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Law, Public Policies and Energy Transition: The Brazilian Energy Matrix

Direito, Políticas Públicas e Transição Energética: A Matriz Energética Brasileira

Derecho, Políticas Públicas y Transición Energética: La Matriz Energética Brasileña

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ABSTRACT: This paper, based on an analysis of data and official information, as well as an extensive body of literature published between 2015 and 2022, addresses the concept of energy transition, the historical context of energy production in Brazil, and the challenges of decarbonizing the Brazilian energy matrix. The methodology employed is the law and public policy approach, understanding the reality of the Brazilian energy matrix and how decarbonization targets can be achieved.

KEYWORDS: energy transition; zero carbon; public policies; human rights and social development.

RESUMO: Este trabalho, com base em análise de dados e informações oficiais e de extensa produção bibliográfica publicada entre os anos 2015 e 2022, aborda o conceito de transição energética; o contexto histórico da produção de energia no Brasil e os desafios quanto à descarbonização da matriz energética brasileira. Utilizou-se, por metodologia, a abordagem direito e políticas públicas, compreendendo-se a realidade da matriz energética brasileira e a forma pela qual as metas de descarbonização podem ser atingidas.

PALAVRAS-CHAVE: transição energética; meta carbono zero; políticas públicas; direitos humanos e desenvolvimento social.

RESUMEN: Este trabajo, basado en el análisis de datos e información oficial y una extensa producción bibliográfica publicada entre los años 2015 y 2022, aborda el concepto de transición energética; el contexto histórico de la producción de energía en Brasil y los desafíos en cuanto a la descarbonización de la matriz energética brasileña. Se utilizó, como metodología, el enfoque de derecho y políticas públicas,

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comprendiendo la realidad de la matriz energética brasileña y la forma en que se pueden alcanzar las metas de descarbonización.

PALABRAS-CLAVE: transición energética; meta carbono cero; políticas públicas; derechos humanos y desarrollo social.

1. Introduction

This paper reflects the product of master's research carried out within the scope of the institutional partnership between the Postgraduate Programs in Law of the Pontifical Catholic University of Campinas and the University of Salamanca, and also within the scope of the Center for Studies on Energy Transition (CPTEn) of São Paulo, whose general objective was to understand the current situation of the Brazilian energy transition to ascertain the (im)possibility of achieving the goal of zero carbon emissions by the year 2050, as per the commitment assumed by Brazil at the United Nations Climate Conference in Glasgow (COP26), to reduce 50% of greenhouse gas emissions by 2030 and to neutralize carbon emissions by 2050.

At the time this research was conducted, there was an international consensus on the need to take effective action to meet the targets of Sustainable Development Goals 7 and 13 of the United Nations Agenda 2030. This was significantly compromised, at the beginning of 2025, with the US withdrawal from the Paris Agreement and the announcement of an industrial policy based predominantly on fossil fuels. COP30, which will be held in Brazil at the end of 2025, and until recently was expected to be capable of enhancing actions to achieve environmental goals, now appears to be more an event of resistance than conquest.

Nevertheless, relevant results were obtained in the development of this research. Information and data produced by public bodies and institutions, companies, and national and international associations, as well as scientific articles published between 2015 and 2022, related to public policies that deal with incentives for renewable energy and consequently enable the energy transition to a low-carbon or carbon-neutral economy in the country, were compiled, analyzed, and confirmed.

This paper argues that despite its globally competitive renewable energy matrix and its international commitments, Brazil faces significant institutional and political barriers —such as a lack of consistent public policy and a historical over-reliance on a centralized hydropower model— that hinder its transition to a 100% renewable, zero-carbon economy. This analysis will demonstrate that the country's decarbonization efforts are compromised not by a lack of natural resources or technical know-how, but by a gap between its climate ambitions and the reality of its legal and political actions.

In the survey of scientific articles that explicitly address Brazilian public policies related to the energy transition, the keywords "public policies" and "renewable energy"; and "public policy" and "energy transition" were searched in the Capes Journals Portal from 2015 to 2022. Terms in other languages were not used to identify the policies, as the research focused on Brazilian public policies related to the reduction or neutralization of carbon emissions from energy matrices.

It should be noted that the initial milestone above was selected when the establishment of the Millennium Development Goals (MDGs) in 2015 was considered, and because it was in that year, with the Paris Agreement, of which Brazil is a signatory, that decarbonization targets were set worldwide for the first time.

Based on the results obtained, we investigated how the implementation of renewable energy sources has been handled and, consequently, the need to include energy transition in the agenda-setting of public policies by the Brazilian state, identifying the points that could be overcome through projects aimed at replacing the non-renewable energy matrix with a renewable one, and consequently achieving zero carbon emissions.

Despite the debates on the relationship between climate and energy held in the 1970s, attempts by international organizations to combat climate change and regulate energy production and markets were unsuccessful (Aykut; Castro, 2017).

However, the issue is extremely relevant because in order to maintain the fundamental rights and guarantees provided for in the Constitution of the Federal Republic of Brazil, especially the rights to life, health, food, and adequate housing, among others, measures to maintain (and improve) current climate conditions are necessary.

According to Guanipa and Tous (2022), the climate emergency is of such an unprecedented magnitude that, to protect human rights, it is necessary to reduce GHG emissions, which, according to the consensus of experts, can only be achieved through energy transition.

In this regard, Wewerinke-Singh (2022, p. 16), argues that safeguarding the global energy transition process is a prerequisite for ensuring the human rights of the population and achieving the goals of the Paris Agreement on climate change.

Energy transition is, therefore, part of a complex, unequal, and multi-speed international scenario, and at the same time, the system needs to cope with the increased demand for energy (IEA, 2018, p. 37). Hence, it requires specific planning, considering the particularities of each territory, and its long-term execution by the countries.

