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Review

Hydropower in the Energy Market in Poland and the Baltic States in the Light of the Challenges of Sustainable Development-An Overview of the Current State and Development Potential

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Abstract: The energy crisis is affecting a number of countries, but particularly those that are heavily dependent on the traditional energy generation formula (e.g., Poland), as well as those neighbouring the territory of the ongoing war in Ukraine, i.e., Poland, Lithuania, Latvia and Estonia. With this in mind, the authors of this study decided to explore the issue of water energy as a source of green (cheap and environmentally safe) energy in these countries. The main objective of the paper is to review the available literature, which is needed to identify the role hydropower plays in energy security and energy transition in these energy markets. This paper is based on a review and critical appraisal of the available literature and studies together with an inference. The structure of the paper consists of an introduction, the main part of the review and conclusions. The geopolitical location and socio-economic conditions of the adopted set of countries, form the basis of the review of the existing literature on the theme explored and the substantive inference. The main findings of this review indicate that the literature is most strongly focused on the overall assessment of the energy transition of the adopted countries for review, where the hydropower thread is most often taken up as one source of renewable energy supply. Hydropower, due to its relatively low share in the energy systems of the adopted set of countries, is, according to the authors, insufficiently explored. The most significant gap relates to the aspect of the potential for hydropower development in these areas, considering both the construction of new hydropower plants and opportunities signalled in the literature for the modernisation or restoration of existing ones. In this respect, the need for analyses (studies and simulations) of hydropower development, considering the economic benefits associated with their development juxtaposed with the safety dimension of this course of action for the environment (analysis and assessment of environmental costs) is indicated, which is the main recommendation of the review.

Keywords: clean energy resources; renewable energy; hydropower; green energy technologies; sustainable energy; energy market; electricity prices

1. Introduction

Modern times have created a number of challenges for countries, businesses [1] and communities. Decades of human existence in the socio-economic dimension have left their irreversible mark on the natural environment, the deepening of which is a priority for development policies at the level of individual economies. Changes to the natural environment include the overexploitation of natural resources, the disruption of water management and the functioning of ecosystems, as well as environmentally harmful discharges and emissions that are by-products of a range of manufacturing technologies, in which the energy sector plays a particularly important role. In the context outlined above, a transition towards renewable energy sources appears to be absolutely the right thing to do.

The energy crisis and the increase in fossil fuel prices has hit energy consumers around the world hard, particularly in countries dependent on conventional coal-fired power generation technology that are burdened by the serious rising costs of greenhouse gas emission allowances (e.g., Poland). In addition, a drastic increase in prices has been created by the war in Ukraine and the economic restrictions related to it, which particularly affects countries neighbouring the territory of the conflict, most of which have been heavily dependent on fossil fuel supplies from its parties for years (e.g., Poland and the Baltic States). This situation is having a significant impact on the socio-economic sphere, as energy is an essential determinant of its functioning. This background reinforces the significance of energy security as a fundamental challenge in maintaining the functioning of economies.

In response to the above challenges, the authors of this study decided to review the available literature to identify the role of hydropower in energy security in the selected countries and its importance in the energy transition of their economies. The abundance of general considerations in the sphere of energy transition and energy security of the world's economies indicates the existence of a gap in the sphere of considerations on this topic carried out at the level of the countries considered in the review, with particular reference to water movement as a renewable source of energy supply. A review of the literature carried out in relation to the above thesis will make it possible to determine the directions in which it needs to be supplemented, in order to support pro-development solutions in the sphere of increasing energy security and the energy transformation of the selected countries.

The geopolitical location and socio-economic conditions of the adopted set of countries form the basis of the review of the existing literature in the field of the explored theme and substantive conclusions.

The structure of the review consists of an introduction (Section 1), a main section (Section 2), and conclusions (Section 3). The main section opens with an introductory literature review on energy transition-its background and directions, and the energy security of economies. It continues with a review of the literature addressing the issue of renewable energy with a focus on energy from water movement-including its potential in light of current trends in energy market developments. It further reviews the findings of the literature relating to the challenges of energy from water (including those touching on the technological sphere) and the role it plays in energy security and the energy transition of the selected countries, allowing reference to be made to the thesis adopted in this review.

This review paper is based on a critical appraisal of the available literature and studies together with a conclusion. It covered the available literature with reference to industry reports and statistics in the field of hydropower in Poland and the Baltic States, as well as statistical studies, which are studies related to the European Union energy market. Literature was searched in databases such as Web of Science, Scopus, Google Scholar, Eurostat, among others, based on keywords included in the following phrases: "hydropower in Poland, Lithuania, Latvia and Estonia", "water resources of Poland and the Baltic States", "share of hydropower in RES in Poland and the Baltic States", "hydropower potential of Poland and the Baltic States", "hydropower development in Poland and the Baltic States", "hydropower efficiency in Poland and the Baltic States", and including names of selected rivers and hydropower plants, with the term "Poland and the Baltic States" used interchangeably with "Poland, Lithuania, Latvia and Estonia" in the search process.

The literature review involved a literature selection (critical review) in terms of its fit with the adopted review objective, oriented towards identifying the role of hydropower in energy security in the selected countries and its importance in the energy transition process of these economies, as well as an assessment of the available literature resources in terms of identifying the required directions for further hydropower penetration in the adopted countries. This is because the abundance of general considerations in the sphere of energy transformation and energy security of the world's economies indicates the existence of a gap in the sphere of considerations on this topic in relation to the selected configuration of countries.

For the findings of the above, the literature adopted for the review was assigned to the following thematic threads in relation to the adopted countries:

x_1-renewable energy sources including waterpower, energy transition including hydropower;
x_2-hydropower conditions (hydropower resources, hydropower potential) of the countries;
x_3-technique and technology in hydropower;
x_4-hydropower plants, share of hydropower in RES and energy mix of countries;
x_5-economic justification of hydropower plants;
x_6-hydropower plants in the light of environmental aspects;
x_7-social aspects of hydropower development.

