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The Renewable Energy Market's Regulatory Requirements

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Abstract. This paper deals with how the "free" energy market works in Brazil and around the world in relation to the means of energy production used, seeking to show how the environment that defines the energy market adjusts to the evolution of energy generation technology and vice versa. The aim is to synthesize an understanding of the current energy commercialization scenario and present the main technological aspects of each means of energy generation, in order to develop tools or paths to improve the performance of systems and machines belonging to the electrical area, thus making a scientific contribution to the Generation, Transmission and Distribution of Electric Energy – GTD market. It is a fact that global energy demand has increased, and due to the high emission of gases that contribute to global warming in the energy generation process, it is necessary for renewable energy generation to increase to the detriment of the reduction in thermoelectric power plants. In this sense, there is a need to understand the regulatory requirements of the market for the distribution of renewable energy, its challenges and opportunities and the influence of consumers on this distribution. In this way, 10 base articles were chosen through a systematic literature review process, as well as visiting the regulatory framework in different countries (developed and developing). The aim was to synthesize the studied themes and topics, focusing on the differences between the regulatory requirements for wind and solar distribution, as well as onshore and offshore wind. It was possible to notice that developed countries have a very solid energy transmission and distribution infrastructure, initially focusing on the quality of supply, and later on energy policies aimed at promoting the use of renewable sources. Thus, even if the energy matrix is largely renewable, it is necessary to diversify it, as in the United States, and invest in delivering quality to consumers, and then, subsequently, implement policies to promote renewables.

Keywords: Renewable Energy; Sustainable Development; Energy Market; Offshore Wind Farm; Solar Energy; GTD (Generation, Transmission and Distribution of Electric Energy).

1 Introduction

The transition to renewable energy has become a pressing global concern due to the finite nature of nonrenewable energy sources and the environmental damage caused by their combustion. The growing demand for energy, coupled with the adverse effects of heavy reliance on fossil fuels, has led to a heightened focus on renewable energy. This form of energy, derived from replenishable natural resources such as sunlight, wind, water, thermal energy, and organic materials, offers a sustainable alternative to traditional nonrenewable sources.

In this sense, some of the energy policies that stand out in developed countries, such as Germany, the United States and Japan, were highlighted in order to subsequently compare them with Brazil and thus enable a critical analysis regarding the current scenario of the Brazilian energy sector.

2 Analytical Framework

2.1 Developed Countries

Germany

The German energy sector has undergone significant transformation in recent years, characterized by a shift towards renewable energy sources and away from traditional fossil fuels. This transition, known as the “Energiewende”, aims to increase the share of renewable energy in electricity GTD, reduce greenhouse gas emissions, and phase out nuclear power. [1]

In Germany, Feed-in Tariffs (FiTs) are one of the main instruments of energy policy aimed at encouraging the production of renewable energy, such as solar, wind, biomass, and hydroelectric power. The FiTs guarantee that producers of renewable energy receive a fixed price for each kWh of electricity generated and fed into the grid; The producers can enter long-term contracts with energy distributors or the government, ensuring a stable revenue stream for a specified period. [1]

It’s important to note that the feed-in tariff rates vary depending on the renewable energy source and the scale of the project. Generally, rates are higher for smaller projects and for more expensive or mature technologies. Besides that, the costs associated with feed-in tariffs are passed on to all electricity consumers through charges on the energy bill.[1]

Because of these policies to encourage renewable energy, its increase raises concerns related to grid overload, especially when there is a large amount of renewable energy generation, such as solar and wind. [1]

In response to this challenge, Germany utilizes various energy storage methods, including setting up stationary batteries; implementing large-scale storage systems with lithium-ion batteries and compressed air, usually installed in renewable energy plants or substations to offer grid-level storage. [3]

Another approach is pumped hydro storage, which involves using surplus energy to move water from a lower reservoir to a higher one during low-demand periods.

