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Assessment of the Current Potential of Hydropower for Water Damming in Poland in the Context of Energy Transformation

Bartłomiej Igliński [1,*], Krzysztof Krukowski [2], Jarosław Mioduszewski [2], Michał Bernard Pietrzak [3], Mateusz Skrzatek [1], Grzegorz Piechota [4] and Sebastian Wilczewski [3]

[1] Faculty of Chemistry, Nicolaus Copernicus University in Toruń, Gagarina 7, 87-100 Toruń, Poland; mateusz.skrzatek@abs.umk.pl
[2] Faculty of Economic Sciences, University of Warmia and Mazury in Olsztyn, Oczapowskiego 2, 10-719 Olsztyn, Poland; kkruk@uwm.edu.pl (K.K.); miodus@uwm.edu.pl (J.M.)
[3] Faculty of Management and Economics, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland; michal.pietrzak@zie.pg.gda.pl (M.B.P.); swilczew@zie.pg.gda.pl (S.W.)
[4] GP CHEM, Laboratory of Biogas Research and Analysis, Legionów 40a/3, 87-100 Toruń, Poland; gp@gpchem.pl
* Correspondence: iglinski@chem.umk.pl

Abstract: The present paper indicates that hydropower, including small hydropower plants (SHPs), may play a very important role in Poland's energy transformation in the near future. The development of SHPs may also increase water resources in the steppe Poland. Additionally, the aim of the present research is to conduct the PEST analysis of SHPs in Poland, taking into account the SHP potential. For the first time, maps showing the power and location of potential SHPs on the existing dams in Poland are presented. SHPs should be an important element of energy transition in Poland, especially on a local scale—it is stable energy production. Our analysis shows that there are 16,185 such dams in Poland, while the total capacity of potential hydropower plants in Poland would be 523.6 MW, and the total number of new jobs is estimated at 524. It was calculated that the annual avoided carbon dioxide emissions will amount to 4.4 million tons, which will reduce Poland's emissions by 1.4%. The construction of SHPs can bring significant environmental and economic benefits. As far as the PEST analysis is concerned, the political environment of SHPs in Poland can be described as unfavorable (2.86 points). The economical nature of PEST analysis (3.86 points) should be considered as friendly for the development of SHPs. The social nature of PEST analysis can be considered as neutral (3.36 points). The technological nature of the PEST analysis can be considered as neutral (3.21 points).

Keywords: hydropower; small hydropower plants; energy transformation; water retention; PEST analysis; renewable energy

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1. Introduction

Water plays many important functions in the natural environment. It is indispensable in agricultural production because it affects the quantity and quality of crops. Water also plays a very important role in biological ecosystems and is important for maintaining natural water resources. The unification of natural habitats, the intensification of agriculture as well as urbanization and the construction of drainage systems have caused changes in the soil cover, which means that less water is retained in the catchments than in the past [1,2].

The circulation of matter and water in the catchments is faster than it was many years ago, which increases the frequency of droughts and floods. When the natural water retention capacity of a catchment area decreases, natural "pathways" for the rapid drainage of rainwater and snowmelt are created. These phenomena intensify during rapid precipitation and during the intense melting of snow. An additional effect of the more intensive circulation of water in the basin is the decrease in water quality in the river. The water flowing to rivers and lakes brings the increased amounts of nutrients leached from agricultural areas [3].

The first drive machine that replaced the strength of human and then animal muscles was the water wheel. At the beginning, the wheel was used to draw water and to grind cereals. It is known that the first horizontal shaft water wheels already existed in the 1st century BC. in the territory of the Roman state, and they were described by Marcus Vitruvius Pollio, the court architect of Emperor Octavian Augustus. The mill described by him had a water wheel with a horizontal axis, and was already equipped with a toothed gear through which the tread millstone was driven whilst mounted on a second vertical shaft. This type of mill is called a "Roman mill" in world literature. Most likely, there were mills with wheels even before water bodies deposited on the vertical shaft together with the tread stone. The very simple solutions had a rotor rotating in a horizontal plane, to which the water was fed via a pipe with a significant slope. These rotors were spray type water wheels. The water hit numerous half-plates or diagonal boards mounted on their perimeter. Water wheels powered various devices in processing plants (e.g., grain mills, gunpowder and fulling sheets), sawmills and forges, also known as hammer mills. At the end of the Middle Ages, water wheels became the most important source of mechanical power, reaching a power rate of up to tens of kilowatts. They largely contributed to the industrialization of Western Europe, thus increasing its economic importance [4].

The proper design and construction of small hydroelectric power plants (SHPs) should comply with the principles of sustainable development, i.e., the investment should be designed and performed technically in accordance with the applicable standards and regulations, bring specific economic benefits and, most importantly, guarantee no threats to the environment [5].

In the era of globalization and rapid economic growth, consumption is also increasing, resulting in an increasing demand for energy and energy carriers. The production of energy from fossil fuels resources disturbs the environmental balance in many regions of the world [6,7].

The continuous increase in the demand for energy carriers and energy means that the energy sources used so far are becoming insufficient. Generating energy from conventional sources is harmful to the environment, and its production is becoming less and less profitable [8,9]. Therefore, there are economic and environmental reasons for the energy transformation towards low-emission and zero-emission energy sources [10,11]. The shift to a "green economy" has already become a global phenomenon, based on the gradual replacement of fossil fuels by clean energy sources and a more efficient use of energy (energy efficiency) [12]. The process of energy transformation is understood as a transition from the current energy system using conventional fuels to an energy system based mainly on renewable energy sources (REs). It covers the gradual replacement of exhaustible hydrocarbons and uranium RE fuel in each sector of the economy (for instance, energy, heating, transport, industry, agriculture and construction) [13,14].

Each of the EU members undertook the transformation of the energy system, which has become an important goal in the fight against progressive climate change. Moreover, the transformation lead to the improvement of energy security, increased competitiveness and economic attractiveness of Europe [13–16]. Political trends in the EU climate policy determine the future structure of electricity generation [17]. By joining the EU in 2004, Poland undertook the challenge to adapt and integrate its institutional model [18]. Poland, similar to other new member states, committed to reducing greenhouse gas emissions by ratifying the Kyoto Protocol and participating in the EU's common climate policy [19].

Poland is at the beginning of its energy transformation. An energy mix should be developed along with energy storage. It is worth developing stable energy sources, which include hydroelectric power plants. SHPs allow for the production of electricity, increasing the so-called "little retention" in the Polish steppe.

The present paper indicates that hydropower, including SHPs, may play an important role in Poland's energy transformation in the near future. The development of SHPs may also increase water resources in the Polish steppe. Additionally, the aim of the present research is to present the PEST analysis of SHPs in Poland, taking into account the potential of SHPs. For the first time, maps showing the power and location of hydroenergy potential on the existing dams in Poland are presented. SHPs should be an important element of energy transition in Poland, especially on a local scale—it is stable energy production.

2. Energy Transition in Poland

RE sources will play an increasingly important role in the energy sector of Poland. In 2030, the share of RE in the energy mix will be at least 32%. For this purpose, mainly offshore wind farms and photovoltaics will be developed. To achieve such a level of RE in the balance sheet, it is necessary to expand the network infrastructure, energy storage technologies and the development of hydrogen technologies [20].

The greatest challenge for the Polish energy sector is high emissions. Currently, the energy sector is responsible for almost 40% of CO_2 emissions and it is the largest source of GHGs in Poland. The high share of coal in the energy mix (70% in 2020) places our energy sector in second place in the EU in terms of emissions. The ratio of GDP to CO_2 emissions for Poland is also unfavorable. Poland has a clearly lower result than not only the EU average, but also the countries of the Visegrad Group. In the Energy Transition Index ranking, Poland ranks 75th, ahead of only Bulgaria among the EU countries. Our country was rated the worst in categories, such as policy stability for business (102nd), primary energy emissivity (108th), flexibility of the power system (110th) and the share of electricity from coal (112th place) [20].

Investments in the green economy result not only from growing environmental awareness, which translates into the expectations of the voters, but also from economic conditions. The combination of the fall in green technology prices and the rise in CO_2 emission allowance prices in Europe, reducing the competitiveness of high-carbon installations, puts economic pressure on states as well as on individual companies to adapt to the trend. The green economy is therefore not a matter of choice, but often of an economic calculation resulting from the fact that the continuation of the status quo, with increasingly restrictive legal conditions, may cost more than the transformation of the economic model [20].

The "Polish energy policy until 2040" aims to carry out the energy transformation towards low- or zero-emission production. The process will be carried out with the involvement of the domestic industry and the active role of the end-user, which will provide a growth impulse for the economy, while ensuring energy security, in a socially acceptable, innovative manner and with respect for the environment and climate. The energy transformation to be carried out in Poland will be:

- Just–will not leave anyone behind;
- Participatory, bottom-up and local—everyone can participate in the process;
- Focused on innovation and modernization—it is a plan for the future;
- Stimulating economic development, competitiveness and efficiency—it will be the "engine" of economic development [20].

The energy transformation in Poland is based on three pillars:

- Just transformation. Particular emphasis is placed on helping and providing new development opportunities for communities (e.g., miners) and regions that will be most affected by the transition to low-carbon energy production. Activities related to the transformation of coal regions will be supported by a sustainable development program. The transformation will also be attended by individual energy customers who, on the one hand, will be protected against rising energy prices, and, on the other hand, will be encouraged to actively participate in energy production and storage (e.g., prosumers). It is thanks to this that the energy transition will be carried out in a sustainable and fair manner; everyone, even small households, will be able to participate in it. Estimates show that the energy transformation may generate up to 300,000 jobs in Poland. New jobs will be created in industries related to RE sources, nuclear energy, network infrastructure, electromobility, digitization and the thermal modernization of buildings.

- Zero-emission energy system. In order to reduce emissions from the energy sector, offshore wind energy and nuclear energy will be implemented, and the role of prosumer and distributed energy will be increased.
- Good air quality. Thanks to the investments in the electrification of transport, the transformation of the heating sector and the promotion of passive and zero-energy houses, air quality will significantly improve, which will have a positive impact on the health of the society (lower smog emissions). The most important effect of the energy transformation noticeable by every citizen will be the provision of clean air in Poland [20].

Poland must base its production capacity on the RE mix. Energy production from multiple sources supported by energy storage and green hydrogen will allow Poland to achieve national energy self-sufficiency. The development of biomethane and green hydrogen technology is slowly achieving energy self-sufficiency in Poland not only in the energy sector, but also in the heating and automotive industries.