Further evaluation of the literature was done in terms of its relevance to this review, in terms of assessing the degree of discussion of the problem in relation to the countries adopted for the review and the following categories were assigned:

A-problem discussed to a high degree;
B-problem discussed to a medium degree;
C-problem poorly addressed.

The evaluation categories, according to the applicability of the considerations of the review, reveal the scale of the need for further research and additions to the literature in relation to the adopted country configuration. The distribution of the results obtained is visualised in the summary.

The layout of the review (scope of the review, arrangement of key words, evaluation criteria, input into the review) has carved out its limitations, which are also influenced by differences in the methodology of defining the various scopes in the literature. In addition, the layout of the countries adopted for the review limited the comparative spectrum to their area. This literature review is intended to serve as a general overview of the literature in the sphere of the issues explored and to outline further needs for its exploration in line with the stated aim.

2. Hydropower in Poland and the Baltic States in the Light of Energy Transition and Energy Security-Literature Review

2.1. Introductory Literature Review on Energy Transition and Energy Security of Economies

The literature strongly emphasises the importance of energy for the uninterrupted functioning of the socio-economic sphere [2–4], locating it as a driving force for the development of economies [5–8]. Hence, the literature recognises the provision of energy security [9–12] at the state level as an absolute necessity, as highlighted by P. D. Williams et al., F. Hedenus et al., C. Flaherty et al., and C. Winzer. In addition, Rehman et al., point to the need for an orientation towards reducing energy production based on conventional energy generation formulas-that are disruptive to the environmental economy [13]. Hence, the indicated direction towards which world energy policies are oriented is energy production based on renewable energy sources, as signalled by S. A. Apostu et al. and M. Panait et al. [14,15], which are opening the way to cheap and environmentally safe energy [16]. The above is captured in the sustainable development agenda of the countries of the world affiliated to the UN (e.g., in the regulation "The 2030 Agenda for Sustainable Development", as pointed out by D. J. Sachs [17]), and in the sustainable development regulations of the European Union (e.g., Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and the amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [18]). A review of the sources reveals that the objective of sustainable development and the energy market development policy adopted according to it, globally or at the level of the European Union [19], is the decarbonisation of the electricity system and the improvement of its flexibility [20], as well as (as a dimension of the contemporary energy strategy included in the European Union norms) [21]:

(a) increasing energy efficiency through energy production based on renewable sources;
(b) increasing the degree of innovation in the sphere of obtaining energy from renewable sources, together with the promotion of energy from renewable sources, in order to strengthen the adopted direction of change in the energy sector;
(c) orientation towards market-oriented [22] energy cooperation of economies with support for innovative technological solutions to ensure access to green, cheap energy;
(d) strengthening the energy security of economies as a derivative of the above elements.

The above points to the importance of greening the energy dimension on the way to achieving a certain degree of energy self-sufficiency, as emphasised by G. Bahgat [23], and establishing a formula for energy supply with the capacity to cover the state's needs, at an affordable price (energy security according to the approach of P. D. Williams and M. McDonald, or A. Cherp and J. Jewell) [9,24]. In this sphere, M. X. Lin et al. emphasise the influence of economic and environmental conditions on the energy transition process towards low-carbon energy production. J. Chovancová and J. Tej supplement the above with the theme of economic efficiency [25], which, according to W. E. Rees and I. Overland leads to increased attractiveness and competitiveness of economies [26]. The social aspect is also important [27] and can be jointly assessed using the informative PEST method, which considers the political, economic, social and technological aspects of the measure in question. The above is discussed more extensively by, among others, A. Gupta, or L. Racz et al. [28,29].

There are many ways of obtaining energy from renewable sources. In addition to energy from the sun [30], wind [31], earth energy [32], or biogas [33], discussed by the authors of this review in separate studies, water can be a source of energy supply by driving hydroelectric power plants. For years, the movement of water has been regarded as having important energy potential, giving it a prominent role among RES sources, as pointed out by C. Llamosas and B. K. Sovacool, A. Demirbas, P. S. Nigam et al., W. Guo et al., F. Qu et al., and K. Spanoudaki et al. [34–39]. The share of energy from water in the global energy system is assumed to increase intensively by 2050, as articulated by Hamududu et al. [40]. According to the International Energy Agency, hydropower aspires to be the most powerful source of renewable energy supply in the future, hence it is expected to play the most important role in decarbonising the world's energy system [18]. This thesis has been raised in the literature, including in studies by C. Llamosas and B. K. Sovacool [34,41], among others, which justify the need, noted by the authors, to perform this review in relation to the established objective of the study.

According to a report by A. Bartle, in 2009, energy production from water supplied about 16% of the world's electricity system (about 3551 TWh/year), with a 26% generation share, under the criterion of total installed capacity [42]. Since then, a steady increase in global hydropower production at an average of 2.3% per year has been indicated, with an average of 3.1% per year in the European Union, giving rise to projections of further growth at a rate of 2.4–3.6% per year until 2030, as indicated by B. Hamududu and A. Killingtveit [40]. Importantly, the hydropower potential of the world has been highlighted for a number of years, with an emphasis on the Asian region (China) and the countries of Europe [43], in particular Eastern European countries, as highlighted by B. Lehner et al. [44]. Investment in hydropower technologies-oriented towards the extraction of energy from water is, according to R. Peters et al., a recognised course of action [45] for strengthening the RES energy market and protecting the environment. In doing so, it is worth pointing to the layout of the world energy system in 2020, which-according to the IEA report-assumed the following structure [43]: hydropower: 29%, coal: 28%, natural gas: 27%, oil: 8%, nuclear: 3%, other sources: 3%.