Additionally, excess heat from high-production periods can be stored thermally in materials like molten salts for later electricity generation when required. [3]

United States

In the United States, the energy situation is characterized by a diverse mix of energy sources, including coal, natural gas, nuclear, hydroelectric, wind, solar, and other renewable energies. The country is one of the largest energy producers in the world and has a robust infrastructure for electricity generation, transmission, and distribution. [1]

The energy sector in the United States has undergone significant changes in recent years, with an increase in natural gas production due to the development of shale gas extraction techniques, such as hydraulic fracturing (fracking). This has led to a decrease in the share of coal in the energy mix and a reduction in greenhouse gas emissions. [4]

Though still predominantly relying on thermal power plants for energy generation, the United States has efficient energy policies related to incentivizing the use of renewable energy sources, such as tax credits, Renewable Portfolio Standards (RPS), investments in Research and Development (R&D), and Electric Vehicle Incentives. [9]

Included among the tax credits for renewable energy, it is worth highlighting the Production Tax Credit (PTC), which is related to a tax credit offered for each kWh of renewable electricity produced during a specific period, and the Production Tax Credit for Renewable Fuels (PTC), which provides a tax credit for each gallon of biofuel produced. [9]

Japan

In Japan, the GTD of electrical energy are dominated by utility companies, known as "utilities." The country's energy mix is diverse, with a significant dependence on imported energy, especially after the Fukushima nuclear disaster in 2011, which led to the temporary shutdown of several nuclear plants in the country. Japan has been seeking to increase its renewable energy capacity, especially solar and wind, and is also investing in energy storage technologies and smart grids to improve the efficiency and reliability of the electrical system.[1]

This country has several initiatives in its energy policy, including strict regulations and oversight related to energy efficiency, as well as financial subsidies. Like in Germany, Japan utilizes Feed-in Tariffs - FiTs, which ensure a fixed price per kWh of electricity generated from renewable sources. These tariffs are provided for a specified period and vary depending on the type of technology and the scale of the project.[5]

Furthermore, the Japanese government facilitates access to financing and credits for clean energy projects, offering special credit lines with favorable interest rates for companies and individuals wishing to invest in renewable technologies. [5]

2.2 Brazil

The Brazilian Energy Sector

The Brazilian energy sector is diversified, with a predominately renewable energy matrix, prominently featuring sources such as hydroelectric, biomass, and wind power.[1]

The country also relies on thermal power plants, primarily natural gas-based, to supplement energy supply, especially during dry periods.[1]

Electricity production is primarily overseen by state-owned entities such as Eletrobras, yet Brazil's electrical industry has experienced a privatization shift, now featuring involvement from private enterprises in GTD. [6]

Despite advancements in diversifying the energy matrix and expanding generation capacity, the sector faces challenges related to infrastructure, the need for modernizing the power grid, and the pursuit of cleaner, more sustainable energy sources.[7]

Brazil has implemented policies to promote renewable energy production, such as energy auctions and tax benefits. Nonetheless, obstacles like environmental permitting, financing, and transmission infrastructure remain hurdles for the comprehensive advancement of the energy industry in the nation.[8]

The Structure

The structure of Brazil's electricity sector is quite intricate, involving numerous entities and organizations. Here's an outline of how the system operates:

Ministério de Minas e Energia (MME): This government department is tasked with crafting energy policies and overseeing the functioning of the country's electricity sector.[10]

Agência Nacional de Energia Elétrica (ANEEL): It is the regulatory agency responsible for regulating and overseeing the generation, transmission, distribution, and commercialization of electric energy in Brazil. ANEEL is responsible for establishing rules, norms, and tariffs for the sector.[10]

Operador Nacional do Sistema (ONS): ONS is in charge of coordinating the generation and transmission of electricity within Brazil’s interconnected grid. It continuously monitors supply and demand to ensure the system’s stability and reability.[10]

Câmara de Comercialização de Energia Elétrica (CCEE): It is responsible for the operation of the electricity market in Brazil, carrying out the accounting and financial settlement of transactions between generators, distributors, and free consumers.[10]

Generating Companies: These are companies responsible for generating electric energy from various sources, such as hydroelectric, thermal, wind, solar, among others. They can be public or private companies.[10]

Transmission Companies: These companies build, operate, and maintain the high-voltage transmission lines that transport electricity from generating plants to distribution centers.[10]

Distribution Companies: Distribution companies deliver electricity directly to consumers within their designated service areas. Some are owned by the state, while others are operated by municipalities.[10]

Consumers: This category includes residential, commercial, industrial, and agricultural users of electricity. Additionally, there are "free consumers" who have the freedom to choose their electricity suppliers and negotiate contracts independently.[10]

This is a basic outline of the institutional model of the Brazilian electricity sector, which aims to ensure the safe, efficient, and sustainable supply of electric energy throughout the country.