For example, the book [21] calculated the potential of RE in Poland. In total, the calculated amount of obtainable energy from waste biomass is 22.25 TWh/year, and heat is 129 PJ. The wind energy potential is 4.1 TWh, which results from the Distance Act [22]. The relaxation of the Act may significantly increase the wind energy potential in Poland. Additionally, the construction of offshore wind farms has been planned. The potential of photovoltaics based mainly on roof installations is 6 TWh—this potential can be significantly increased by placing solar installations in open spaces (wastelands, post-industrial areas and closed landfills are recommended). The potential of heat pumps in Poland was calculated at the level of 36.8 PJ in the first year and 117.3 PJ in the next 10 years.

3. Hydropower Plants as a RE Source—Literature Review

SHPs are objects that use inland water energy, which is obtained by them, and then converted into mechanical and the electrical energy by using hydrogenerators and water turbines. The construction of the SHPs can bring significant economic and environmental benefits [23].

The priorities of the energy policy include: how to reduce emissions, increase efficiency by reducing network transmissions, as well as a security of energy supply. They grant the validity of investments in small units with the application of renewable resources and localization close to the recipients. The features of the large-scale generation of electricity based on coal or gas cause significant losses in the processes of fuel conversion and transport. An alternative is microgenerative dispersed sources, such as small hydropower plants [24].

SHPs belong to the class of efficient and safe objects. They are also characterized by a long life cycle, the ease of use and high reliability [25]. Moreover, they are based on national hydropower resources, which play a very important role in the pursuit of self-sufficiency and energy security. The power plant can be fully automized with the regulation of the turbine set depending on the amount of water available to reach the maximum production of the electricity. This function is performed on the basis of the measurement of the upper water level and flow at a given moment. Additionally, SHPs facilities favorably affect the power system by improving the parameters of the low and medium voltage distribution network. The electrical energy from SHPs is consumed by receivers from the nearest neighborhood. It eliminates energy losses on transmission, transformation and distribution, which take place in the case of large system power plants, and amounts to up to several percent in Poland [4,26].

The main accusation against SHPs is their negative impact on fish. The morphological continuity of the river is interrupted, and it is possible to damage the fish flowing through the turbines. It should be noted that currently most of these SHPs are built almost only on the already existing dams. What is more, the construction of culverts is obligatory and, thanks to these investments, the continuity of the rivers is not interrupted at present. Species of potamodromous fish, such as, lazy or spring trout, and anadromous species that periodically flow into rivers from the sea, such as golden trout or salmon, may end up in previously inaccessible spawning grounds in the upper rivers. It should be emphasized that in the case of small watercourses, which are not important migration routes for fish, sometimes finding an investor who is interested in the construction of SHPs is a chance to obtain funds necessary to restore their continuity. Moreover, damming up water can be used for fishing and recreation [27–29].

Senarath et al. [30] conducted a study at the Denawaka mini hydropower plant Ganga, in order to present the impact of this type of power plant (run-of-the-river type) on the natural environment and local community. It was found that the investigated power plant did not cause any potential negative environmental impacts in terms of the hydrological regime of the river, which allows the flow of food ingredients from the top to bottom. A positive impact on the local community was found. What is more, RE was produced. Overall, the advantages of a mini hydroelectric power plant definitely outweigh the disadvantages.

Kachaje et al. [31] studied the influence of climate change on an SHP using the example of the Lujeri power plant (Malawi). The study analyzed the impact of the changes in temperature and precipitation on the amount of electricity produced. It was found that in January, July and December, the rainfall was higher, while in February, April, May, June, September, October and November, the rainfall was lower. The analysis of the annual rainfall distribution showed a general downward trend over time. Increased temperature causes an increase in evaporation, which negatively affects the operation of SHPs. Therefore, appropriate adaptation measures, such as RE, water storage mechanisms and electricity storage systems, need to be taken to ensure that electricity is available all year round, especially in the dry and hot seasons when water flows are usually low.

Plans for the launch of new SHPs must already take into account the observed climate changes. Tzoraki [32] suggests that it is worth developing SHPs even on rivers with a periodic flow (Greece), as this will reduce the production of energy from conventional fuels. When investing in SHPs, many aspects must be taken into account, including the aforementioned climate changes, environmental variables (variability of precipitation, flow rate and precipitation) and human interference in the ecosystem's water budget (including irrigation, water pumping and water abstraction). Caceres et al. [33] analyzed the impact of climate change up to 2100 for 134 hydropower plants in Brazil, Colombia and Peru. It was found that the average monthly productivity of power plants would increase for Colombia and Peru, while for Brazil the productivity would increase or decrease depending on the local climatic conditions. The obtained results may help to make the future decisions regarding the energy plans of a given country, as well as the plans of energy "cooperation" of the above-mentioned countries.

The negative impact of large hydropower plants increases the interest in SHP investors [34]. The first step is to determine the SHP potential in the field—"mapping" with the GIS method. Geospatial analysis allows us to obtain "green" energy and significantly improve the water quality in accordance with the principles of sustainable development.

Turner et al. [35] determined the influence of global warming on the production of energy from hydropower plants based on 3 models. It was found that global warming will negatively affect the production of energy from water energy in 3 areas: southern Europe, the Middle East and North Africa. Electricity generation in the Balkan countries will fall the most, even by 20%. The models show that in Scandinavian countries [36] and in Central Asia, there will be an increase in electricity production (5–15%) without investing in any new water plants.

Hydropower plays a significant role as the RE in some countries. Tomczyk and Wiatkowski [37] presented the challenges related to the development of hydropower in

4 countries with a different share of electricity from hydropower plants: Estonia (0.3%), Poland (1.1%), Slovenia (25.7%) and Albania (100%). Although the share of hydropower varies, it is an important link in energy diversification. The development of the hydropower sector enables the harmonious and sustainable development of each country. Although Estonia, Poland, Slovenia and Albania use different energy sources, they have similar goals and plans related to the development of the RE, the reduction of greenhouse gases and increasing energy efficiency.

SHPs are used in the energy mix of Baltic countries (Lithuania, Latvia and Estonia) [38]. They are a reliable and effective source of energy. The use of existing damming structures as SHP locations is the best practice in the above-mentioned countries. These are, i.a., old water mills, of which there are about 1500 in the Baltic States.

The proper design of SHPs should comply with the basic principles of sustainable development. This means that the investment should be properly planned and carried out in accordance with applicable regulations, which not only bring economic benefits, but, above all, guarantee no threats to the environment [4,39].

Kishore et al. [40] undertook a full development related analysis, including worldwide SHP costs. Research has shown that certain problems exist everywhere in one form or another, the most persistent problems occurring between energy production, the economy and the environment. When investing in SHPs, a compromise should be sought to generate energy in a sustainable way. The best solution can be obtained by a cost analysis method that analyzes the benefits and costs of both the developer and the general public. It is worth investing in hybrid sources nowadays, such as SHPs in combination with small wind turbines (e.g., Savonius) and/or photovoltaic farms.

Jung et al. [41] emphasize that it is worth investing in SHPs, as they are characterized by a short construction time and are easy to maintain. SHPs also have a higher "energy density" than other REs. The hydropower potential is fairly easy to calculate from the water flow or from precipitation. In the next article, the authors [42] simulated the future perspective of SHP potential for the period 2021–2100, taking into account climate change for 3 power plants: Deoksong, Hanseok and Socheon. The results show an upward trend, with the largest increase being for the Deoksong power plant (23.4%). The authors postulate that, if the SHP potential increases with global warming, it is necessary to revitalize SHPs so as to use renewable hydropower to the maximum extent. SHPs may become a very important source of electricity in the energy mix of many countries.

Alam et al. [43] presented a business model for the development of SHPs, in which the local community becomes the owner of a 50 kW hydropower plant. It focuses "on community", "community" and "for community", in line with sustainable development. Having your own power plant "engages" the local community to joint action; it also provides jobs, thanks to which there is less outflow of young people from the countryside to the city. The local community earns around USD 112,000 per year on electricity sales, and the avoided emissions of CO_2 into the atmosphere is around 160 tons. The local community is financially independent to some extent and the money earned can be spent on, for instance road repairs, melioration and agricultural development. The development of SHPs is the independence of the local community and its sustainable development.

The energy policy of many countries supports the development of RE, including hydropower, but most of all SHPs [44]. Global synthesis shows that almost 85,000 SHPs are already operating in the world. This number can even triple if the available potential is used.

As a result of water damming, within the weir diverse ecosystems are created, and the surface and groundwater retention increases, which in turn improves soil and water relations. It is significant to realize that the maintenance of the weir, cleaning the grates, the removal of waste trapped on the grate or the maintenance of the river bed is the responsibility of the owners of the SHP. This ensures, especially in winter and flood conditions, the proper exploitation of the weir (not allowing the formation of congestion and ensuring the free flow of water through weirs), as well as reduces the occurrence of water from the river bed and mitigates the effects of floods. Garbage is sedimented on the grid protecting the turbines and other elements of the power plant, from where they are periodically removed. The power plant is sometimes equipped with some additional garbage disposal devices, such as the "scoop", which is shown in Figure 1 [45].

Figure 1. Purification of water from "thick" pollution at an SHP (photography: B. Igliński).

The hydro energy sector also means new jobs. Based on the data of the IRENA (International Renewable Energy Agency) [46], as well as our own observations, it was assumed that there will be estimated new jobs in Poland in the amount of 1 person/1 MW. The estimated number of new jobs is therefore 524. It is worth emphasizing that these are the jobs to be performed in the countryside, and therefore in regions with a high unemployment rate.

4. Water Energy in Poland

Apart from food milling, relatively old (12th century) milling devices were used in forges and wire mills for crushing stones, for the production of gunpowder and for the production of paper [4]. The ventilation of the mine, drainage and irrigation of fields, these are the other uses of water mills in Poland. The fact that water energy plays a great role in the economy and culture of Poland is evidenced by the numerous coats of arms of disctricts communes and towns.

Even after the Second World War, it was possible to count several thousand small water mills (Figure 2) and the hydropower plants on the territory of Poland. Nowadays, very few of them are left. The destruction of mills and SHPs caused significant changes in water relations. As a result of the destruction of the damming constructions, there was a sudden slope at the bottom and the water level, resulting in progressive erosion and a deeper indentation of the river beds. The groundwater level also lowered [4].

Several thousands of water facilities guaranteed the so-called "low retention", especially during droughts, increasing water resources while preventing flooding during heavy rains [4].

Poland is a country of modest water resources, which puts it at the end of the list of EU countries [47]. The first mills were built in the 9th century, and the first hydropower plant was put into operation in 1896 [4].

