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RENEWABLE ENERGY SOURCES - BENEFITS AND DRAWBACKS FROM THE PERSPECTIVE OF THE EXPERIENCES OF CHINA, BRAZIL, CANADA AND THE UNITED STATES

Edyta NARTOWSKA[1*], Alina ROZENVALDE[2]
[1] Faculty of Environmental Engineering, Geomatics and Renewable Energy, Kielce University of Technology, Kielce, Poland
[2] Faculty of Engineering, Latvia University of Life Science and Technologies, Jelgava, Latvia

A b s t r a c t

The aim of the article was to identify actions, based on the experiences of China, Brazil, Canada, and the United States, that countries can implement to increase the share of hydro, solar, and wind energy in their economies. The analysis relied on a literature review and data obtained from the Our World In Data database. The findings indicate that there are effective strategies for clean energy adoption that can be applied worldwide. Key considerations include investing in appropriate infrastructure, developing new energy storage technologies, and implementing environmentally friendly methods for disposing of photovoltaic panels. It is essential to provide financial support for scientific research, particularly in assessing the long-term potential of renewable energy, considering geographic distribution, and evaluating public acceptance. Regulatory frameworks should strike a balance between promoting renewable energy expansion and avoiding excessive growth.

Keywords: hydropower, solar energy, wind energy, renewable energy, climate change, sustainable development

1. INTRODUCTION

In light of the main challenge of the 21 st century, climate change and the depletion of underground resources, it has become imperative for people to alter their conventional way of life, promote resource, and minimize greenhouse gas emission [1]. To combat climate change, the Kyoto protocol was enacted on 11 December 1997, followed by the Paris Agreement of the United Nations on 22 April 2016, which established regulations to prevent global warming above 2 °C (with a recommended limit of 1.5 °C) and achieve carbon neutrality by 2050. One crucial step towards this objective is the complete abandonment of fossil fuels in favor of renewable energy sources. These sources encompass less efficient options like wood and agricultural waste, as well as cleaner and more efficient alternatives such as hydropower,

* Corresponding author: Edyta Nartowska, Kielce University of Technology, al. Tysiąclecia PP 7, Kielce, 25-314, Poland, enartowska@tu.kielce.pl

solar, and wind energy [2]. In recent years, there has been a rapid advancement in the renewable energy sector [3-5**].** According to ourworldindata.org, the largest share of renewable energy is derived from hydropower. Wind energy ranks as the second most utilized renewable resource, followed by solar energy. Other renewable sources, including geothermal, biomass, waste, wave, and tidal energy (excluding traditional biomass energy), make up the fourth category. In 2021, worldwide renewable energy production amounted to 7,931 TWh, with hydropower accounting for over half of all renewable energy generated (4,274 TWh), followed by wind energy (1,862 TWh), solar energy (1,033 TWh), and other renewables (763 TWh) [6]. It is important to note that the figures for renewable energy encompass not only electricity but also transportation and heating. Despite the goals outlined in the Paris Agreement, the progress and implementation of renewable energy vary among different countries.

The main obstacles preventing countries from fully transitioning to renewable energy can be categorized into social, economic, political, and environmental factors [7-9]. Many countries, particularly those rich in mineral resources, not only meet their own energy needs but also supply neighboring nations. The extraction of these resources creates job opportunities for the citizens of the host country, thus reducing unemployment rates. In the case of Poland, aligning with the goals of the Paris Agreement would necessitate the complete closure of coal mines. To address the potential unemployment impact on the 83,000 individuals currently employed in the mines, the country intends to offer alternative employment opportunities in the renewable energy sector [10-11]. Overcoming the scientific, socioeconomic, and technological challenges is essential for effectively harnessing renewable resources and achieving independence from fossil fuels [1, 12-14]. It is important to acknowledge the disadvantages associated with renewable energy, as they are often overlooked [15]. Achieving sustainable economic development requires a significant increase in the utilization of renewable energy sources. Given the imperative to reduce carbon emissions, global collaboration is indispensable [1, 4]. Consequently, it is crucial to learn from countries with the highest production of renewable energy sources and examine the solutions they have implemented.