The Free Energy Market

The free energy market in Brazil is a competitive electricity trading environment in which participants can freely negotiate commercial conditions, including the supplier, price, type, and quantity of contracted energy, supply period, and payment methods.[10]

Until recently, only consumers with a load greater than 500 kW could buy electricity from any supplier, normally electricity bills greater than R$ 150, that is, industries and larger enterprises such as shopping centers, malls, and hospitals. However, starting from January 1, 2024, the opening of the free energy market for high voltage consumers with a load of less than 500 kW was approved, and around 166,000 high- and medium-voltage consumer units will be allowed to migrate to the free energy market.[10]

According to the Brazilian Association of Energy Traders (Abraceel), the free market's share of the total Brazilian energy distribution market is expected to increase from 37% to 50%, and the opening of the market to all consumers should begin in January 2026, with expectations of providing savings of 18% on the electricity bill, in addition to releasing more than R$ 20 billion for the purchase of goods and services.[11]

In the free energy market, consumers buy energy directly from generators or traders through bilateral contracts with freely negotiated conditions. There is the possibility of contracting conventional or incentivized energy. The incentivized energy is used by the government as a stimulus for the expansion of generators from renewable sources such as biogas, Small Hydroelectric Plants, solar energy, wind energy, and geothermal energy, among others. The purchaser of these types of energy receives discounts on the tariff for using the distribution system. Conventional energy comes from other types of generators, such as thermal gas plants or large hydroelectric plants, and those who consume do not receive a discount on the tariff for using the distribution system.[10]

The Brazilian energy market is divided into the Regulated Contracting Environment (ACR), which are captive consumers, and the Free Contracting Environment (ACL), formed by free consumers. Captive consumers are those who purchase energy from distribution concessionaires in their regions. The consumer unit pays an energy bill per month, which includes the distribution service and energy generation, with tariffs regulated by the government. Free consumers, on the other hand, buy energy directly from generators or traders, through bilateral contracts with freely negotiated conditions.[10]

The main advantage of the free energy market is the economy. Compared to the captive market, a purchase of energy on the free market can generate up to 30% savings on the electricity bill. Other benefits are exemption from the charging of tariff flags, common in concessionaires' bills, and predictability, since a contract of up to five years makes it possible to know the monthly amount in advance.[10]

3 Results

Brazil holds considerable potential for renewable energy, particularly in hydropower, solar, and wind resources. Efforts to boost the utilization of these energy sources in the country include financial incentives, subsidies, and established bioenergy programs driven by ethanol production from sugarcane. Nevertheless, the heavy reliance on hydropower leaves the system susceptible to drought periods. Moreover, substantial investments in infrastructure are required to expand the capacity for renewable energy.

Germany stands as a global frontrunner in energy transition, placing significant emphasis on renewable energy sources. Its feed-in tariffs (FiTs) policies have effectively promoted decentralized energy production. However, the transition incurs high costs, which are reflected in consumers' energy bills. Despite efforts to reduce emissions, there persists a continued dependency on coal for energy generation. Additionally, integrating intermittent renewable energy sources into the grid presents challenges.[2]

In the United States, the diversity of energy sources, including natural gas, nuclear, wind, and solar, is notable. Additionally, there is a strong investment in technological innovation and research and development, with a growing participation of renewable energy in the energy matrix, especially solar and wind. However, the country's energy policy is fragmented due to the decentralization of regulatory power among the states. Another aspect to highlight is the country's ongoing dependence on fossil fuels and the influence of the fossil fuel industry in the political process.

In Japan, there is considerable investment in renewable energy technologies, especially after the Fukushima disaster. However, there are significant challenges in diversifying the energy matrix due to the country's historical dependence on nuclear energy and fossil fuel imports. The development of renewable energy is significantly bureaucratic.