It is worth quoting here the data from the inventory of objects carried out in 1954 powered by water. There were 6330 operating plants throughout the country, and 800 were closed. The juxtaposition of these figures clearly shows the enormous degree to which these last 35 years of devastation of national wealth have had on this single industry [48].

Figure 2. The water in the Ethnographic Museum in Toruń (photography: B. Igliński).

As a result of the energy crisis that arose in 1973, most developed countries took certain measures, the main goal of which, among other things, was to create new sources of electricity not based on fuels (including primarily liquid fuels), but using RE. Hydropower has come to the fore among these sought-after new sources. That is why small power plants and hydropower plants that were shut down in previous years aroused great interest. There was an interest in the possibility of using the existing water damming structures for energy purposes for various purposes. Thus, the very intensive development of SHPs began in the world, including hydroelectric power plants with installed capacities generally up to approx. 5 MW, and in some countries up to 10 MW. The legal basis for the development of SHPs in Poland was the adoption on 7 September 1981 by the Council of Ministers of Resolution No. 192 of the development of small hydropower plants. This resolution allowed for the implementation and use of SHPs with a capacity of up to 5000 kW for economic entities other than the professional power industry, including natural persons [4,48].

In Poland, the technical resources of rivers are, respectively: the Przymorze area—2.3%, the Odra—20.1% and the Vistula—77.6%. The potential of Polish rivers is currently used only in 19.4% of the country, while in some EU countries its use is above 80% [49].

Larger power plants are usually located in the mountains and foothills, while SHPs are often located in the lowlands [4]. Currently, the capacity of devices producing electricity with the use of water turbines in Poland is nearly 1 GW in nearly 800 hydroelectric power plants (Figure 3) [50]. The biggest hydropower plant in Poland in terms of capacity is the Włocławek Power Plant (the center of Poland). Włocławek Power Plant consists of the following elements: front dam, weir closed with mantle gates, power plant and navigation lock with dimensions of 12 m × 115 m, designed for a capacity of about 6 million tons per year. Additionally, a water pass was placed in the partition pillar between the power plant and the weir. The power plant has six Kaplan hydro sets with a total installed capacity of 160.2 MW [4].

In Poland, there are 6 pumped-storage power plants in operation: Żarnowiec Hydroelectric Power Plant (716 MW), Porąbka-Żar Hydroelectric Power Plant (500 MW), Solina Hydroelectric Power Plant (200 MW), Żydowo Hydroelectric Power Plant (156 MW), Niedzica Hydroelectric Power Plant (92.7 MW) and the Dychów Hydroelectric Power Plant (88 MW). Their task is to stabilize the power grid throughout the day [50].

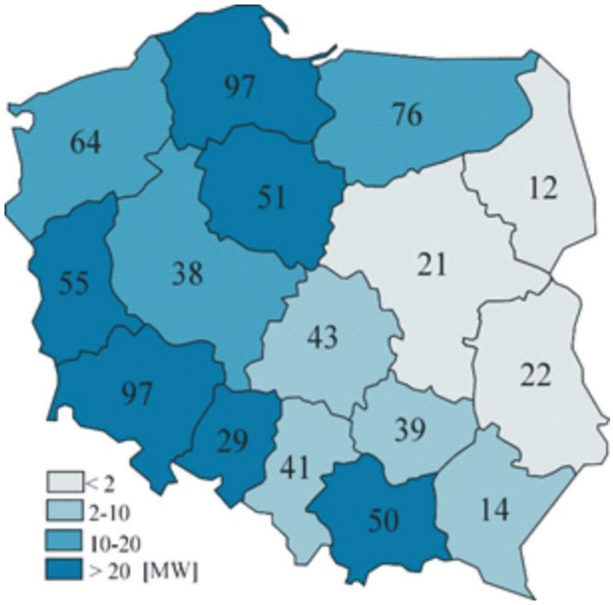

Figure 3. Number and power of water energy plants in Poland (own elaboration from [50]).

The SHPs should be located in place of the existing dams, which will allow water to be used more effectively. The reconstruction of the retention facilities, apart from economic effects (hydroelectric power plant), may appear to be an interesting element of the landscape, a place of recreation as well as a habitat constituting the biodiversity of the reception basin [4].

The advantages include the fact that hydropower plants (including pumped storage power plants) play an important role in stabilizing the operation of the National Power System, thanks to the possibility of the immediate start-up/shutdown and increase/decrease in generation capacity. Additionally, hydropower plants are used to cover peak energy needs (mainly in the morning and evening). An additional advantage of SHPs is the fact that they are connected to the power grid at a low or medium voltage level, which reduces the load on the transmission networks as well as transmission losses. In the case of SHPs, it should be taken into account that their operation is largely dependent on the current hydrological conditions of the river than on large hydropower plants with retention reservoirs [51].

Small water retention is an extension of the time and route of water circulation and its contamination in the reception basin, aimed at improving the water relations in the reception basin purification of water and the regulation of sediment transport.

One can speak about when water from thaw and intensive precipitation is stored in the soil in its water-bearing layers, water reservoirs and on the surface. Such retained water in the latter, supplies the watercourses and is used by plants. The improvement of the reception basin retention does not introduce the major changes in the natural hydrological cycle, but only introduces adjustments that improve the water balance without disturbing the biological balance of the ecosystem.

In the field of increasing the available surface water resources, we need to focus on:

- Construction and reconstruction of water facilities on small rivers and watercourses;
- Water damming of the lakes;
- Using the rural ponds and meshes as retention areas;
- Constructing the small retention reservoirs;
- Using the existing excavations as retention reservoirs;
- Using the wet areas as natural retention reservoirs and water treatment plants.

5. Climate Change vs. SHPs in Poland

The annual precipitation totals in the period from 1981 to 2017 also show a slow upward trend (Figure 4) [52].

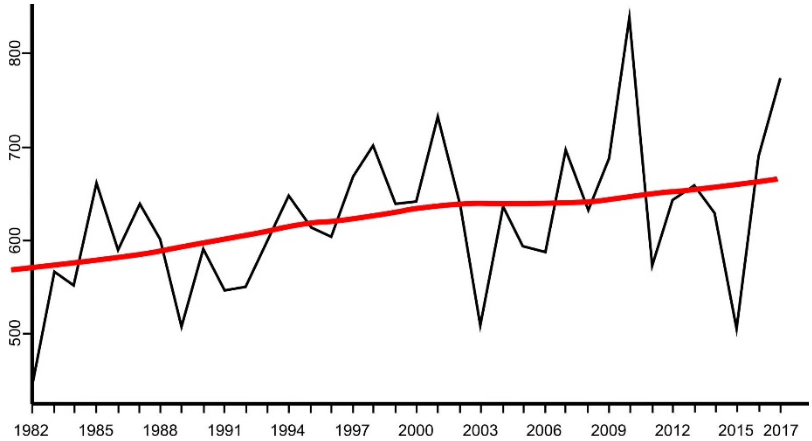

Figure 4. Annual total rainfall in Poland in the horizon from 1981 to 2017 (own elaboration from [52]).

Analyses of the changes in the temperature and precipitation in Poland were carried out for 2 development scenarios described with the abbreviations RCP4.5 and RCP8.59. The "moderate" scenario of RCP4.5 assumes a gradual increase in carbon dioxide concentration to 540 ppm in 2100, respectively, and the achievement of radiative forcing of 4.5 W/m^2. In turn, the RCP8.5 extrapolation scenario corresponds to an increase in carbon dioxide concentrations to 940 ppm in 2100 and an increase in radiation to the level of 8.5 W/m^2. The annual rainfall according to the RCP4.5 scenario until 2065 will not change significantly. There will be a slight upward trend and cyclical volatility over several years. After this period, the upward trend will be stronger, while maintaining the aforementioned cyclicality visible in the course of the annual average values. According to the RCP8.5 scenario, by 2035 the annual sum of precipitation will slightly increase and will be slightly lower than in RCP4.5. By 2075, there will a constant upward trend in the annual total rainfall. By the end of the 21st century, the amount of precipitation will increase by approx. 50 mm per year for RCP4.5 and approx. 100 mm per year for RCP8.5, compared to the present conditions [52,53].

Increased rainfall increases the amount of water in rivers and thus the productivity of SHPs in Poland. On the other hand, an increase in temperature will increase evaporation, depleting the water resources. Global climate change is the biggest challenge facing humanity today. The impact of the expected temperature rise and fluctuation changes in the rainfall regime will be particularly severe for agricultural production. The increased rate of surface flows combined with the expansion of urban development will become a problem of growing importance, as the threat of floods will increase. Moreover, the probable changes in the infiltration capacity of the land surface and the reduction of soil retention capacity can significantly increase the risk of drought and floods, and consequently make the water less available to the plants [53].

It can be expected that by the year 2050, the average temperature in Poland may increase by 1.7–3.6 °C, with seasonal rainfall. The greatest threat of no precipitation will appear in the east of Poland, then in the west and south and finally in the north. In the warmer climate of Poland, one should be afraid of increasing the frequency of extremes in the area of 3 basic water problems: too little water, too much water and water pollution. Changing the form of winter precipitation will reduce the winter retention in the snow cover and will change the seasonality of flows in rivers. The winter flow will increase, the low water levels will increase in the summer and the water will be much lower and the water will be contaminated [54].

In Poland, the water deficit increases every year. All the actions performed to increase the water retention is extremely significant, both on the national and local scale. The so called "small retention" [55,56] must be performed. This may occur, through the use of old small water reservoirs after the mills and other plants use water energy. The small water reservoir can be used economically by setting up the SHPs. The objective of the present research was to define the localization of the small water reservoir in every voivodeship (province) in Poland, as well as to define the power and energy that it would be possible to obtain, owing to such hydropower plants [57]. The calculation data was provided the National Water Management Board, including the localization, slop, flow and type of droughts.

Poland's water resources are definitely not large, and they are placed among the smallest in Europe. They come mainly from atmospheric precipitation, directly feeding the area of the country in the amount of 187.2 billion m^3 in the middle of the year, which corresponds to the average height of the water layer, 602 mm. It is estimated that the amount of 53.4 billion m^3 outflows from the rivers, i.e., around 28.5%, due to the fact that about 5.2 billion m^3 of water flows into the territory of Poland from outside its borders; therefore, in the middle of the year, the total annual mass of water flowing away from the river beds in Poland to the sea and abroad corresponds to the amount of 58.6 billion m^3 [4].

