Challenges and perspectives in search for sustainable energy sources: a global analysis

Desafios e perspectivas na procura de fontes de energia sustentáveis: uma análise global

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ABSTRACT

The text addresses the pressing need to find sustainable solutions to the growing global energy demand, considering the environmental and climate impacts of the predominant sources. It highlights the responsibility of developed countries in leading the search for new energy sources, while developing countries face more significant economic and social impacts. The detailed analysis of various energy generation technologies in different countries highlights the importance of a holistic and adaptive approach in the transition to cleaner energy sources. The study provides insights for countries seeking to address the challenges of climate change and environmental degradation by diversifying their energy matrices.

Keywords**:** sustainable energy; climate change; energy matrix; developing countries; energy diversification.

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RESUMO

O texto aborda a urgente necessidade de encontrar soluções sustentáveis para a crescente demanda global por energia, considerando os impactos ambientais e climáticos das fontes predominantes. Destaca-se a responsabilidade dos países desenvolvidos na liderança da busca por novas fontes energéticas, enquanto os países em desenvolvimento enfrentam impactos econômicos e sociais mais significativos. A análise detalhada de diversas tecnologias de geração de energia em diferentes países ressalta a importância de uma abordagem holística e adaptativa na transição para fontes de energia mais limpas. O estudo oferece insights para países que buscam enfrentar os desafios das mudanças climáticas e da degradação ambiental, diversificando suas matrizes energéticas.

Palavras-chave**:** energia sustentável; mudanças climáticas; matriz energética; países em desenvolvimento; diversificação energética.

1 Introduction

The search for sustainable solutions to growing energy demand is emerging as a crucial challenge in contemporary 21st century society. The imperative to provide the world with energy, in the face of exponential shortages, becomes pressing, considering that the predominant sources, especially oil derivatives, are significant emitters of greenhouse gases (Mikhaylov *et al*., 2020). These, in turn, are the modulators of our climate, leading to global warming, the impacts of which are becoming increasingly discernible (Harvey, 2018).

In this context, it is essential to underscore the significant influence exerted by the energy sector on greenhouse gas emissions, as this sector alone accounts for a substantial share of global emissions – estimates indicate that energy production and use are responsible for approximately 73% of anthropogenic carbon dioxide emissions (Nejat *et al*., 2015; Schmalensee e*t al.*, 1998). This predominance stems primarily from the combustion of fossil fuels for electricity generation, transportation, and heating, which intensifies the atmospheric concentration of gases such as CO_2, CH_4, and N_2O – key drivers of the planet's radiative imbalance (Kanakidou, 2024). Accordingly, the technological and policy choices made within the energy sector have direct implications not only for the trajectory of future emissions but also for societies' capacity to mitigate the adverse effects of global warming and to foster a more sustainable and climate-resilient development model.

Additionally, it is imperative to acknowledge that the challenge related to the transition toward renewable energy sources is likely to intensify in the coming years, as technological advancements – particularly in the field of artificial intelligence (AI) – impose new and substantial energy demands. The growing dependence on AI systems – whose training, operation, and data storage processes require high-performance computational centers with significant energy consumption – has markedly increased pressure on the global electrical infrastructure (Song e*t al*., 2024; Ukoba e*t al.*, 2024). Recent studies estimate that the development of some large-scale language models alone consumes more energy than hundreds of households over the same period (Dauvergne, 2020; Jin *et al.*, 2020). This reality renders even more urgent the need to expand access to clean, sustainable, and highly efficient energy sources to prevent the ongoing digital revolution from becoming an additional catalyst for greenhouse gas emissions.

It is necessary to consider some of the challenges that this issue imposes on society at this crucial moment in history: enabling everyone to have access to forms of energy; minimizing the environmental and human health impacts of energy production; mitigating dangerous climate change and providing energy security (Kang *et al*., 2020). Thought must be given to what the process of transforming energy procurement looks like regionally and globally, as well as the political and financial issues that permeate it if the transition is to be feasible (Mccollum *et al.*, 2012).

