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Paths to drive the low-carbon energy transition process in the electrical energy sector: A comparative analysis between Germany and Japan

As rotas para conduzir o processo de transição energética de baixo carbono no setor elétrico: uma análise comparativa da Alemanha e o Japão

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ABSTRACT: The following paper analyzes the public policy paths to drive the low-carbon energy transition from a comparative perspective between the German and Japanese cases. For this purpose, qualitative research was carried out based on the comparative study between both countries and of literature about Policy Mix. Therefore, a mapping of the public policy packages adopted in each country to drive the decarbonization of the electric matrix was performed, allowing to identify the type of instruments considered, the scope of the governmental efforts implemented, and the technological options contemplated to replace fossil sources. Among the main results, it was found that the incentive policies to increase the capacity to generate electricity from renewable sources are moving from pricing schemes with an impact on the consumers' tariffs to the establishment of pricing schemes that respond to market signals, due to the reduction of the installation and electricity generation costs from variable renewable sources. The study identified differences in the technological options considered to drive decarbonization, such as phasing out nuclear power generation in Germany and its reactivation in Japan. In both cases, it was identified that public policies are also moving towards an adaptation of the electricity systems to the dynamics of variable renewable sources. Finally, the scope of the governmental policies in both countries aims at boosting economic development through the construction of new productive and technological capacity.

Keywords: low-carbon energy transition; Policy Mix; public policies; Germany; Japan.

RESUMO: O seguinte trabalho analisa as rotas de política pública para conduzir a transição energética de baixo carbono a partir de uma perspectiva comparada dos casos da Alemanha e Japão. Para isso, foi realizada uma pesquisa qualitativa a partir do estudo comparativo de ambos os países com base na literatura sobre *policy mix*. Dessa forma, foi realizado um mapeamento dos pacotes de política pública adotados em cada país para conduzir a descarbonização da matriz elétrica, permitindo identificar os tipos de instrumentos considerados, o escopo dos esforços governamentais implementados e as opções tecnológicas contempladas para substituir as fontes fósseis. Entre os principais resultados, encontrou-se que as políticas de incentivo ao aumento da capacidade de geração de eletricidade a partir de fontes renováveis estão transitando de esquemas de precificação com impacto na tarifa dos consumidores para o estabelecimento de esquemas de precificação que respondam a sinais de mercado, em decorrência da redução dos custos de instalação e geração de eletricidade a partir das fontes renováveis variáveis. O estudo identificou diferenças nas opções tecnológicas consideradas para impulsionar a descarbonização, tendo como elemento notável, a desativação da geração de energia nuclear na Alemanha e a reativação dessa fonte no Japão. Em ambos os casos, identificou-se que as políticas públicas também caminham para a adaptação dos sistemas elétricos à dinâmica das fontes renováveis variáveis. Finalmente, o escopo das políticas governamentais dos dois países almeja o impulso do desenvolvimento econômico por meio da construção de nova capacidade produtiva e tecnológica.

Palavras-chave: transição energética de baixo carbono; *policy mix*; políticas públicas; Alemanha; Japão.

1. Introduction

With signing of the Paris Agreement in 2015, the international community established a watershed moment in the determination to address the climate emergency, through the implementation of efforts aimed at averting the increase in Earth's temperature and maintaining it at 2°C in relation to pre-industrial levels (IRENA, 2019). To achieve this objective, the reduction of greenhouse gas emissions resulting from the use of fossil energy sources emerges as the pivotal issue in this endeavor, given that they constitute the primary cause of emissions (OCDE, 2021). However, substituting fossil sources is not a trivial issue, considering that they account for more than 80% of the primary energy consumption in the world (BP, 2020)[1,2].

In recent decades, concerns regarding the impact of fossil energy sources on emissions have influenced a shift in the orientation of public policies and in the business plans of various companies, aiming to encourage the development and dissemination of cleaner energy sources. As a consequence, stemming from the development and commercial deployment of new renewable sources, mainly photovoltaic solar and eolic energy, the option of electrifying energy systems based on these novel technologies has emerged in order to progress in decarbonization of the nations' energy matrices. Thus, electricity generation, responsible for 48% of the total emissions from the global energy industry sector, turned into the sphere that has witnessed the most significant progress, in addition to standing at the forefront of the efforts to drive the low-carbon energy transition (IEA, 2020a).

However, despite advancements in the diffusion of new renewable sources across several countries, the results are still insufficient to favoring the

[1] According to data from IEA (2020a), the global CO_2 emissions have sustained a consistent growth path for over a century, rising from less than 5 gigatons in 1900 to a peak of 33.5 gigatons in 2018.

[2] In the global energy mix, crude oil has a 33% share, followed by coal (27%) and natural gas (24%) (BP, 2020).

reduction of CO_2 emissions to the levels advocated by the scientific community to avoid the onset of irreversible planetary effects (OCDE, 2020). Unlike the previous transitions, the current one implies a structural change process with no precedents in history (Goldthau et al., 2020).

The ongoing energy transition entails destabilization of the prevailing socio-technical regime, shaped by the technological regime stemming from fossil fuel paradigm, its substitution with a new socio-technical arrangement, comprised of a combination of already existing technological options, and which are yet to undergo improvements (incremental innovations), with technologies that are only in their incipient developmental stages, or with solutions that are yet to be conceived (Kivimaa & Kern, 2016; IEA, 2020b). Similarly, the determination to transition towards the substitution of fossil sources with a vast and novel array of technological options, including technologies not directly associated with the energy sector (such as Artificial Intelligence) should encompass management of the economic, social and political impacts of this change process to ensure its viability (IRENA, 2019; WEC, 2019).