Comparative table of the electricity sector in countries

	Germany	Brazil	Japan	United States
Main generation sources	Thermal, nuclear and wind.	Hydroelectric, thermal, wind and solar.	Thermal, solar and nuclear.	Thermal, nuclear and coal.
Investments	Directed towards developing the potential of renewable sources, focusing on technological advancement for infrastructure and System efficiency.	Directed towards developing the potential of renewable sources and infrastructure of the electrical system, based on modernizations or expansions, whether in transmission or distribution.	Directed towards developing the potential of renewable sources and infrastructure of the electrical system, through modernizations or expansions.	Directed towards developing the potential of renewable sources and infrastructure of the electrical system.
Main problems currently	With a “small” territory, challenges are	The resulting expansion in power of intermittent	With limited energy resources, it	There is still a very large dependence on fossil fuels,

	encountered in implementing onshore solar and wind farms in the country. Consequently, sources of electrical energy production based on fossil fuels are widely used. Furthermore, to increase the efficiency of the System, there are energy storage stations, which currently present an expensive technology with sustainability problems.	sources, mostly concentrated in a specific region of the System, has brought to light a transmission infrastructure problem. Furthermore, there are still no decisions taken to deal with the intermittent characteristic of these sources to increase the efficiency of the system and resolve regulatory issues.	depends heavily on oil imports.	due to the rapid growth in electricity consumption in the country, not accompanied by the expansion of installed power from renewable sources.

For a more comprehensive analysis of GTD in Brazil, interviews were conducted with several researchers, professors, and professionals in areas related to energy generation and commercialization, in which important aspects related to the presented topics were discussed. With the complement of the interviewees' perspectives, it was possible to visualize that the future of Brazil's electric sector infrastructure will be based on the control and dissemination of renewable energies within the energy matrix as regulatory details develop and fiscal incentives adapt so that technologies become self-sustaining. In parallel, there is the commercial scenario, in which Brazil should follow the development example of first-world countries, such as those mentioned, so that consumers are increasingly free to choose their energy provider and purchasing method, making the market more competitive and, consequently, more qualified in offering services.

However, some problems remain, such as the country's socioeconomic and socio-environmental issues. According to the interviewees, there are still difficulties in raising awareness among the population about the free energy market, its benefits, and its operating rules. This occurs due to the country's economic and educational situation, preventing the topic from reaching a large portion of the population. Another problem related to economic inequality is the imbalance that could arise from self-generation or migration to the free energy market by the middle/high-income population: those unable to acquire their own generation systems would be harmed by high utility tariffs, to compensate for migration and distributed generation.

Moreover, considering that the socio-environmental issue involves the emission of polluting gases, it is necessary to analyze emissions from raw material extraction to the end of the generation system's useful life. In this regard, there is the concept of "energy payback time," which is the calculation that demonstrates whether renewable generation systems "pay back" the energy used for their manufacturing[12]. That is, it shows if the systems are self-sustaining, already considering the manufacturing and transportation process, and it corroborates the importance of these sources for environmental preservation.

Furthermore, when addressing the structure and means of energy generation, it is known that Brazil's potential for production through renewable sources is abundant, given that its energy matrix is predominantly composed of renewables, and its annual energy demand is met by more than 50% from these sources. There are still many projects related to larger implementations in the territory. According to the interviewees' opinions, the trend is for growth, even in the face of the difficulties encountered in controlling intermittent sources and the variation in the prices of technologies related to sources that require sophisticated equipment. To address these challenges, research and incentives must be promoted to develop solutions, as a country's production and energy control capacity is crucial for its development in many aspects. In this context, the main aspect discussed in the interviews was storage as a solution for this control, which, as mentioned earlier, is already widely used in Germany. The interviewees agreed that hydrogen storage is the trend, as it presents a more sustainable and clean solution in the long term.