Each form of energy, whether fossil or renewable, comes with its own set of advantages and disadvantages [5, 7-9, 15-16]. Evaluating these factors helps determine which type of renewable energy is most suitable. Maradin (2021) emphasized the importance of analyzing the utilization of specific renewable energy sources within national economies [17]. The author acknowledged that each country has its unique characteristics, and it is crucial to consider which renewable energy source can be maximized to foster sustainable development and economic progress. While it is essential to approach renewable energy solutions on a country-specific basis [17], it is also valuable to examine the advantages and disadvantages of introducing renewable energy from the perspective of countries that dominate the production of a particular renewable energy source. Understanding the approaches taken and the challenges faced can guide other nations in harnessing their own renewable energy potential.

Therefore, the aim of this study is to identify actions that countries can undertake to increase the proportion of hydropower, solar, and wind energy in their economies. These actions are derived from the experiences of China, Brazil, Canada, and the United States. To achieve this goal, a literature review and analysis of data from the Our World In Data database [6] were conducted. The article also discusses the advantages and disadvantages of hydropower, wind power, and solar power, and identifies areas for future research that should be pursued to foster the growth of clean energy.

2. ADVANTAGES AND DISADVANTAGES OF HYDROPOWER, WIND AND SOLAR ENERGY

Hydropower is experiencing rapid growth as a renewable energy source, with its consumption steadily increasing over time [18]. However, it is important to consider the advantages and disadvantages of hydropower (Table 1). While the development of hydroelectric projects offers benefits, it also brings unavoidable impacts, making it crucial to conduct detailed studies that assess these impacts based on sustainability criteria [19].

Wind energy installations have evolved from individual windmills, primarily used for food production and local water supply systems, to sophisticated wind farms that provide electricity to hundreds of thousands of consumers. The implementation of wind energy technologies is influenced by four primary factors, in addition to the availability of financial resources for investment: the regulatory environment, political environment, public attitude, and land availability. Each of these factors encompasses various aspects that can either support or hinder wind energy development (Table 1) [20].

Solar energy possesses greater potential than any other renewable energy source. Studies indicate that with just 5% solar energy, we can fulfill the global energy demand and yet this potential remains largely untapped [21-24]. The utilization of solar energy and the installation of solar panels in residential and municipal settings are still in their early stages, but hold immense promise for the future. The primary challenge in solar energy production lies in finding sustainable solutions for maximizing the utilization of solar panels [25-26]. Already, efforts are underway to seek environmentally friendly approaches that enhance the viability of this energy source. Over the past decade, the solar photovoltaic industry has experienced an average growth rate exceeding 30% and is expected to continue to rise [27].

Table 1. Advantages and disadvantages of different renewable energy sources

Advantages	Disadvantages	Ref.
	HYDROPOWER	
The hydroelectric station serves the purpose of flood control and ensures a water supply during dry seasons.	A dam has the ability to regulate the flow of a river within its location, but it also brings about changes that disrupt aquatic life both upstream and downstream of the reservoir.	[19]
Lower GHG emissions, 4-14 g CO_2 eq/kWh.	Downstream flows can cause erosion, and hydroelectric dams contribute to the production of greenhouse gases by reducing the oxygen levels in the water.	[18,19]
Hydropower helps mitigate the risks associated with climate change, such as floods and droughts.	The balance of the ecosystem is disrupted as the river becomes fragmented into two or three parts, affecting natural irrigation.	[19]
It offers a high energy capacity with relatively low production costs, approximately 0.05 USD/kWh.	The construction of hydroelectric power plants necessitates substantial investments.	[19]
Hydropower eliminates the need for fossil fuels as an energy source.	Overreliance on hydropower exacerbates environmental degradation through excessive water usage.	[19]
It exhibits a high efficiency coefficient, ranging from about 55% to 92%.	Hydroelectric plants require intricate solutions and localized modifications in order to maintain consistent efficiency, especially in areas with high flow rates and minimal climatic fluctuations or seasonal changes.	[19]
Hydropower operations require minimal human labor, with an average of 0.25 personnel per 1 megawatt (MW) of energy.		