R. Peters et al. point out that in recent years hydropower has reached a level of about 60% of the share of energy generated from renewable sources in the world [45], with a global capacity in excess of 1300 GW [46], and with 7.5% of hydropower capacity contributing to the world's installed RES capacity [47]. According to the International Energy Agency, the global capacity addition in 2020 was 21 GW, with a global annual net zero energy production of 4418 TWH, showing a 3% increase [43]. The IEA indicates that the world leaders in waterpower generation are China (44.1 TWh), followed by the European Union (8.5 TWh), Turkey (6.2 TWh), the United States (5.3 TWh), and strongly followed by India (3.9 TWh) and Brazil (3.8 TWh) [43].

Following widespread recognition that the movement of water is the most efficient and irreplaceable source of renewable energy-signalled by B. Wagner and others [48], there has been a significant development of hydroelectric power plants. As reported by C. Zarfl et al., the observed boom in this field includes planned or ongoing investments in a number oscillating around 3700 projects, with capacities exceeding 1 MW [49]. The strongest expansion of hydropower in the period 2021–2030, according to the IEA, is projected for China (93 GW), followed by the Asia-Pacific region (64 GW), Europe, Eurasia and North America (33 GW), Africa and the Middle East (24%) with 86% from emerging and developing countries, and Latin America (15 GW) [43].

According to the International Hydropower Association, investments in the current decade are likely to be in the region of EUR two trillion and could create some 600,000 new jobs [50]. E. Branche points out that investment in hydroelectric power is an important aspect of decarbonising the environment and stabilising the energy system [51], while at the same time increasing the energy security of economies and orienting towards energy price optimisation while strengthening the global labour market. The development of this energy field is therefore justified, as argued in a number of referenced sources.

The literature review presented indicates the number of studies presenting introductory content. This breadth of the review indicates a worldwide openness to obtaining energy from renewable sources juxtaposed with the common view of a strong, inexhaustible source of energy located in the potential of moving water. This is an important strand in energy transition, which can bring consumers closer to low-cost energy from renewable sources and higher energy security.

The outlined dimension is an introduction to a further overview of the issues explored at country level-following the layout presented in the introduction.

2.2. The Potential of Water in Hydropower-A Review of the Literature on the Subject

Nearly 71% of the globe's surface is covered by water [52,53], hence water is seen as having the most significant potential for an emission-free energy supply, which, as E. Przybyło points out, has been estimated at 2.857 TW, with its use at less than 6% [54]. The essence of deriving energy from water is a process of converting potential energy into kinetic energy based on the movement of water using water turbines (or wheels) and power generators. The extraction of energy based on this energy conversion process is applied in classical hydroelectric power plants that draw on the mechanical energy of flowing water or set water in motion using dams (requiring extensive infrastructure). A modern solution in this area indicated in the literature is the use of innovative technologies in the form of hydrokinetic turbines placed directly in a body of water, which derive energy from the flowing water of rivers, as well as waves, tides and currents [55]. The spectrum of hydropower is widely discussed in the literature highlighting, among other things, the fact that the energy of waves, tides and currents is created differently from that of flowing water and carries different energy potentials [56]:

- Offshore wave energy is generated as a result of the interaction between wind and water, initiated by solar energy causing gusts of wind, creating an energy potential of 3 TW;
- Tidal energy is generated from the movement of water masses due to the interaction of the Earth's gravitational forces, as well as the Sun and the Moon, creating an estimated energy potential of 200 GW [56];

- The energy of ocean currents, which is derived from the interaction of wind, temperature differences, water density and changes in atmospheric pressure, can create an estimated energy potential of 7 TW.

The energy of waves and currents is considered to be the energy with the highest potential, as highlighted by R. Cascajo et al. and D. Curto et al. [57,58]. For hydropower purposes, water resources such as thermal energy of the seas and oceans, or diffusion energy, generated due to the difference in salinity concentrations of fresh, saline water resources, can also be used, and the conversion process can be realised using water engines (turbines), hydrogenerators in hydropower plants, or hydroelectric power plants [59]. Depending on the existing hydropower potential, the following solutions specific to [59] are used:

(a) Inland water resources:
  - Run-of-river power plants (stream HPPs) without water storage, dedicated to deriving energy from the mechanical energy of flowing rivers (with continuous flow of the watercourse);
  - Derivative power plants, dedicated to deriving energy from rivers with a strong current but little flow, by damming them higher and increasing their output;
  - Reservoir (regulating) power plants, which accumulate water to compensate for potential power drops that adversely affect the generation time of a unit of energy;
  - Pumped storage (hydro-accumulating) power stations, a variant of regulating power stations with double reservoirs (water accumulating), which generate power independent of the force of water flow by pumping water between reservoirs.

(b) Marine water resources:
  - Tidal power plants (tidal HPP), oriented to derive energy from the movement of sea and ocean water masses (tides);
  - Wave power plants, oriented towards the extraction of energy from sea waves.

A review of the literature on the subject indicates that hydropower is not a new subject—it had its beginnings in Eastern Europe at the end of the 19th century and, for example, in the 1920s and 1930s in Poland there were about 8000 facilities using water for energy production, and the year 2012 revealed the existence of about 14,000 facilities damming water for this purpose [47]. Taking into account the historical outline, hydropower abounds in a number of solutions, characterised by varying degrees of technological advancement and the associated level of flexibility of solutions to changes created by forces of nature or climate change. Of the solutions currently in practice, pumped hydro energy storage plants (PHES) are highly regarded as the most economical in terms of storage and cycle efficiency, as indicated by G. Pavesi et al., J. S. Anagnostopoulos et al., B. Steffen, [60–62] and Y. Liu and W. Guo, and J. G. Brown [63,64].