It is well known that the most developed and industrialized countries, because they consume substantial amounts of energy, have emerged as protagonists in the emission of pollutants, assuming a preponderant responsibility for climate change (Vanderheiden, 2011). In this context, there is an urgent need for these nations to lead the search for new energy sources and the mitigation of greenhouse effects, in addition to reducing the impact on the environment, especially on their forests and on developing countries (Wei *et al*., 2012).

At the same time, developing countries, with more limited resources to deal with climate change, are the most affected, both economically and socially (Sachs *et al*., 1999; Silva, 2024). Thus, tackling environmental issues becomes an essential pillar in the fight against climate change and global warming (Glicksman *et al.*, 2023) and will have to take into account the socio-economic conditions, as well as the environmental issues of each country or region (Ravindranath *et al.*, 2002).

The preservation of forests, recognized as major carbon dioxide sinks, is a crucial component of this environmental strategy (Mitchard, 2018). Nevertheless, a large part of the vast forest reserves is concentrated in developing countries, thus outlining a significant part of the solution to environmental challenges (Silva, 2023). In this way, it is clear that the fight against global warming must be considered holistically, taking into account the conditions of each country and region as a whole, especially its environment (Fearnside, 1999).

In the current context, the economies of both developed and developing countries are intrinsically linked to growing energy consumption (Tang *et al.*, 2018). However, in developed countries, this consumption is often associated with polluting activities, while in developing countries it is linked to environmental degradation (Ahmed *et al.*, 2015). It is essential to design new forms of energy production, or rethink those already in use, so that they have the least possible impact on the environment, are efficient and thus make it possible to minimize climate change (Olabi; Abdelkareem, 2022).

Furthermore, it is essential to emphasize that the success of the energy transition does not rely solely on technological advancements or governmental decisions but also depends decisively on the conscious engagement of the public. Society must be adequately informed about the urgency of replacing fossil energy sources with renewable alternatives, even if such a transition initially entails additional costs or adjustments to current consumption patterns. This is a strategic and imperative measure to confront climate change and to promote a more sustainable environmental future. However, for this engagement to materialize, it is critical to counter the widespread misinformation circulating on the internet and social media, which often denies the climate emergency or discredits scientifically grounded solutions (Silva, 2025, 2022).

This text proposes an analysis of various energy generation technologies in practice around the world, through countries that stand out in each of the ways of obtaining them, exploring their viability in specific locations and evaluating their replicability in other regions. This analysis considers the economic capacity and environmental conditions of the countries, offering a comprehensive and well-founded perspective on the options available.

2 Methodology

The methodology adopted in this study analyzes the processes underway in the search for sustainable energy sources in different parts of the world. To achieve this goal, parameters such as diversity of scope, costs involved, long-term viability and the possibility of replicating the models identified were considered.

Selection of Ongoing Processes and their Feasibility: Ongoing processes in various countries were selected, covering a variety of approaches in the search for sustainable energy sources. This selection aims to capture the diversity of strategies adopted globally, providing an insight into the practices being developed and whether they are applicable in other contexts.

Environmental Impact Assessment: The analysis considered the environmental impact associated with each way of obtaining energy. Understanding the potential environmental impact guided the assessment of the sustainability of these sources, contributing to the identification of alternatives that minimize damage to the environment.

Several forms of energy generation were examined throughout this study, with emphasis on their applications across different geographical and socio-economic contexts. Hydropower, for instance, was discussed through a case study in a country where this source is predominant and compared with other scenarios, given its global relevance. This form of generation is based on the gravitational force of falling or flowing water (Bagher *et al*., 2015). Regarding wind energy, the study investigated a country that has gained prominence using wind turbines, demonstrating the feasibility of this energy source under various conditions. Wind energy is ultimately derived from solar radiation, which is absorbed by the atmosphere and transformed into kinetic energy by large air masses (Portilla, 1995). Solar energy initiatives were also analyzed, focusing on both photovoltaic and thermal systems in a nation recognized for its leadership in this field, with particular attention to efficiency and adaptability across diverse geographic conditions.