WIND ENERGY		
Wind energy is an abundant and renewable resource that is freely available.	Wind energy cannot be stored entirely, meaning that there are limitations in storing excess energy generated by wind turbines.	[28,29]
The generation of energy from wind turbines does not produce greenhouse gas emissions or other harmful pollutants.	Inaccurate wind forecasts can result in insufficient energy production from wind sources.	[28,30]
The land used for wind turbine installations can still be utilized for various purposes, such as agriculture or offshore activities.	Significant financial investments are required to initiate wind energy research and development.	[2930]
Wind energy has the potential to provide electricity to remote rural areas.	The maintenance costs for wind energy systems are generally high throughout their life cycle.	[30, 31]
The electrical current generated by wind turbines is in the form of alternating current (AC), which facilitates easier connection to AC electrical grids.	Wind farms can have an impact on biodiversity, particularly on bird populations.	[30, 31]
Wind power plants do not require water for their operation.	Wind turbines produce aerodynamic noise during operation.	[30, 32]
The proximity of wind generators to consumers results in significantly lower power transmission losses. Wind turbines can be installed as close as 300 meters to populated areas.	The flickering effect caused by rotating wind turbine blades can have an impact on individuals in close proximity.	[29,30]

SOLAR ENERGY		
Solar panels generally do not require complicated, time-consuming, and complex maintenance.	Research in solar energy necessitates significant financial investments to commence.	[24,33]
Ongoing research and development efforts are focused on innovative solutions, enabling higher energy yields from solar panels.	Solar energy production is weather-dependent, as it relies on sunlight availability.	[2433]
Solar energy is an environmentally friendly solution that does not generate greenhouse gas emissions.	Energy storage for solar power can be costly, and it often requires immediate utilization.	[24]
New solar technologies incorporating phase-change materials are being developed to enhance heat accumulation and improve the efficiency of photovoltaic panels.	The conversion efficiency of solar energy into electrical energy is relatively low, typically around 25%.	[25,26, 33]
	There may be potential challenges and issues related to the utilization of solar panels in the future.	[34]
	The installation of solar panels requires a significant amount of space due to their size and quantity needed.	[34]

3. ADVANTAGES AND DISADVANTAGES OF RES FROM THE PERSPECTIVE OF EXPERIENCED COUNTRIES

In 2021 the five countries that generated electricity from hydropower were China (1,300 TW), Canada (377,16 TWh), Brazil (362,82 TWh), USA (246,47 TWh) and Russia (214,5 TWh) (Fig.1).

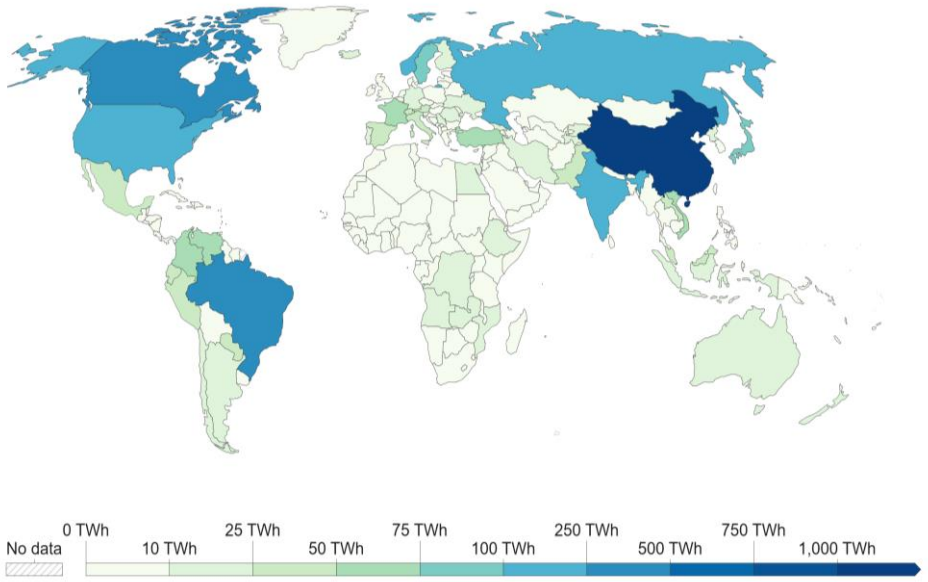

Fig. 1. Hydropower generation in the world, 2021. Source: ourworldindata.org/energy CC BY

According to data from ourworldindata.org, China is the leading country in hydropower utilization for energy production. Its extensive use of hydropower resources contributes to its progress towards sustainable development [35]. Brazil follows China as the second-largest generator of hydroelectric power. Hydropower is deeply intertwined with socio-economic development in Brazil, as it plays a significant role in the country's energy production. While Brazil generates a considerable amount of electricity, it also relies on importing some of its supply through regional grids in collaboration with neighboring countries [36].