The literature points to the number of determinants of hydroelectric power capacity (e.g., A. Gupta et al., E. Asmelasch et al., E. F. Moran et al., S. Stenovic et al., P. Punys et al.) [65–69], with a range of solutions dedicated to differentiated needs in the sphere of water energy extraction. We are talking about the power of solutions and the division of power plants formed on this basis where, as E. Przybyło points out, one distinguishes [54]:

- Pico power plants, with negligible power-max. up to 5 KW;
- Micro power plants, with low power ranging from 5–100 KW;
- Mini power plants, with output ranging from 100 KW to 1 MW;
- Small power plants, with a capacity of 1–15 MW;
- Medium-sized power plants, with a capacity of 15–100 KW;
- Large power plants, with a capacity exceeding 100 MW.

The diversity of solutions in terms of the operation formula and power of hydroelectric installations creates wide potential for their proper selection in order to combine the economic aspect of the undertaking with the best effects in the sphere of impact on the environment, taking into account environmental protection. This is an extremely important observation from this part of the literature review.

2.3. Hydropower Considerations in the Light of Hydropower Development in Poland and the Baltic States-Results of Literature Findings

According to the UN Global Compact Network Poland report 'Small hydropower plants in Poland', the share of energy from water in the Polish energy system in 2020 was 2% (2.9 TWh of 157.7 TWh total production), while in connection with the ongoing energy transformation of the economy, the current-(about 28%) share of RES sources in the Polish energy mix is expected to increase to 32% by 2030, in which the development of hydropower is anticipated [47]. The Polish Energy Policy of 2009 confirms the above [70], which assumes the development of hydropower.

E. Przybyło points out that Poland's annual hydropower resources reach a level oscillating in the range of 13.7 GWh, where, in a structural division into water reservoirs, the Vistula River creates 45.3% of these resources, the Oder River 9.8%, and the rivers of the Pomeranian region 1.8%. The utilisation rate of the resources in question reaches 12% with a capacity of 2024 MW, with an existing total capacity potential of 12.2 GW, including utility power plants (11 GW) and hydroelectric power plants (1.2 GW) [54].

Studies of available studies provide knowledge that the structure of hydropower solutions in Poland is dominated by power plants with a capacity of up to 0.5 MW with a total capacity of 296 MW, of which there are currently 770, and hydropower facilities in the category of up to 5 MW, of which there are five, while the number of power plants with an installed capacity in the range of 50–500 KW is 343. These facilities generate 43% of energy in the RES segment with a result of 146 GWh [47,71]. Among the technological solutions, run-of-river power plants (mainly micro, with a capacity of 850 MW) and small hydropower plants predominate [47], run-of-river-mostly pumped storage, generate 1366 MW of energy, which represents about 7.3% of the share of installed capacity in the electricity system [54]. Among the main hydroelectric power plants in Poland, existing studies include the following facilities: [72].

(a) Żarnowiec Hydroelectric Power Station (Piaśnica River, capacity 716 MW);
(b) Porąbka-Żar Hydroelectric Power Plant (river Soła, power 550 MW);
(c) Solina hydroelectric power station (river San, power of 200 MW);
(d) Żydowo power station (River Radew, 156 MW);
(e) Włocławek hydroelectric power station (River Vistula, capacity 162 MW);
(f) Nidzica Hydroelectric Power Plant (River Dunajec, 90 MW);
(g) Dychów Hydroelectric Power Plant (river Bóbr, power 79 MW);
(h) Rożnów Hydroelectric Power Plant (river Dunajec, power 50 MW);
(i) Koronowo hydroelectric power station (river Brda, power 26 MW);
(j) Tresna hydroelectric power station (river Soła, power 21 MW);
(k) Dębe Hydroelectric Power Plant (River Narew, power 20 MW);
(l) Porąbka Hydroelectric Power Station (Soła River, power of 12.6 MW).

The assessment of the armament of Poland in small hydroelectric power plants presented in the available studies indicates that the existence of small hydroelectric power plants is justified. It is emphasised that the dispersion of facilities and their location near energy consumers determines the rationality of energy resources management and the efficiency of drawing on the potential of water energy locally. Furthermore, it is pointed out that 1 MWh of energy extracted in a hydroelectric power plant from the potential of water movement allows the elimination of CO_2 emissions of 1264 kg and SO_2 emissions of 15,825 kg [34].

Small hydropower plants are therefore considered an important, pro-development element of energy supply. The development of this dimension of the power supply is recommended in the plans for the development of hydroelectric power plants in Poland and is to be focused on improving the use of existing facilities, their reconstruction, or modernisation in order to improve their efficiency and significantly reduce the negative impact on the surrounding environment, including the construction of active fish ladders. According to the position of the European Commission, power plants must operate in accordance with the sustainable development goals of the European Union and be socially recognised [73]. The promising ones in terms of potential for the development of the electric power industry in Poland (new installations) include Pomerania, the Mazurian Lake District, the Sudety Mountains and the Carpathian Mountains [54]. According to development assumptions, the installed capacity of hydroelectric power plants is expected to increase to 1150 MW by 2030-as indicated by I. Gody'n [74], and the promoted direction of hydropower development in Poland is small hydropower plants.

Hydropower in Lithuania, like in Poland, is presented in the literature as a renewable source that has been used for electricity generation for many years-the first hydropower plant was built here as early as 1890. According to R. Magor, Lithuania's favourable hydropower conditions are created by 733 rivers with an aggregate length of nearly 77 km, and the largest river potential is located in central Lithuania (the Nemunas River basin region, 469 km long on Lithuanian territory, with an extensive basin with tributaries of the Neris, Nevėžis, Dubysa and Venta rivers [75]. The above-mentioned researcher estimates the developable water potential of Lithuania to be about 2.2 billion kWh/y, with the main part (80%) created by the Nemunas and Neris rivers and 20% by several medium and small rivers (about 0.5 billion kWh/y) [75]. According to the conditions presented, the largest hydropower plants in Lithuania are located on the Nemunas River near Kaunas and Kruonis.

