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Water Energy in Poland in the Context of Sustainable Development

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Abstract: The current production of water energy in Poland is much lower than the theoretical and technical potential. The aim of the article is to analyse the current state of hydropower in Poland as well as the prospects and conditions for development. Poland's total technical hydropower potential is estimated at 12,000–14,000 GWh/year, but currently, approx. 20% of this potential is used. The considerations undertaken in the study concern, for example, pumped-storage power plants and the development of small hydropower plants. Hydropower plants are not only important from the point of view of electricity production and storage, but also fulfill many other functions, including the general social, which is an essential element of the implementation of the concept of sustainable development. The analyses show that the hydropower sector in Poland may be an important element of low-carbon energy and an important element of energy security. Increasing the volume of electricity production from hydropower by 5% will contribute to the growth in CO_2 reduction by 140,702 tons. The stabilization function of the power system in Poland is also significant.

Keywords: hydropower; sustainable development; environment; Poland

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1. Introduction

The countries of the European Union, in accordance with the implemented climate and energy policy, are implementing ambitious plans to reduce CO_2 emission. The original reduction targets (by at least 40% by 2030 from the 1990 emission) have been extended to at least 55% [1]. Reaching this level requires a lot of reforms and new programs, including the area of the EU emission trading system, increasing energy efficiency and further development of energy based on renewable sources [2]. The "Fit for 55" package mentioned above is certainly one of the most politically ambitious projects in the field of energy economy in Europe after the Second World War. It is especially ambitious for the countries of Central and Eastern Europe, where there are development lags in the area of modernization of technologies used for energy production in relation to Western Europe [3]. One such country is Poland, where most electricity still comes from power plants that run on hard coal and lignite [4,5].

It is worth emphasizing that hydropower plays an important role in achieving the EU's goal of reducing the carbon dioxide emission [6]. The importance of hydropower for electricity production in the EU is relatively low, as it contributed 13.8% of the total net electricity production in the EU-27 in 2020 [7]. Moreover, many studies propose to increase the role of hydropower in the energy mix in the EU [8]. In Europe, Scandinavian countries, mainly Norway, have a particularly high percentage of power generated in hydroelectric power plants. Taking into account the EU-27 countries, the largest production in hydropower is recorded in Sweden, France, Italy and Austria (Figure 1).

