temperature oscillating within 200 °C) and a wide range of water mineralisation parameters: 1–200 g/dm^3 [24,30]. The physical geothermal resources of Poland are hydrogeothermal resources located in sedimentary-structural basins of natural origin, which are carried by hot groundwater of multi-application, including widely understood heat engineering (heating of buildings and utility buildings, hot water) and also in the field of balneotherapy and recreation [31,32].

The practice of extraction technology indicates that the highest profitability of geothermal exploitation (deep geothermal) requires the availability of efficient deposits, located at an average depth of 2 km, with a temperature of 65 °C and salinity of less than 30 g/L, and such conditions apply to an area covering 40% of the country's territory [23].

The geothermal conditions in Poland are characterised by geothermal degree (temperature rise in the depth of the Earth) + 1 °C every (on average) 35–70 m, with the reported range in this range being 10–110 m [33]. The above provides a basis for analyses of the profitability of building deep geothermal installations in Poland—detailed locations of geothermal waters along with characteristics of geothermal conditions in Poland are included in the Atlas of Geothermal Waters [33].

Undertakings connected with the construction of geothermal installations are serious investment challenges [34], the cost of which amounts to several hundred million Euros and grows together with the current price changes (of materials, work) on the market. Due to the average significant salinity of geothermal waters in Poland, a major part of the installations operating there are based on the doublet formula, i.e., boreholes for depleting the resource from the deposit and reverse injection boreholes for highly mineralised water. In this context, the issue of technical boreholes, the wells for measuring the reservoir, as well as (during the operation of the reservoir) the periodical reconstruction of the boreholes and the replacement of borehole casings, must not be overlooked. As the value of boreholes constitutes an significant cost of a deep geothermal investment, the outlined realities determine the high cost of investments of this type in Poland. It is worth mentioning that investment plans of deep geothermal development in Poland include the construction of a geothermal installation in Nowy Targ and Szaflary with a 7-km-long borehole, with access to a reservoir with temperature oscillating around 200 °C [30].

Geothermal installations generally cover only part of the energy demand and are supported by alternative energy sources. The efficiency of the installation is determined by the temperature of the deposit. The highest temperature of water drawn from the Earth's energy resources in Poland based on deep geothermal energy reaches the range of 83–86 °C (Geotermia podhalaństa, Geotermia Stargard); a review of selected deep geothermal installations in Poland (with total temperature above 50 °C) is specified in Table 1.

Table 1. Overview of selected deep geothermal installations in Poland [23,35].

Lp.	Geothermal	Max Temperature [°C]	Share of Geothermal Capacity in Total Installed Capacity [MW]	Geothermal Capacity in Installed Capacity [%]
1.	Geothermal energy in Podhale	82–86	40.7	50%
2.	Geothermal Szymoszkowa	80	0.3	100%
3.	Geothermal stargard	78–83	10	100%
4.	Geothermal energy Poddębice	68–71	3.8	100%
5.	Geothermia Uniejów	68	3.2	64%
6.	Bukovina Geothermal	65	0.35	100%
7.	Geothermal energy Pyrzyce	61	14.8	31%

A review of selected deep geothermal installations in Poland reveals an average maximum temperature obtained in these installations of 72.5 °C. Moreover, significant differences are observed in the share of the total geothermal power in the installed power (range 0.3–40.7 MW). An interesting observation is also the fact that in more than 57% of installations, geothermal power in the installed capacity reaches the level of 100%, while the remaining part, almost 43%, is geothermal power in the installed capacity at the average level of 48.33%. This can be considered a good result.

Poland stands out among the Baltic States included in the study in terms of the richness of the geothermal deposits located in the country. The richness of Lithuania, Latvia and Estonia in this respect is not often mentioned in the international literature, so it is worth reviewing.

Lithuania has geothermal resources located especially in the western part of the country, in the Baltic Sea region. In this area, heat flow is recorded at a level twice as high as the average specific for the Eastern European province, reaching 100 mW/m^2 [36]. The Earth's heat source in this area is derived from the decay of radioactive elements (K, Th, U), creating prospects for the development of geothermal energy in this area [37]. The above assumes significance in relation to activities and plans in the sphere of achieving the sustainable development of the energy sector based on renewable energy sources.