The Kruonis facility (a 900 MW pumped storage plant) [76], with a generating capacity of 760 MW providing 94% of the country's energy reserves, is identified as the hydroelectric plant of greatest importance in Lithuania [77]. Industry studies note that to increase energy production at Kruonis, a project is underway to cover the plant's reservoirs with photovoltaic panels, which is expected to generate peak power of 200–250 MWp by 2025 [78]. The energy efficiency of such solutions has been pointed out by S. Jung et al. and X. Xu et al. [79,80], among others, and D. K. Dancso points to the possibility of integrating hydropower stations with wind farms [81].

According to available studies, the second largest hydropower plant in Lithuania is the Kaunas plant with an installed capacity of 100.8 MW and a generating capacity of 50.4 MW. The remaining installations are small hydropower plants with a total installed capacity of 26.44 MW (e.g., Kavarska power station with a capacity of 1.5 MW, Anykščiai district, Sveti river; Balskė power station with a capacity of 2.91 MW, Tauragė district, Jura river; Angiriu power station with a capacity of 1.3 MW, Kiejdan district, Shushov river; Antalieptė power station with a capacity of 2.55 MW, Zarasai district, Sveti river) [77].

An important finding of the review is that due to the boom in the construction of hydropower plants in Lithuania in the period 1999–2004 (increase in installed capacity over 5 years from 9 MW to 21.2 MW-77 hydropower plants), the Lithuanian water law established a ban on the construction of hydropower plants on 169 rivers (including the Nemunas with the highest energy potential) until 2020 [75], justifying this on environmental grounds [82]. The above corresponds with the European Commission's regulation 'Hydropower requirements, taking into account EU nature conservation legislation', indicating the risk of negative impacts of hydroelectric power plants on the river and lake ecosystem, including fish, aquatic life, fauna and flora [83].

A pro-development approach to the development of hydropower plants in Lithuania is presented in the literature in a similar way as for Poland. In fact, in the development of this energy field, small hydropower installations (low power) with lower requirements on the parameters of watercourses are preferred, which makes them more attractive for practical application. The lower cost of the installation and the lower impact on the environment are also arguments for the possible re-establishment of the market development of small hydropower plants in Lithuania.

Studies in the sphere of hydropower in Latvia reveal that the potential of the country's water resources oscillates around 7.2 TWh/y, with the technical-economic availability (i.e., technical feasibility combined with the economic justification for this action) being around 4 TWh/y [84]. In terms of the use of water resources for energy production, Latvia does not differ from Lithuania. According to local sources, Latvia has three large and 155 small hydropower installations with a total water storage function of 1558 MW and a production capacity of 2636 GWh [85], wherein [86]:

- Plavinu power station-the largest in the Baltic States and the second largest in the European Union, with a connecting capacity of 868 MW generates an annual production of 1733 GWh;
- Riga Power Plant-the second largest in Latvia, with a connecting capacity of 402 MW generates an annual production of 735 GWh and additionally acts as a synchronous compensator for voltage and frequency regulation of the power system;
- Kegum power station-Latvia's third large hydroelectric power station, with a connecting capacity of 264 MW generates 571 GWh annually.

A distinctive feature of Latvian power plants is their location on the plain of the Daugava River, hence the efficiency of the plant is determined by the meteorological conditions creating the water level in the basin, which influences the fact that the share of hydropower in the country's energy mix fluctuates. The above causes public discussion regarding the further development of power generation at such a landform, as the presence of power plants contributes to the reduction of natural fish migration, muddying of the area and pollution of the water body, confirmed by the increased presence of blue-green algae. The counterarguments in this discussion are the need to derive energy from renewable sources, and that the advantage of water over wind and solar is justified by the continued availability of the resource-regardless of weather, time of day, time of year. An opportunity for the development of hydroelectric power plants-similarly to Poland and Lithuania-can be seen in Latvia in the potential of small hydroelectric power plants equipped with modern technological solutions which increase their efficiency and energy consumption and reduce their negative environmental impact.

Estonia's hydropower conditions are presented in the literature as relatively low, which is determined by the flat shape of the country's territory the limited length of rivers (up to 10 km on average) and their limited flow rate (up to 2 m^3/s on average)-fast flowing rivers are missing [87]. Ü Liiber points out that the energy potential of Estonia's waters fluctuates around 30 MW, with a physical availability of about 10 MW [88]. According to local sources, there are 50 hydroelectric power plants in Estonia (e.g., Jägala Joa Power Plant, Jägala River-2 MW; Kunda Power Plant on Kunda River-336 KW; Kamari Power Plant on Poltsamaa River-500 KW; Leevaku Power Plant on Vohandu River, 185 KW; Saesaare Power Plant on Ahja Reach, 170 KW)-47 of these were integrated into Estonia's power grid by 2011, increasing its capacity by 8.09 MW, with development plans to commission further hydroelectric plants-small and micro, with a total capacity of 1224 MW [87]. This plan includes the refurbishment of existing, extinguished facilities, despite the existing potential to erect a new unit, e.g., on the Omut River, but the economic justification for this investment has been questioned. Environmental aspects play an important role in this issue, which have been raised in Estonia, as in the other countries considered in the review [89]. In this regard, J. Tambets and R. Järvekülg draw attention to the change in water levels in watercourses, the weakening of watercourse flows due to hydropower installations, the increase in sediment levels and the decrease in oxygenation levels that change the quality of rivers with the result that-aquatic and terrestrial ecosystems are disturbed [90]. In addition, it is highlighted that due to the terrain, the vicinity of hydropower plants becomes floodplains, forcing the local community to resettle [87].