In terms of wind energy production, the top five countries in 2021 were China (655.6 TWh), the United States (378.2 TWh), Germany (115.7 TWh), Brazil (71.5 TWh), and India (68.09 TWh) [Fig. 2, ourworldindata.org]. China, being the world's largest energy consumer and carbon emitter, is investing in wind power as it offers a cost-effective way to reduce emissions. However, a potential limitation in the future could be the noticeable decline in wind speeds in China [22]. In the united states, offshore wind power has been successfully utilized for several decades, particularly in Texas. However, compared to onshore wind power, the offshore wind industry remains underdeveloped [24]. In the US, rural areas house the dominant capacity for wind power generation [33].

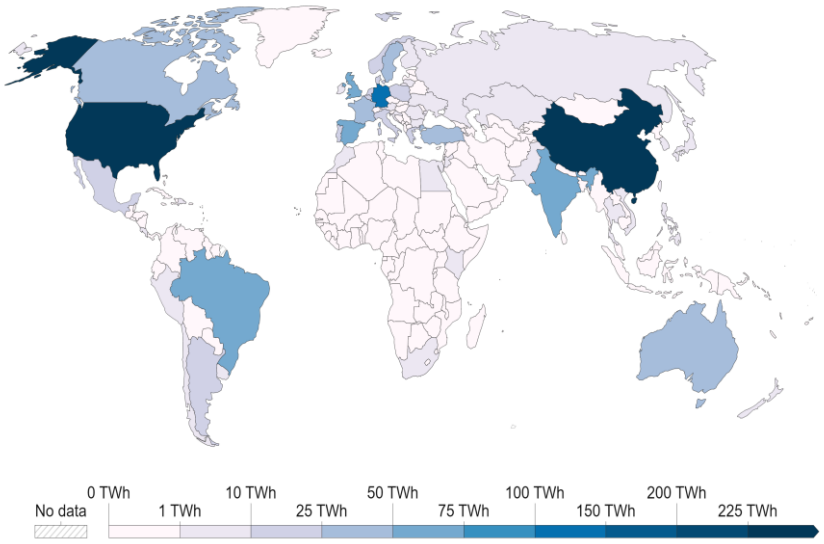

Fig. 2. Wind generation in the world, 2021. Source: ourworldindata.org/energy CC BY

According to ourworldindata.org, in 2021, the top five countries that generated the most electricity from solar were China (327 TWh), the United States (164.42 TWh), Japan (88.7 TWh), Germany (51.09 TWh), and Australia (28.04 TWh) (Fig. 3). China holds the title for being the world's largest producer of solar energy. However, its output varies across the country due to different climatic conditions [28]. The United States ranks as the second-largest user of solar energy. Active installation of solar panels in the United States began in 2006, with substantial government support and initiatives to encourage consumers to switch to solar energy. As of the first three quarters of 2022, solar energy accounted for 45% of all new electricity-generating capacity added in the US.

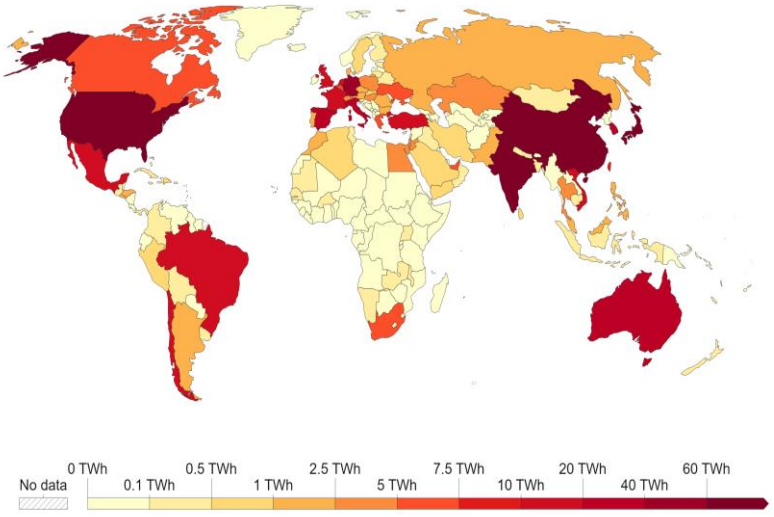

Fig. 3. Solar energy generation in the world, 2021. Source: ourworldindata.org/energy CC BY