Furthermore, it is a costly process that requires internal and external cooperation. The document "Mobilizing Investment for Clean Energy in Brazil Country Deep Dive", produced by the Energy Research Company (EPE), the World Economic Forum (WEF), and the Inter-American Development Bank (IDB), shows that US$ 90 billion of national and international capital would be needed for Brazil to reach, by 2030, the clean energy rates it has proposed (2022e, p. 4).

Concerning the present study, it is necessary to highlight what should be understood as energy transition; the historical context of energy production in Brazil; the challenges regarding the decarbonization of the energy matrix; and the share of renewable energy that makes up this matrix. At this point, the direct relationship between SDG 7 (Affordable and Clean Energy) and SDG 13 (Action against Extreme Climate Events) of the 2030 Agenda, objectives that underpin the need to promote the energy transition, is inescapable.

Regarding the methodology, the object of this research, of a normative and regulatory nature, is approached in a multi and transdisciplinary way, in terms of a methodology specific to the subfield of Law and Public Policies (LPP), which uses the method of institutional analysis to, based on the collection of data on public policies, organize the design of public policies at all stages of their cycle, “crossing the hypotheses raised by field researchers with the measurement of concepts and the establishment of relationships with the forms of coding under development" (Bucci, 2019, p. 800).

Bucci (2019) presents the Law and Public Policies approach method because she believes that the lack of a structured approach imposes limitations on the development of knowledge on the subject of public policies, in addition to trivializing it. Thus, she exposes the LPP method, which uses "representation schemes and conceptual systematization" (Bucci, 2019, p. 802), to simplify the understanding of public policies,[4] demonstrating how they are created, treated, and controlled by the Government in a way that is not restricted to Law, encompassing other areas of knowledge.

From this perspective, Bucci and Souza (2022, p. 10) emphasize that, through the LPP approach, the object of the law is not only the legal norm, but also the institutions responsible for legislative activity and jurisdictional control, that is, the entire context of creation and institution of public policies by the Brazilian state regarding the establishment of renewable energy and the energy transition will be the target of analysis, but not in an exhaustive manner.

The present study, based on the LPP approach, conducted a systematic document analysis, drawing on data and official information from various sources. Key institutional documents analyzed included the National Energy Balance (BEN), produced by the Energy Research Company (EPE), as well as specific reports from EPE on topics like clean energy investment and climate change. Information was also gathered from the Greenhouse Gas Emissions and Removals Estimation System (SEEG) and reports from international organizations like the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).

For the literature review, the analysis involved triangulating data from these diverse sources to identify key themes and challenges, such as the decarbonization of various sectors and the evolution of Brazilian energy legislation, enabling a comprehensive evaluation of the energy transition process.

[4] There are notable disparities in the conceptualization of public policy, both within Brazil and in other countries, such as the United States, where the field of study originated. For a detailed discussion, cf. Souza (2006), and Mastrodi and Ifanger (2019).

2. Energy transition

According to ENEL Green Power (2022), energy transition is the "shift from an energy matrix based on fossil fuels to a matrix that produces very limited, if not zero, carbon emissions, based on renewable energy sources". In other words, there is an energy transition when a country stops producing energy based on fossil fuels and switches to producing energy with a 100% renewable matrix, with extremely low or zero carbon emissions.

For Energy Tracker Asia (2022), energy transition is an ongoing process on different scales, global, regional, national, and sub-national. In this context, it is not appropriate to talk about the energy transition of a single delimited area, since the efforts of Government officials of the most diverse sectors, involving agencies from all over the country, are essential.

As reported by EPE (2022f), for the energy transition to take place, it is necessary not only to reduce fossil fuel sources, but also to increase energy efficiency, energy storage, encourage sources that do not emit greenhouse gases (GHG), and the establishment of technologies to remove emitted carbon.

Similarly, Dunlap (2015) points out the main factors influencing the development of sustainable energy systems: (a) availability of resources; (b) economic and technological factors; (c) socio-environmental factors; (d) political factors; and (e) integration between new and old technologies.

Currently, the main features of the energy transition are the so-called 3Ds: decarbonization, decentralization, and digitalization. Some studies, however, consider 4Ds or 5Ds, including democratization,[5] the goal of universal access to energy foreseen

[5]Through a social approach, democratization aims to reduce energy poverty, enabling access to clean energy at reasonable costs (EPBR, 2022). On the access to clean energy for Brazilian households, cf. Mastrodi *et al.*, 2024

in SDG n. 7, as well as market design[6] as pillars of the transition. This study addresses the energy transition especially related to decarbonization, but for the contextualization of the concept, the 3Ds are briefly presented.

The 3Ds are instruments that enable energy transition, serving as a pillar for the generation of more sustainable energy and, consequently, reducing the greenhouse effect and global warming. The focus of decarbonization is the neutralization of carbon emissions, while decentralization focuses on energy generation and digitalization on the digital transformation of the energy sector.

According to Silvestre *et al*. (2018, p. 484), the term decarbonization "indicates the decline in the average carbon intensity from primary energy thanks to the exploration of new and clean energy sources". Its objective, therefore, is to maintain social and economic development with reduced carbon emissions, aiming for climate neutrality through energy transition.

Decentralization aims to provide more flexible and efficient energy production through greater diversification and multiplicity of agents. It aims to break the centralized energy production, enabling energy generation closer to consumers and greater access by the population.

The energy transition is affected by decentralization, especially by Distributed Energy Resources (DERs), which are "electricity generation and/or storage technologies, located within the limits of the area of a given distribution concessionaire, generally next to consumer units, behind the meter" (EPE, 2018, p. 2). DERs include, for example, electric vehicles, distributed micro and mini generation, and solar thermal and photovoltaic energy.