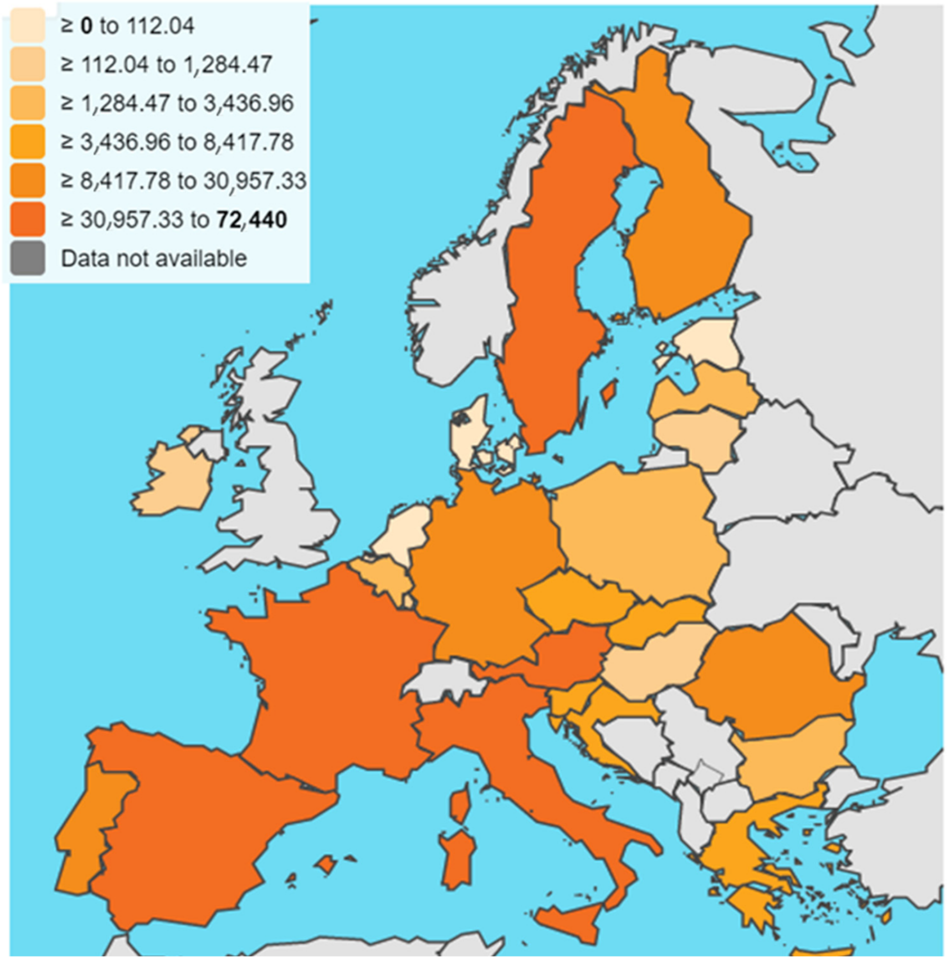

Figure 1. Generation of hydropower in UE-27 in 2020 (in GWh) [9].

The literature on the subject mentions a lot of classifications of hydropower plants, taking into account various criteria (e.g., depending on the power criterion, water drops, i.e., differences between the upper and lower water level, etc.) [10]. From the technical point of view, the possibility of cooperation with the power system includes: dammed reservoir, run-of-river, gravitational vortex and pumped storage. The literature on the subject discusses in detail the technologies used in hydropower plants, along with the construction details of the turbines and dams used [11]. Moreover, the literature on the subject compares different types of hydropower plants using methods of environmental impact research (including LCA) [12,13]. This is very important because in addition to energy efficiency and the associated technological advancement, the transition to a low-carbon electricity future also requires up-to-date information on environmental and socioeconomic aspects of the technologies concerned [14].

Hydropower is currently experiencing a boom in southeast Europe [15]. In total, in 2020, 374,534.736 GWh was produced in the EU-27 countries, of which 72,440 GWh was produced in Sweden and 66,532.417 GWh in France. Hydropower generation capacity in the EU varies considerably between countries. Poland is not one of the countries generating the most electricity based on hydropower. The main reasons for this situation are natural conditions and too little investment in this renewable source (Table 1).

Table 1. Hydropower electricity production capacities in EU countries (in MW) [9].

Specification	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Union—27 countries	142,433.708	143,073.780	144,156.131	144,329.264	146,291.976	147,816.738	148,584.348	148,613.314	148,996.193	148,982.176
Euro area—19 countries (from 2015)	109,781.708	110,455.780	111,299.131	111,931.164	113,438.998	114,784.371	115,393.459	115,471.281	115,831.376	115,891.468
Belgium	1426.000	1427.000	1429.000	1431.000	1422.000	1419.100	1417.100	1417.800	1414.100	1415.800
Bulgaria	3108.000	3181.000	3203.000	3219.000	3219.000	3223.000	3371.550	3379.000	3378.350	3376.456
Czechia	2023.000	2029.000	2064.000	2062.000	2069.000	2071.000	2080.890	2080.598	2080.955	2081.012
Denmark	9.000	9.000	9.000	9.000	6.878	9.267	7.153	7.153	7.263	7.263
Germany	11,367.000	11,185.000	11,197.000	11,190.000	11,212.000	11,164.000	11,078.000	10,652.000	10,698.000	10,757.000
Estonia	5.000	8.000	8.000	5.000	6.000	6.000	7.300	7.300	6.000	8.000
Ireland	237.000	529.000	529.000	529.000	529.000	529.000	529.000	529.000	529.000	529.000
Greece	3224.000	3236.000	3238.000	3389.000	3392.000	3392.000	3392.000	3409.000	3412.000	3417.000
Spain	18,197.000	18,207.000	18,818.000	18,856.000	19,686.000	19,711.000	19,710.000	19,710.572	19,744.667	19,747.592
France	25,454.181	25,469.754	25,458.073	25,398.027	25,368.096	25,435.177	25,517.417	25,542.147	25,674.256	25,496.113
Croatia	2127.000	2127.000	2176.000	2178.100	2192.100	2189.100	2190.300	2196.800	2197.000	2197.200
Italy	21,568.000	21,752.000	21,890.000	21,979.000	22,099.000	22,181.000	22,307.160	22,393.119	22,434.666	22,604.426
Cyprus	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latvia	1571.000	1573.000	1585.525	1586.748	1586.693	1563.196	1563.260	1563.339	1585.204	1584.755
Lithuania	876.000	876.000	876.000	877.000	877.000	877.000	877.000	877.000	877.000	877.000
Luxembourg	1132.300	1132.300	1132.300	1328.300	1328.300	1328.300	1328.580	1328.508	1328.508	1328.508
Hungary	55.000	56.000	57.000	57.000	57.000	57.000	57.000	57.000	58.000	58.000
Malta	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Netherlands	37.000	37.000	37.000	37.000	37.000	37.000	37.000	37.000	37.000	37.000
Austria	12,642.227	12,773.726	12,848.233	12,997.089	13,112.909	13,570.598	13,717.985	14,088.138	14,162.000	14,169.295
Poland	2345.000	2350.000	2354.000	2363.000	2369.000	2385.000	2389.559	2390.768	2396.512	2399.102
Portugal	5529.000	5706.000	5655.000	5709.000	6162.000	6954.000	7219.731	7229.642	7255.885	7234.706
Romania	6411.000	6455.000	6509.000	6523.000	6619.000	6644.000	6610.437	6617.714	6602.737	6565.675
Slovenia	1137.000	1138.000	1183.000	1180.000	1179.000	1177.000	1230.926	1227.716	1230.090	1230.273
Slovakia	2494.000	2493.000	2493.000	2493.000	2495.000	2493.000	2493.000	2496.000	2494.000	2496.000
Finland	2885.000	2913.000	2922.000	2946.000	2947.000	2947.000	2968.000	2963.000	2949.000	2959.000
Sweden	16,574.000	16,411.000	16,485.000	15,987.000	16,321.000	16,454.000	16,484.000	16,413.000	16,444.000	16,406.000