Table 2. Benefits and drawbacks of hydropower, wind energy and solar energy from the perspective of different countries

Benefits	Drawbacks	Ref.
HYDROPOWER - China		
With the development of hydropower, China has a significant opportunity to fulfill its commitments under the Paris Agreement. Research indicates that the total carbon emissions associated with hydropower projects in China amounted to 1.87E+08 tons for the period of 2006-2015.	The early development of hydropower plants contributed to environmental degradation, particularly affecting local river waters. The construction of dams impeded fish migration and flooded their spawning grounds.	[35, 37]
Hydropower has become a crucial element of China's energy security strategy. The comprehensive life cycle assessment of hydroelectric projects has been conducted, considering potential catastrophic factors. China has reduced its dependence on energy imports by meeting a significant portion of its domestic energy demand through hydropower.	Hydropower projects involve extensive resettlement procedures for residents, and the compensation provided does not always meet the resettlers' demands. In some cases, resettlement areas are economically disadvantaged and less suitable for development, particularly in agriculture.	[35]
HYDROPOWER - Canada		
Hydropower serves as a reliable and lucrative revenue stream for Canada. Provincial governments in regions with substantial hydroelectric production levy royalties on hydroelectric plant operators. Additionally, hydroelectric plant owners benefit from lower rates on gross revenues for the first 700 GWh of annual production per station.	The Ontario government has introduced water royalties set at approximately $1.9 billion below their market value, leading to excessive consumption and overproduction of hydroelectric power plants.	[38]
The fees imposed by the Ontario government aim to safeguard water resources and fund environmentally-related programs.	Only a few provinces allocate a portion of the royalties for water conservation and environmental programs. Consequently, neither consumers nor producers bear the externalities associated with hydropower.	[38]
Canada relies on hydropower for 60% of its electricity generation.	The lack of a fair and systematic approach to determining royalties creates an uneven playing field for the development and utilization of hydropower. High costs can impact the profitability of projects.	[39]
HYDROPOWER - Brazil		
The utilization of hydropower in the Brazilian Interconnected System (BIS) has enhanced operational efficiency and reduced the necessity for fossil fuel-based power plants.	Brazil, especially its northeastern region, is susceptible to droughts, which can pose limitations to the growth of the hydropower sector.	[40, 41]
Municipalities where hydropower plants are constructed experience a 20% increase in job opportunities and a 10% rise in wages.	When constructing hydroelectric plants, adherence to regulations is essential to protect the residents in the affected areas and ensure a safe environment.	[18,40]
Tax revenues from the construction of hydroelectric power plants have seen a significant 61.5% increase in collection within one year.	In northern Brazil, the population heavily relies on hydropower, which is concerning considering the potential impact of climate change on the efficiency of this energy source in the future.	[18,40]