Recognition of the complexity underlying the low-carbon energy transition process has encouraged the adoption of a more proactive role by the State, particularly in those countries where concerns about the climate emergency have already attained a higher priority degree within the governmental agendas (Rogge & Reichardt, 2016; Rogge & Johnstone, 2017; IEA, 2019). As a result, these countries have devised governmental plans characterized by the simultaneous adoption of a broad array of public policy tools, oftentimes encompassing diverse spheres beyond the energy sector, such as Science, Technology and Innovation (ST&I), industrial development and environment, among others. Based on these public policy packages called "Policy Mixes", each country has outlined a particular path to drive this long-term transition. Considering the complexity and the still incipient nature of this process, it becomes fundamental to understand the approach to public policies undertaken by the leading countries in this endeavor.

The objective of this paper is to analyze the public policies devised to drive the low-carbon energy transition in the electricity sector, from a comparative qualitative approach focusing on the German and Japanese cases. It is worth noting that, in both countries, fossil-fueled thermoelectric generation (coal in Germany and natural gas in Japan) dominates the electricity matrix structure. Additionally, in both nations, nuclear power generation has always constituted a fundamental element to ensure electricity supply as well as technological and industrial development.

Thus, the paper was divided into five sections, in addition to this Introduction. The first section conducts a literature review on Policy Mixes, aiming to examine the increasingly proactive role to be played by the State the energy transition process; in addition to the scope of public policy instruments that are being adopted to ease this change process. The second section describes the methodology and criteria used for the comparative analysis between the countries considered. The third one reviews the public policy packages and instruments that the countries included in the study are adopting. Subsequently, section four seeks to compare the German and Japanese cases based on the analysis criteria defined in section three. Finally, the definite reflections of this paper are pointed out.

2. The role of public policies in the energy transformation: A brief literature review on Policy Mixes

The energy matrix decarbonization process in the world is a complex issue and is associated with the scope of the structural transformations that will need to take place at the technical, economic, social and political levels. Putting an end to the current socio-technical regime dominated by fossil energy sources, unlocking the dissemination of new renewable sources in energy systems and simultaneously managing the disruptive effects of this change, warrant active intervention by the State to ensure effective long-term results. Management of the risks inherent to this process constitutes an objective that cross-permeates various State organizations responsible for the execution of public policies in diverse fields such as energy policy, but which also extends to its articulation with other public policies related to macroeconomics, the environment, industrial development and ST&I, among others.

An approach that proves suitable for understanding the type and scope of State intervention to address challenges such as decarbonization of the electrical energy generation systems is found within the literature on Policy Mixes. Such approach has been frequently used to analyze public responses to complex phenomena, mainly within in the fields of environmental economics, innovation economics and political sciences (Braathen, 2007; Kern & Howlet, 2009; Lehmann, 2012; Kivimaa & Kern, 2016; Rogge *et al.*, 2017).

The concept of Policy Mix reflects a situation in which one or more State organizations, sometimes with differentiated rationalities and varying governance structures, choose to implement a coherent set of public policy instruments with the purpose of achieving certain objectives in a more efficient and effective way than by solely relying on a single instrument (Kivimaa & Kern, 2016; Li & Taeihagh, 2020). The combination of public policy instruments, oftentimes referred to as public policy packages, is used with the intention of enhancing the effectiveness of policies executed individually, or that, on their own, fail to achieve the desired objective, simultaneously aiming to mitigate any unintended consequences (Givoni *et al.*, 2013).

Based on these literature materials, it was possible to analyze several aspects inherent to the process of public policies in the experiences regarding the implementation of packages targeted at sustainable transitions. Some studies have used this approach to understand the rationality and logical path underlying the elaboration of the public policy packages that are implemented (Li & Taeihagh, 2020)[3]. This rationality is associated with perceiving that there is a problem requiring State intervention, thereby initiating the cycle of public policy elaboration or revision: inclusion in governmental agendas; formulation of policy instruments; legitimization and adoption; implementation, evaluation; adaptation; succession; and termination (Rogge & Reichardt, 2016). A core characteristic of the studies on transitions based on adopting the concept of "Policy Mix" is the analysis about how

[3] This rationality seeks to achieve ultimate objectives, wether in an abstract way or specific objectives in certain fields inherent to public policies (Kern & Howlett, 2009; Rogge & Reichardt, 2016; Li & Taeihagh, 2020).

policy instruments emerge and interact with each other (Del Rio, 2009; Philibert, 2011).

In this way, it was possible to deepen the studies through assessments about the influence and quality of the results stemming from policy packages, in the pursuit of attaining the objectives proposed, based on the adoption of different analysis dimensions: effectiveness, efficiency, advantages or disadvantages, consistency and coherence, among others (Carbone, 2008; Fisher & Preonas, 2010; Rogge & Reichardt, 2016). Continuing in the realm of interaction, more in-depth studies have adopted the concept of Policy Mix to analyze issues such as integration of the policies and their coordination through multiple State organizations at various governmental levels and, therefore, considering different geographical clippings. Given the aforementioned, some studies started to consider analyzing the actors involved as part of the efforts to understand the process to elaborate policy packages and their results (Rogge et al., 2017).