In 2011–2020, hydroelectric power generation capacities in EU countries increased by a total of 6548.47 MW, of which the largest increase was recorded in Portugal (by 1705.71 MW), Spain (by 1550.59 MW), Austria (by 1527.07 MW) and Italy (by 1036.43 MW). The combined growth in these four countries accounted for 89% of the total capacity increase in the EU. Production capacity decreased in four countries, most of which were in Germany (by 610 MW) and Sweden (by 168 MW). In addition, a reduction in power was recorded in Belgium (by 10.2 MW) and Denmark (by 1.74 MW).

Geographically, the greatest amount of energy from water is obtained in the EU countries located in the west, south and north. It is worth noting that the impact of climate change on water resources will require additional wind and solar power in southern countries [16]. In 2020, 2936.988 GWh was produced in Poland as part of hydropower. For comparison, in the Czech Republic, 3436.963 GWh was produced; in Slovakia, 4799 GWh was produced; and in Romania, 15,701.386 GWh was produced. Obviously, Romania's technical hydropower potential (34.5 TWh/year) is nearly 3 times greater than that of Poland, but the level of its use is much higher. Similarly, in the Czech Republic, where the theoretical potential is 13.1 TWh/year, the technical potential is 3.4 TWh/year, but 70.1% of it is used [17].

Due to its membership in the European Union, Poland is obliged to increase the share of renewable energy in the production of electricity and heat. This is a difficult and costly task, as the Polish power industry has been based on hard coal and lignite for decades. The current policy of the European Union regarding the reduction of greenhouse gas emissions and the related market regulations (including financial ones) significantly increase the costs of producing energy generated from fossil fuels. There is a gradual development of renewable energy sources and a decline in the share of coal in the national energy mix, but over 70% of electricity in Poland is still generated from coal.

There is no doubt that the energy policy should be conducted in a low-carbon manner, and an important element is the synergy of economic and social processes with counteracting climate change. Due to economic, social and legal conditions, energy production based on solar radiation and wind energy have developed relatively quickly in Poland in recent years. Especially significant developments in wind energy were recorded until 2016, when due to changes in economic conditions (oversupply of green certificates lowering the profitability of many renewable energy projects, mainly wind farms), the development of new investments was abandoned. In addition, unfavourable changes in the studied subject matter were related to the entry into force of the so-called distance act (increasing the minimum distance of wind turbines from buildings), which has effectively limited the pace of the development of installed capacities in this RES sector [18]. The rapid development of the green energy sector in Poland in recent years is mainly related to solar energy [19]. Moreover, the years 2020 and 2021 were the best years in the history of photovoltaic development in Poland, and at the end of 2021 the installed capacity in photovoltaics amounted to 7.6 GW (the increase in new capacities year-on-year was over 3.7 GW) [20]. Poland is at the forefront in the European Union in terms of increasing installed PV capacity.

The preliminary remarks presented above make it possible to notice the uneven development of renewable energy sources by type in Poland and the relatively low use of the hydropower potential in this respect. The main goal of this study is to analyse the current state of hydropower in Poland as well as the prospects and conditions for development. The entire study was considered against the background of the aspects of sustainable development and the currently implemented tasks related to the objectives of the climate and energy policy. The article fills the cognitive gap regarding the role and potential scale of using hydropower in the context of the ongoing energy transformation in Poland. The subject of the considerations and the scope of this study are in line with the issues of sustainable socioeconomic development, which when considered in the example of Poland must take into account the reconfiguration of assumptions based on conventional energy sources (coal) towards renewable sources (including hydropower).