Brazil possesses the longest river in the world, presenting a substantial potential for hydropower energy generation.	Over time, the potential of hydropower will diminish due to its negative effects on the environment and water quality. The construction of reservoirs in Brazil has been associated with an increased incidence of malaria, Chagas disease, leishmaniasis, and other parasitic diseases.	[18,42]
WIND ENERGY - China		
China possesses excellent conditions for wind farm development, with a wind energy potential of 25.6 PWh per year. The lower economic and geographic constraints are cited as contributing factors, and wind power is expected to become increasingly cost-competitive in the future.	The wind energy potential in China varies by region It is important to assess the potential for 3-MW units, taking into account technological and policy requirements.	[22, 23]
	In offshore areas there are technical constraints, such as shipping lanes, inadequate water depth, and distance from shore. The most abundant areas for wind energy are far from large cities, which requires adequate transmission capacity.	[23, 27]
In China, wind farm projects can be approved by local governments, which has fostered the growth of wind installations.	A significant issue is the hasty implementation of government plans for uncoordinated expansion of capacity installations and power transmission networks. The rapid growth of wind power has occurred without proper coordination with other energy sources, leading to an imbalance in the power structure. This problem is particularly pronounced in areas where wind resources and coal resources overlap spatially, such as the 'three northern regions'. As a result, intense competition between wind power and coal power is inevitable, further exacerbating the challenge of reducing reliance on wind power.	[27]
WIND ENERGY – United States		
The implementation of wind energy has had positive impacts on rural areas, where a significant number of wind farm projects have been established.	Local residents lack the professional skills to install wind turbines. They need to be trained.	[33]
Hydropower utilization in China benefits from preferential property tax rates..	Living conditions for residents in counties where wind farms are being built may be reduced for a while due to noise. A temporary increase in the price of residential rents has also been observed.	[33]
The construction of wind farms in certain areas of China has resulted in a 2.5% decrease in unemployment rates.	Government policy is an integral element that affects the demand for wind energy. According to some, these policies are very costly and can negatively affect the energy market.	[33, 34]
Wind projects contribute substantial tax revenues to counties, which are committed to developing infrastructure and services.	There is a risk that wind power will not be available at times of peak demand due to the lack of adequate energy storage.	[33, 34]
SOLAR ENERGY - China		
China is making investments in promising solar concentrator technology (CSP) and heavily focuses on research and development in the solar energy sector. These investments have led to a decrease in the technological cost of solar energy.	There is a lack of scenarios for the impact of climate change on solar output in different regions of China.	[19, 28]

China is focused on the research and development of solar energy, as it invests a lot of money in this sector, which has an impact on the decrease in the technological cost of solar energy.	Solar panels only last about 30 years, and China does not have specific regulations on solar panel recycling.	[20, 31]
Renewable energy resources, including solar energy, play a key role in reducing emissions in the electricity sector.	The challenge is to involve the public and manufacturers in environmental programs for recycling used photovoltaic panels.	[28, 31]
Subsidy-free solar energy has become cheaper than coal energy in most parts of China. A recent study by UC Berkeley and Tsinghua University indicates that the use of solar energy could contribute up to 7.5% to GDP and 5.9% to total employment in China by 2030. To promote the use of solar energy, the Chinese government is implementing various support measures for individuals and legal entities.	The challenge is to involve the public and manufacturers in environmental programs for recycling used photovoltaic panels.	[20, 28]
SOLAR ENERGY – United States		
Farmers can diversify their sources of income by installing solar panels on their farmlands. The US offers various extensive financing mechanisms for solar energy.	The location of solar installations can affect agricultural land, leading to disputes over land use.	[21, 29]
Homeowners and businesses have the option to sell excess energy to the national power grid, a program that applies to 90% of states in the US.	Many solar panels installed 25-30 years ago are nearing the end of their useful life, posing challenges for their proper utilization. Solar panels end up in landfills, and the substances in them (lead, selenium, and cadmium) can pollute groundwater.	[21, 30]
The solar energy industry in the US has seen significant growth, with over 50% more individuals employed in the sector compared to 2010. It is currently the fastest-growing job market in the country.	The U.S. economy imposes trade restrictions that discourage investors from investing in solar energy.	[30, 32]

4. DISCUSSION

In the evaluation of the advantages and disadvantages of the aforementioned renewable energy types, it is evident that all available renewable energy sources currently possess significant advantages and disadvantages that limit their usability [16].

When considering these renewable energy resources collectively, it is apparent that solar and wind energy are gaining increasing popularity in today's world. These energy sources are more easily accessible and represent fully carbon-neutral forms of energy production, aligning with the objectives of the European Union. However, the primary challenge associated with these two renewable energy resources is energy storage. Various solutions are being explored, and research is underway to identify the most accessible and efficient methods for energy storage. Different forms of energy storage are being analyzed in studies, taking into account their efficiency, benefits, and drawbacks. Yu et al. [43] suggest that pumped hydro storage of wind energy shows the most promise. Regarding solar energy storage, batteries are the main type of household storage. Nevertheless, batteries have limited capacity and tend to degrade over time, resulting in the generation of hazardous waste that must be appropriately disposed of [44].

When assessing the effectiveness and efficiency of hydropower, similar to solar and wind energy, it does not generate emissions during energy production. However, hydropower may not be suitable for all countries. Its main potential lies in countries with abundant rivers where the installation of

hydroelectric power plants is feasible. Nevertheless, hydropower has its drawbacks, particularly related to biodiversity preservation, as the construction and operation of hydroelectric plants can disrupt the habitats of various fish species residing in rivers. This can lead to environmental impacts such as erosion and reduced oxygen levels, affecting the organisms in the affected rivers [35].