In a large part of Poland (with the exception of the coastal waters and high mountains), we can observe a clear precipitation deficit. The sum of the monthly rainfall is clearly smaller than the amount of evapotranspiration. Growing plants use soil and groundwater reserves, which are accumulated during the winter period, and in case of a shortage of that water there is a phenomenon of drought. On the other hand, we experience a rapid outflow of water into the river after thaw and greater atmospheric precipitation, causing flood damage [4,54].

The essence of the drought is the lack of moisture in the air and soil, disturbing the natural water balance of the area. The drought is dynamic and a specific development cycle. It is preceded by a lack or relatively small atmospheric precipitation, reducing not only the water resources in the hydrosphere, but also the content of water vapor in the atmosphere. This type of drought is call an atmospheric drought. The lower air humidity, in turn, affects the growth of its drying effect on the soil and the plant cover covering it. The prolongation of the duration of rainfall shortages results in the over-drying of the surface and then the deeper layers of soil. This stage is called a soil drought. The last phase is a hydrological drought. During that drought, the outflow of the surface water to groundwater decreases, which entails a reduction in the flow of water in rivers [4,54]. There is also a significant reduction in the groundwater levels, and the drying out of springs and small watercourses.

The droughts occurring in Poland also result from the following:

- Excessive deforestation in Poland;
- Water melioration, mainly drainage;
- Excessive subordination of agricultural areas to the requirements of mechanization through the elimination of many landscape elements that impede the operation of the equipment, e.g., ponds and green enclaves;
- Improper use of land;
- Draining swamps and wet areas;
- Defective water economy in individual agricultural households;
- Incorrect assumptions in the regulation of watercourses;
- Too much water consumption [4,54].

In Poland, droughts occurred every 5 years in the period of 1951–1981, then in the period of 1982–2008 they occurred every two years. At the same time, the sequence of years with the precipitation deficiency causing droughts and the following years of the excess or similar to medium fall were also observed. The driest regions of Poland include: almost the entire middle region and its north-west and central-east regions. Droughts are the most common in these areas and they are the severe, with extremely long sequences of rain-free days. In the last 25 years, droughts in Poland have been appearing more and more frequently, and they are becoming more intense and cover significant areas of the country [54].

The negative impact of droughts in Poland is manifold and can be observed in various areas of the national economy. It is most visible in agriculture, supplying water to towns and villages as well as adverse changes in hydrological conditions. The impact on agriculture and its water management is diversified. It depends on the amount and distribution of the precipitation in the period preceding the drought, and the duration and intensity of the drought. The negative impact of drought on fauna depends primarily on the plant species, soil type and geographic location. Autumn and early spring droughts reduce the yield of winter crops, while in spring droughts, the yields of spring crops, first hay growth and pasture yield are reduced. A summer drought usually negatively affects the potato yield, the second hay gains and the cultivation of forage [4,54].

6. PEST Analysis of the SHPs in Poland

The PEST (Political, Economic, Social, Technological) method is one of the analyses used to examine the environment, in this case the SHP sector (Figure 5) [58,59]. In PEST analysis, the environment can be defined as:

- Political macro-environmental factors: including legal framework, RE policy and political stability;
- Economical macroeconomic factors: including the labor market, the current business environment in Poland and in the world and interest rates;
- Social macro-environmental factors: including the structure of human resources, demography, availability of workforce and knowledge of RE sources;
- Technological macro-environmental factors: including new technologies in the RE sector and technology transfer [60].

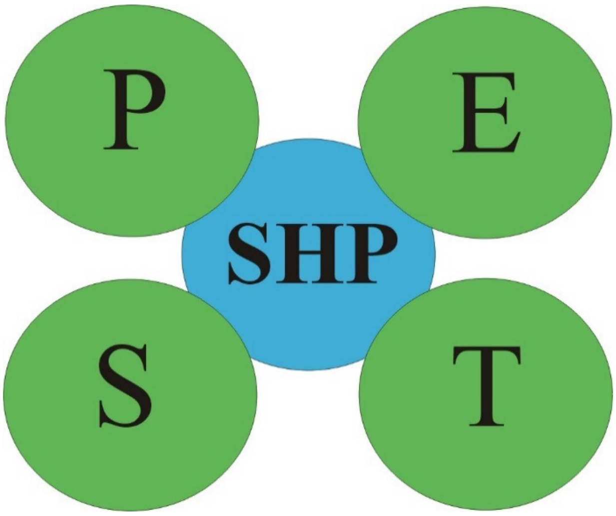

Figure 5. Macro-environmental factors SHP; P—political, E—economical, S—social, T—technological (PEST analysis) (own elaboration).

The PEST methodology includes the presentation of the examined factors on a point scale, depending on how they favor or not the development of the SHP in Poland. Within the scale used, the individual points from 1 to 5 are defined as:

- 1—a highly unfavorable factor;
- 2—an unfavorable factor;
- 3—a neutral factor;
- 4—a favorable factor;
- 5—a highly favorable factor.

It was decided to use the formula of the mean value of the selected factors, assuming that the impact on the development of SHPs is as follows:

- Below 2.00 points—a highly unfavorable macro-environmental factor;
- Between 2.00–2.99 points—an unfavorable macro-environmental factor;
- Between 3.00–3.49—a neutral macro-environmental factor;
- Between 3.50–4.49—a favorable macro-environmental factor;
- Between 4.50–5.00—a highly favorable macro-environmental factor.

PEST analysis was carried out using all the available information: the data from literature sources, information provided by RE producers, legal acts and regulations of the EU and Poland and RE sources development strategy. The scores were awarded on the basis of the authors' "brainstorming".

6.1. PEST Analysis—The Political Environment

The political environment of SHPs in Poland in the context of its environmental development potential is presented in Table 1.

Table 1. The political environment of SHPs in Poland in the context of its development potential.

	Factor	Friendliness of the SHP
1.	The political systems in the country	3.50
2.	Efficiency and functioning of public administration	2.50
3.	The SHP policy at the state level	2.00
4.	The SHP policy at the regional level	2.00
5.	The Renewable Energy Act	4.00
6.	The lobby of conventional energy	1.00
7.	The membership in the EU	5.00
	General assessment	**2.86**

The SHP's political environment is largely based on the country's political system. Poland is a parliamentary republic and implements the principles of sovereignty and independence, as well as a democratic state of law, civil society, tripartite power, pluralism and the rule of law [61]. The development of SHPs in Poland is positively influenced by a fairly stable political system, the independence of important state institutions and the administrative order.

Polish public administration is not operating efficiently in Poland. For many years, investors in Poland have been struggling with extensive bureaucracy. The construction of SHPs involves dozens of different permits that require a lot of self-denial, time and knowledge.

The Act on RES of 2015 [62] introduced an auction system in place of green certificates. It consists of the fact that, during the auction, the government orders a strictly defined amount of energy from RE. Its producers join the auction, and the winner is the one who offers the lowest price. The auction system ensures stable conditions for further development of SHPs, because projects selected in the auction system will receive support for a period of 15 years.

The development of SHPs in Poland strongly opposes the lobby of conventional energy, mainly the coal lobby. The lobbying in trade unions is openly opposed to further investments in RE in Poland. What is more, the lobby negates climate change as well as benefits resulting from the development of the RE.

Membership in the EU gave Poland a "civilization leap", and stimulated the development of many sectors of the economy, including the RE. The development of the SHP sector in Poland was fostered by the elimination of borders in political relations resulting from the processes of globalization. Upon joining the EU community, Poland took over the achievements of the EU in the field of research. It also created great opportunities for scientists and entrepreneurs to function in the "European Research Area". This allowed for the free movement of research and development staff, conducting joint research projects and the creation of international research and development centers.

6.2. PEST Analysis—The Economical Environment

The economic environment of SHPs in Poland in the context of its development potential is presented in Table 2.

Table 2. The economic environment of SHPs in Poland in the context of its development potential.

	Factor	Friendliness of the SHP
1.	The socio-economic development	3.50
2.	Economy in the world, prices of energy and fuels	5.00
3.	The labor market	4.00
4.	Finance SHPs from their own resources	2.00
5.	Availability of loans and credits, interest rates	3.50
6.	Green certificates and auctions	4.00
7.	The globalization–movement of services, capital and goods	5.00
	General assessment	**3.86**

Economic growth is still observed in Poland. Their own and the EU funds, as well as loans and credit, stimulate development in the economic sector in Poland. This implies the demand for innovation from the side of science and increases the number of jobs. Nowadays, it can be stated that there is practically no unemployment in Poland [63]. The prices of consumer services and goods in August 2021, compared to the same month last year, increased by 5.5%; compared to the previous month, the prices of services and goods was higher by 0.5% [64].

The prices of energy carriers remain at a high level; in October 2021, the price of crude oil was USD 84 /barrel [65], the price of hard coal was around USD 127/Mg [66] and the price of natural gas was around USD 5.21/million bt [67]. The energy prices in the world, and in Europe in particular, have reached historic highs, and this has been an unprecedented profitable period for zero-emission renewables.

At least 60–90 thousand people work in the entire RE sector in Poland, including several hundred people in the hydropower sector. Importantly, RE is one of the few sectors of the Polish economy in which employment is still growing. According to our forecasts, in 2030, at least 110–120 thousand people will work in the RE sector in Poland.

The interest rates in Poland were at a record low (but last time they increased). The reference rate is 0.50%, the Lombard rate is 1.00%, the deposit rate is 0.00% and the rediscount rate is 0.51% [68].

Investors who want to develop SHPs in Poland can apply for loans/funding from both EU and domestic funds. It is worth emphasizing that this does not only concern the subsidies, but, is above all, concerned with clear accounting rules, market access and not experiencing problems with connecting the SHPs to the network. Moreover, investment opportunities should be popularized, including the possibility for the investor to deduct the amounts invested in RE from personal income tax.

Until mid-2016, the SHP investors received support in the form of green certificates. Then, there was a transition period. During the suspension of the functioning of the support system in anticipation of new regulations, in which investors waited with uncertainty for the possibility of launching their facilities or completing investments, more discouragement was observed. For the hydropower sector, where the administrative procedures consume a lengthy amounts of time and are expensive, it was very frustrating to wait several months for the opportunity to participate in the auction after passing these procedures. From the perspective of the hydroelectric sector, both the volume and reference prices planned for auctions, which for the hydroelectric power plants that amount to 550 (less than 500 kW), 500 (500 kW–1 MW) and 480 PLN/MWh, respectively (capacity above 1 MW), would allow for the implementation of many investments [60].