Given the scope diversity in the studies focused on analyzing policies for sustainable transitions based on adopting these literature materials on Policy Mixes, for the objectives of this research, it proves particularly useful from a normative point of view to understand how the process to devise public policy packages takes place, briefly summarized in Figure 1.

Based on the general objectives, strategies are formulated that constitute long-term guidelines comprised by interdependent purposes (objectives) and means to reach these purposes (public policies) (Li & Taeihagh, 2020). The objectives (the first component of the strategies) are consubstantiated by long-term targets with quantified ambition levels, and can be based on views about the future.

The second component of each strategy is defining action plans, which will be labeled as guidelines in this study, outlining the overarching path proposed by the governments to achieve the objectives. They can include conventions, guidelines, strategic action plans and scripts (Rogge & Reichardt, 2016). The plans contain public policy instrument packages formulated to achieve the objectives in each strategy. Finally, public policy instruments constitute concrete tools designed to attain specific targets and which, along with the other instruments, contribute to achieving the objective that motivated formulation of the action plan. These tools are defined as measures, programs or policies (Rogge et al., 2017; Li & Taeihagh, 2020).

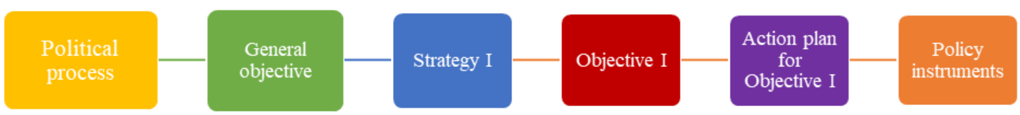

FIGURE 1 – The Policy Mix design process.
SOURCE: prepared by the authors based on Li & Taeihagh (2020) and Rogge & Reichardt (2016).

The process to prepare the policy packages takes place meeting the various dimensions that are useful for our research objectives. The first dimension is related to the different performance area of the State that can be considered in policy packages. In the case of the public policies targeted at sustainable transitions, they can include policies in sector such as energy, climate and environment, ST&I, industrial development and foreign policy, among others.

The second dimension has to do with the governance levels in formulation and implementation of the policies, with the possibility of being at an international, national, state or local scale. Likewise, the governance levels can be understood through the entities involved, which may involve ministries, departments and secretariats at the federal, state and municipal levels, as well as other instances subordinate to these bodies (Rogge & Reichardt, 2016).

The third dimension is related to the geographical clipping, which constitutes the space covered by the policy packages. Finally, we have the time dimension where, as already mentioned, it is understood that policy packages evolve over time as a result of several variables, which include the previous path of State organizations in policy implementation (path dependence), changes in the institutional conditions, of a socio-economic nature, or in the dynamics of the political process where various actors interact while advocating their interests (Howlett & Rayner, 2007; Kern *et al.*, 2019). Consequently, the literature on Policy Mixes offers various inputs to direct the elaboration of the guiding methodological framework for the comparative analysis regarding the experiences of the countries considered.

3. Methodological aspects

In order to achieve the objectives of the paper, an exploratory research study with a qualitative approach was conducted based on the comparative study between the German and Japanese experiences (Bulgacov, 1998; Dezin & Lincoln, 2006). For the comparative analysis, several criteria for data and information analysis were established, aiming to identify similarities and differences in the guidelines and scope of the public policies implemented by the selected countries to drive the low-carbon energy transition in the electricity sector. The comparative analysis also sought to identify the choices in terms of public policy instruments. Likewise, the analysis seeks to understand the technological options considered to substitute fossil sources.

The analysis criteria were divided into four groups. The first one seeks to determine the scope of the governmental efforts to drive the transition. For this purpose, the share corresponding to the renewable sources and to nuclear energy of the electricity matrix of the countries analyzed was identified. Subsequently, the share increase targets for these sources in the electricity matrix until 2030 were identified. Based on this information, two categories were established to qualify the scope of the governmental plans to drive decarbonization:

- **Gradual**: Increasing > 30% and < 50% the electrical energy volume generated from low-carbon sources until 2030, when compared to the 2018 levels.

- **Accelerated**: Increasing > 50% the electrical energy volume generated from low-carbon sources by 2030, when compared to the 2018 levels.

The second analysis criterion, complementary to the previous one, seeks to identify the scope of the governmental plans beyond decarbonization of the electricity matrix. For this purpose, in addition to the two categories already presented, another two related to the States' interest in driving economic development were included. The four categories of objectives are described as follows:

- **GTLC**: Gradual Transition to a Low-Carbon electricity matrix.
- **ATLC**: Accelerated Transition to a Low-Carbon electricity matrix.
- **PCD**: Productive Capacity Development in specific sectors from the supply chain of devices and services for the electricity sector. In order to define productive capacity, the definition developed by Moreira (2004) was used, understanding Productive Capacity as the maximum number of items/products and/or services that can be produced by the national business sector in a competitive way in terms of economic efficiency, deadlines and quality.
- **TCD**: Technological Capacity Development in specific sectors from the supply chain of devices and services for the electricity sector. For the definition of technological capacity, it was decided to use the one formulated by Mori *et al.* (2013), understood as the companies' capability of absorbing, using, adapting, generating, developing, transferring and disseminating technologies. This capacity is enabled by the diversified range of resources, the skills (organizational, operational and relational) and the learning mechanisms they employ. According to the authors, capabilities are second-order constructs derived from a set of elements that anchor and mirror a company's absorption, operational and technological innovation (adaptation and generation) capacity.