2.4. Advantages and Disadvantages of Hydropower According to the Findings of the Literature

Hydropower is an important element in the sustainable development of economies, positively influencing its progress. According to E. Przybyło, it is a source of green energy, determined by the availability of water resources and dependent on natural water migration processes in nature [54]. Hydropower is reflected in nature. The regulation of rivers in connection with the erection of dams and reservoirs has a destructive effect on the geomorphology of natural water bodies, their biochemical processes and biodiversity. This fact is signalled in a number of scientific studies, including, among others, by C. Zarfl and A. Lucía, G. E. Grant, J. C. Schmidt, S. L. Lewis, et al. [91–97]. The above should be complemented by the adverse hydromorphological changes of rivers due to interference with their natural course, as pointed out by E. F. Moran, M. C. Lopez, N. Moore, N. Müller and D. W. Hyndman [67]. This is an extremely important observation, given that less than 37% of naturally flowing rivers with a length of more than 1000 km remain, and investment trends, according to G. Grill et al., will significantly reduce this dimension in future periods [98]. Therefore, I. Kougias et al. and A. L. Caceres et al. [99] note that the challenge facing current operations is how to increase the efficiency of hydropower plants and their flexibility in relation to current energy needs, grid fluctuations and variability in water flow rates determined by climate change (as particularly highlighted by A. Ranzani et al., S. A. Ali et al., M. Minville et al., S. W. D. Turner, and Z. W. Kundzewicz et al.) [100–104], as well as the sustainability of solutions and the minimisation of negative impacts on the environment [105]. K. Bódis et al., S. W. D. Turner et al., and B. Iglinski et al., and M. Pang et al., A. K. Sharma et al. [106–108] highlight the importance of small hydropower plants [109,110]. T. B. A. Couto et al. point out that the number of small hydropower plants could increase significantly [111]. The UN Global Compact Network Poland report, 'Small hydropower plants in Poland' points out that the right choice of the type of hydropower plant can significantly reduce their negative impact on the environment [47]. The environmental impact most often takes into account interference with the natural course of water bodies and, as pointed out by F. Mazano-Agugliaro et al., disruption of the continuity of rivers [112], disturbance of ecosystems of aquatic organisms, as well as alteration of the natural circulation of water, leading to disruption of water management and, for example, exacerbation of the effects of drought, or local flooding, land clearing or abrasion of the banks of water bodies. An important observation, however, is the issue of the emissivity of hydroelectric power plants, categorised as low due to the reduction of water throughput, which impairs the metabolic system of the river-its siltation and the release of methane, CO_2 and other harmful gases by the debris in the dam reservoirs, resulting in the deterioration of the water quality of the river course downstream of the power plant line [47]. There are studies in the literature on methods for analysing the environmental impact of hydroelectric power plants (e.g., T. H. T. Nguyen), or analyses exploring this impact (e.g., D. Anderson) [113,114], however, this area requires further in-depth research on a local basis. The great advantages of small hydropower plants are that they can be located in inaccessible locations, have low energy requirements for self-maintenance, have a high level of automation (unmanned), and have a relatively long operating time of up to 6.5 thousand hours per year [115].

M. Sojka points out that an important determinant of safe and efficient hydropower plants is to ensure the compliance of the installation with the applicable regulations and proper planning [116]. The above aspects are indicated as serious barriers to the development of hydropower, as the time for planning the investment and obtaining the relevant permits is relatively long (1–4 years), which is compounded by the very significant cost of project implementation, which is-generally higher compared to the cost of construction and commissioning of conventional power plants, reaching up to several tens of millions of PLN [47]. In this respect, however, it is worth supplementing the literature with detailed comparative analyses of outlays in relation to the effects that can be obtained from the implementation of the investments in question-it is important to capture the environmental costs (the above in relation to local markets). Cost analyses can be found in the literature-particularly of small hydropower plants, undertaken by e.g., T. S. Kishore et al., B. Ogayar et al., G. Cavazzini, et al., R. Carapellucci et al. F. Forouzbakhsh, and D. A. Zema et al. [117–126], which shape the general view of the problem.

P. Terlikowski and J. Łuć point to insufficient support for investment projects in hydropower-including European Union co-financing, hence working out the level of profitability of the projects in question is generally limited [115], making hydropower potential relatively inaccessible. However, based on the presented literature review, hydropower can be considered an important future direction in the context of increasing RES sources in the energy mix of countries, oriented towards increasing energy security and stabilising the market price per 1 KW of energy in the market. The observed trend of promoting small hydropower plants seems to be fully justified, as, in combination with new technologies, the negative environmental impact of small hydropower plants can be significantly reduced. The above is particularly important with regard to the existing series of extinguished plants in the analysed countries [127,128]. In this regard, solutions related to locating hydro turbines in the middle of watercourses to draw on stream energy in the main watercourse are indicated [86]. Hydropower is open to innovation, hence further research into reducing the negative impacts of hydropower facilities on the surrounding environment is absolutely justified and an addition to the literature in this area is necessary.

3. Conclusions

The literature on hydropower in the adopted configuration of countries relates most strongly to current trends in energy policy changes and the need to strengthen renewable energy sources in the energy mix of economies in general. The above provides grounds for considering the general dimension of information power supply as the topic of highest research popularity. In this respect, this literature review enables the development of an opinion on the general situation of the water energy market in Poland and the Baltic States. It provides knowledge on the achievements of the established configuration of countries in the explored topic, in the light of the articulated challenges, leading to the conclusions that:

1. The share of RES sources in the energy mix of the adopted countries is gradually increasing-Poland reached 16%, Lithuania 20%, Latvia 53%, Estonia 29%, with an average share of RES in the energy mix of the European Union in 2020 of 37% [129];
2. The strongest development of hydropower—considered in terms of incremental waterpower capacity—is being realised by Estonia (+67% 2019–2020 y/y), where hydropower is the least developed of the set of adopted countries. In addition, development is observed in Latvia (+23% 2019–2020 y/y) and Poland (+8% 2019–2020 y/y), while Lithuania reveals a correction in hydropower (−12.95% 2019–2020 y/y) [129];
3. The highest price levels and their rate of increase apply to countries with the lowest share of RES in the energy mix (against the background of the adopted countries, Poland is the weakest (+12.5% 2020–2021 y/y) and Latvia the strongest (−1.94% 2020–2021 y/y) [129]. The above indicates a correlation between the share of renewables in the energy system of economies and the stabilisation of energy prices in the local market. The above argues for efforts to obtain cheap energy from renewable sources;
4. The direction of the development of hydropower, which in Eastern Europe reaches a level of 13% of the share of renewable sources in the energy systems of individual countries [47] (the share of hydropower in the structure of RES sources of the European Union is 12.71% [130]) may help to achieve the goal of increasing the share of renewable sources in the energy mix of economies, as any justified action is important. In this regard, the literature points to the growing development of small-scale hydropower installations, which in large part involves the revitalisation of existing (often extinguished) facilities. The literature indicates that arming classic, imperfect solutions with innovative solutions in technology and techniques can create tangible benefits in the sphere of efficiency of drawing energy from the movement of water, while at the same time significantly reducing the risk of negative impacts on the environment in places where installations are already located. Improving the efficiency of small hydroelectric plants can significantly increase installed capacity, helping to achieve sustainable development goals considering environmental standards. This

dimension, however, needs to be precisely investigated and captured in studies that can fill a gap in the literature.

The available literature on hydropower, with reference to Poland and the Baltic States, needs appropriate additions. A limited number of reviewed sources deal with the issue of water resources in these countries, and when compared with the analysis of the energy potential of these resources, the literature base appears to be even more scarce. Similarly, the theme of the existing technological solutions of hydropower in Poland and the Baltic States is mostly taken up in general outline, only reaching higher level considerations of detail in principle with regard to the analysis of single (and the newest) hydropower facilities. The general information supply leads to the creation of general conclusions, which strengthens the need for research additions in this area.

Following the analysis of the needs for increasing the share of RES in countries' energy mixes, an analysis of the development potential of individual RES sources is carried out. In the case of the issue of energy from water movement, the negative environmental effects of the solutions undertaken are signalled. This scope is again in the vast majority of cases discussed at a high level of generality, and the need for research in this area is articulated in the literature, although there are studies indicating the positive impact, or environmental neutrality of small hydropower plants, juxtaposed with the benefits to the local community (e.g., studies by P. G. Senarath et al.) [131].

Another dimension that requires additions is that of the technical-economic findings, which give an idea of the profitability of this type of project (such as the study by T. Bockman exploring another market) [132] by taking into account the environmental costs of such an action. This type of study was the least reported in the review.

The review and assessment of the literature, according to the themes and criteria identified in the introduction, identified areas discussed in the literature that were exhaustive, moderately exhaustive, and poorly exhaustive.

The arrangement of the literature in the matrix according to the variables defined in the introduction (x_1–x_7) and the qualification into compartments according to the assumptions made, led to the conclusion that:

1. A high degree of explanation-category A (score according to the distribution of variables above 40%) covers the area of:
   - Renewable energy sources including energy from water and energy transformation including hydropower (x_1);
   - Hydropower conditions (hydropower resources, hydropower potential) of countries (x_2).

The issues in question received the highest interest from researchers, hence they can be considered the most relevant.

2. Average degree of explanation—category B (the result of the distribution of variables in the range of 20–39%), includes the themes of:
   - Technology and techniques in hydropower (x_3);
   - Hydropower plants, the contribution of hydropower plants to RES and the energy mix of countries (x_4).
3. Weak melt of explanation-category C (result of the distribution of variables in the range of 0–19%), covers the themes of:
   - The economic justification for the operation of hydropower plants (x_5);
   - Environmental aspects of hydropower operation (x_6);
   - Social aspects of hydropower development (x_7).

A weak and average degree of explanation creates the potential for research challenges. A visualisation of the results is presented in Figure 1.