The amount of energy delivered by the Sun to the Earth is immense and can be illustrated by major atmospheric and oceanic currents, the water cycle, and other natural phenomena dependent on this force (Crabtree; Lewis, 2007). In the case of biomass energy, initiatives from a country that has consolidated this form of energy utilization were assessed, considering both economic and environmental factors. This energy source encompasses any solid, liquid, or gaseous fuel – or any electrical energy – originating from organic matter, including plant-based materials, urban, commercial, or industrial waste derived from plants, or agricultural and forestry residues (Kurchania, 2012). Tidal energy was also addressed, based on the practical implementation in a country that employs it on a large scale, illustrating both its effectiveness and associated challenges. Tidal energy refers to electricity generated by the rise and fall of sea levels caused by tidal phenomena (Greaves *et al*., 2018). Geothermal energy, in turn, was explored through projects that harness the Earth's internal heat for electricity generation, heating, and hot water production in a country where this resource is widely used, demonstrating its applicability in diverse regions (Glassley, 2014). Finally, the ongoing reliance on fossil fuels – particularly in the United States – was analyzed, despite global expectations of their phase-out. This issue was discussed at COP 28, held in Cairo in 2023, and highlights the persistence of these sources, which are formed naturally through the decomposition of dead organisms and are rich in carbon, the main element responsible for combustion in coal, oil, and natural gas (Alpern; De Sousa, 2002).

Analysis of Practical Examples: For each type of energy listed, practical examples were identified and analyzed in countries that adopt these technologies on different scales. This approach made it possible to assess the feasibility and specific challenges associated with each type of energy source (Gryznova *et al.*, 2019), considering the peculiarities of its implementation in different contexts.

The combination of these elements in the methodology adopted provides an informed approach to the analysis of sustainable energy sources underway on the global stage, contributing to an understanding of the practical implications and potential solutions to contemporary energy challenges (Sinsel *et al.*, 2020).

3 Results

Countries that are exponents were selected for analysis, addressing the advantages and disadvantages that have been perceived in their implementation, with the limits imposed by their characteristics, considering the possible replication and implementation in other countries.

These are the energy sources, their respective countries and an overview of the use of these sources at the beginning of 2024 (table 1):

Table 1: Framework Renewable Energy Sources and National Experiences

Energy Source	**Country**	**Summary of Experience**	**Potential for Replication**
Solar Energy	China	China has established itself as a global leader in solar energy, driven by public policies, significant investments, and technological advances. Its solar industry is globally prominent in both production and innovation.	High, especially in countries with solar incidence and infrastructure capacity.

Tidal Energy	Japan	Japan has been pioneering the integration of tidal energy due to geographic challenges and energy diversification policies. Strategic partnerships and pilot projects demonstrate feasibility.	Moderate, depending on coastal and tidal conditions.
Hydropower	Brazil	Hydropower dominates Brazil's energy matrix. The country has developed large-scale plants such as Itaipu and Belo Monte. Challenges remain regarding environmental and social impacts.	High in countries with river systems and regulatory capacity.
Geothermal Energy	Philippines	Thanks to its volcanic geography, the Philippines uses geothermal energy as a pillar of energy diversification. Projects in Leyte and Mindanao have expanded energy capacity.	High in tectonically active regions.
Biomass Energy	China	China promotes biomass use through public policies and advanced technologies. The country converts agricultural and urban waste into energy, aligning sustainability and rural development.	High, particularly in agricultural or urbanized regions.
Fossil Fuels	United States	Despite environmental pressures, the U.S. remains heavily reliant on fossil fuels, due to economic structures and energy security. The shale boom strengthened this dependency.	Not advisable for replication due to emissions and climate targets.

Wind Energy	Germany	Germany is a global benchmark in wind energy, implementing onshore and offshore parks supported by incentive policies. The Energiewende policy exemplifies a strong national commitment.	High, especially in countries with suitable wind potential and policy support.