The sources of statistical data were official public statistics in Poland, data from the Energy Regulatory Office in Poland and Eurostat. This study focuses mainly on two components: pumped hydroelectric energy storage and small hydropower plants. This is in line with global trends. As noted by Ardizzon et al. [21], due to the economic and environmental benefits, there is renewed interest in pumped hydroelectric energy storage (PHES) around the world and a great need for the rehabilitation of old small hydropower plants [22]. Small hydroelectric plants (SHPs) play a significant role worldwide, contributing to the goals of sustainable development and social empowerment. According to Kałuża et al. [23], hydropower plants have a chance to play an important role in energy transformation in Poland. This is due to the fact that hydropower plants are characterized by relatively stable conditions and operating effects in terms of the volume of energy production [24]. It is worth emphasizing, however, that climate change and more frequent periods of drought may have a negative impact on the usually stable production of energy based on hydropower, as was the case in Western Europe in 2022.

The study consists of four parts. After the introduction, the history of the development of the hydropower sector in Poland was presented, with the periods of increased interest in the use of hydropower resources. Then, analyses were performed on the basis of statistical data and the directions and conditions of development in the studied subject were presented. The paper ends with conclusions and recommendations.

2. Historical Overview of the Development of Hydropower Industry in Poland and Description of the Current State

Hydropower has a long tradition in Poland. Originally, it was used in grain water mills, and the first of them operated in Poland in the 12th century. One of the first water mills in Poland was built by the Cistercians (e.g., at Radunia and the Oliwa Stream). In the years 1348–1356 in the vicinity of Gdańsk, the several-kilometres-long Raduński Canal was built, which supplied the city of Gdańsk and the local Teutonic castle with fresh drinking water. The water from the canal drove 12 hopper wheels of the Great Mill, which was one of the largest hydropower plants in Europe at that time [25].

Originally, the energy of water was used not only in grain water mills, but also in forges [26]. For example, a forge built in the 16th century in the Oliwa Stream, which functioned until the middle of the 20th century, is still one of the tourist attractions [25]. Scientific and technical progress contributed to the development of more perfect techniques in the field of hydropower. In 1896, the first hydroelectric power plant in Poland—Struga in Słupia—was launched [27]. Significant development in this area was carried out in Pomerania, for example, the Gałażnia Mała hydroelectric power plant and the Straszyn hydroelectric power plant. Hydropower facilities were also developing in other regions that belong to Poland at that time. In Lower Silesia and the Lubuskie Region, stone and concrete dams with power plants in Kwisa, Bóbr and Bystrzyca Kłodzka were built at the beginning of the 20th century. Throughout this period, water wheels were withdrawn and replaced by water turbines. New projects of hydroelectric power plants were also created in the territories annexed by Austria and Russia. Due to the physiographic and hydrographic conditions, much more intensive preparatory work in this area was carried out in the Austrian partition, e.g., in 1898, a 45 kW hydroelectric power plant was built in Nowy Targ [27]. After World War I, the Gródek hydropower plant (in 1927, power 3.9 MW) and the Żur power plant (in 1929, 8.8 MW) were built. The Żur power plant was the largest hydropower plant in the Second Polish Republic, and it was officially commissioned by the President of the Republic of Poland, Prof. Ignacy Mościcki. It is worth noting that the Żur Power Plant was built in a record time of 16 months [28]. As Steller points out, at the beginning of the 1930s, 6536 hydropower plants were operating in Poland with a total capacity of 167 MW, including 253 power plants with a total capacity of 21 MW [25]. In 1935, there were 8000 water energy plants and dozen other installations using water energy in Poland [29]. In the interwar period, the domestic production of mill machines also developed, which enjoyed success not only in Poland, but also abroad [30].