Digitalization is coming so that the growing energy demand can be met in a more planned and strategic way. With the use of modern and advanced technologies, such as the Internet of Things, Big Data, Data Analysis, and Artificial Intelligence (AI), energy production becomes more efficient.

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[6]Market design is related to the formation of policies and regulatory environments that ensure the implementation of renewable energy and reduce risks so that market agents can cooperate in the process of replacing fossil sources with renewable ones (EPBR, 2022).

The 3Ds are interconnected, influencing each other, either directly or indirectly. Many of the technologies needed to decarbonize the economy are not yet mature (IEA, 2020), and it is expected that digitalization can at least partially solve this problem.

Furthermore, the 2030 Ten-Year Energy Expansion Plan (PDE 2030) shows a significant expansion of distributed generation, linked to decentralization, while there is a reduction in the installed capacity of coal, diesel and oil, a reflection of decarbonization.

According to EPE (2022f), one of the biggest challenges facing the Brazilian energy transition is the transportation sector, which uses fossil fuels almost exclusively. In addition, the lack of local organization for energy transition, the lack of space for building institutional dialogue between local actors, political bodies, and the scientific community in official public documents conducting energy policy, and the impact of the dismantling of Brazil's environmental institutions are also presented by Lampis *et al*. (2021) as obstacles to the transition.

According to Araújo (2014), the term “energy transition” brings to the table a notion of urgency for global effort, which was not present in previous major transitions.

Nonetheless, ECLAC (2022) emphasizes that Latin America and the Caribbean are well positioned to benefit from the energy transition, as they have the necessary inputs for clean and affordable energy to fill social gaps (16.7 million people without access to electricity).

3. Historical context of energy production in Brazil

Until the 1930s, Brazil had a national policy focused on monetary stability, within an agro-exporting economic context, under the “coffee with milk” politcs. Tavares (1982) classifies the period as an “outward-looking development model”, in which the Brazilian economy served, mostly, external interests, focused on exports concentrated on specific primary products.

However, this generated excessive external dependence and vulnerability in the country. Therefore, after the 1929 crisis, a new development model called "inward-looking" was adopted. According to Tavares (1982), this model stimulated the internal industrialization process and fostered the diversification of production. The evolution of Brazil's industrialization is shown in Baer (1996, p. 56), as in 1919, light industries were predominant, such as textiles and footwear, while in 1939 metallurgical industries were dominant, that is, basic industry.

Industrial growth affected the energy sector, leading to an increase in demand. Thus, the first decades of the 20th century were marked by the expansion of the construction of hydroelectric plants. In this context, in 1934, the Water Code emerged, integrating natural resources (mineral and hydropower) into the assets of the Union, with the first regulations of the electricity sector ensuring the supply of energy input and further leveraging activities related to industrialization.

The Code makes the industrial use of water possible only with Federal authorization and ensures that the Government can exercise stricter control over electricity concessionaires, legally authorizing the technical and financial supervision of companies in the sector. The power to legislate and grant concessions for public electricity services is assigned, by the Code, to the Union.

Article 195 of the Water Code established that "authorizations or concessions shall be granted exclusively to Brazilians or companies organized in Brazil", reducing international participation in the sector. As a result, with the unstoppable increase in demand and a limitation in the energy supply, "the Government expands its role beyond regulatory and supervisory attributions: it begins to intervene directly in production" (Gomes *et al*., 2002, p. 5).

Thus, in the 1940s, shortly after the end of the Second World War, the first state concessionaires were created, which further boosted the energy sector, causing the demand for energy to continue on an upward curve. Lorenzo (2002, p. 152) exemplifies this by citing the State Electric Energy Commission of Rio Grande do Sul, which generated the State Electrification Plan, with a reorganization of the production and distribution of electricity being foreseen.

In 1946, the National Electrification Plan was created, which identified the energy sector as one of the main causes of restrictions on the country's industrial growth and recommended a more comprehensive energy expansion plan, interconnecting the various energy sectors (Gomes *et al*., 2002, p. 05). The plan stated that investments should be concentrated in small and medium-sized power plants, with the State playing a coordinating role, and also included the formation of a National Electricity Fund (FNEJ), the creation of Eletrobrás and encouraged the national production of electrical equipment.

In 1948, under the Dutra government, the Salte Plan was proposed. It was the first plan to organize and stimulate the joint development of energy with several other sectors. Based on this plan, the Paulo Afonso Hydroelectric Plant was built on the São Francisco River.

In this scenario, the gradual change in the conduct of the State becomes clear, as it begins to act as a promoter of development, with Brazil ceasing to serve external interests and focusing on internal development, based on industrialization and, consequently, on the formation of a strong energy base.

The 1950s brought such changes to the country's industrial sector. Until then, the national industry was based on the production of perishable and semi-durable consumer goods, with import substitution in response to external energy restrictions (Gomes *et al*., 2002, p. 6). However, with the beginning of a new phase of industrialization, which aimed to consolidate the capital goods and intermediate goods industry, a structural change was necessary across the entire energy sector.

Therefore, in 1952, a “document entitled ‘Organization of services and guidelines for the development of the country’s electrification’ was approved, as an introduction and justification for a bill on the same subject” (Leite, 2009). According to Corrêa (2007), the document criticized the Water Code and encouraged the development of regional electrification plans, considering the existing models in Brazil. Consequently, during the decade mentioned above, almost all Brazilian states established state-owned electric power companies, based on the nationalization of services previously provided by foreign companies.