Fonte: o autor (2025)

Solar energy in China: In the first decades of the 21st century, the People's Republic of China emerged as a global leader in the adoption and expansion of solar energy, establishing itself as a crucial player in the transition to renewable sources. The Asian country has witnessed exponential growth in solar power generation capacity, driven by proactive government policies, significant investments and technological advances. The Chinese government has implemented subsidy policies, ambitious installed capacity targets and strict energy efficiency standards, aiming not only to meet the growing demand for electricity, but also to address environmental concerns and promote technological innovation. The Chinese solar sector has experienced remarkable consolidation, with local companies gaining global prominence in the production of solar panels and associated components. In addition, China has played a crucial role in the development of more efficient and affordable photovoltaic technologies, contributing to the economic viability of solar energy on a global scale. This phenomenon highlights not only China's prominence in the sustainable energy arena, but also its impact on global geopolitical and environmental dynamics (Liu *et al*., 2010).

Tidal energy in Japan: In recent years (since the second decade of the 21st century), Japan has been a pioneer in incorporating tidal energy into its energy matrix, demonstrating a significant commitment to renewable sources. Faced with the need to diversify its energy mix and reduce dependence on fossil fuels, the Japanese government has actively promoted the development of tidal energy. The country, located in a region prone to seismic and volcanic events, has realized the need to adopt more sustainable and resilient alternatives. Tidal energy, which harnesses the movement of the tides to generate electricity, has gained prominence in pilot projects and commercial initiatives in Japan. Substantial investments and strategic partnerships have been established to boost the research, development and implementation of efficient technologies in this sector. In addition, the country has sought to align its environmental and emissions reduction targets with the expansion of tidal energy, aiming not only for energy security but also for environmental sustainability in line with international commitments. This upward movement reflects Japan's strategic vision of exploring alternative and innovative sources to meet contemporary energy challenges, consolidating its position as a leader in the transition to a cleaner and more sustainable matrix (Novo; Kyozuka, 2021).

Hydropower in Brazil: Brazil has witnessed a remarkable growth in the use of hydropower, consolidating its position as one of the main global players in this sector. The country's vast territory offers significant hydroelectric potential, and hydroelectric power plays a leading role in the Brazilian energy matrix. Over the last few decades, Brazil has developed and implemented a series of large-scale hydroelectric projects to meet the growing demand for electricity and promote energy security. Among the emblematic projects are the Belo Monte Hydroelectric Power Plant and the Itaipu Power Plant, the latter representing a binational collaboration with Paraguay (De Sousa Júnior; Reid, 2010). The Brazilian hydroelectric sector not only contributes significantly to energy generation but also plays a crucial role in the stability of the national electricity system. However, it is important to point out that the continued growth of this energy source is giving rise to debates about environmental issues, social impacts and the need to diversify the matrix to guarantee long-term sustainability. In this context, Brazil is seeking to balance the expansion of hydroelectric power with the promotion of renewable sources and the implementation of sustainable practices, with the aim of reconciling economic development and environmental responsibility (Von Sperling, 2012).

Geothermal Energy in the Philippines: The Philippines has emerged as an international reference in the utilization of geothermal energy, establishing itself as one of the leading nations in the significant exploitation of this renewable resource. Benefiting from a geographically favorable location characterized by intense volcanic activity, the Philippine archipelago possesses vast reserves of the Earth's internal heat, which has enabled the development of geothermal power plants. The country has demonstrated a remarkable commitment to diversifying its energy matrix, aiming to reduce dependence on fossil fuels and mitigate the associated environmental impacts. The successful implementation of geothermal projects – such as those in Leyte and Mindanao – has substantially contributed to the Philippines' total energy generation capacity. The exploration of geothermal fields, coupled with technological advancements and strategic partnerships, has fostered a significant expansion in the use of this resource, positioning the Philippines as a regional leader in sustainable development and the effective adoption of geothermal energy. This scenario reflects not only progress in the nation's energy security but also a firm commitment to environmentally responsible practices and the promotion of renewable energy sources (Sussman *et al.*, 1993).