Consequently, by mapping the public policies to drive the transition, it was possible to identify several combinations of objectives in the governmental plans:

i. GTLC
ii. ATLC
iii. GTLC + PCD
iv. ATLC + PCD
v. GTLC + PCD + ICD
vi. ATLC + PCD + TCD

The third set of criteria for the comparative analysis between the countries pertains to the public policy packages that the nations are adopting to encourage diffusion of renewable energies, ensure their safe, flexible and economically efficient integration into the electricity system, and promote industrial and technological development in these sectors. In this sense, the taxonomies established by Daszkiewicz (2020) and Edler & Fagerberg (2017) in terms of energy policy, industrial policy and ST&I policy were used as reference points (see Table 1).

Finally, the fourth criterion for the comparative analysis pertains to the technological options that have already been adopted, as well as those envisioned by the governmental plans to accelerate decarbonization of the electricity matrix. In this sense, the technologies pointed out by IEA (2019) in the electrical energy generation, buildings and system integration sectors were taken as a reference (Table 2).

Consequently, the methodological guidelines to perform the comparative analysis between the German and Japanese cases were defined.

TABLE 1 – Public policy tools to drive sustainable transitions.

Public policy category	Type of tool
Definition of targets and strategic planning	Energy-related strategies Action plans Objectives
Policies targeted at initial investment costs	Grants Discounts Loans with preferential conditions Tax benefits/incentives Direct funding for RD&I in companies
Policies targeted at energy generation	Feed-in tariffs Feed-in-premium tariffs Auctions Bids Certificates Policies related to electricity self-generation, self-consumption and sale to the grid
Regulatory	Connection and dispatch rules Duties and obligations Standards Labels Regulatory environment that does not prohibit or allows corporate PPAs
Incentives for industrial and ST&I development	Training policies and Competencies Policies to promote entrepreneurship Technical and counseling services Policies to promote clusters Policies to support collaboration Policies of the Innovation Network Using the State's Purchasing Power Pre-commercial acquisition Awards for innovation Technological prospection

SOURCE: Prepared by the authors based on Daszkiewicz (2020) and Edler & Fagerberg (2017).

TABLE 2 – Technological options to drive decarbonization in the electricity and residential sectors.

Sector	Technologies considered
Electrical energy generation	Photovoltaic solar; onshore eolic; offshore eolic; hydroelectric; bioenergy; concentrated solar power; ocean energy; nuclear energy; alcohol-based energy; and Carbon Capture and Storage (CCUS) in electricity.
Buildings	Construction envelopes; heating; heat pumps; cooling; lighting; devices and equipment; data centers and networks.
System integration	Energy storage; Smart Grids; hydrogen; and response to demand.

SOURCE: prepared by the authors based on IEA data, 2019.

4. The study cases: Analyzing the paths to drive the energy transition in the electricity sector: The German and Japanese cases

4.1. Germany

Germany is one of the countries with the longest history of implementing policies targeted at meeting the climate emergency. Formulation of the public policy package aimed at addressing this phenomenon began to take shape at least in the 1980s, becoming part of the governmental agenda alongside other issues sensitive to the country's energy and climate policy, such as vulnerabilities due to crude oil imports and concerns over the perils associated with nuclear energy development (Kuittinen & Velten, 2018). Thus, the progressive inclusion of public policies into the mix allowed important results in the diffusion of new renewable sources within the national electricity matrix, reaching 36% of the total electricity generated in the country in 2018 (IEA, 2020c).

In 2018, the country's electrical energy generation matrix reached a volume of 664 TWh. Of this total, coal accounted for 37.5%, followed by eolic energy (17.3%), natural gas (13.2%), nuclear (11.8%), bioenergy and waste (9.1%), solar (7.4%), hydroelectric (2.8%), crude oil (0.8%) and geothermal (0.03%) (IEA, 2020c) (see Figure 2).

At the federal level, management of the transition policies is concentrated across several ministerial departments, with the following among the main ones: Federal Ministry for Economic Affairs and Energy (BMWi), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Ministry of Transport and Digital Infrastructure (BMVI), Federal Ministry of Food and Agriculture (BMEL), Ministry of Education and Research (BMNF), and Federal Ministry of Finance (BMF) (Kuittinen & Velten, 2018).

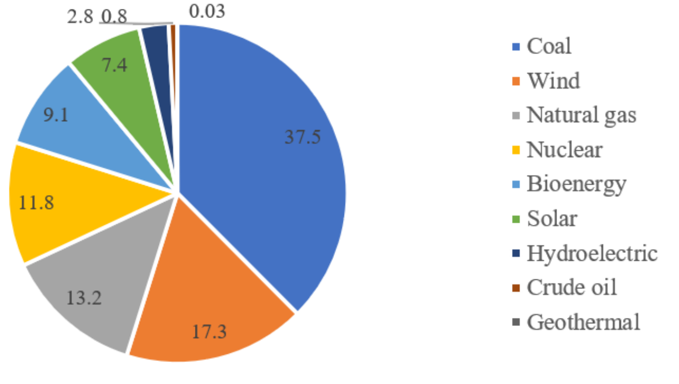

FIGURE 2 – German electrical energy generation matrix in 2018.
SOURCE: prepared by the authors based on IEA data, 2020c.