The structural change in the energy sector is particularly evident in the Southeast region, the country's economic center. Initially unprepared for the supply of energy in the face of unbridled and growing demand, the region was experiencing supply problems, with frequent power outages. Given this scenario, the Government had to penetrate even further into the energy sector, aiming especially at maintaining economic development. Therefore, to resolve the contradictions in the Southeast region, the mixed-economy company Central Elétrica de Furnas was established at the Rio Grande to avoid energy rationing and assist the industrial sector (Feliciano, 1988).

In the same year that the Furnas plant was created, 1957, Decree 41,019 was approved, regulating energy services. Leite (2009) stresses that the aforementioned decree established the normative structuring for electricity services until 1974. In 1962, the mixed-economy company Centrais Elétricas Brasileiras S.A. – Eletrobrás was created.

Between the 1960s and 1970s, the country faced development difficulties, with strong inflationary periods, political instability, and lack of national private investment in the electricity sector, but relevant historical milestones for national development deserve mention, such as the Economic Miracle (1968-1972) and the Second National Development Plan (II PND, 1974-1979).

With the oil crisis[7] in 1973, the Brazilian government once again encouraged the hydroelectric power production sector, solidifying a dependence on hydropower that, although a positive and necessary step for guaranteeing access to clean energy, would later prove vulnerable to climate-related water scarcity. Plan 90, which considered the Brazilian system as unique, foreseeing the interconnection of the North/Northeast and South/Southeast regions, projected the use of water resources for power generation, introducing the idea of replacing energy sources (Mercedes; Rico; Pozzo, 2015, p. 21).

[7]The oil crisis presented two shocks. The first, in 1973, occurred when Middle Eastern countries were faced with the finiteness of oil, understanding that it was a non-renewable resource and would therefore eventually run out. The price of barrels rose considerably at that time, since production was drastically reduced (Fishlow, 1986).

Additionally, there was the creation of Proálcool, which encouraged the replacement of gasoline with ethyl alcohol, aiming precisely to reduce Brazil's dependence on imported oil.

However, during the years 1973 and 1974, according to Leite (2009, p.17), Brazil decided to make a major expansion effort based on external loans at market interest rates, to implement import substitution and complete infrastructure and industrialization. This, in turn, generated more burdens than benefits for Brazil, since the country took out loans in an unfavorable international situation, with very high interest rates, mainly with the United States (US).

In the 1980s, the national economy suffered the consequences of external financing. As Lorenzo (2002) explains, during this period, in addition to the reduction in the State's capacity to mobilize resources for investments, there was a gradual loss of efficiency in the energy sector.

Realizing that it was impossible to maintain the monopoly on energy production and distribution, the Federal government created the National Privatization Plan (PND) in 1992, to privatize state-owned companies, especially in the electricity sector. These privatizations led to institutional reforms in the Brazilian energy sector, creating a free market system and limiting government intervention (Goldenberg; Prado, 2003).

With the enactment of Law n. 8,631, in 1993, which promoted a broad settling of accounts in the electricity sector and set tariff levels for the public electricity service, ending tariff equalization, and Law n. 8,987, in 1995, which provided for the concession and authorization of public services, the necessary conditions were established for generating and distributing companies to be able to compete in the energy market.

This new model required several bodies for the management/maintenance of the electricity sector. A regulatory body, the National Electric Energy Agency (ANEEL), and an operator for the national electricity system, the National Electric System Operator (ONS), were then created.

However, there has been an emptying of the reservoirs of hydroelectric plants since 1997. Hence, in 2000 the Federal Government launched the Thermoelectricity Priority Program (PPT), aiming to attract entrepreneurs to build thermal plants, reinforce guarantees, and avoid another energy crisis (Abbud; Tancredi, 2010). The Program, however, failed. In 2006, Brazil emerged as having one of the most expensive energy tariffs, ahead of developed and underdeveloped countries (Galvão dos Santos *et al*., 2008).

Then, according to Pase and Rocha (2010, p. 52), between 2003 and 2010 there was an increase in public energy infrastructure policies, with the regulation of Public-Private Partnerships (PPP) and the management of hydroelectric projects by Special Purpose Companies (SPE).

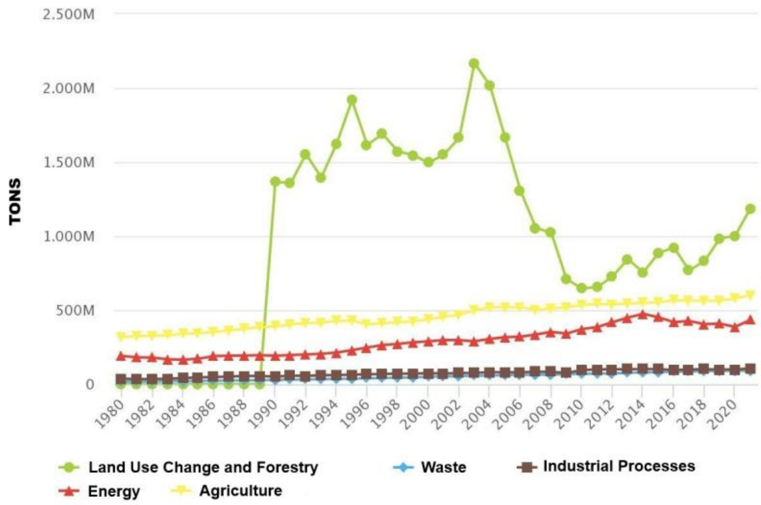
All the events and historical milestones presented culminated in the current operating structure of the energy sector, conceived under an ideal of institutional balance between government agents, and public and private agents.