Deposits with a temperature of 150° (with the highest economic potential) are found only in the form of rock heat at a depth of 4.3–4.4 km (the southern coast of Lithuania), while, in other areas, the depth of the deposits reaches 5–6 km (Klaipeda), or 7–8 km in the east of the country. At the same time, it is worth noting that the average depth of

5000 m of the deposit location is not a barrier that strictly limits the development in the field of deep geothermics nowadays, while the technology of extracting the Earth's heat from rocks by means of water or steam is a demanding process (technology of stimulated dry rocks—HDR/EGS—with underground heat exchanger and drilling by means of rock hydrofracturing) [37]. The Earth's heat in this approach is extracted by circulating water (injection–pumping) that draws heat from the hot rocks, with the rate of possible hot water flow determining the output of the geothermal power plant.

The geothermal power plant in Klaipeda, Lithuania is the first plant in the Baltic States to use the presented approach. The technical parameters of the facility are described by a water circulation depth of 910–1100 m, with a flow volume of 500–700 m^3/h and a useful temperature of 38 °C, extracted using three boreholes (two production and one absorption borehole) with the use of four heat pumps (absorptive) [38]. The total installed capacity of the Klaipeda heat plant is 41 MW, with a geothermal capacity of 17 MW [38].

Geothermal energy in Latvia (as in Lithuania) is abundant in deposits located in the heat of crystalline rocks (petrothermal energy) in the Kaliningrad region (with elevated temperature of single zone sedimentary dome 40–97 °C, with heat flow rate 60–100 MW/m^2), with a hot spot near Riga (100 °C at a depth of 2750) [39]. Latvia, moreover, has geothermal waters, the deposits of which are formed by a multi-level groundwater system with different configurations in different regions of the country. The most significant (in terms of temperature) Earth heat deposits in Latvia are located in the southwestern part of the country in the vicinity of Lipawa (at a depth of 1192–1714 m, with a temperature of 38–62 °C) and Jurmaly (at a depth of 1100–1436 m and with a water temperature of 33–55 °C, with the Eleja anomaly area indicating a deposit temperature of 20–30 °C for a depth of 488–586 m, or 160–180 °C for a depth of 6000 m) [40]. The remaining resource is a zone of waters with temperatures in the range of 7.5–20 °C.

The use of geothermal energy in Latvia in the process of achieving the goal of a low-carbon economy is not currently considered an important element of this programme. However, this thread is worthy of attention, as the energy potential of Latvian geothermal deposits has been estimated at 65,000 PJ, which is equivalent to 1.6 billion tonnes of oil [41].

The geothermal conditions in Estonia are not fully known. Based on borehole studies, the temperature was estimated for the Jõhvi area (20–21 °C for the depth of around 770 m) and for the Paldiski area (16 °C for the depth of around 750 m); other areas accepted for the study did not reach temperatures above 10 °C, while the analysis of the results of the findings gives grounds for assumptions of 32 °C at 1400 m depth for Jõhvi and 24 °C at 1400 m depth for Paldiski [42]. Estonia is a cold country, with crustal heat flow in the range at the level of 40–50 mW/m^2 and with ground temperatures slightly higher (by 1–2 °C) than the average temperatures (6–8 °C); thus, the conditions for the water convection process are initially assessed as not sufficient [42]. Estonia has a need for current, more advanced research to realistically assess the country's geothermal potential in the context of the possibility of extracting energy from the Earth based on high-temperature geothermal energy, seeing geothermal energy as an important prerequisite for increasing the share of RES in energy production in order to reduce the consumption of non-renewable fuels, protect the environment and improve the living comfort of communities.

The energy potential of the Earth is enormous, but the question of its availability for use in the territories of individual countries is significant. The development of technology and techniques makes it possible to drill ever deeper exploration and exploitation wells, but there remains the question of the economic resources enabling this, as well as the aspect of economic effectiveness in relation to the parameters characterising the deposit and the location of the deposit. The temperature of the reservoir is extremely important, since deeper wells are generally associated with lower heat flux density and a smaller temperature gradient.

Geothermal is the absolute future. Although the countries considered within the framework of this study are characterised by different types, layouts and availability of geothermal deposits, as well as different degrees of drawing on the advantages of

deep geothermal, all of them see potential in this sphere, which is particularly important in fulfilling the assumptions of sustainable development of the economy for the next several years.