The Policy Mix in the German electricity sector is organized under the umbrella term of Energiewende (Energy Transition in German), the long-term national plan to drive the low-carbon energy transition (Figure 3). This initiative is framed within several public policy documents, such as the Renewable Energy Act of 2000, the Energy Concept of 2010, different editions of the Energy Research Program executed since 1977, the Climate Action Plan 2050 from 2016, and other documents encompassing more specific public policy instruments.

As can be seen in Figure 3, the mapping of the instruments that comprise the German Policy Mix was organized based on achieving three complementary strategies:

(1) Decarbonizing the electricity system based on diffusion of the renewable sources, including nuclear energy;

(2) Adapting the electricity system to the dynamics imposed by the new renewable sources; and

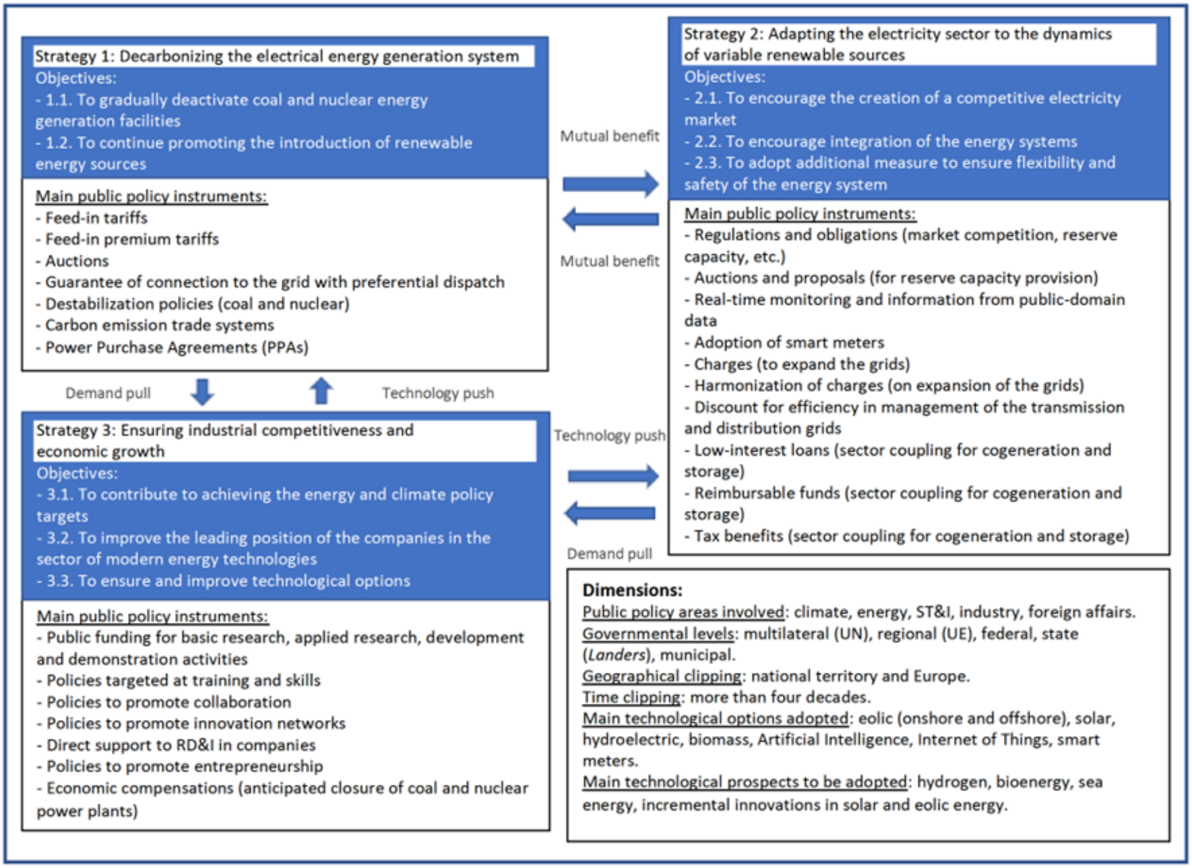

FIGURE 3 – Policy Mix to drive the low-carbon energy transition in the German electricity sector.
SOURCE: prepared by the authors.

(3) Guaranteeing industrial competitiveness and economic growth.

Thus, the governmental plans expect that the electricity sector may contribute to reducing by 55% the CO^2 emissions by 2030, when compared to the 1990 levels. Based on these strategies, the country expects to increase the share of the new renewable sources in the electrical energy raw consumption to 65% by 2030, and to 80% up to 2050 (IEA, 2020c).

In the scope of Strategy 1, the Policy Mix includes both instruments to put an end to unwanted socio-technical regimes in the electricity matrix and instruments to promote the new renewable sources. The first group of instruments comprises regulations and mandates for the scheduled decommissioning of electricity generation facilities powered by nuclear energy and coal in 2022 and 2038, respectively (BMU, 2021; Wettengel, 2020).

To promote the expansion of the electrical energy generation capacity from new renewable sources, the German mix has been establishing regulations and mandates for over three decades, with its most notable expression found in the Renewable Energy Act of 2000. In the scope of this Law, the State initially determined the guarantee of connecting the renewable sources to the transmission grid, and with priority for dispatch. It also established the Feed-in tariffs to encourage investments in expanding the electrical energy generation capacity from the new renewable sources (mainly eolic and solar). In 2014, the Law was amended and Feed-in premium tariffs were introduced for new generation plants with a minimum price threshold. In 2017, auctions were introduced in substitution of the Feed-in schemes, aiming to generate greater competition and adapt the electricity tariffs to the market reality (Germany, 2017).