After the end of World War II, the potential in hydroelectric power plants was rebuilt, although the damage to the hydrotechnical infrastructure turned out to be relatively small in relation to the enormity of war losses. Taking into account the period from the 1950s to the present day, the dynamic development of Polish hydropower takes place in the years 1961–1971. During this period, the installed capacity in power plants operating on natural inflow was doubled, and the first pumping station was put into operation. In the 1960s, large hydropower plants were built in Poland in Solina, Żydów, Włocławek and Kornów. In the following years, one of the largest power plants in Poland was built in Żarnowiec, Nidzica and Porąbka-Żar. In general, the greatest increase occurred at the turn of the 1980s and 1990s, after the commissioning of two pumped hydroelectric energy storage plants (Porąbka-Żar 500 MW and Żarnowiec 680 MW) [31]. It is also worth emphasizing the legislative changes at the beginning of the 1980s, which improved the development of small hydropower [32]. In the 1990s and in the last decades, virtually no spectacular investments in the studied area were recorded. Examples of new investments/significant modernizations include Czorsztyn-Niedzica (92 MW) in 1997; the modernization of Solina (200 MW) in 2003 [31], the construction of the Oława Hydroelectric Power Plant (a 3.2 MW flow-through power plant), put into operation in December 2013 [33]; and the modernization of the Głębinów Hydroelectric Power Plant in 2016 [34].

Obtaining energy from water energy in Poland in 2013–2020 is presented in Figure 2.

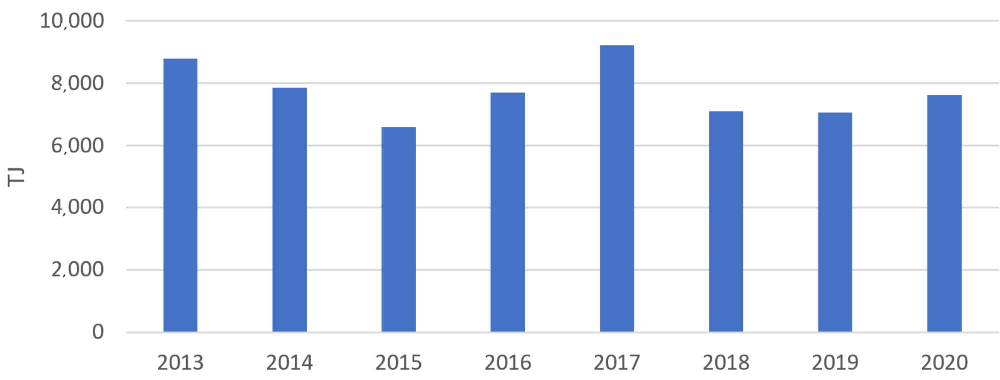

Figure 2. Obtaining energy from water in Poland in 2013–2020 [35].

In 2020, 7626 TJ of energy from water resources were generated in Poland, i.e., 1155 TJ less than in 2013. In the analysed period, most energy from this renewable source was generated in 2017, and the least in 2015 (unfavourable hydrological conditions—drought). Variable weather conditions (floods, flooding or lowering the water level in rivers) significantly affect the variability of electricity production in this type of facilities. This is especially true of small hydropower.

From the point of view of the conducted considerations, i.e., the production of electricity from water resources, a special role is played by pumped hydroelectric energy storage. The important role is due to the fact that pumped hydroelectric energy storage plants offer regulation possibilities. The total capacity of all six pumped hydroelectric energy storage plants in Poland is approx. 1.8 GW (Figure 3).