Biomass energy in China: China has experienced remarkable growth in the use of biomass energy, consolidating itself as a major player in promoting renewable sources in its energy matrix. The increase in demand for energy, together with the need to reduce greenhouse gas emissions, has driven the search for sustainable alternatives, highlighting biomass as a viable option. The growing implementation of advanced biomass conversion technologies, such as biogas production from agricultural waste and electricity generation from municipal solid waste, has played a crucial role in this scenario. Government policies, including financial incentives and favorable regulations, have fostered significant investment in the sector. In addition, China seeks to address environmental issues and promote rural sustainability through the development of bioenergy projects. This growing interest and investment indicates a strategic shift towards cleaner and renewable sources, highlighting China's prominent position in the international energy transition scenario (Jingjing *et al.*, 2001).

Fossil fuel energy in the United States: The United States has maintained a significant pattern of continued reliance on fossil fuels in its energy mix (Melosi, 1987), despite growing environmental concerns and global efforts to mitigate climate change. Oil and natural gas exploration and production have been fundamental pillars of the country's economy and energy infrastructure, contributing substantially to meeting national energy demand. The shale oil boom of the last decade has further boosted domestic oil production, consolidating US energy self-sufficiency (Kobek *et al.*, 2015). Although measures have been taken to diversify the energy matrix by promoting the use of renewable energies, the existing infrastructure and economic interests continue to maintain a high dependence on fossil fuels. This scenario highlights the challenges associated with the transition to cleaner sources and underscores the complexity of reconciling short-term economic interests with the urgent need to reduce greenhouse gas emissions to tackle global climate change.

Wind energy in Germany: Germany has stood out as one of the world leaders in the expansion and successful integration of wind energy into its energy matrix. With a notable commitment to promoting renewable sources and reducing greenhouse gas emissions, the country has witnessed significant growth in installed wind power capacity. The effective implementation of incentive policies, such as feed-in tariffs and auction schemes, has driven significant investment in the sector, culminating in an extensive network of onshore and offshore wind farms. Germany has reached significant milestones in terms of renewable electricity generation, with wind energy playing a crucial role in this progress. Germany's energy transition, known as the "Energiewende", highlights the country's emphasis on achieving carbon neutrality and promoting environmental sustainability (Von Hirschhausen, 2014). This scenario underscores not only the effectiveness of German policies in promoting wind energy, but also its position as a global benchmark in the transition to cleaner, renewable energy sources (Goetzke; Rave, 2016).

4 Discussion

The applicability of the various forms of energy needs to be analyzed, as diversification must be the key to tackling climate change and environmental destruction. The countries chosen were the energy matrices that stand out and, in order to discuss their potential, the exponents in the use of each of the sources were listed.

China has been actively seeking to diversify its energy matrix, incorporating biomass energy as part of its efforts to promote renewable sources. However, the implementation of this energy source faces notable challenges (Rosillo-Calle, 2016). Historical dependence on coal and other fossil fuels has resulted in traditional infrastructure and technologies needing to be adapted for biomass energy production. In addition, China's population and industrial scale intensifies competition for resources, raising questions about the sustainability and availability of biomass (Zhou *et al.*, 2009).

The advantages of biomass energy lie in its renewable nature and its ability to harness agricultural and organic waste, contributing to the reduction of waste and emissions, a key issue in a highly polluting country such as China (Vassilev *et al.*, 2015). However, the extensive use of land for biomass cultivation can generate environmental pressures, including competition with food production and the alteration of ecosystems, something that has to be considered in a country with such a large population and several fragile ecosystems (Datta *et al.*, 2019). Compared to other sources, biomass can be a more affordable transition option, especially in rural areas where there is an abundance of organic waste (Zheng *et al.*, 2010).

The viability of biomass energy for other countries, rich or poor, depends on various factorS (Nunes *et al*., 2020). In wealthy nations, the existing infrastructure may need significant adaptation, and the availability of biomass waste may vary. Poorer countries can benefit from biomass as an affordable alternative, contributing to sustainable development and energy security (Bhutto *et al.*, 2019). Nevertheless, the efficient management of resources and the mitigation of environmental and public health impacts are essential to ensure long-term sustainability (Gahlawat, 2017). Thus, the successful implementation of biomass energy requires a comprehensive approach, considering local conditions, environmental challenges and the need for an equitable energy transition.