4. Challenges for decarbonization

The energy transition, as discussed in Chapter One, is related to the 3Ds: decarbonization, digitalization, and decentralization. Considering the focus of this research, the biggest challenges for the decarbonization of the energy sector will be presented.

The graph below shows the level of energy-related carbon emissions in the country, which has been on an increasing curve since 1980:

Figure 1 Greenhouse Gas Emissions and Removals Estimation System



Source: Climate Observatory, 2022.

That said, and adding to this the Brazilian State's goals for energy transition by 2050, there is an undeniable need for changes in the sector, especially concerning the management and generation of electricity. However, for changes in the energy sector to occur, it is necessary to identify the main targets for analysis and transformation, and what is done in this item regarding decarbonization.

The E+ Institute (2022) recognizes that the biggest challenge for the electricity sector is its expansion to meet the demand of other sectors without increasing carbon emissions. To this end, the Institute points out that it is essential to expand the installed capacity of renewable energy in synchrony with the installation of highly flexible resources, while at the same time avoiding the stimulation of fossil fuel production by government policies.

However, such expansion is difficult to achieve and is one of the obstacles faced in the decarbonization process. The Brazilian renewable energy matrix is mostly composed of hydroelectric plants. During periods of drought,[8] thermal plants, based on fossil fuels, are almost unanimously used, increasing carbon emissions. This, in turn,

[8]The country faces severe drought and dry spells, and this cannot be ignored when analyzing energy production, since water sources account for 53.4% of domestic supply (EPE, 2022a). For more information on this subject, see the maps by the National Water Agency (Agência Nacional de Águas, 2025) and the drought monitoring maps and reports by the Ministry of Science, Technology and Innovations (Ministério da Ciência, Tecnologia e Inovações, 2025).

generates instability in the country's emission levels, since it is never known for sure which energy source will be used.

Moreover, the energy sector faces obstacles in reducing greenhouse gas emissions, given the particularities of each sector in replacing fossil fuels with renewable fuels. Therefore, one obstacle in the decarbonization process is that it is not enough for the Government to adopt a general policy to reduce gases in the energy, transportation, and industry sectors, among others. Each sector must be the target of a unique and specific analysis, with the consequent adoption of measures.

However, an in-depth study in each area is essential for specific sector action. Therefore, more time and resources are required to implement measures. Nonetheless, the energy sector as a whole cannot be disregarded. This sector-specific challenge is exacerbated by the lack of consistent public policies that provide tailored incentives for industrial and transportation actors to transition away from fossil fuels. This represents a sound example of how a fragmented regulatory framework directly impedes technical and economic progress in decarbonization.

From this perspective, the E+ Institute (2022) affirms that the industrial sector requires investment in energy efficiency to reduce greenhouse gases, while the transport sector depends on diversification of transport modes to achieve this.

Another obstacle to the decarbonization process was detected in a study carried out by EY Parthenon together with OC&C (2021). By identifying the population's reasoning profiles regarding sustainability and decarbonization, the report shows the lack of engagement from the population, demonstrating the lack of a sense of urgency regarding the need for decarbonization as soon as possible in the cities.

Furthermore, in Brazil, as the energy matrix has a large share of renewable energy, there is the false impression that investment in renewables and energy efficiency is not urgent (Hollanda *et al.*, 2016).

Rockstrom *et al*. (2017) highlight the same problem regarding the national governments, stressing the lack of national commitments to progress on the paths of decarbonization.

Regarding national governments, Papadis and Tsatsaronis (2020) highlight that the countries' climate policies, which are inconsistent or sometimes non-existent, impact private investors, reducing financial incentives for the development of the energy sector. The stagnation of the sector, in turn, creates uncertainty about installed energy capacities and energy efficiency.

The industrial sector was considered by EPE (2021) to be the largest energy consumer, with consumption of more than 35% of the energy produced in Brazil. Finally, we will briefly point out the main difficulties in decarbonizing the sector that consumes the most energy in the country.

Gross (2021) describes the difficulties in decarbonizing the heavy industry sector, also called basic industry, such as cement, steel, and iron. Initially, she emphasizes that heavy industry production processes require a high level of heat, which is difficult to achieve without burning fossil fuels. Although the challenges of decarbonizing heavy industry are significant, the lack of specific public policies aimed at providing economic and technological incentives exacerbates the problem, leaving these sectors with few viable alternatives to traditional fossil fuels.

The author also stresses that industrial processes produce carbon dioxide as part of a complex chemical reaction, and not as a combustion product itself. Therefore, to eliminate CO2 production, it would be necessary to find another chemical process that does not produce the gas or capture the gas and store it, actions difficult to carry out, considering the technical unfeasibility.

The cost of new machinery, especially engines that are highly polluting, is also seen as an obstacle to the decarbonization of the industrial sector.

The IEA (2022b) also highlights the lack of technology capable of assisting in the decarbonization process of heavy industry, while technologies are already available for net zero emissions in light industry.

Ruiz *et al*. (2020), in turn, show the obstacles to decarbonization in the light industry, food, clothing, and home appliances. The problems of entrepreneurs' resistance to replacing fossil fuels with hydrogen, due to the high cost, as well as the volatility of energy prices, which affects the strategic planning of the light industry, are explored in the authors' paper.

Given the above, it is clear that decarbonization is essential for an effective energy transition and the maintenance of environmental and social standards within parameters that enable the well-being of the population. However, it is a complex process that is difficult to implement.

5. Renewable energy in Brazil

Renewable energy, as we know, is energy obtained through sources that cannot be exhausted and generate less environmental impact than non-renewable energy (CEMIG, 2022). Wind, solar, marine and hydroelectric power are examples of renewable energy.