4.2. Shallow Geothermal Market Analysis in Poland and the Baltic States

The degree and direction of geothermal energy development is determined by the type and scale of resources at the disposal of individual countries [27], correlated with the local socio-economic energy demand structure.

However, tapping into the Earth's heat resources does not have to be done only on the basis of deep geothermal deposits with high temperatures, as there are rich geothermal resources located in the upper layers of the Earth's crust, which define the dimension of shallow geothermics. The availability of ground heat resources makes shallow geothermal a solution that can be used by a wide range of energy consumers, including individuals, from rural, suburban or urban areas [43], in response to energy demand. Shallow geothermal technology uses low-temperature heat from the Earth, extracted by shallow geothermal boreholes (borehole heat exchangers—GWCs) [15]. An attribute of these installations is the orientation towards the use of energy dispersed in the ground or underground waters—with a constant annual temperature. The acquisition of energy in this way is carried out by compressing it and giving it a higher thermodynamic level with the use of heat pumps—nowadays characterised by the efficiency coefficient at the level of 3.5–4.5 (relation of electric energy consumption driving the pump (kWh) to acquired thermal energy (kWh)) [24]. The final parameter of the installation, which is the heating power, creates a number of conditions concerning its parameters, which should be taken into account at the design stage [44] (among others, the number and location of heat exchangers). The characteristics of the building that the installation is to serve (e.g., energy parameters of the building/building) should be taken into account, as well as the type of system (heating, cooling, hybrid) [45] and the type of considered technological solution (vertical, horizontal, geosolar installations).

There are many types and variants of heat pumps, distinguished according to their mode of application or power range. These include [46]:

(a) air-to-water heat pumps for central heating and also for cooling in the case of reversible pumps;
(b) brine-to-water heat pumps for central heating (with cooling option);
(c) air-to-water heat pumps for domestic hot water;
(d) Variable Refrigeration Flow (VRF) pumps for heating and cooling systems;
(e) air-to-air heat pumps and split air conditioners;
(f) gas heat pumps (compressor and absorption).

The number of solutions available creates the ability to respond to a wide range of customer needs, providing a multitude of solutions—from simple low-power installations to more advanced solutions.

Currently, there is ongoing intensive development of the use of geothermal energy for direct application in the world. A summary of the installed capacity in Poland, Lithuania, Latvia and Estonia for the direct application of geothermal energy (according to available data for 2020) is shown in Table 2.

Table 2. Comparison of installed capacity in Poland, Lithuania, Latvia and Estonia for the direct application of geothermal energy (based on available data for 2020) [47].

Country	MWt	TJ/yr
Poland	756	4175.98
Lithuania	125.5	1044
Latvia	1.63	31.81
Estonia	63	355

The above summary reveals that Poland leads in terms of installed capacity in the area of direct geothermal application among the countries accepted for the study, as of 2020, followed by Lithuania, and then Estonia and Latvia.

Low-temperature geothermal is increasingly chosen by energy consumers in the RES market. In particular, the number of installations with a capacity not exceeding 390 MW and an annual energy level of 2000 TJ is increasing [23]. The intensive development of this area concerns the use of heat pumps. They are counted as solutions with significant environmental effects, which, combined with modern infrastructure and ease of use, are attracting an increasing number of users [48]. Table 3 shows the market for heat pumps in use in Poland and in selected Baltic States in 2018–2019 [pcs.], with Latvia not included in the study due to a lack of comparable data in this area.

Table 3. Market analysis of heat pumps in use in Poland and selected Baltic States in 2018–2019 [pcs.] [28].

Country	Year: 2018 Pumps [pcs.]			Year: 2019 Pumps [pcs.]		
	Air Pumps	**Ground Pumps**	**Sum**	**Air Pumps**	**Ground Pumps**	**Sum**
Poland	81.636	53.486	135.122	112.950	60.196	173.146
Lithuania	3466	3268	6734	4145	3311	7456
Latvia	no data	no data	no data	no data	no data	no data
Estonia	146.737	15.875	162.612	161.747	17.625	179.372

Among the countries accepted for the study, Estonia dominated the heat pump market in terms of the number of heat pump installations put into operation, according to 2019 data. Poland came next (with a slight loss to Estonia in 2019), followed by Lithuania.