Germany is a global leader in the implementation of wind energy, standing out for its commitment to the energy transition and the diversification of its energy matrix (Ziegler *et al.*, 2018). The challenges faced in implementing wind energy include variability in production due to fluctuations in wind intensity, requiring energy storage solutions (Velarde; Carpintero-Santamaría, 2012). The advantages, on the other hand, are remarkable, involving a significant reduction in greenhouse gas emissions, independence from fossil fuels and the creation of jobs in the renewable energy sector.

Compared to other energy sources, wind energy stands out for its availability in suitable areas, offering a cleaner and more sustainable alternative. However, the initial costs of installing and maintaining wind farms can be high, although they have declined over the years due to technological advances and an increase in the scale of production (Cheng; Zhu, 2014).

The viability of wind energy for other countries, rich or poor, depends on several factors. Nations with robust financial resources and favorable geographical conditions may find wind energy an attractive option, considering the reduction in associated costs and the environmental benefits. For less developed countries, the initial economic challenges may be more pronounced, but the possibility of reducing dependence on fossil fuels and promoting sustainable development makes wind energy an option to consider (Tong, 2010).

The environmental impact of wind energy is relatively low when compared to traditional sources of energy generation, with no direct emissions of atmospheric pollutants. However, issues such as the visual impact, effects on wildlife and possible noise generated by wind turbines have been points of discussion (Yuning Zhang *et al*, 2016).

The analysis of the implementation of wind energy in Germany reveals a positive scenario, with challenges overcome by substantial economic and environmental benefits (Müller; Morton, 2021). For other countries, viability will depend on the ability to overcome initial costs, exploit favorable geographical conditions and implement appropriate policies. Wind energy remains a promising option for making a significant contribution to the global transition to more sustainable energy sources (Nelson, 2009).

The Philippines has stood out internationally for its remarkable use of geothermal energy as a significant source in its energy matrix Parte superior do formulário (Fronda *et al.*, 2020). However, the implementation of this technology is not without its challenges. The region presents considerable geotechnical and volcanic risks, requiring specific technologies and careful management of geothermal resources (Pan *et al.*, 2019). Furthermore, although geothermal energy is a low-emission source and constantly available, the need for significant initial investments and the costs associated with drilling and maintaining geothermal wells can be considerable obstacles (Cataldi, 2001).

The advantages of geothermal energy in the Philippines include the reliability of the source, the reduction of greenhouse gas emissions and the diversification of the energy matrix, contributing to energy security (Kulasekara; Seynulabdeen, 2019). Compared to other sources, geothermal energy stands out for its constant nature, regardless of weather conditions, and has a relatively low environmental footprint (Brophy, 1997).

The viability of geothermal energy for other countries, rich or poor, will depend on the specific geology and location (Tester *et al*., 2006). Nations with volcanic activity or tectonically active areas can benefit from geothermal energy, especially if the infrastructure and technical expertise are available. Nonetheless, economic viability must be weighed against drilling and maintenance costs, and is more challenging for less developed nations (Okolie *et al*., 2019).

In terms of environmental impact, geothermal energy is considered a more sustainable option, generally associated with lower greenhouse gas emissions compared to fossil sources. However, it is crucial to adopt responsible management practices to mitigate possible local impacts, such as decreasing geothermal pressure in reservoirs (Dickson; Fanelli, 2005).

Therefore, analyzing the feasibility of geothermal energy for other countries requires a careful assessment of geological, economic and environmental factors, seeking a balance between the availability of the resource, the associated costs and the mitigation of environmental impacts (Shortall *et al*., 2015).

Hydroelectric power plays a fundamental role in Brazil's energy matrix, standing out as the country's main source of electricity (De Lima Andrade; Dos Santos, 2015).