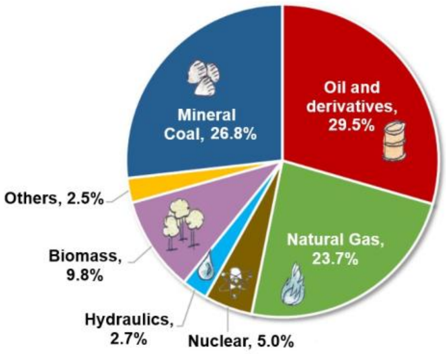
Renewable sources are called “clean” precisely because of their lower environmental impact, as they emit fewer greenhouse gases (GHG) than fossil sources (EPE, 2022c).

According to Oliveira *et al*. (2018), the high airflow in several regions of the country, the levels of solar radiation, and the high biomass production capacity make the Brazilian territory a potential source for the development of a renewable energy matrix.

The Brazilian energy matrix is considered one of the most renewable in the world. While the global energy matrix has only 15% renewable energy, Brazil has almost half of its production based on clean energy.

While the global energy landscape is predominantly non-renewable, Brazil's matrix presents a unique profile, with a much larger share of clean energy sources. The following chart details the composition of the Brazilian energy matrix. The “others” field includes other renewable sources, in addition to hydropower and biomass, such as solar, wind, and geothermal.

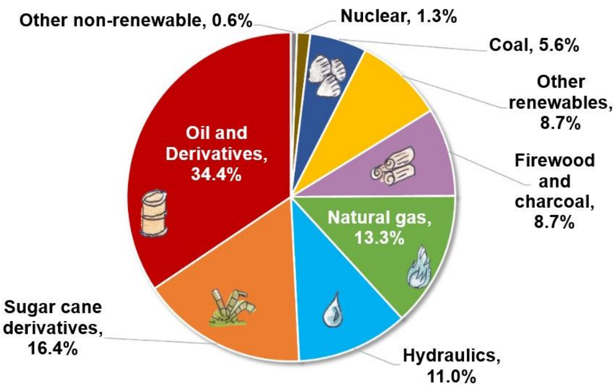
Figure 2. Composition of the Brazilian Energy Matrix



Source: EPE, 2022d.

Likewise, the graph of the Brazilian energy matrix indicates that by adding firewood and charcoal, hydropower, sugarcane derivatives, and other renewable[9] sources, renewable sources in Brazil total 44.8%:

Figure 3. Composition of the Brazilian Energy Matrix



Source: EPE, 2022d

It is clear, therefore, that the country is at an advanced level compared to the rest of the world in terms of renewable energy production. However, for an energy transition,

[9]The distribution of the supply of "Other renewables" occurs between 8 categories of energy sources with the largest shares of chlorine, wind energy and biodiesel, which together are equivalent to more than 80% of "Other renewables" (EPE, 2022b, p. 17).

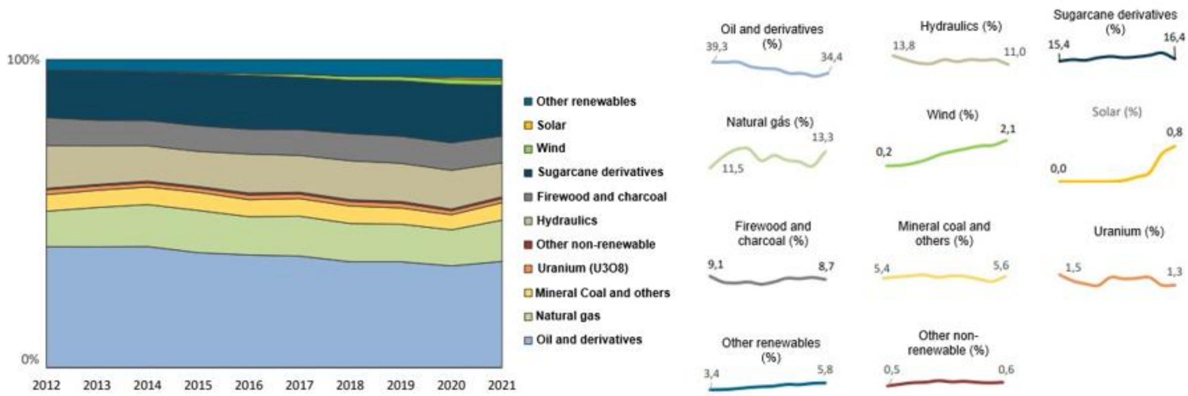
with zero carbon emissions, it is still necessary to modify practically half of the national energy production.

The Internal Power Supply (IPS) concerns the energy needed to drive the country's economy (Ministry of Economy, 2022). Based on the IPS, it is possible to verify what type of energy is being used and how energy is being produced in the national territory.

The 2022 National Energy Balance (NEB) demonstrates the IPS between 2012 and 2021. Based on this data, it can be seen that most renewable energy sources have increased their participation rate, while non-renewable energies have decreased.

The use of oil and derivatives went from 39.3% to 34.4%, while most renewable energies, except for hydroelectric power,[10] firewood, and charcoal, showed a percentage growth in the same period.

Figure 4. Internal energy supply 2021-2021



Source: IEA, 2022a.

The country's renewability index was also relevant. According to Bergier and Salis (2011, p. 8), renewability is "the amount of "natural or cyclical" energy that the production system uses". In this regard, it is nothing more than the development of products that use renewable energy, which cause less environmental impact. The share

[10]There was a reduction in the share of renewables in the energy matrix between 2012 and 2014 due to the drop in hydro supply. From 2015 onwards, renewable sources resumed a growth trajectory with the expansion of the supply of sugarcane derivatives, wind power and biodiesel, reaching 48.5% in 2020. However, with the water shortage in 2021, the level of renewables fell to 44.7%. (EPE, 2022, p. 19). The instability that hydropower plants generate in national energy production is evident, given that they are dependent on rainfall.

of renewable energy in the Brazilian electricity matrix reached considerable levels, with 78.1% renewability in 2021 (EPE, 2022b).