Analyzing the utilization of individual renewable energy sources in countries with high rates of energy production from these sources, the benefits of their implementation become evident, regardless of the specific type of renewable energy. A well-developed renewable energy source alone can contribute significantly to a country's commitment to the Paris Agreement. Additionally, countries benefit from reduced dependence on energy imports, and over time, the prices of renewables become more competitive. The development of renewable energy sources has also stimulated job growth in the sector, higher wages, and increased tax revenues. Moreover, users of solar installations have the opportunity to sell unused solar energy back to companies. Drawing from the experiences of China, Brazil, Canada, and the United States, Table 3 summarizes the recommended steps that should be taken in the future by countries striving for sustainable development through the development of renewable energy sources.

Table 3. Future targets for renewable energy sources

	Actions towards sustainable development of Renewable Sources
Hydro energy	Implement proactive and environmentally friendly measures during the initial phases of hydropower construction.
	Ensure clear specifications and proper management of land acquisition and resettlement projects.
	Relying too much on hydropower could be risky due to climate change
	Recognize that the potential of hydropower diminishes over time due to its impact on water quality.
	In tropical countries, the construction of new hydroelectric reservoirs can potentially contribute to the spread of parasitic diseases.
Wind energy	When assessing the potential of wind energy, it is crucial to consider technological, geographical, and political requirements.
	When implementing incentives and strategies to accelerate wind energy development, it is essential to consider the energy needs of the region and ensure that they are balanced with other available energy sources. This approach will prevent uncoordinated expansion of wind installations.
	Tax credits play a significant role in promoting the construction of wind turbines.
	Providing training programs for wind farm installation is a crucial step towards their development.
	Efforts should be directed towards finding cost-effective methods for storing wind energy.
Solar energy	Funding allocated to research and development of solar energy can lead to a reduction in technology costs.
	It is crucial to consider that climate change can have an impact on solar energy resources.
	Efforts should be made to explore environmentally friendly methods for disposing of photovoltaic panels.
	Elimination of commercial restrictions that hinder manufacturers from supplying necessary equipment for solar investments is important.
	Legal regulations should govern the placement of solar panels on agricultural land.
	Introduction of financing mechanisms, support programs, and tax measures is necessary to encourage investment in solar panels

4. CONCLUSIONS

There are several actions that countries can take to increase the share of hydro, solar, and wind power in their economies. The experiences of China, Brazil, Canada, and the United States provide successful strategies that can be applied globally. These include:

1. *Infrastructure:* Investing in the development of appropriate infrastructure for hydropower, solar, and wind, as well as expanding transmission grids to enable efficient distribution of generated energy.
2. *Technology:* Developing more efficient solar panels, higher-capacity wind turbines, and cost-effective energy storage technologies could help increase the global production share of these energy sources. It is also important to seek environmentally sound methods of disposing of photovoltaic panels.
3. *Legislation:* Implementing appropriate regulations that do not hinder the development of renewable energy sources, while preventing their overexpansion. States should establish supportive policies and clear regulations for purchasing energy from clean energy producers. Additionally, regulating the location of solar installations and wind farms on agricultural land and regulating commercial restrictions is crucial.
4. *Research&Innovation:* Future research should focus on identifying new renewable energy technologies that can reduce technological, environmental and economic costs. Providing financial support for scientific activities in this field is essential. Furthermore, scientific activities are needed to assess the potential environmental impact of investments; evaluate the long-term potential of hydropower, wind and solar energy considering geographic distribution, and assess public acceptance of specific renewable energy sources.
5. *Society:* Educating and raising public awareness about the benefits and significance of hydro, solar and wind energy is crucial. Strengthening educational programs, information campaigns, and community initiatives can contribute to greater understanding and support for clean energy sources.

Declaration

[Edyta N.] had the idea for the article. The literature searches were performed by [Alina Z.] and [Edyta N.]. All authors contributed to the data analysis. The first draft of the manuscript was written by [Edyta N.] and all authors commented on the previous version of the manuscript. All authors read and approved the final manuscript. The revised version of the manuscript was written by [Edyta N.].

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