To adapt the electricity market design to the dynamics of new renewable sources, Strategy 2, the Policy Mix, encompasses a set of regulatory framework reforms and public policy instruments aimed at exposing both producers and consumers to an environment marked by increased competitiveness and flexibility in electricity supply, demand and storage. The governmental policies seek to deal with the following key aspects related to electrical energy generation:

i) The intermittence of the new renewable sources;

ii) The use of natural gas in thermoelectric sources;

iii) Hydroelectric storage with reversible power stations; and

iv) Into the future, by expanding the biogas flexible generation capacity and the battery storage capacity (IEA, 2020c).

With this objective in mind, among the measures, the Policy Mix encompasses instruments to promote competition in the electricity market to the extent possible, incentives to promote energy system integration and the inclusion of backup measures and sources to manage the intermittence of new renewable sources, among other actions (BMWi, 2017; Chen *et al.*, 2019; IEA, 2020c).

In 2016, the Renewable Energy Act was amended, and the Act on Further Development of the Energy Market was enacted, stipulating that the electricity generation capacity should be in line with the demand from consumers. Likewise, new rules were established for remuneration through energy redispatch, cost reduction through the expansion of the transmission and distribution grids, and freedom for the market actors to decide which flexibility options to use (storage, gas peakers, demand-side management) (BMWi, 2017).

Aiming to promote integration and flexibility in the electricity system, Germany has been adopting incentives such as low-interest loans and subsidies to enhance storage capacity through sector coupling of the electricity and heating sectors (IEA, 2020c). The governmental plans also seek to improve and expand the transmission and distribution grids in the country and to other European markets[4].

Consequently, the actions seek to overcome the limitations that preclude transmission between northern and southern Germany, burdening the consumers' tariffs. Thus, on the one hand it is sought to avoid the need to adopt SWAP or redispatch measures in the South to make up for the acquired electrical energy that cannot reach this region of the country. On the other hand, it is also sought to compensate the electric energy generation reduction in the North, where the operators request the generators to disconnect to avoid congestion (IEA, 2020c).

For this purpose, in 2016, tariffs for consumers were also adopted, allowing investment costs to be immediately recognized in the grid charges (with the costs annually adjusted to ensure that consumers consistently benefit from lower capital costs) (BMWi, 2017). In 2017, the State introduced measures to gradually homogenize the tariffs until 2023, starting in 2019 (BMWi, 2021).

Through demand-side management promotion measures and in conjunction with the framework for smart grid development, in 2016, the Parliament approved the law on digitization of the Energiewende, stipulating the phased installation of smart meters (IEA, 2020c; BMWi, 2015).

In 2016, the requirement for a reserve capacity was also established, which is separate from the electricity market and does not affect competition or prices. This reserve capacity is intended to be used in case of extraordinary or unforeseen events. Additionally, in 2017, the federal government established the reserve capacity volute at 2 GW. To select reserve capacity providers, the electricity power stations can make offers in auctions organized by the transmission system operators (BMWi, 2021).

Finally, Strategy 3 was incorporated into the Policy Mix with an emphasis on public policy documents discussing the Energiewende in terms of opportunities to drive Germany's and the rest of Europe's industrial and technological development.

At the federal level, most of the ST&I policy instruments that are currently in force are funded by means of the seventh edition of the "Energy Research Programme", launched in 2018[5]. The aforementioned program defines the ambitious principles, priorities and objectives in the development of innovative energy technologies to attain energy transition. These objectives are pursued by implementing specific projects or through funding by research institutions both in the country and abroad – mainly in the European Union scope. The program has 6.4 billion Euros in funds to be spent between

[4] To overcome these limitations, the federal government has set a goal to build 7,700 kilometers of transmission grids, including four high-voltage grids connecting the North and South, as well as high-voltage direct current (HVDC) lines (IEA, 2020c).

[5] According to data from the International Energy Association, public investments in R&D in the energy sector in 2019 were around USD 1.586 billions (IEA, 2021a)

2018 and 2022. The funds are distributed among BMWi, BMEL and BMBF, and implementation of the projects is coordinated with science and technology universities and institutes (the Helmholtz Association) and companies (BMWi, 2020)[6].

Among the technological options prioritized in the electricity sector, there is a focus on funding projects aimed at incremental innovations in solar and eolic energy, as well as the continued development of thermal power plants using biogas. In the scope of technologies to ease the integration of new renewable sources, the program has prioritized technologies targeted at network development, energy storage, sector coupling and hydrogen. Research areas permeating energy systems, or even beyond the energy sector, are also considered, including topics such as digitalization, resources management and CCUS (IEA, 2020c; BMWi, 2020).

Among the instruments identified, we found funding of basic research, applied research and demonstration projects for technological and regulatory solutions for the options prioritized in the government plans (Germany, 2017). Likewise, direct funding from companies to implement RD&I projects with governmental funds was identified. The 7th Research Programme puts emphasis on supporting small- and medium-sized companies, Start-ups and entrepreneurship in different programs and projects. In fact, since 2018, it started to have a platform comprised by experts in this theme (Kuittinen & Velten, 2018).