The development of the heat pump market in the study area is confirmed by their sales results. Table 4 shows the air source heat pump market in Poland and selected Baltic States in 2019 (sales/units); Latvia was not included in the study due to a lack of comparable data.

Table 4. Air source heat pump market in Poland and selected Baltic States in 2019 (sales/units summary) [28].

Country	Air Pumps [pcs.] Year: 2019			
	Air–Air Pumps	**Water–Air Pumps**	**Other**	**Sum**
Poland	11.018	20.286	10	31314
Lithuania	610	69	0	679
Latvia	no data	no data	no data	no data
Estonia	15.010	13.700	1280	30

An analysis of air source heat pump sales in the selected group of regions reveals that the highest number of air source heat pumps are sold in Estonia, according to 2019 data, followed by Poland and then Lithuania.

Table 5 shows the ground source heat pump market in Poland and selected Baltic States in 2019 (sales/unit); Latvia was not included in the study due to a lack of comparable data.

An analysis of ground source heat pump sales in the group of countries adopted for the study reveals that the highest number of them are sold in Poland, according to data for 2019, followed by Estonia and then Lithuania.

The presented research leads to the conclusion that the heat pump market is growing in the analysed set of countries. The results of the analyses reveal that despite the low installed capacity for the direct application of shallow geothermal energy in Estonia, the

country leads in the number of (presumably small capacity) heat pumps in use. The observed trend is substantiated by the high (in the group of countries analysed) number of sales of air source heat pumps, with Poland being the absolute leader in this ranking.

Table 5. Ground source heat pump market in Poland and selected Baltic States in 2019 (sales breakdown/units) [28].

Country	Ground Pumps [pcs.] Year: 2019
Poland	6710
Lithuania	43
Latvia	no data
Estonia	1750

4.3. Heat Pumps in User Evaluation–Survey Results

The use of available green energy resources and the increase in their share among the sources of energy supply in the market contribute to the strengthening of pro-environmental actions [49] through the direct protection of non-renewable deposits and reduction of harmful emissions [50] as a result of the reduction in the conventional mode of energy production. It is the orientation towards the realisation of long-term environmental goals [51] with the use of geothermal energy, which is derived from the prospect of reducing the size of emission allowance charges, that, to a significant extent, determines the current price of 1 KW of energy on the market in Poland. Therefore, apart from limiting damage to the environment, the geothermal market opens up access to cheap energy, which, in the conditions of the progressing crisis affecting many economies in the world, assumes particular significance in the economic sphere. The ability to obtain cheap energy from the Earth contributes to increasing energy security and stabilising the functioning of economies [52]. It is also a green alternative to expensive energy purchasing on the international market [53]. The above arguments contribute to the intensification of activities for the promotion of green energy in order to change consumer behaviour and increase the openness to green energy [10,13,54] from renewable sources, resulting in increased demand for solutions specific to the RES market and its strong development [55]. These are extremely important aspects in the sphere of energy market changes from countries significantly connected with energy production in the conventional mode, e.g., Poland.

Modern green energy production must be economically viable; otherwise, the implementation of sustainable economies would not be possible. Energy consumers are looking for solutions to reduce heating and water costs. The demand for alternatives to conventional solutions in this area is boosted by rising gas, fuel oil and biomass prices. Another motivator in this respect is the progressive increase in electricity prices on the market, so individual consumers are deciding to invest in green energy.

To generate findings on practical grounds, an in-house survey was carried out, entitled "Analysis of the heat pump market in Poland" (February 2022), which was targeted at individual and institutional users (small home-based businesses), located in the Lubuskie, Wielkopolskie and Zachodniopomorskie voivodeships in Poland. The survey was attended by 61 heat pump users out of 92 units surveyed. The results of this research show that investments in green energy are appreciated in Poland. A survey of heat pump users confirmed full confidence in the implemented solution (100% satisfaction of respondents with heat pump installation).