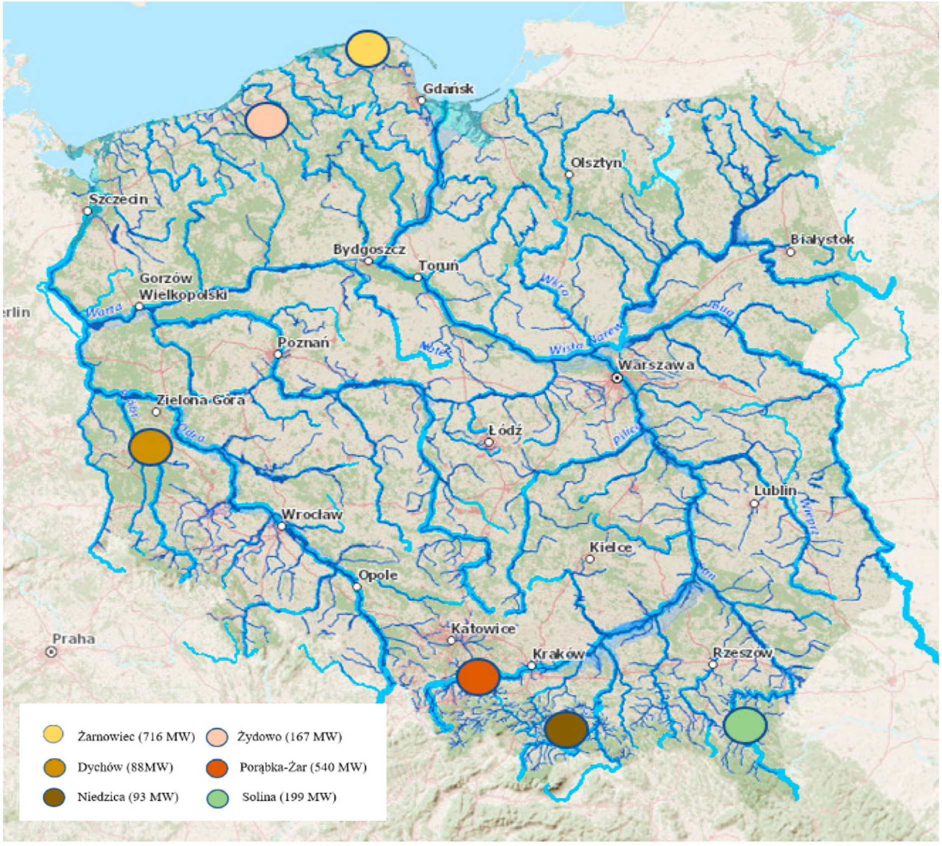

Figure 3. Location of pumped hydroelectric energy storage plants in Poland and installed capacity [36].

The two largest hydropower plants in Poland are Żarnowiec (716 MW) and Porąbka-Żar (540 MW), owned by PGE. The PGE Capital Group is the largest enterprise in the power sector in Poland in terms of revenues and generated profit.

On the other hand, hydropower plays an important role in smaller facilities. In Polish conditions, a small hydropower plant (SHP) is a power plant with an installed capacity of less than 5 MW. This criterion is used in Poland, although in the literature there are other values for "small" power plants (usually up to 10 MW) in relation to conditions in Europe. The current state of affairs, based on the data of the Energy Regulatory Office of 30 June 2021, in the analysed subject matter is as follows. In Poland, there are 775 power plants with a capacity of up to 10 MW with a total installed capacity of 295.687 MW, including 770 power plants with a capacity of up to 5 MW with a total installed capacity of 259.491 MW [37].

To summarize, 20% of Poland's technical hydropower potential (considering the available technologies), estimated at 12,000 GWh/year, is currently used [38]. The literature on the subject also provides other potential values, e.g., theoretical hydropower resources (taking into account natural and climatic conditions) are estimated at 25,000 GWh/year, while technical resources for 14,000 GWh/year [25]. Moreover, the potential of hydropower is unevenly distributed in the spatial aspect. Most of it (approx. 68%) occurs in the Vistula river basin, while approx. 17.6% occurs in the Odra river basin [39]. There are also other enumerations in the literature on the subject. Granatowicz [40] writes about 80% of the potential of the Vistula River, with almost 52% of the hydropower potential on the lower Vistula, 7% on the upper and around 22% on the middle. The hydropower potential of the Lower Vistula (measured from Warsaw) is 4200 GWh/year with an installed capacity of approximately 850 MW.

The most important natural conditions for the location of hydropower plants include drops in rivers and flow rates. Formal and legal factors are also significant, including the form of nature protection (if any) and the spatial development plan existing in a particular area [41]. In addition, economic and social issues are important. The location of potential sites for the development of hydropower in Poland is publicly available to potential investors and anyone interested in this subject and was created as part of the Renewable Energy Sources Transforming Our Regions (RESTOR) Hydro project. The database is in the form of a map [42]. The map shows that the greatest number of potential locations are in Małopolska and Silesia, as well as in Lower Silesia (including the Sudetes).

3. Prospects and Limitations of Development in the Context of Sustainable Development and Current Geopolitical Conditions

Due to the costs and environmental constraints (including large-scale protected areas), it is difficult to expect significant progress in terms of new infrastructure in the form of pumped hydroelectric energy storage plants. The exception is the pumped hydroelectric energy storage plant in Młoty (50°17′51″ N 16°32′45″ E), where the construction of a power plant was already planned in the 1960s. In the 1970s, construction of a power plant began in Młoty (around two kilometres of underground corridor workings were made then), but the investment was interrupted in 1982 due to lack of funds [43]. Due to the current geopolitical situation and environmental issues (the Kłodzko poviat, where the power plant is located, is a potentially flood risk area), the investment has a chance to be completed. Steps have already been taken in this regard (the power plant is included in the "Development plan for meeting the current and future electricity demand for 2023–2032" published by Polish Power Grids), and the planned plant is to be the largest power plant of this type in Poland with a capacity of 750 MW. Polish Power Grids performs the role of the electricity transmission system operator in Poland [44].