However, despite the high index in 2021, the fact is that the last five years have shown greater renewability. According to EPE (2022b, p. 35), the decline in the index occurred due to the drop in hydropower supply,11 which was partly offset by the increase in thermoelectric generation.[12]

6. Law and Regulation in Brazil

Despite the data shown in the previous item, Brazil is still ahead of the rest of the world when it comes to renewable energy. While OECD members, in 2020, had a renewability rate of 30.8%, Brazil had a rate of 83.8%.

However, when it comes to legislation related to energy transition, the country is not a model on the international scene. The first legislation that directly addresses the energy transition was created at the beginning of 2022.

Law n. 14,299/2022 established an economic subsidy for small-scale public electricity distribution service concessionaires and created the Fair Energy Transition Program (TEJ) for the coal region of Santa Catarina. It serves as a prime example of a public policy that, while not resolving the broader energy transition issue, attempts to manage the social and economic impacts of decarbonization by providing an economic subsidy to that coal-producing sector. This approach aims to prepare the region for a future without carbon-intensive activities, mitigating economic disruption; however, it does not directly tackle the core problem of reducing carbon emissions from the source.

Based on Brazil's commitments made at COP26, when the TEJ was created, the legislation aims, under the terms of Art. 4, §1, to prepare the coal-producing region for the likely end, by 2040, of the domestic coal-fired thermoelectric generation activity that

[11] The lowest renewability rate occurred in 2014, precisely as a result of the water crises.
[12] There was an increase in thermoelectric generation in 2021, especially through the use of natural gas.

does not reduce carbon dioxide emissions, ending the exploration of the mineral in the region.

Although it is possible to identify bills[13] related to the transition in progress, there is currently no other national legislation in force that specifically addresses energy transition in Brazil, which ends up negatively impacting the transition scenario. Therefore, the judgment of the Audit Report n. 9222023 by the Brazilian Court of Accounts (TCU, 2023) understood that there is a "lack of technical solutions for the challenges expected with the energy transition and climate change".

The national legislation closest to the energy transition, in this regard, are laws related to renewable energy, which do not yet appear in the energy regulatory framework in a robust and consolidated manner. Law n. 11,097/2005, for example, only introduces biodiesel into the Brazilian energy matrix, but does not bring any major developments related to the energy sector.

Likewise, Law n. 9,478/1997, which deals with Brazil's national energy policy, makes scant mention of renewable energy, merely stating that the national energy policy should encourage its use. Law n. 10,438/2002, which created the Program to Encourage Alternative Sources of Electric Energy (Proinfa), seeks to promote energy from renewable sources, such as wind, biomass and hydroelectric power, but does not go into the "instruments" for this purpose.

Law n. 13,576/2017, which established the National Biofuels Policy (RenovaBio), aims to increase the share of biofuels in the Brazilian energy matrix, encouraging the production of biofuels, such as ethanol and biodiesel. Law n. 14,120/2021 promoted changes to Law n. 10,438/2002 to regulate the generation of renewable energy in buildings by public service concessionaires and permit holders.

In 2022, Law n. 14,300/2022 established the legal framework for micro and mini-energy generation. This law regulated the production, by consumers, of their energy from renewable sources.

[13] For example, Bill n. 2308/23 includes green hydrogen (H2V) in the National Energy Policy with the aim of enabling regulation and an energy market. Similarly, Bill n. 327/21 seeks to create a policy to regulate the transition from the current energy model to a new standard based on renewable sources.

The European Union (EU) provisions on this topic can therefore serve as a reference for Brazilian regulations. This is because the European Union has implemented several legislative acts to ensure that Member States achieve positive results related to the energy transition and decarbonization.

Directive n. 2018/844 introduced changes to Directive n. 2010/31 to bring about improvements in the energy performance of buildings. It encouraged Member States to renovate existing buildings and to implement strategies to ensure that new buildings are built sustainably.

For example, it was after Directive n. 2018/844 was issued that a long-term renovation strategy was established to support the renovation, by 2050, of the national stock of residential and non-residential buildings, to make it a decarbonized and highly energy-efficient building stock.

Directive n. 2018/2001 provided regulations for the development of renewable energy in the electricity and transport sectors of the European Union countries. In addition, through this Directive, national renewable energy targets were set individually for each country.

The most recent Directive, n. 2023/1791, introduced new provisions related to energy efficiency. It pointed out that energy efficiency should be considered as an energy source in itself and characterized energy efficiency solutions as a political, investment, and planning priority. It also set a legally binding target for the European Union to reduce final energy consumption, compared to the 2020 scenario, by 11.7% by 2030.

The European Union's legislative framework offers key lessons for Brazil's energy transition. Unlike Brazil's current policies, the EU model is characterized by legally binding targets, which provide a clear signal to both public and private sectors, reducing investment uncertainty. Moreover, its comprehensive approach to energy efficiency in buildings and transportation highlights the need for a holistic strategy that extends beyond just power generation. The EU's directives also show the relevance of integrating digitalization and decentralization as core pillars of a modern regulatory framework.

Therefore, these Directives can drive the formulation of Brazil's regulatory base, serving as a model for the country to build a legal framework for the energy transition based on its own reality. To fully leverage its natural advantages, Brazil must move beyond a piecemeal legislative approach and establish a consolidated legal framework that aligns national policy with its long-term decarbonization goals.