Polish investors, despite extensive bureaucracy, show great activity and entrepreneurship in building SHPs. Often, these are their own ideas that improve an already existing technology. More and more investors are developing 2 or more types of RE, eg SHP and photovoltaic panels. For example, the company named Energa Wytwarzanie started a pilot implementation of an innovative project for the installation of solar panels on water. In the reservoir near the hydroelectric power plant in Łapina, PV panels producing electricity on water were placed for the first time in Poland [69,70]. These installations were designed to improve their efficiency and increase the level of generated energy. After obtaining positive effects, the Energa Group did not exclude the possibility of a wider application of this solution.

Poland's accession to the EU enables the free movement of technologies, goods and services. The latest technological achievements of the EU (including SHP) are more and more often implemented in Poland. It is worth emphasizing that many SHP devices are also found in the EU or the world market. For example, the Hydroergia Company [66], as the only company in the Polish market, produces turbines individually designed for the requirements of a given investment, which allows for the most effective use of a watercourse. The innovative solutions proposed by the company were recognized twice in the prestigious GreenEvo program—a green technology accelerator organized by the Ministry of the Environment.

6.3. PEST Analysis—The Social Environment

The social environment of SHPs in Poland in the context of its development potential is presented in Table 3.

Table 3. The social environment of the SHPs in Poland in the context of its development potential.

	Factor	Friendliness of the SHP
1.	The demography in the country	1.00
2.	The level of education in Poland	3.50
3.	The knowledge about the SHP	2.50
4.	The social acceptance for the SHP	3.50
5.	The social acceptance for small water retention	4.00
6.	The impact of the SHP development on employment	4.00
7.	The membership in the EU	5.00
	General assessment	**3.36**

The population of Poland has been slowly declining for over a dozen years. At the end of 2020, there were 38,265 million Poles, i.e., 273,000 less than ten years earlier. On November 9, 77,980 people died from the coronavirus [71].

In 2020, 22.7% of men and 22.2% of women had primary education, while 33.4% of women and 29.5% of men had higher education. Recent years have seen a gradual increase in secondary and higher education in Poland [72].

In Poland, the knowledge about the RE, including the SHP, is still too superficial. The average Pole does not know how much electricity is produced or how a power plant operates. In "energy education", the kindergartens and primary schools play very important role, whereby educating children often results in the parents receiving the "ecological knowledge" through their own children. The already existing installations of the SHP should play the leading role in the education of the society. Getting to know how RE installations operate, including SHPs, will reduce the reluctance to this type of installation in Poland [4,11].

The hydropower sector, the same as the solar energy sector, is favorably supported by the Polish society. Some investments still have their opponents, but, most frequently, it results from ignorance about the benefits of the SHP. The investor's task is to inform local communities about the project, construction and operation of SHPs [4,11].

In recent years, the interest in RE has increased, so that about 50 universities in Poland expanded their offer to include RE-related studies. Hydropower is a subject of classes at many Polish universities as part of the "Renewable energy sources" course.

As it has been mentioned before, the dynamically developing RE market requires employees, and most often from the rural areas. The development of SHPs may to some extent reduce the unemployment in the rural areas of Poland. Moreover, SHPs may constitute for the rural community an element stabilizing the energy system based on distributed energy facilities.

The membership in the EU, and thus the lack of borders, brought closer all people associated with the SHP. They can meet at joint conferences to exchange their experiences in the field of the hydropower.

6.4. PEST Analysis—The Technological Environment

The surroundings of SHPs in Poland in the context of its development potential is shown in Table 4.

Table 4. The technological environment of the SHPs in Poland in the context of its development potential.

	Factor	Friendliness of the SHP
1.	The developments in the SHP and the RE sectors	3.00
2.	The power grid condition in Poland	1.00
3.	The availability of the SHP installations	3.50
4.	The usage of the water dams for constructing the SHP	4.00
5.	The ability of economy–science cooperation	2.00
6.	The efficiency of obtaining energy from water	4.00
7.	Transfer of technology and technician	5.00
	General assessment	**3.21**

The SHP and RE sectors are the fastest growing branches of the economy in the world and in Poland. Numerous studies in research centers resulted in an increase in the efficiency of obtaining energy from RE sources, as well as a decrease in the prices of RE installations. Every year, several dozen SHP installations are constructed in Poland. The investors and owners are supported by the Towarzystwo Rozwoju Małych Elektrowni Wodnych TRMEW Sp. z O.O. (Small Hydro Power Development Association TRMEW Sp. z O.O.) [73], as well as the Małe Elektrownie Wodne (Small Hydro Power Plants) [74]. The industry quarterly journal called *Energetyka Wodna* (*Hydro Power*) was published, in which the innovative activities in the field of the SHP in Poland and abroad are discussed.

The electricity network in Poland is outdated and overloaded. The RE investors increasingly face problems with connecting the plants to the power grid. What is worse, many investments, mainly the wind mills, remain only on a paper, and the permits issued for the connection curtail the real investments in Poland.

As of today, no problems are met while purchasing the entire SHP installation or its specific part in Poland. Investors can use the services of both domestic and foreign companies. Some of the investors apply and implement their own technological ideas.

There is still a poor cooperation between the industry and science in Poland. Universities create publications or patents about which the SHP sector knows nothing. On the other hand, the technological needs of the SHP rarely find a response in the form of scientific research.

The hydroelectric power plants produce electricity with twice the efficiency (60–80%) of conventional coal and brown coal (36%) in Poland.

Poland's membership in the EU (knowledge transfer and cooperation within the European Research Area), the development of telecommunications techniques and the development of the information society are a chance for the development of the potential of SHPs.

7. Technical Potential in Hydropower Plants in the Voivodeships—Empirical Results

The authors used the following methodology for calculating the technical potential of hydropower. Power P distributed to the network by a hydropower plant assuming ρ = 1000 kg/m^3, and g = 9.81 m/s^2 is:

$$P = 9.81 \cdot Q \cdot H \cdot \eta \tag{1}$$

where:

Q—the volume of a stream of water flowing through the turbine within 1 s (capacity of water turbine) (m^3/s)′

H—head (m);

η—efficiency of the water turbine, the gear and the generator.

Assuming the efficiency at the level of 85%, we obtain the following model:

$$P = 8.34 \cdot Q \cdot H \tag{2}$$

Assuming that the power plant will operate at its full power of 6000 h/year, the amount of energy E_k from the hydropower plant will be:

$$E_k = 21.6 \cdot P \tag{3}$$

The detailed analysis of the water dams located in every region of Poland was carried out. It is worth stressing that such an analysis has not been carried, to date. On the basis of the Formula (2), the power of hydropower plants that can be obtained in each voivodeship was calculated. These are almost exclusively for the SHPs. The location and power of hydropower in the individual voivodeships in Poland are presented below (Table 5). The data for the location, damming height and flow were obtained from the National Water Management Authority. This made it possible to determine the power of the power plant.

Table 5. Potential of SHPs in Poland (own elaboration).

Voivodeship	Capacity [kW]							
	Below 5	5–10	10–20	20–50	50–100	100–500	Above 500	All
Dolnosląskie	582	204	177	171	89	204	34	1461
Kujawsko-Pomorskie	57	23	46	40	12	21	15	214
Lubelskie	356	166	220	77	18	9	1	847
Lubuskie	180	24	32	44	18	46	37	381
Łódzkie	463	82	92	103	57	21	2	820
Małopolskie	1517	462	195	131	48	35	4	2392
Mazowieckie	1620	115	143	108	52	12	2	2052
Opolskie	244	81	58	43	21	13	30	490
Podkarpackie	505	83	62	37	13	20	7	727
Podlaskie	171	52	50	27	12	16	1	329
Pomorskie	154	95	88	67	35	48	3	490
Śląskie	910	201	146	171	35	15	3	1481
Świętokrzyskie	258	51	55	64	34	16	1	479
Warmińsko-Mazurskie	230	58	49	87	43	33	2	502
Wielkopolskie	1836	187	129	130	39	32	21	2374
Zachodniopomorskie	853	92	86	54	23	36	2	1146
Poland Summary	**9936**	**1976**	**1628**	**1354**	**549**	**577**	**165**	**16,185**
	16,185							

The power of all potential hydropower plants in the Dolnosląskie voivodeship on dams is 95.2 MW (Figure 6).

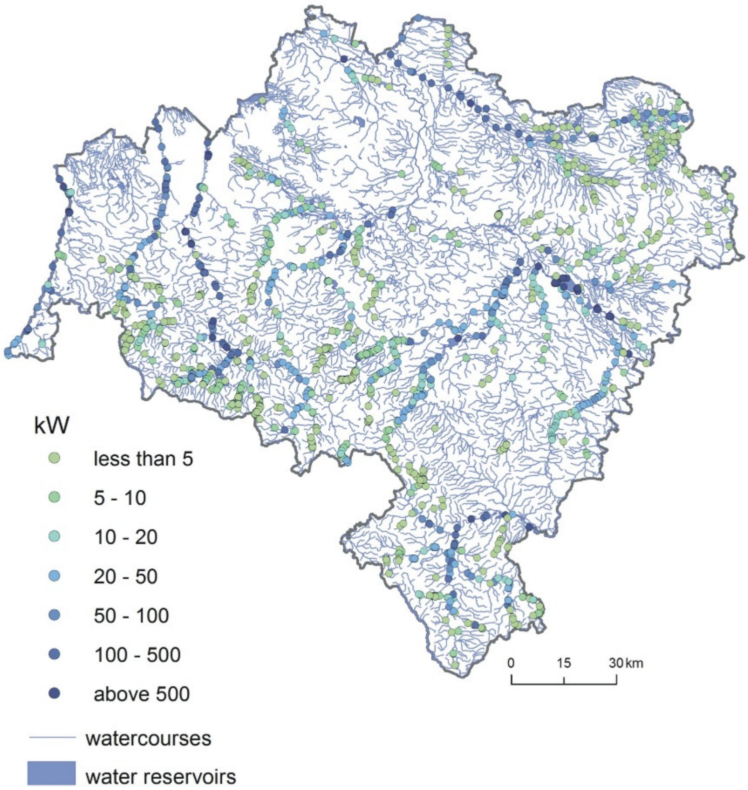

Figure 6. Localization of water dams and power of the potential hydropower plants in the Dolnośląskie voivodeship (own elaboration).

The power of all the potential hydropower plants in Kujawsko-Pomorskie voivodeship on dams is 95.2 MW (Figure 7) is 28.6 MW.