In the long-term perspective, it is possible to use relatively large hydropower facilities and infrastructure after coal mines in Poland for the construction of new power plants (e.g., the complex in Turów and the area of the Bełchatów mine). Due to the planned further coal mining in these locations, it is a rather distant future. In terms of technology, it is possible to use the active shafts of the closed mines as gravity energy stores. There is, among other things, the possibility of recovering energy from the stream of technological water transported to the workings through the fire-fighting pipeline in the shaft. Concepts of the energy recovery system from the shaft pipeline have been presented in the literature on the subject, for instance by Lazar et al. [45]. In an exploited mine, it is also possible to install a pumping station using the existing mine drainage system. The proposals presented above would contribute to the implementation of the principle of sustainable development in the field of energy in Poland, i.e., the use of existing resources with a positive effect in the area of three fundamental dimensions—economic, environmental and social. The potential of energy storage and its conversion with the use of mine water is particularly important in the studied topic [46]. In addition, issues related to water retention, flood protection systems, etc., are important as well.

Pumped hydroelectric energy storage plants in Poland are constantly modernized and their importance in the energy system is increasing. An example of such an investment is the project to build a large-scale Battery Storage for Electricity at the Żarnowiec Pumped Hydroelectric Energy Storage Plant with a power of not less than 200 MW and a capacity of over 820 MWh. The energy storage will use lithium-ion batteries. The commissioning of this energy storage is to take place in 2025 [47]. The resulting innovative hybrid installation will also be important from the point of view of the planned investments in offshore wind farms in the Baltic Sea.

On the other hand, the development direction in the studied topic may be the use of small water power plants on local resources of rivers and streams. It is for ecological and social reasons that the construction of small hydropower plants, which can often be located in rural areas, is the most desirable. For this purpose, it is not always necessary to build new dams. It is possible to use the existing barrages, currently closed, which were used for energy purposes in the past, and for water-damming facilities, for example, in melioration [48]. The use of existing facilities is important because the process of building and putting new facilities into service is very long in Poland. In the report "Small Hydroelectric Power Plants in Poland", which was created as a result of the UN Global Compact Network Poland framework agreement with the Ministry of Development and Technology for the implementation of the UN Sustainable Development Goals—in particular Goal 7 on clean energy (Affordable and Clean Energy)—it was indicated that that the experience of investors shows that in Poland it takes from one to four years to obtain the necessary documents enabling the creation of SHP. Furthermore, the cost of implementing a small hydropower plant ranges from several hundred thousand to even several dozen million PLN per 1 MW of power [49]. The potential of using such places, where there used to be hydropower facilities in Poland, is very large. The previous chapters presented a historical outline, and above all it is estimated that there are approx. 6000 places where there have been or are mills, water wheels, weirs, etc. [50]. The return on investment can be estimated at 7–10 years [51]. Assuming that the construction of small hydropower plants costs an average of approx. PLN 8.5 million/MW and the development for this purpose of 6000 facilities (with an average capacity of 1 MW), this gives a total cost of PLN 51 billion. Not all costs have to be covered by private investors. Work is underway to increase the use of the hydropower potential of Polish rivers financed from public funds. The possibility of building small hydropower plants through Polish Waters, with the use of dams owned by the State Treasury, is being analysed [52]. In turn, the cost of building the Młoty pumped hydroelectric energy storage (mentioned at the beginning of this chapter) is estimated at approximately PLN 4 billion [53]. Obviously, the development of hydropower must guarantee the absence or the maximum minimization of threats, including for the biodiversity of rivers and unfavourable changes in the hydrological conditions of rivers. The literature on the subject mentions a number of adverse environmental and social effects (see e.g., Crnobrnja-Isailović et al. [54], Mišić and Obydenkova [55]); however, the issue of building new power plants is completely different than modernizing and restoring existing facilities to use. As mentioned earlier, due to the high costs of construction of new structures and hydrotechnical and hydropower infrastructure, as well as the relatively low technical potential in Poland, the proposed development path is the modernization and reconstruction of the existing facilities. It is also possible to use existing dams, mainly dams and weirs, which are built for flood control, regulatory, retention and/or recreational purposes [17]. Taking into account environmental and legal conditions, it is necessary to be very careful about the development of hydropower in Poland, considering the numerous protected areas [56]. In the literature on the subject, there are voices in favour of more stringent regulations and integrated catchment management plans for the construction of small hydropower plants [57]. In addition, it is estimated that in Poland there are approx. 30,000 potential locations for the construction of small hydropower plants [58]. Above all, it is necessary to develop, at the local and regional level, case studies and scenario analyses of the development of hydropower, taking into account the possibilities and barriers in the technological, environmental, social, economic and institutional spheres [59].