Interestingly, the impulse for making the decision to invest in the construction of heat pump installations was, in 76%, due to the recommendations of installers, but mainly the opinions of satisfied users of such installations, supported by financial arguments. The main determinants of the decision were (in multiple-choice) economic reasons (100% of respondents), ecology (87% of respondents) and convenience (53% of respondents). Invest-

ment activities were undertaken both by owners of existing buildings (58% of respondents) and investors who erected new buildings (42%).

The survey results indicate that 82% of retrofitted facilities benefited from government subsidies of eco-solutions supported under environmental programmes. The most recent support of this type is regulated by the Clean Air Programme, which supports the following processes [46]:

(a) replacing conventional heat sources (solid fuel cookers and boilers) with environmentally friendly, energy-efficient forms;
(b) improving the thermal performance of the facility (including insulation);
(c) installation of RES solutions (e.g., photovoltaic installations, heat pumps);
(d) installation of mechanical ventilation with heat recovery.

The above, although not indicated in the survey results, arguably also provided the motivation for action in this regard.

Figure 1 presents the visualisation of the research results.

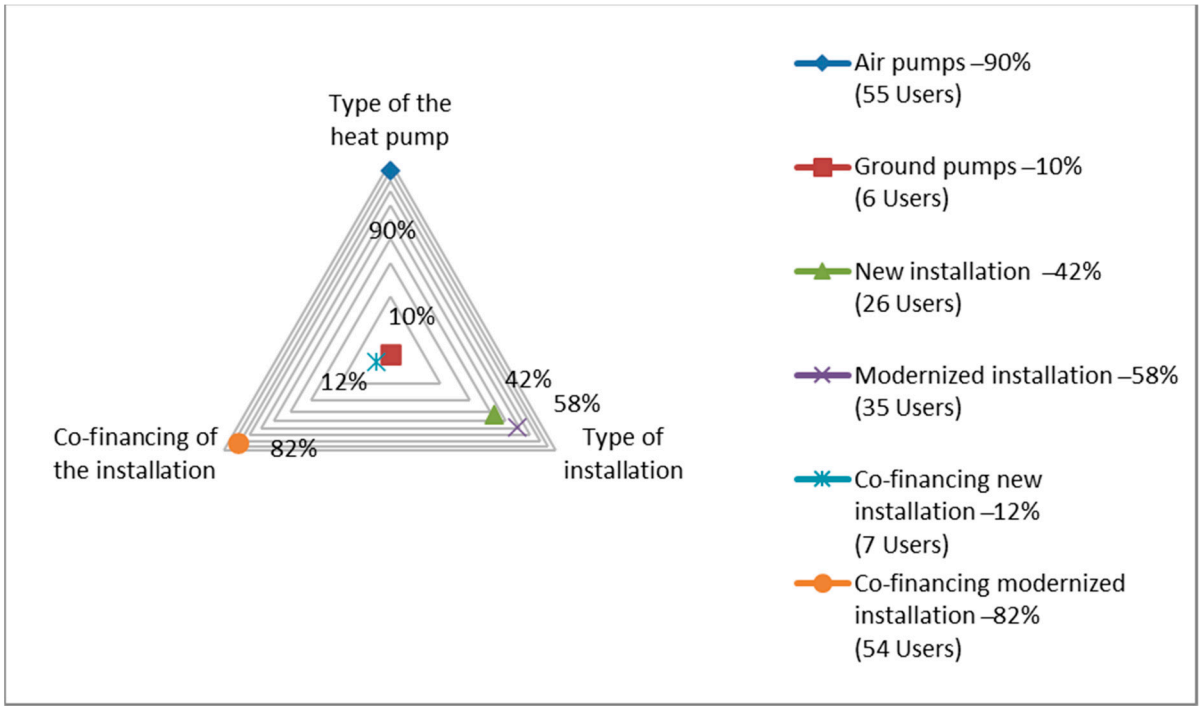

Figure 1. Analysis of heat pump installations—the results of research.

The literature reports provide information about the current heating prices by allocating the cost level to a specific source. Findings indicate that the cost of heating a 130 m^2 house together with domestic water heating, using electricity 24 h a day (tariff G12), is as follows [47]:

(a) gas heat pump: EUR 336;
(b) air-to-water heat pump (wall heaters): EUR 330;
(c) air-to-water heat pump (underfloor heating): EUR 274;
(d) brine-to-water heat pump (wall heaters): EUR 300;
(e) brine-to-water heat pump (underfloor heating): EUR 253;
(f) electric boiler: EUR 1030;
(g) condensing boiler: EUR 717;
(h) condensing gas boiler: EUR 568;
(i) coal-fired boiler: EUR 534;
(j) pellet boiler: EUR 491;
(k) wood-fired boiler: EUR 306.