Comparative Table of Interviews on Renewable Energy

Question	Pedretti	Geremi	Kristie	Tiepolo
How do you assess the effectiveness of current government incentives in promoting the development of the clean energy market in the country?	The effectiveness of tax incentives such as ICMS exemption on the purchase of photovoltaic kits and materials related to wind generation is specific. They stimulate the commercialization of clean energy systems by taking the market out of inertia. However, it	Government incentives such as ICMS exemption on the purchase of photovoltaic kits and materials related to wind generation are significant for promoting the development of clean energy. These incentives reduce costs and improve the economic viability	Tax incentives are efficient tools for developing technologies by shortening the establishment time and creating a value chain. They promote industrial development and empower professionals.	Tax incentives have been highly attractive and essential for developing solar and wind energy in Brazil, saving reservoir water and reducing the need for hydropower generation.

	is important to consider whether these subsidies are the best use of public resources compared to other state government priorities.	of investments in renewable energy. However, the effectiveness of these incentives can vary by state and local conditions, making the analysis more complex.		
Do you think the differences between the new legal framework for DG (Distributed Generation) and ANEEL Resolution No. 1059-2023 will make much difference in adherence to renewables?	The new DG law and ANEEL RN No. 1059 - 2023 may have impacts especially due to the change in TUSD charges. Despite the reduction in subsidies, renewable technologies remain economically attractive. Adherence to renewables may be affected by the perception of less advantage, but in the long run, DG is expected to remain a viable option.	The new DG law and ANEEL RN No. 1059 - 2023 may impact adherence to renewable energies due to the introduction of the B wire which represents an additional cost. However, this change also brought benefits such as greater legal certainty for systems installed before the new law. The economic viability of installations may vary by type of generation and location and analysis must be done on a case-by-case basis.	The gradual removal of subsidies is appropriate, and the technology has already developed sufficiently to sustain itself without them. The measure should be carefully taken to avoid negatively affecting the market.	The gradual removal of subsidies is necessary to avoid unfair competition. And the technology should sustain itself without subsidies in the long term.
How do you think it is possible to raise consumer awareness of these forms of energy generation such	Raising consumer awareness is a challenge due to the complexity of energy contracts. It is necessary to invest in	Raising consumer awareness about the free energy market (ACL) and distributed generation (DG) can be	Awareness should focus on economic advantage. Education campaigns about electricity are	Awareness should be based on economic advantage and the experience of other

as DG and ACL?	education campaigns that clarify the economic advantages of ACL and DG. Migration to ACL requires specialized knowledge, and many consumers may fear the financial risks involved.	done through interactive tools, informative materials, and awareness campaigns. It is essential to inform about migration costs and the financial advantages of each option. Price comparison and a clear explanation of benefits are crucial to helping consumers make informed decisions.	necessary because electricity is abstract and intangible to much of the public.	countries. Educational campaigns are important to explain electricity in an accessible way.
Do you think the next step is to open the free market to those who receive low voltage? What would be the impact of this?	Opening the free market to low voltage consumers should be done with caution. Lack of knowledge and adequate infrastructure can lead to bankruptcies if companies do not know how to contract correctly. It is crucial to have regulations to ensure a safe and fair transition, avoiding financial problems for consumers.	Opening the free market to low voltage consumers is a significant challenge that requires a well-consolidated regulatory structure. While freedom of choice and increased competition can lead to lower prices, there are risks, especially for low-income consumers who may have difficulty understanding the market. Inequality in access to the free market and the possible discouragement	Opening the free market should be done carefully to avoid problems. It is important to have a set of rules to ensure that everyone has access and to avoid mass disconnection from the grid.	Opening the free market will bring greater competitiveness and choice for consumers, but a careful regulatory framework is necessary to avoid problems such as mass disconnection from the grid.