One of the most important problems of the Polish energy sector is the lack of appropriate distribution networks; the condition of overhead power lines is largely inadequate. In the coming years, numerous reconstructions and extensions of overhead power lines are planned to adapt them to the increased thermal capacity and current legal regulations. The scope of the modernization is varied; sometimes it concerns single pole positions or short sections of lines. Works of a more comprehensive nature are also planned, including the reconstruction of the line along its axis or in the technological belt [60]. The issue of regulating the organizational distribution of energy from renewable sources by adapting the methods of managing production from small local producers, which include small hydropower plants and other new hydrotechnical sources of electricity production, has been described in the literature by Pilch [61].

Nevertheless, the positive aspects related to the development of hydropower are large, especially in the context of reducing CO_2 emissions. In this article, the share of hydropower in reducing CO_2 emissions was calculated using the standard carbon consumption required for the same energy production (where one degree of electricity consumes 360 g of standard coal; 1 ton of raw coal = 0.714 tons of standard coal). The carbon dioxide emission factor per ton of crude coal is 1.9003 kg-CO_2/kg. Accordingly, the formula is CO_2 reduction = electricity generation * 0.36/0.714*1.9003/10 [62]. Table 2 presents the results of analyses based on the data on energy production from hydropower in Poland in 2021 (2936.988 GWh) and scenarios of energy production growth by 5, 10, 15 and 20%.

Table 2. Estimates of the reduction in CO_2 emissions as a result of increasing energy production from hydropower in Poland.

Specification	5%	10%	15%	20%
Generated energy (100 million kWh)	30.838374	32.306868	33.775362	35.243856
CO_2 emission reduction (10,000 tons)	295.4731	309.5432	323.6134	337.6835

The analyses show that the investments will not only increase the production of clean energy, but also reduce air pollution, which is an important element in the context of the implementation of the EU climate and energy policy framework. The production of energy from hydropower in Poland in 2021 allowed for a reduction in CO_2 by 2,814,029 tons. A 5% increase in production volume will contribute to an increase in the reduction by 140,702 tons.

4. Conclusions and Recommendations

Poland is a lowland country with relatively low total water resources. High soil permeability, which additionally adversely affects the possibility of building this type of installation, is another unfavourable factor for the development of hydropower in Poland. The natural and hydrological conditions of Poland do not allow for extensive development of hydropower as is the case in China, Paraguay, Brazil, Venezuela and in the most developed countries in Europe—Norway, Sweden and France. Nevertheless, the existing technical potential is used at a very low level.

Modern hydropower plants can be an important, strategic element of the energy system in Poland, especially in the current geopolitical situation. In this case, not only the volume of production (which will not be large due to natural and environmental constraints) is important, but also ensuring energy security in the long term, while meeting the sustainability and low-emission conditions, and thus securing the continuity of energy supplies. From the point of view of energy efficiency, ecological issues and energy security of Poland, it is worth undertaking research and implementation work in the field of hydropower development (both in terms of construction and modernization of large facilities (pumped hydroelectric energy storage plants) and facilities based on local, small and medium power. Potentially, there are 30,000 places where small hydropower plants can be located. This is important from the point of view of prosumer energy development and energy storage. Despite the prevailing unfavourable natural conditions in Poland, it is possible to use the potential of pumped hydroelectric energy storage plants, which may contribute to more efficient use of renewable energy by storing excess energy from wind or solar installations. The small size of pumped hydroelectric energy storage plants will also make it possible to relieve outdated power networks, which currently inhibit the development of renewable energy sources in Poland. Progress in this area will have a positive impact on the entrepreneurship and competitiveness of the regions (development of tourism, development of agribusiness). Small hydropower plants fulfill important energy goals to harness natural energy sources and to power peripheral areas. Moreover, they may turn out to be important in terms of the problem of energy poverty, creating economic and technical opportunities for access to electricity for vulnerable customers (e.g., small farms).

In the current geopolitical situation, there is a need to revise the approach to shaping the energy mix so far. The current situation on the energy market in Europe may lead to a more positive perception of the development of the hydropower sector as an important element of increasing the level of energy independence of countries/regions. Based on technical, economic, social and environmental criteria, this direction of RES development also seems inevitable for Poland. The high potential for decarbonization, while minimizing flood risks and preventing the effects of drought (by slowing runoff and water retention in the catchment area), may strengthen public support for the construction and modernization of barrages and reservoirs for hydropower. This requires a comprehensive interdisciplinary debate, taking into account environmental components and social (including economic) issues, with an objective demonstration of the benefits and threats of their construction and/or expansion.

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