The extensive implementation of hydroelectric plants has provided significant advantages, such as large-scale electricity generation, contributing to energy security and reducing greenhouse gas emissions compared to fossil sources. However, the construction of large dams and reservoirs faces environmental and social challenges, including the impact on river ecosystems, the displacement of local communities and the alteration of natural water flows (Ruffato-Ferreira *et al*., 2017).

The advantages of hydropower in Brazil include its capacity to respond to electricity demand, its operational flexibility and its contribution to regional economic development (Raupp; Costa, 2021). However, excessive dependence on this source can make the system vulnerable to extreme weather events, affecting the availability of water for power generation (Von Sperling, 2012).

Compared to other sources, hydropower is an economically viable option for countries with abundant water resources. However, the costs associated with building and maintaining hydropower infrastructure can be substantial, and viability is strongly influenced by the specific geographical and climatic conditions of each nation (Fakehinde *et al*., 2019).

The environmental impact assessment of hydropower in Brazil highlights the need to balance economic benefits with environmental conservation. The sustainable expansion of this source requires the implementation of integrated watershed management practices and the consideration of cleaner and more resilient alternatives (Nayak, 2023).

Therefore, although hydroelectric power is a valuable option for countries with favorable geographical characteristics, the analysis of its viability must take into account costs, social and environmental challenges, and the search for a balance between the various energy sources available (Yuksel, 2013).

Japan has been exploring tidal energy as a promising alternative in its search for renewable energy sources (Bricker *et al*., 2017). However, the implementation of this technology faces considerable challenges. Japan's specific geographical conditions, with its coastal shores susceptible to earthquakes and tsunamis, make the construction of tidal infrastructure a complex and costly technical task. In addition, tidal variability and the need for specific technologies to capture the energy of water movements pose operational challenges (Neill *et al*., 2018).

The advantages of tidal energy in Japan include the constancy of tidal movement, offering a predictable source of electricity generation and contributing to the diversification of the country's energy matrix. In addition, this source is more predictable and stable than some renewable sources, such as solar and wind, mitigating challenges related to variability (Gorlov, 2001).

Compared to other energy sources, the viability of tidal energy in Japan depends on the cost-benefit ratio. The initial costs of building tidal installations are high, but long-term sustainability and predictability can compensate for these investments. However, for other countries, rich or poor, viability will depend on specific geographical conditions and the availability of resources for infrastructure and research (Shetty; Priyam, 2022).

In terms of environmental impact, tidal energy is considered a clean source, with no greenhouse gas emissions during operation. However, the construction of coastal infrastructure can have local impacts, requiring careful management to avoid damaging marine ecosystems (Neill *et al*., 2021).

Therefore, the analysis of the feasibility of tidal energy for other countries must take into account geographical characteristics, initial costs, the stability of the source and local environmental impacts (chowdhury *et al*., 2021). Japan serves as an example of the challenges and opportunities in this field, demonstrating that the adoption of this energy source requires a balanced and context-specific approach.

The use of fossil fuel energy in the United States has been a central part of the country's energy matrix, but it is not without its challenges (Yi *et al.*, 2023). The exploration and extraction of these resources, such as oil and natural gas, often involve significant environmental impacts, such as air pollution, the risk of spills and the degradation of ecosystems. In addition, dependence on these sources contributes to greenhouse gas emissions, exacerbating climate change (Dorian *et al*., 2006).

The advantages of fossil fuels in the US have historically included the accessibility and abundance of these resources, contributing to energy autonomy and economic growth.

However, growing environmental awareness and the costs associated with mitigating negative impacts have led to a reassessment of their long-term viability (Goldemberg, 2006).

Compared to other energy sources, fossil fuels face challenges in terms of sustainability and diversification of the energy matrix. Emerging technologies, such as renewable energies and energy storage, are gaining ground as cleaner and more sustainable alternatives (Wang *et al.*, 2014).

The viability of using fossil fuels for other countries, rich or poor, depends on several factors (Armaroli; Balzani, 2011). Rich countries may have the necessary infrastructure to exploit and use these resources more efficiently and safely. However, for poorer nations, dependence on fossil fuels can be limited by the costs associated with infrastructure, as well as local and global environmental impacts.