The results of the presented research ("Analysis of the heat pump market in Poland", February 2022) made it possible to determine the actual average annual cost of heating an object with an area of 130 m^2, including water heating, which amounted on average to EUR 279.19 with the use of heat pumps. The main part of the analysed installations are air pumps (90%), with a pump power reserve of 12–20% in relation to the demand for heating area (pump power range: 8–11 KW). In all analysed cases, the power source for the pump was a photovoltaic installation, which gave a heating cost of 1 m^2 for a model area of 130 m^2:

(a) for air pumps in the range: 2.07–2.29 EUR/m^2,
(b) for ground source pumps in the range: 1.92–1.97 EUR/m^2.

Clear differences in the cost-effectiveness of heating in the studied systems are determined by the type of heating system distribution in the building. The best parameters in this respect were obtained for underfloor heating (range: 1.98–2.11 EUR/m^2), and in the case of wall radiators or a combination of wall radiators and underfloor heating, for which heating costs were generated in the range of 2.21–2.29 EUR/m^2.

According to the indications of respondents in this survey, 92% of new installations were based solely on photovoltaic-powered heat pumps, with the remaining 8% supporting fireplaces for occasional use (e.g., holidays). For retrofit installations, heat pumps powered by photovoltaics were the primary source of energy supply in 76% of cases. The remaining 24% represented in an equal proportion the use of heating sources with a gas cooker, pellet cooker or fireplace with a water jacket. Supplementary heating was used by respondents only in the case of a strong decrease in temperature, as a temporary support. It is worth mentioning that these elements of support are the heating installation solutions from the period before modernisation. The cost of using these solutions after modernisation was not separately calculated by their users on annual basis.

Figure 2 shows a visualisation of the research results in the field of the analysis of power sources/support of heat pump installations and the satisfaction of heat pump users with the installation.