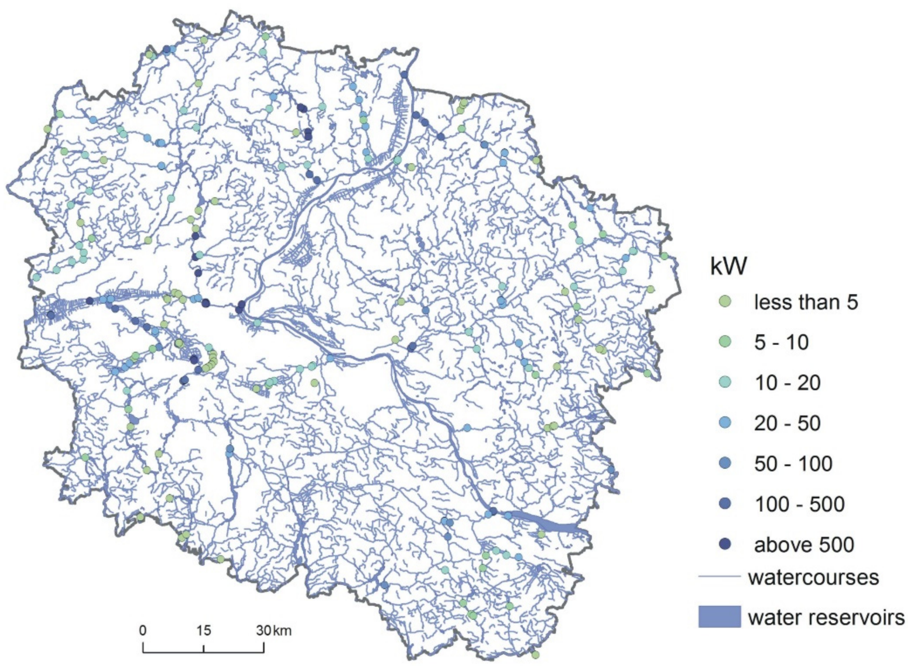

Figure 7. Localization of water dams and power of the potential hydropower plants in the Kujawsko-Pomorskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Lubelskie voivodeship on dams is 9.0 MW (Figure 8).

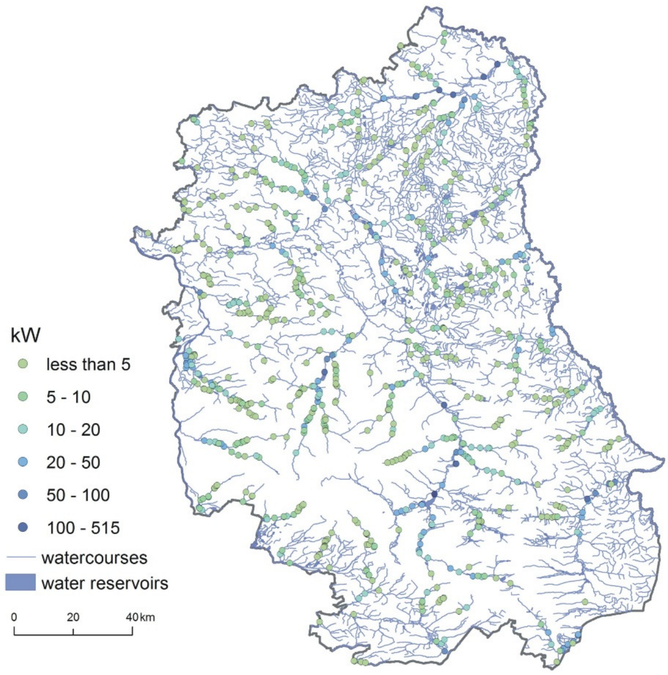

Figure 8. Localization of water dams and power of the potential hydropower plants in the Lubelskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Lubuskie voivodeship on dams is 54.4 MW (Figure 9).

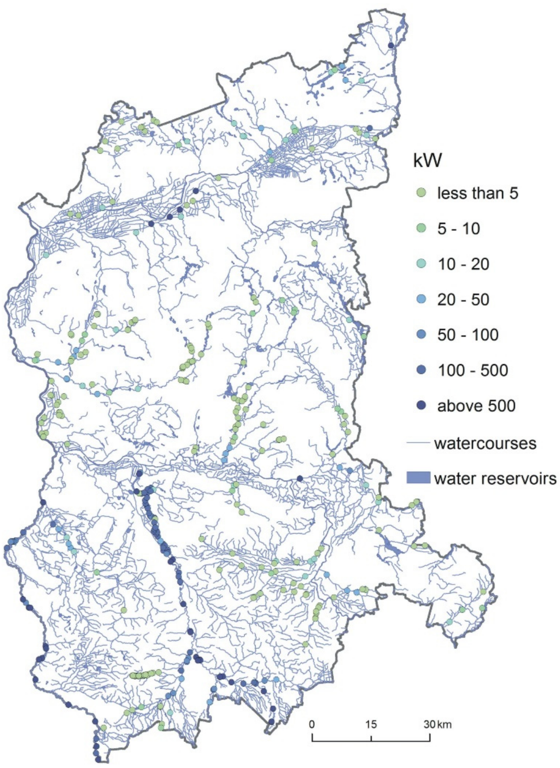

Figure 9. Localization of water dams and power of the potential hydropower plants in the Lubuskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Łódzkie voivodeship on dams is 21.1 MW (Figure 10).

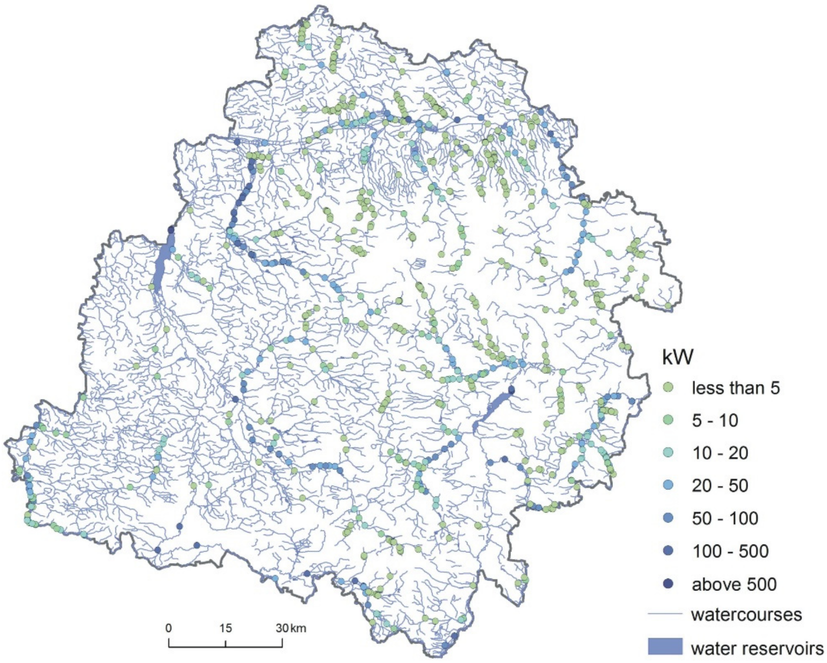

Figure 10. Localization of water dams and power of the potential hydropower plants in the Łódzkie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Małopolskie voivodeship on dams is 101.0 MW (Figure 11).

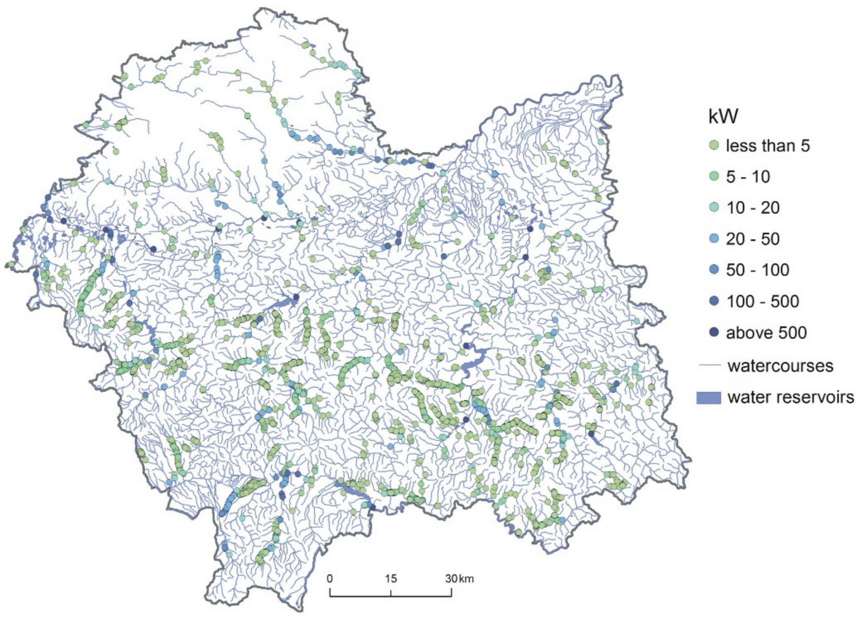

Figure 11. Localization of water dams and power of the potential hydropower plants in the Małopolskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Mazowieckie voivodeship on dams is 14.8 MW (Figure 12).

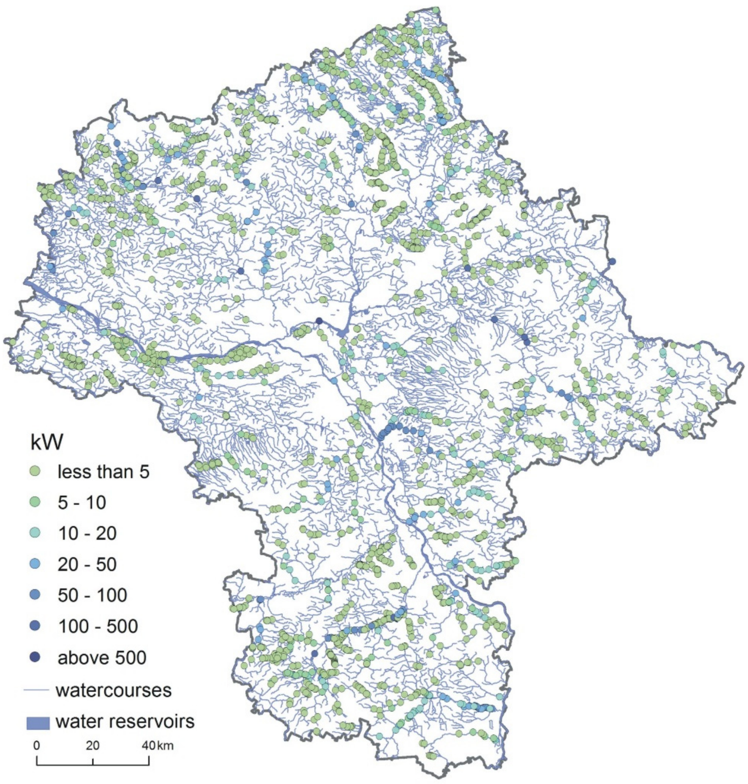

Figure 12. Localization of water dams and power of the potential hydropower plants in the Mazowieckie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Opolskie voivodeship on dams is 53.8 MW (Figure 13).