The economic and environmental cost of fossil fuels, considering their role in climate change and pollution, has led many countries to consider transitions to cleaner sources (Arutyunov; Lisichkin, 2017). Therefore, analyzing their viability requires careful consideration of the associated costs, not only in economic terms, but also in relation to social and environmental impacts, encouraging the search for more sustainable and innovative alternatives.

China has emerged as a global player in the implementation of solar energy, demonstrating a remarkable expansion in this sector over the years (Liu *et al.*, 2010). The challenges facing the integration of solar energy in the country include the need to overcome the variability in solar irradiation, especially in northern regions, and to tackle issues related to energy storage (Li; Huang, 2020). Furthermore, despite the progress made, China still relies substantially on conventional energy sources, which implies challenges in the transition to a cleaner and more sustainable matrix.

The advantages of solar energy in China are vast (Korsnes, 2019). The large-scale production of solar panels, combined with favorable government policies and an attractive investment environment, has resulted in considerably reduced installation costs (Geall; Shen, 2018). Solar energy offers a renewable source, mitigating greenhouse gas emissions and contributing to the diversification of the energy matrix, crucial aspects in the search for a sustainable transition.

Compared to other energy sources, solar energy stands out for its availability and potential for application on various scales, from residential systems to large solar parks. Its viability for other countries, rich or poor, is influenced by accessibility to solar resources, investment capacity and infrastructure (Hossain *et al.*, 2011). In wealthier nations, solar energy can be an economically viable and sustainable option, while in poorer countries, the reduction in the cost of solar equipment has made this source an attractive alternative for meeting energy demands, especially in regions with good solar irradiation (Sampaio; González, 2017).

The environmental impact of solar energy is generally lower compared to traditional energy sources, since it does not emit atmospheric pollutants during the generation of electricity

(Hernandez *et al*., 2014). Nevertheless, the production and disposal of solar panels raises environmental concerns related to materials and waste.

The analysis of the implementation of solar energy in China highlights not only its environmental and economic benefits, but also the challenges inherent in this energy transition. The Chinese experience serves as a valuable case study for other countries, indicating that the viability of solar energy depends not only on the availability of solar resources, but also on the formulation of effective policies, adequate investments and careful environmental considerations (Li; Huang, 2020).

5 Final considerations

The analyses presented in this article yield multiple conclusive points that not only address the objective outlined in the introduction but also offer significant contributions to academic discourse, social engagement, and public policy formulation. Firstly, the study confirms the inherent complexity of the global transition toward sustainable energy sources, demonstrating that no single model is universally applicable. The technical, economic, geopolitical, and environmental viability of each energy source is fundamentally contingent upon regional conditions, institutional capacities, and the degree of political commitment to sustainability.

Secondly, it is evident that the experiences of countries such as China, Germany, the Philippines, Japan, and Brazil provide both inspiring models of energy diversification and concrete illustrations of persistent limitations and challenges – such as high initial costs, localized environmental impacts, and socio-economic resistance. These limitations have been critically addressed throughout the article, underscoring the need for adaptive public policies, international financial support, and an informed public engagement to ensure a feasible and equitable energy transition.

From an academic perspective, this study contributes to the critical systematization of energy strategies adopted across distinct contexts, enhancing the understanding of replicability and the enabling or constraining factors associated with each approach. Socially, the work highlights the urgency of informing the public about the importance of progressively replacing fossil fuels with renewable alternatives – even when this implies short-term costs – as a means of ensuring long-term collective well-being. In this regard, the article emphasizes the need to combat climate misinformation, frequently spread across social media platforms, as a prerequisite for the strengthening of evidence-based environmental policies.

Finally, in terms of public policy, this study offers concrete insights into the development of integrated energy plans that consider local specificities, available scientific and technological potential, and internationally assumed commitments in the fight against climate change. By recognizing both the opportunities and the limitations inherent in each energy matrix, the article invites policymakers, scholars, and citizens to collectively, critically, and sustainably rethink the energy future of the planet.

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