It also includes actions to transfer technologies and for their fast adoption for commercial purposes by means of instruments targeted at promoting collaboration between S&I institutions and companies. Another measure identified was implementing policies targeted at promoting interaction between the actors. In this sense, the projects are executed with significant involvement of the academic community, industry organizations and companies. Actions targeted at technological prospection and definition of investment priorities were also adopted with some of the platforms created (Energy Research Platform and Energy Research Networks) (Kuittinen & Velten, 2018).

4.2. Japan

In Japan, the current energy policy guidelines coexist with concerns about supply safety, efforts to manage the impact of the Fukushima nuclear accident, and the government's increasing commitments to advance a low-carbon energy transition agenda. Under the premise of Safety Always, the guidelines of Japan's energy policy aim at ensuring a stable energy supply (energy safety) at low prices (economic efficiency), while maximum efforts are implemented to achieve environmental sustainability (METI, 2018).

The Japanese electricity matrix is 80% comprised by imported fossil sources. In 2019, the total electrical energy generation reached 992.5 TWh. The generation share by energy sources was divided as follows: coal (31.9%), natural gas (34.2%), solar (9.4%), hydroelectric (8.1%), nuclear energy (6.4%), crude oil (4.8%), biomass (2.2%), bioenergy (2%), eolic (0.7%) and geothermal (0.3%) (IEA, 2021b) (Figure 4).

[6] Germany is part of the Mission Innovation initiative, a platform of countries aiming to double public investments in R&D to ease the low-carbon transition within a five-year time frame, in line with the private sector (Kuittinen & Velten, 2018).

At the national level, the implementation of transition policies is primarily concentrated within the Ministry of Economy, Trade and Industry (METI), the Ministry of the Environment and the Ministry of Education, Culture, Sports, Science, and Technology (IEA, 2016).

The decarbonization targets and the main public policy instruments to achieve this objective were established in the 2014 and 2018 Energy Strategic Plans, the 2019 Long-Term Strategy to Achieve the Paris Agreement targets, and the 2020 Green Growth Strategy. In 2014, the Japanese government set greenhouse gas emission reduction targets that have been maintained in subsequent documents. In this sense, the country expects to reach a global target of 18% reduction in emissions by 2030, when compared to 2013, where the electricity sector currently contributes with 40% (IRENA, 2021).

After reviewing the governmental plans, it can be stated that the Policy Mix to drive the energy transition was organized by means of at least four strategies:

(1) Promoting an expansion of the electrical energy generation from renewable sources, including the nuclear option among them, given the low level of emissions;

(2) Promoting a reduction of emissions in energy generation from fossil sources;

(3) Transitioning to a more resilient electricity system; and

(4) Driving ST&I to support energy transformation and national economic development (Figure 5).

In relation to Strategy 1, the governmental plans indicate that, by 2030, nuclear energy and new renewable sources are expected to account for a share of the electricity mix ranging from 20% to 22% and from 22% to 24%, respectively. In the nuclear energy scope, the government expects to achieve these targets by reactivating at least 30 out of the 33 still operational nuclear power plants that were shut down immediately after the Fukushima accident, with an 80% capacity factor (IEA, 2021b)[7].

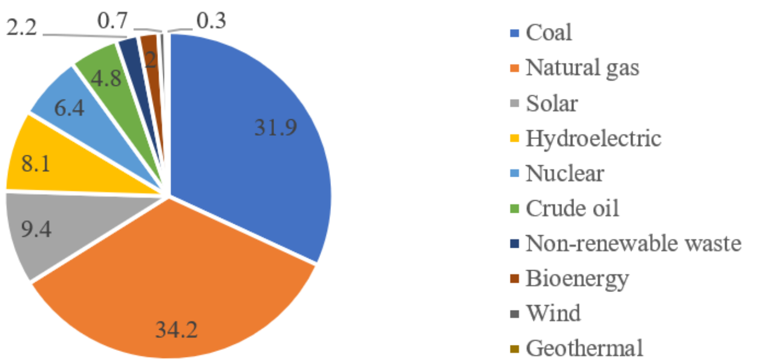

FIGURE 4 – Japanese electrical energy generation matrix in 2019.
SOURCE: prepared by the authors based on IEA data, 2021b.

[7] In order achieve this objective, the nuclear power plants still need to finish the review of the safety conditions performed by the Nuclear Regulation Authority (NRA) (IEA, 2021b).