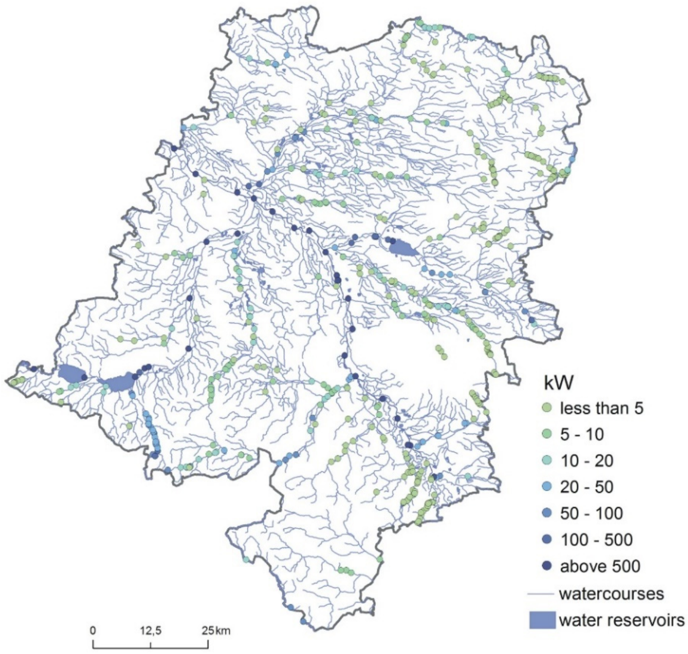

Figure 13. Localization of water dams and power of the potential hydropower plants in the Opolskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Podkarpackie voivodeship on dams is 14.2 MW (Figure 14).

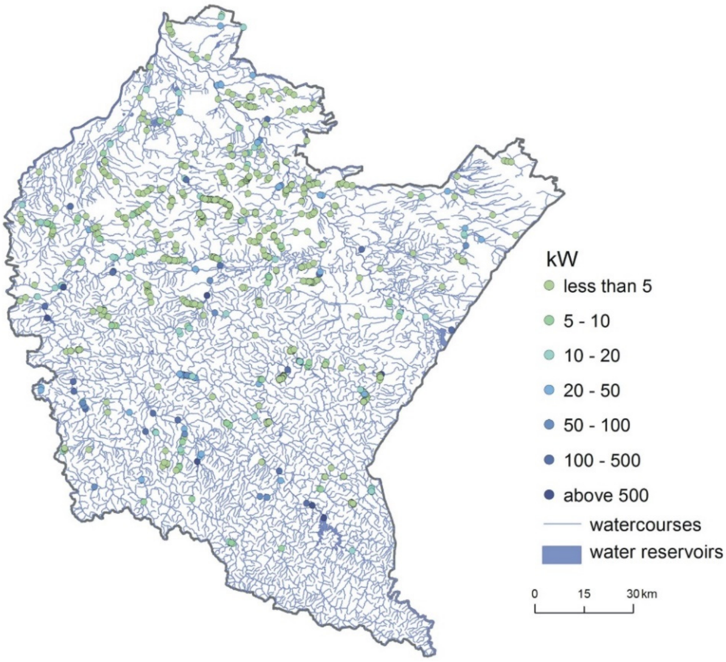

Figure 14. Localization of water dams and power of the potential hydropower plants in the Podkarpackie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Podlaskie voivodeship on dams is 7.4 MW (Figure 15).

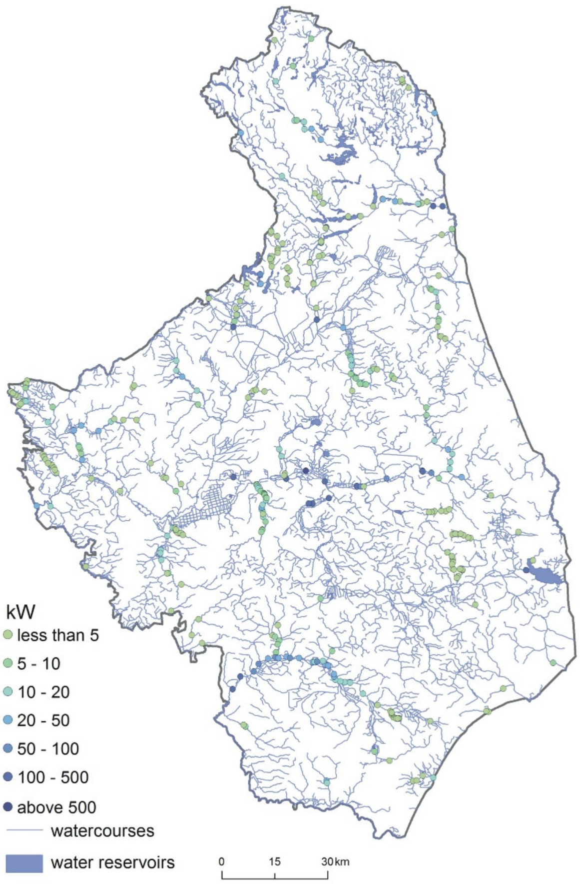

Figure 15. Localization of water dams and power of the potential hydropower plants in the Podlaskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Pomorskie voivodeship on dams is 20.0 MW (Figure 16).

Figure 16. Localization of water dams and power of the potential hydropower plants in the Pomorskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Śląskie voivodeship on dams is 22.1 MW (Figure 17).

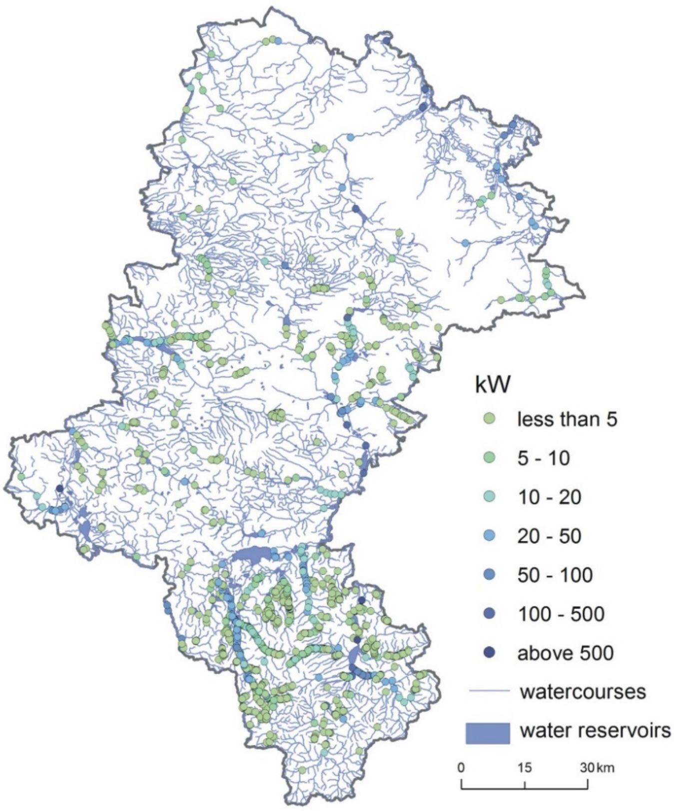

Figure 17. Localization of water dams and power of the potential hydropower plants in the Śląskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Świętokrzyskie voivodeship on dams is 11.5 MW (Figure 18).

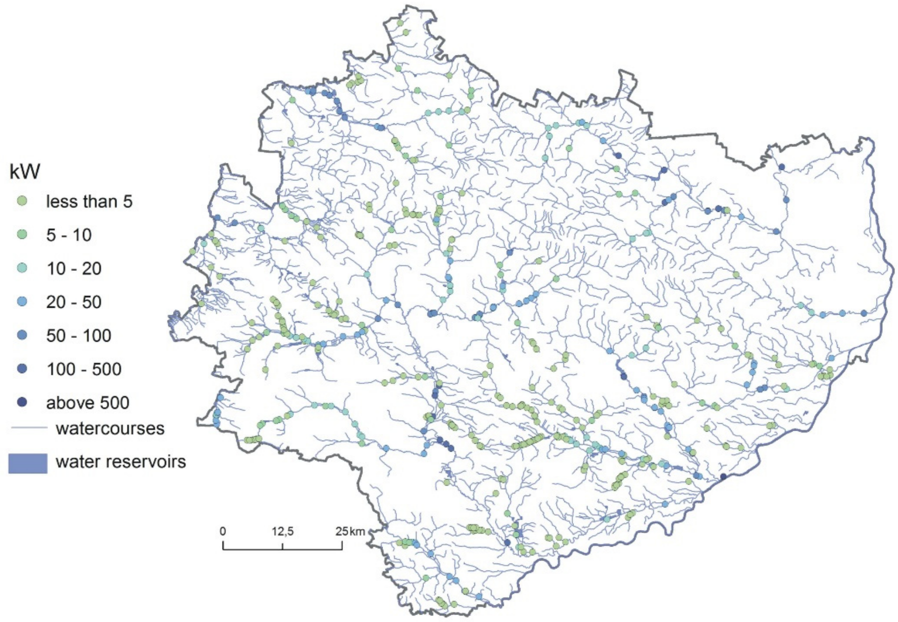

Figure 18. Localization of water dams and power of the potential hydropower plants in the Świętokrzyskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Warmińsko-Mazurskie voivodeship on dams is 16.3 MW (Figure 19).