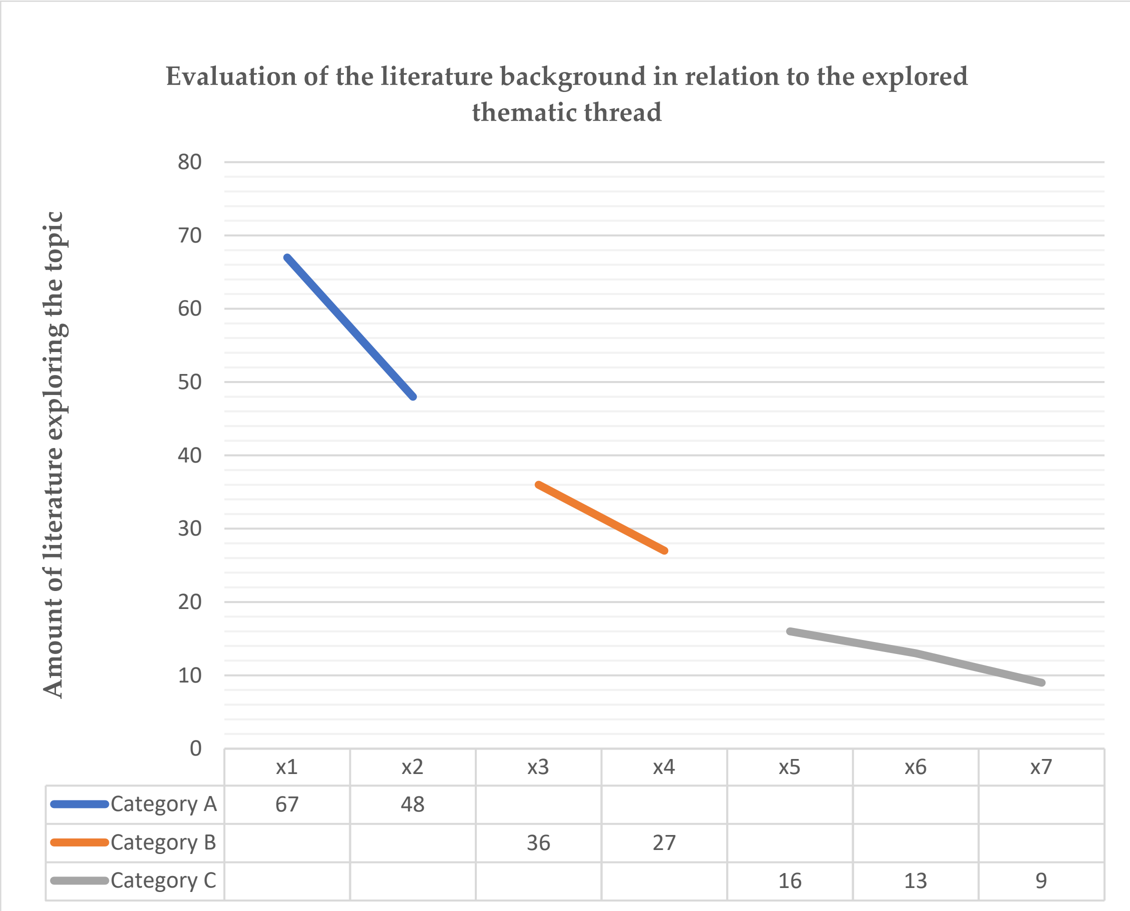

Figure 1. Evaluation of the literature background in relation to the explored thematic thread.

The body of literature on the issues explored must be considered limited. The relatively low amount of scientifically researched information requires reference to source data and individual research, essentially limiting the scope of possible findings. The above leads to a positive verification of the accepted thesis that the literature on the subject is most strongly focused on the general assessment of the energy transition of the countries accepted for the review, and that hydropower is most often taken up as one of the sources of renewable energy supply. As a result of the literature review, the existence of a gap relating to the aspect of hydropower development potential in Poland and the Baltic States was confirmed-taking into account both the construction of new hydropower plants and those existing plants signalled for modernisation or restoration.. The indicated need for analyses (studies and simulations) of hydropower development and capturing them in the literature, moreover, requires the consideration of technical-economic aspects [133] (as e.g., in the analysis by J. K. Kaldellis on the example of the Greek market, or the analysis by M. R. Nouni on the example of India [134]) and environmental aspects (e.g., in the form of analyses of the economic justification of investments in hydropower [134]). In the form of analyses of the economic justification of investments in hydroelectric power plants, studies on the effectiveness of technological solutions, measurement of the fulfilment of environmental objectives in connection with the development of hydropower and searching for solutions to increase the energy efficiency and environmental safety of hydropower installations is the main recommendation of this review.

It can be assumed that interest in the issues being explored is currently increasing. Indeed, this review has shown that the most up-to-date items of literature reviewed are those published between 2020 and 2022, which account for 45.18%, with 2022 alone accounting for as much as 28.14%. The distribution of the topicality of the literature is presented in Figure 2.

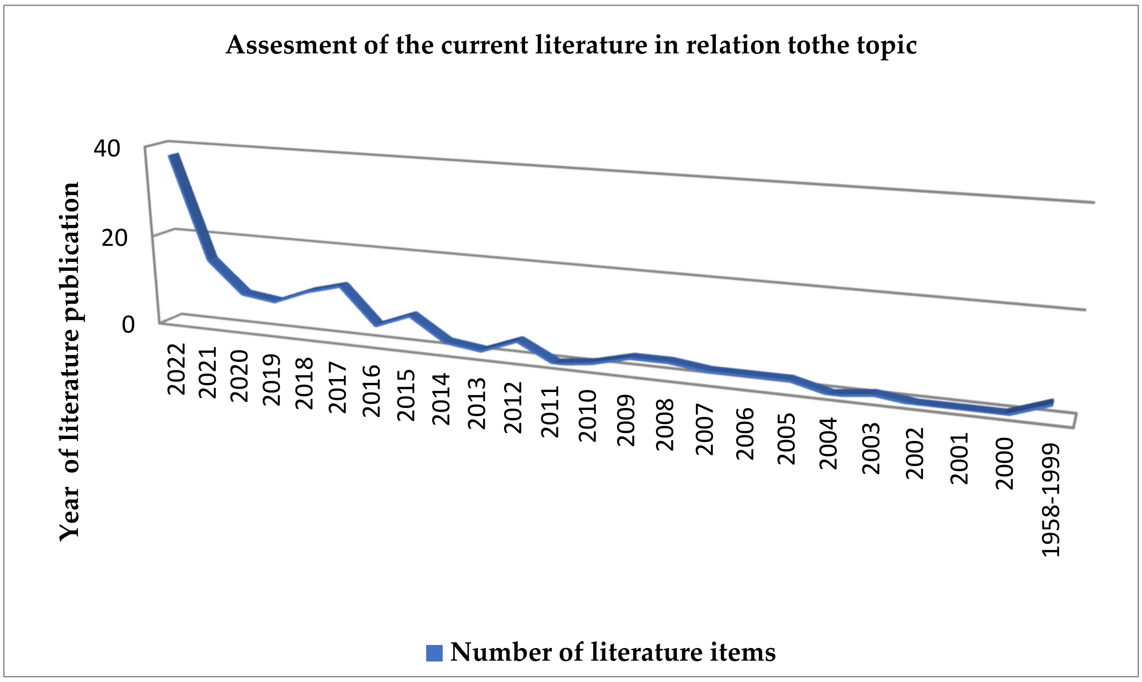

Figure 2. Evaluation of the timeliness of the literature in relation to the thematic thread explored.

Significant deposits of water energy await prudent management, and effective decision making requires the support of a body of expert literature hence this review can inspire research threads in line with the current demand for bridging literature gaps.

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