7. Conclusions

The energy transition is therefore part of a complex, unequal, and multi-speed international scenario, at the same time that the system needs to cope with the increase in demand for energy (IEA, 2018, p. 37). It therefore requires specific planning, respecting the particularities of each territory, and execution by States in the long term.

Furthermore, it is a costly process that requires internal and external cooperation. The document "Mobilizing Investment for Clean Energy in Brazil Country Deep Dive", produced by the Energy Research Company (EPE), the World Economic Forum (WEF), and the Inter-American Development Bank (IDB), stresses that a national and international capital of US$ 90 billion of is needed for Brazil to reach, by 2030, the clean energy rates it has proposed (2022e, p. 4).

Although Brazil's energy matrix is more renewable than the global energy matrix, according to data from the 2022 National Energy Balance report produced by the Energy Research Company (EPE), in 2021, the country was still using 55.3% non-renewable energy. According to EPE (2022b, p. 12), there was a “drop in the supply of hydropower, associated with water scarcity and the activation of thermoelectric plants”.

Therefore, without the direct and continuous intervention of the Brazilian State, together with other sectors of civil society and international organizations, the possibility of the country adopting an energy matrix based on 100% renewable energy is almost nil.

Beyond environmental benefits, energy transition is also often cheaper, driving social and urban development. Katsaprakakis *et al*. (2022) demonstrated that, in addition to contributing to energy and climate conservation, energy transition cooperates with the development of remote areas and solutions to social issues, such as reducing unemployment rates and raising low quality of life standards.

Furthermore, despite its initial costly implementation, renewable energy production requires less investment. The 2021 report by the International Renewable Energy Agency (IRENA) showed that the production of renewable energy added in G20 countries was almost two-thirds cheaper than that of coal-fired power plants. Lower energy costs, in turn, provide democratic access to energy, which is one of the goals of SDG 7 of the United Nations (UN) 2030 Agenda: ensuring universal access to energy by 2030.

It is essential, however, that governments adopt positions that favor energy transition. Nalan, Murat, and Nuri (2009) emphasize that state funding for research in the field of renewable energy can generate positive impacts on the cost of resources and technologies for the area. Brazil, a signatory to the Paris Agreement, has committed to the climate agenda, something that was reinforced at COP26. This time, it is expected that conduct will be consistent with what was agreed.

According to Markard (2018), the key to energy transition is the growth of renewable energies, and the system of such energies is composed of technologies, organizations, institutional structures, finances, and political systems that are integrated.

In this scenario, “due to its wide variety of climates and high biodiversity, Brazil is seen as favored by the amount of natural resources available” (Pereira *et al*., 2011, p. 681). The E+ Energy Transition Institute (2020, p. 23) highlights that the Brazilian territory has an advanced structure for energy transition and consequent transformation of the economy. However, to make the most of these favorable circumstances, the country needs to use energy resources strategically.

However, Brazil does not seem to invest enough in the growth of renewable energy or to establish effective and consistent procedures for energy transition. According to the Energy Policy Tracker (2022), between 2020 and 2021, the Brazilian State made commitments with public money at the level of 0.92 billion dollars for clean energy, while India, an equally developing (or underdeveloped) country, invested 8.92 billion dollars for the same purpose.

Moreover, the update of the Nationally Determined Contribution[14] (NDC), which maintains higher emission levels for the decade than those shown by the country in 2016, in serious contradiction to what was agreed in the Paris Agreement, does not increase Brazil's climate ambition. In this regard, The Talanoa Institute (2022) points to non-compliance with the binding commitment submitted by the country in 2016, which increases the level of emissions allowed in 2025 by 314 million tons of carbon dioxide, regarding the 2016 target, in addition to highlighting the country's failure to contribute to implementing the Glasgow Climate Pact (COP26).

Therefore, although Brazil is considered well-positioned in the clean energy landscape due to its energy matrix being heavily reliant on hydroelectric power plants, climate change (a problem acknowledged by, for example, SDG 13 of the 2030 Agenda) has led to increasingly frequent periods of drought, hindering the normal operation and compromising the efficiency of these plants. This has forced the country to resort to thermoelectric plants based on fossil fuels.

Legislative proposals have emerged aimed at promoting thermoelectric plants, such as those that extend energy production contracts from natural gas and mineral coal. These were included in Bill n. 576/2021, which was approved by the Senate in December 2024, and are seen as a challenge to the need for an energy transition. There have also been proposals for partnerships to develop more hydroelectric plants (Agência Brasil, 2025), which, while potentially viewed as a positive step, does not negate the need for thermoelectric energy during increasingly frequent water shortages.

In other words, even in Brazil, the energy transition is a critical matter. This necessitates the expansion of solar, green hydrogen wind energy systems etc., and the proposal of all possible substitutions aimed at mitigating or eliminating greenhouse gas emissions. Yet there are neither sufficient public policies nor a forecast of policies aimed at implementing the energy transition with the speed that the topic urgently demands.

[14]According to the Brazilian Ministry of the Environment (2022), the Nationally Determined Contribution (NDC) is the Brazilian government document that records Brazil's main commitments and contributions to the future climate agreement that will be negotiated and approved at the end of the year, in Paris.

In conclusion, while Brazil possesses a uniquely favorable position in the global energy landscape, its potential for a full energy transition remains hindered by significant institutional and political barriers. The historical reliance on a centralized hydropower model, the lack of a cohesive legal and regulatory framework, and the gap between national commitments and on-the-ground actions all contribute to this stagnation. In essence, there is a lack of effective planning for a comprehensive and integrated development strategy on the energy transition theme. Overcoming these challenges will require a shift from a fragmented, reactive approach to a proactive, long-term strategy, guided by a clear legislative agenda and the integration of a decentralized and digitalized energy system.

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