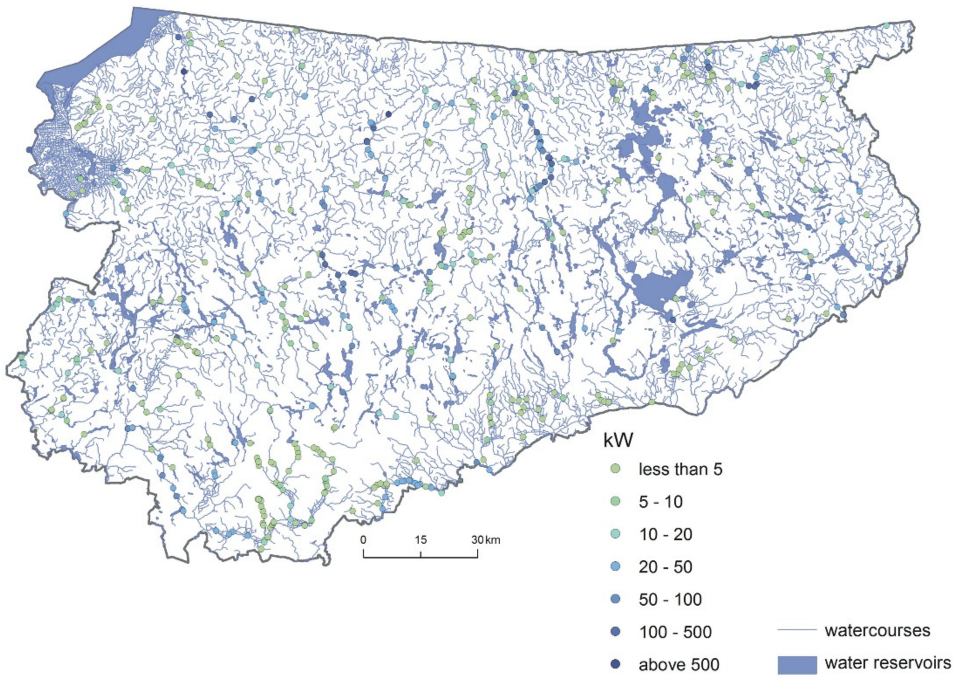

Figure 19. Localization of water dams and power of the potential hydropower plants in the Warmińsko-Mazurskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Wielkoposkie voivodeship on dams is 35.1 MW (Figure 20).

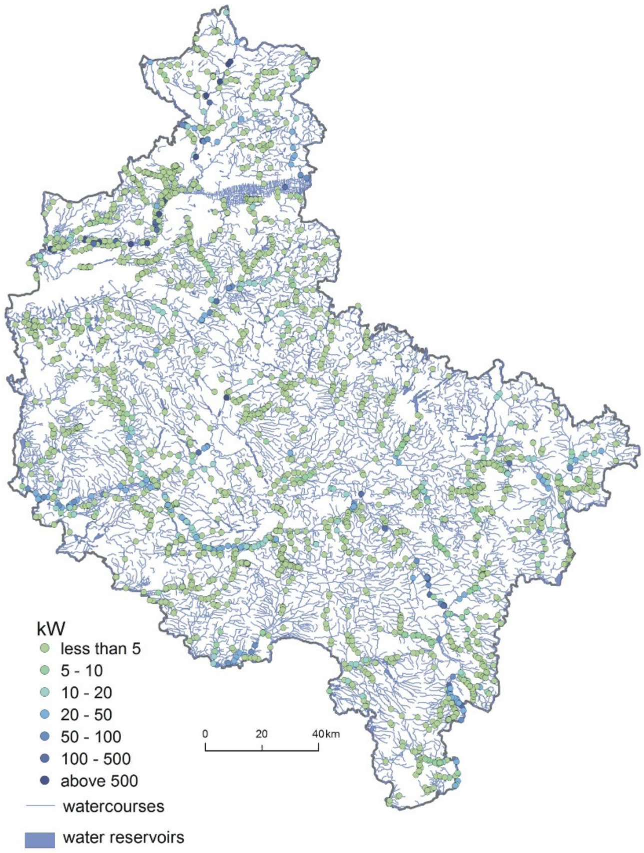

Figure 20. Localization of water dams and power of the potential hydropower plants in the Wielkopolskie voivodeship (own elaboration).

The power of all the potential hydropower plants in the Zachodniopomorskie voivodeship on dams is 18.9 MW (Figure 21).

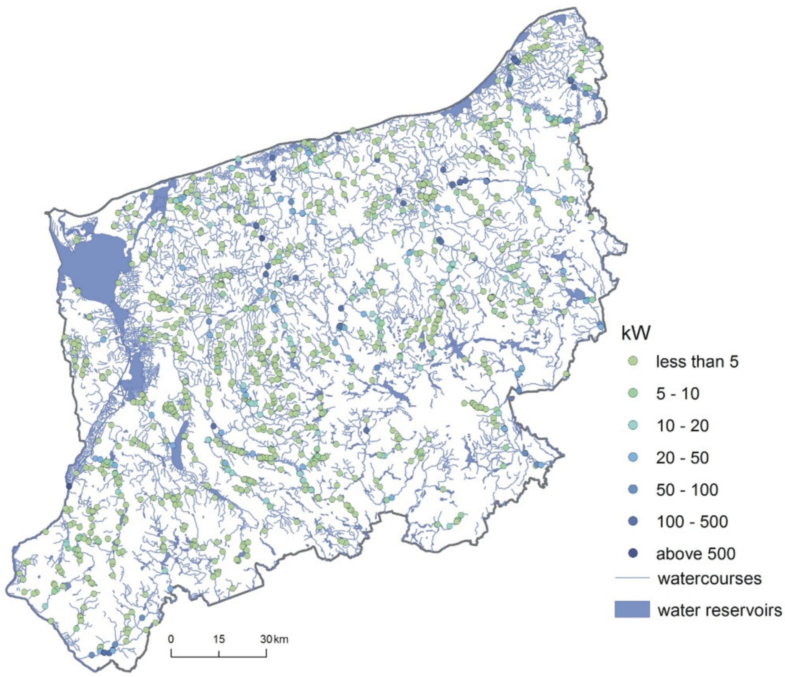

Figure 21. Localization of water dams and power of the potential hydropower plants in the Zachodniopomorskie voivodeship (own elaboration).

8. Discussion and Summary

It is estimated that the use of hydropower resources in Poland is only 19.4%. In comparison, France uses almost 100%, Norway 84% and Germany 80%. The implementation of new technologies, such as turboregulators, enabling the use of charge weirs or flood waters enabling water damming without the need to carry out most of the hydrotechnical works, may bring additional energy gains, which allows for a significant reduction in investment costs in SHPs.

Energy in Poland is mainly produced from coal. The energy transformation of Poland towards RE sources has been observed for several years. Until 2016, wind energy was developing rapidly, and the last 2–3 years were the development of prosumer photovoltaics. However, the development of RE sources must be based on a mix of various energy sources, including hydropower.

Hydropower is a stable source of energy that allows for the production of energy with an efficiency that is approximately twice as high as in the case of coal-based energy. SHPs can be a local source of RE, increasing energy security. The quickest and cheapest way to incorporate them is by placing them on the already existing water dams (for instance, locks and weirs). Our analysis shows that there are 16,185 such dams in Poland, and the possible power to obtain is about 523.6 MW. This would give work to 524 people. For the first time, the locations and power of the SHPs in Poland are presented, broken down into individual voivodeships.

Many of the dams shown in Figures 6–21 are several hundred years old. In these places, there were mills and other factories that used hydropower. The use of hydropower in Poland was widespread and at a high technical level. Water mills and hydroelectric power plants were destroyed during or after World War II—but the dams remained. When developing the mix of RE in Poland, these dams should be used and an SHP should be erected there.

The development of SHPs in Poland should go directly towards a small hydropower plant based on already existing dams. The use of already functioning water dams allows you to reduce investment costs. The SHP is associated with the small retention, which is of very important in the Polish steppe. The construction of the SHPs may bring other significant economic and environmental benefits. They include:

- Diversification of the ecosystems existing within the dam and the surrounding area;
- Creating rest and recreation places;
- Current monitoring of water quality;
- Constructing the fish passes.

The development of SHPs in Poland will also increase the so-called "small retention" in the Polish steppe. Small dams have little impact on the local ecosystem and ensure water "retention" in the environment.

The present study assumes that the obtaining of electricity in SHPs does not imply the emission of CO_2 into the atmosphere (closed CO_2 system). The share of electricity from lignite is 40%, while the share of the hard coal is 60% in Poland (including only hard coal and lignite). Then, CO_2 emissions from the combustion of conventional fuels in power plants and combined power and heat plants would amount to:

$$WE = u_h \cdot WE_h \; u_l \cdot WE_l \tag{4}$$

where *WE*—indicator of carbon dioxide emissions from hard coal and lignite combustion (kg/GJ),

u_h—share of the hard coal in energy production;
u_l—share of the lignite in energy production;
WE_h—indicator of carbon dioxide emissions from hard coal combustion (kg/GJ);
WE_l—indicator of carbon dioxide emissions from lignite combustion (kg/GJ);
WE_h amounts to 95.48 kg/GJ, WE_l 110.76 kg/GJ and calculated *WE* 101.59 kg/GJ [75].

The annual avoided emission of carbon dioxide would amount to 4.4 million tons, which allows for the reduction of Poland's emissions by 1.4% [76].

In the case of the PEST analysis, the political environment of SHPs in Poland can be described as unfavorable (2.86 points). Membership in the EU (5.00 points) and the RE Act (4.00 points) is a chance for the further development of SHPs in Poland. The greatest threat is the lobby of fossil fuels (1.00 points).

The economic environment of the PEST analysis (3.86 points) should be considered as quite beneficial to the further development of SHPs in Poland. Globalization and participation in the EU (5.00 points) offer an opportunity for further development. The greatest threat is the low ability to finance SHP investments from personal funds (2.00 points).

In turn, the social environment of the PEST analysis can be considered as neutral (3.36 points). The greatest opportunity for the development of SHPs is EU membership (5.00 points), and the greatest threat is the rather unfavorable demographic situation of Poland (1.00 points).

The technological environment of the PEST analysis can be considered as neutral (3.21 points). The transfer of technologies within the EU is a chance for development (5.00 points), and the greatest threat is the poor condition of the power grid in the country (1.00 point).

The technical potential of SHPs is presented based on the existing damming in Poland. The "real" potential may be lower or the investments will drag on for years, because the construction of SHPs, for example, is not included in the spacial development plan for the area in which the power plant may be built. Investing in SHPs is also not a "cash jump", as the investment costs are high, so the investment may pay-off only after several years. However, what is an important advantage is the longevity of the SHPs. Many of the operating hydropower plants in Poland are 100 years old and are still operating efficiently. An investment in SHPs is an investment for years, which in Poland is often taken over by the children and grandchildren of the investors.

To sum up, in the near future, we should focus on educating the public about the SHP. The next step should be to simplify procedures so that it is easier to invest in SHPs. In the first place, it should utilize already existing water dams, increasing energy security as well as the small water retention.

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