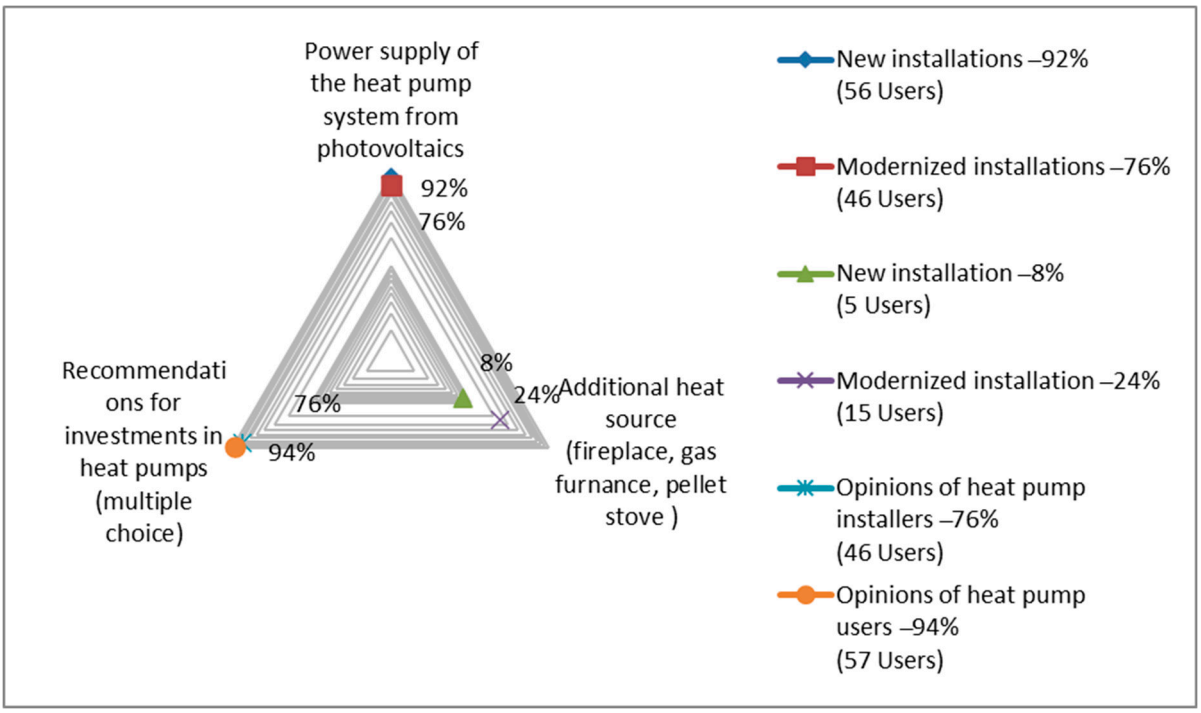

Figure 2. Analysis of power sources/support for heat pump installations and user satisfaction with heat pump installations—summary of research results.

The operating costs of a heating system based on heat pumps should be increased by the service cost, which, according to the respondents' indications, is at the average level of EUR 96 for air pumps and EUR 138 for ground pumps per year, which significantly increases the heating cost. When scrupulously analysing the costs, for all the analysed cases, one should also add the service cost of the photovoltaic installation—in the proportion of using electricity to power the pump (average service cost 53 EUR/year).

The results of the study clearly confirm that the cost of heating 1 m^2 of space using RES sources—when all components of the heating costs are taken into account—is generally lower than conventional sources, with the most expensive sources being approximately 64% lower than heating with an electric boiler and approximately 36% lower than heating with a gas condensing boiler.

At the same time, it is worthwhile to analyse the profitability of the investment project, understood as the cost of outlays borne for the construction of the installation in question, in order to determine after what time the outlays begin to pay off. Based on the findings obtained, it is worth emphasising the full satisfaction of the users of installations using the Earth's heat and the declaration of a full recommendation that the solutions in question should be taken up by potential investors. The research also indicates the strong openness of the respondents to ecology and RES. In the surveyed group of respondents, 63% of them indicated that they were thinking about expanding their photovoltaic installation, 37% were considering installing mechanical ventilation with heat recovery (recuperation), and 4% were considering installing backyard mini wind turbines. These actions were aimed at further optimising the maintenance costs of the facilities, as well as increasing the degree of independence from energy purchased from the market. This is particularly important in view of the current geopolitical situation shaping energy market price levels in the study area.

5. Discussion

Actions to acquire energy from renewable sources are currently an absolute necessity in light of the progressing energy crisis caused by force majeure factors (COVID-19, Russian–Ukrainian war), as well as the environmental crisis due to environmental pollution caused, among others, by conventional energy production. The development of RES is therefore a fundamental direction of energy development for the undisturbed development of economies, improvement of the quality of life of modern society and improvement of the prospects of the Earth's existence.

Investments in RES solutions are the basis on which to reduce CO_2 emissions; thus, in practice, projects are combining low-carbon technological solutions in order to fully respond to the growing energy demand, progressing in connection with the intensive development of urban agglomeration infrastructure, or, e.g., increase in demand for transport services [56–58]. In this regard, efforts are being made to increase the share of geothermal [59] and photovoltaic energy in the structure of energy sources, which will result in an improved environmental effect in connection with energy production in an environmentally neutral mode [60] (emission-free production). Therefore, it is still a challenge to increase the energy efficiency of existing and planned solutions and to take actions to increase the share of renewable energy sources in the energy systems of individual countries [61–63], Europe [64] or the world [65,66].

In relation to the above, the issues discussed in the article are of particular importance for countries that base their energy production mainly on conventional sources (Poland), as well as—in relation to the current geopolitical conditions—for countries supplied with raw materials obtained so far by means of import from Russia (layout of the countries accepted for the study). Hence, the diagnosis of the state of the geothermal market, together with the evaluation of the directions of the geothermal energy market development in Poland against the background of the Baltic States in the current economic conditions, is fully justified.

Despite the limitations of the area (the scope of the study) and the revealed comparative limitations (the layout of the available data), the collected material enables the formulation of conclusions in relation to answering the questions posed in the Introduction, to increase knowledge in the field of environmentally friendly energy technologies.