		of distributed generation are issues to be considered.		
How can the interconnection of different energy sources contribute to the stability and reliability of the electrical system?	The interconnection of different energy sources is essential for the stability and reliability of the electrical system. The use of large reservoirs as energy storage and investment in batteries are important solutions. In the future, green hydrogen can solve many stability problems.	The interconnection of different energy sources is crucial for the stability and reliability of the electrical system. The development of large-scale energy storage technologies such as batteries and intelligent system management can help solve the variability problems of renewable sources. Smart electronic equipment and smart grids are also important for balancing energy supply and demand.	In Brazil, large reservoirs can be used as energy storage, and batteries will play a crucial role in the stability and reliability of the system.	
Do you think offshore wind generation can develop in Brazil with current market energy prices?	Offshore wind generation has potential, but it depends on adequate incentives and policies. The Brazilian coast may not have ideal conditions, and offshore projects face high logistical costs.		Offshore wind generation has potential, but it depends on adequate incentives and policies. The Brazilian coast may not have ideal conditions, and offshore projects	

			face high logistical costs.	
Do you think problems with the control of generation through renewable sources can harm the market situation regarding prices and incentives for these types of sources?	The increasing share of wind and solar has become viable with the construction of diesel oil thermal plants for stabilization. The technology that mitigates this issue is storage. The challenge is to seek all kinds of batteries for various applications.		Controlling the injection of energy into the grid is a challenge, but operational adjustments and benchmarking with other countries can solve the problem.	
What are the opportunities and challenges associated with integrating energy storage systems into the power grid?	Technologies such as batteries are under development and are fundamental to the future of the electric sector.		Integrating energy storage systems faces challenges such as high cost and the need for infrastructure, but it is essential for grid stability.	
What are the ethical and social challenges associated with the development and implementation of renewable energy technologies?	Subsidies should be directed to low-income consumers to avoid only the rich benefiting.		Ethical and social challenges include inequality in access to renewable energy technologies. Decentralized markets can lower prices universally, benefiting everyone.	
How do you evaluate the role	It is important to calculate the life		Renewable energies are	

of renewable energies in reducing greenhouse gas emissions and combating climate change?	cycle of technologies to ensure they are truly more sustainable than fossil alternatives.		fundamental in reducing greenhouse gas emissions. It is important to calculate the Energy Payback Time and Life Cycle Analysis to evaluate true sustainability	
What will be the impacts for the consumer resulting from the implementation of large-scale smart grids?	Having much more information about the operational status of each point of the system enables the system to be operated more efficiently. There is data to make better decisions regarding system changes. So Copel adopted a much more focused initiative on smart metering and network automation. And this does indeed enable many operational efficiency gains, reducing the need for field trips to discover the operational status of a region, for example.		The implementation of smart grids will bring greater efficiency in supply and control over energy flow, resulting in significant improvements in the performance of the electrical grid.	
What can be the benefits of	Hydrogen, being a non-polluting		Hydrogen generation will be	

hydrogen generation for the functioning of the energy market?	and renewable dispatchable source, has great potential for production worldwide.		a major energy vector, offering storage and mobility solutions without producing greenhouse gases.	
How can artificial intelligence and data analysis be applied to optimize the operation and maintenance of renewable energy systems?	There are already initiatives of decision-making systems that are being refined. Systems that can draw human attention more specifically instead of the individual looking at an infinity of data and needing to make multiple cuts.		Artificial intelligence and data analysis are already widely applied in the energy sector, optimizing the operation and maintenance of renewable energy systems.	

4 Conclusion

Therefore, Brazil heavily relies on hydroelectric power, contrasting with Germany's leadership in transitioning to renewable sources like wind and solar. The United States boasts a diversified energy matrix, including natural gas, nuclear, wind, and solar. Meanwhile, Japan depends on nuclear energy and fossil fuel imports, facing challenges related to nuclear safety and waste management.

Despite investments in technological innovation across these countries, the United States grapples with fragmented energy policies due to regulatory decentralization among states, whereas Brazil maintains a more centralized regulatory framework.

While Brazil contends with significant challenges in modernizing its energy infrastructure, the United States enjoys a more advanced and developed infrastructure.

The interviews with experts highlighted that Brazil's electric sector will increasingly rely on renewable energy, supported by evolving regulations and fiscal incentives. While the country must address socioeconomic and socio-environmental challenges, such as public awareness and economic inequality, the potential for renewable energy remains strong. The concept of "energy payback time" underscores the sustainability of renewable technologies. Despite the hurdles in managing intermittent sources and technology costs, Brazil's renewable energy sector is poised for growth. Key to this development will be advancing research and incentives, particularly in energy storage solutions like hydrogen, which promise a sustainable and clean future for the country's energy needs.

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