Summarising the results of the research carried out in this paper (point 4), it should be stressed that the development of geothermics is determined by the abundance and availability of geothermal resources, which is confirmed by the relatively strong position of Poland in the field of the development of deep and shallow geothermics in the area of the countries included in the research. It is also worth mentioning that the actions taken by the examined countries in the field of geothermal development are of a similar character (shallow geothermal heat pumps are the most developed), whereas, in the field of deep geothermal, an interesting observation coming from the research presented in this paper is the orientation towards solutions based on the energy of crystalline rocks in Lithuania and Estonia, determined by the availability of such deposits in this region.

The content of this article proves that the development of energy from renewable sources, including, in particular, geothermal energy, is the right direction for the development of the energy market both in Poland and in the Baltic States. The direction of this development—as in the case of photovoltaics or wind energy—is significantly driven by the energy policies of individual countries and the offered system of support for pro-environmental solutions; hence, the basic recommendation of this paper is to intensify financial support for such projects, along with an information campaign to raise awareness in the field of RES, with particular emphasis on geothermal energy. This campaign should not only concern general information concerning the idea of green energy based on geothermal energy (which is extremely important) but should also focus on aspects related to the availability of geothermal solutions, including the aspect of combining complementary solutions, which give the best economic effect in the utility sphere (e.g., geothermal + photovoltaic, as revealed in the research). The above, to achieve the assumed objectives, requires strong correlation with the energy policy (related directly to the diagnosed energy demand) and the assumptions of sustainable development. The aspect of financial support for actions on behalf of economies and promotion of the ecological mode of functioning in the modern world is also important.

The results of a survey of individual users of heat pump installations on the Polish market presented in this paper (point 4) confirm that the market for shallow geothermal energy, which is strongly targeted at this audience, is particularly dependent on financial support. The research also revealed that, in quantitative terms, small installations drawing on energy from the Earth constitute the core of the geothermal energy market in all countries surveyed. This is particularly evident in the Estonian energy market, where, with a low installed capacity in terms of direct application, the country leads in terms of the number of units in use, which is reflected in the volume of annual sales of heat pumps at a significant level. This may imply that the main participants in the geothermal energy segment (heat pumps) in Estonia are small users.

The diagnosed state of the geothermal energy sector in the Polish and Baltic States markets reveals potential for further development of the observed trends—the authors recommend its further development. At the same time, there is a wide perspective for the development of the deep geothermal market, which is the most strongly developed in Poland in the group of the examined countries. The arguments presented in this paper give grounds for the statement that, in spite of costly research and work connected with the construction of geothermal heat plants (deep geothermal), the strong development of this aspect of energy generation is very likely to take place soon, also in areas where it has not been fully explored at present (e.g., Estonia). On the one hand, such possibilities are provided by the technical and technological progress in this field, and on the other, they are strongly motivated by the need to seek alternatives to conventional production, strengthened by the urgent environmental and economic need and driven by the political and economic situation in the countries concerned, in Europe and throughout the world.

The main conclusion of the study is to confirm the rationale for further development of the geothermal market in Poland and the Baltic States. This development requires strong correlation with energy policy and the assumptions of sustainable development of individual economies in order to achieve the assumed objectives. The aspect of financial support for actions on behalf of individual economies and promotion of the ecological mode of functioning in the modern world is also important.

The economic justification of investment projects in the area of RES, including geothermal energy, should be particularly highlighted. As confirmed by the research (point 4 of the study), this is the main reference factor in the decision-making process in connection with the construction of installations—alongside ecology and convenience. Essentially, the lower—compared to conventional solutions—cost of geothermal energy is the key aspect. Other arguments (which are difficult to quantify) are the improvement in quality of life, in harmony with nature.

Huge reserves of terrestrial energy are waiting to be tapped. This should be the leitmotif for the contemporary economic development of the studied countries, Europe and the world, thus indicating that the role of geothermal energy in the energy market—especially in the area of the countries included in the study—is an important and up-to-date topic. Bearing in mind the above, the authors of this article took up the challenge of presenting current, niche information required in the process of planning and evaluation of geothermal development in the studied region. This information explains selected issues related to the functioning of the geothermal market, deepening the knowledge in the field of geothermics in the countries adopted for the study, providing, at the same time, inspiration and a starting point for further research in the field of RES issues.

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