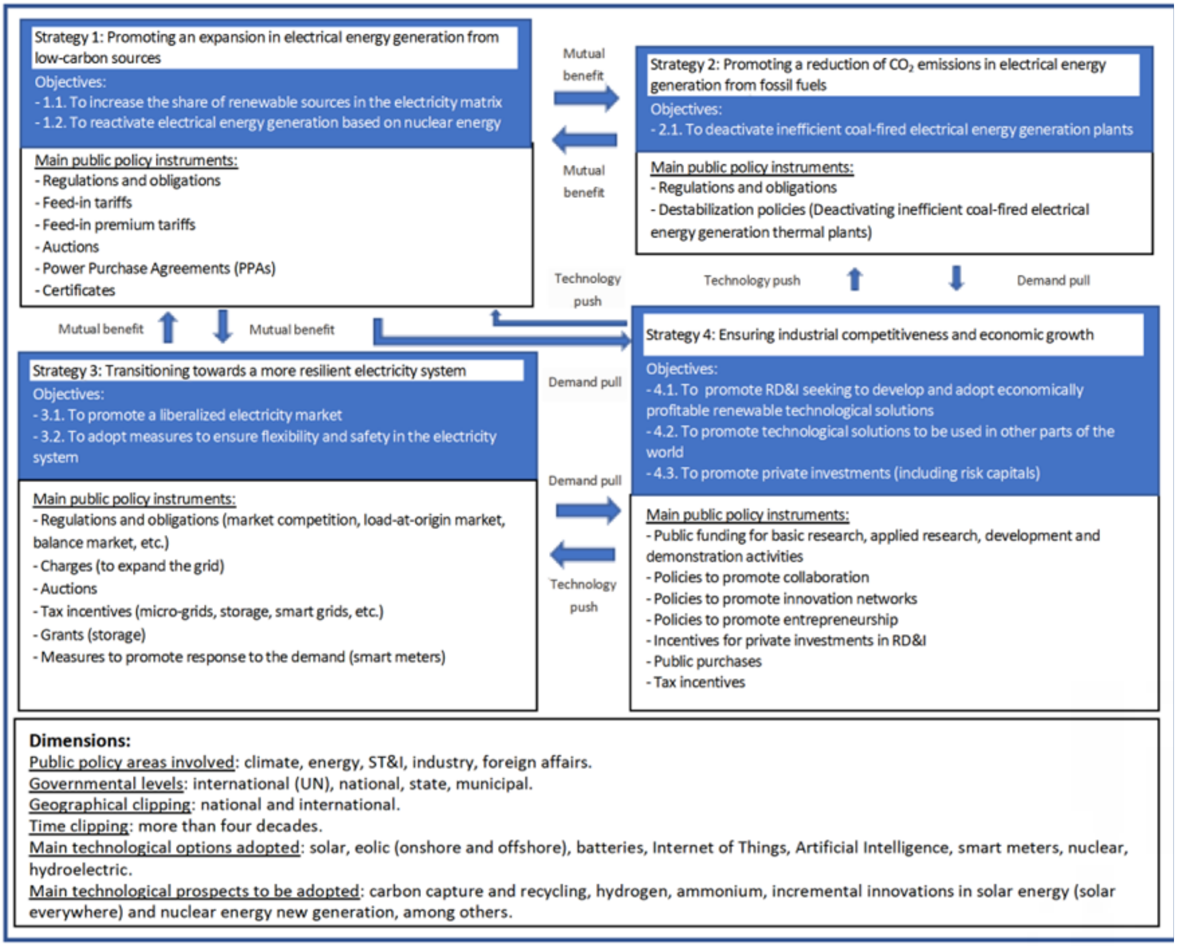

FIGURE 5 – Policy Mix to drive the low-carbon energy transition in the Japanese electricity sector.
SOURCE: prepared by the authors.

Among the measures to promote the expansion of generation capacity from new renewable sources, Feed-in tariffs were introduced in 2012 (METI, 2018; IRENA, 2021)[8]. The auction mechanism for generation projects for volumes equal to or greater than 250 KW was introduced in 2017. Starting in 2020, the Feed-in premium scheme was introduced for large-scale solar, biomass, and offshore eolic energy projects, aiming to introduce competition in energy pricing and seek lower prices for consumers (IRENA, 2021).

[8] The Feed-in scheme would be used to compensate the generation of electricity from photovoltaic solar and hydroelectric projects with a capacity of less than 30 MW, eolic energy, geothermal, biomass and other sources recognized as renewable by the Japanese authorities (IRENA, 2021).

Within the scope of Strategy 2, the governmental plans include measures to reduce emissions even while foreseeing the continued high participation of fossil energy sources in the national electricity matrix[9]. With this purpose in mind, the Policy Mix included voluntary emission reduction programs and incentives to adopt CCUS technologies (Japan, 2019; IEA, 2021b).

Strategy 3 encompasses a wide range of policy instruments aimed at achieving the transformation towards an electricity system that is more resilient to environmental disasters, adapted to the dynamics of new renewable sources, and geared towards reducing energy prices. Unlike the German case, the Japanese electricity system is not interconnected to other countries. The transmission grid is divided into two regions, each one operating at different frequencies. The electrical distribution grid is fragmented into ten regions, a legacy of the sector's organization through the monopolies held by the EPCOs, which hinders system balancing and the ability to accommodate large electricity volumes from new renewable sources. In addition to the aforementioned, a large part of the increase potential in the electrical energy generation capacity from variable renewable sources is far from the main consumption centers (IEA, 2021b).

To change these characteristics in the system, since the 1990s, the Japanese government has implemented regulatory reforms to ease the incorporation of new players to generation, transmission and distribution activities (IEA, 2016)[10]. The energy commercialization market was totally deregulated in 2016. All energy consumers, including small shops and homes, were allowed to choose their energy provider (Jensterle & Venjakob, 2019). In 2019, new regulations established separation of the EPCOs in the electrical energy industry chain. According to the new norms, the transmission and distribution segments should be separated from generation (IEA, 2021b).

In 2016, the Japanese Electric Power Exchange (JPEX), a private energy exchange body, was designated as the wholesale market in the country, aiming to create equal access conditions both for EPCOs and for new entrants and, in general, promote increased competition among market participants. Additionally, in 2019, the government established the creation of a capacity market at origin[11]. The scheme pursues a combination of coal-fired thermal power plants, run-of-river hydroelectric plants, nuclear energy and geothermal sources that excel in stable and cost-effective electricity production and generation. In the decision, bidding rounds were established to participate in this market, lasting 12 months. Thus, the Japanese government seeks to provide distributing companies with access to lower electrical energy prices (Genscape, 2019).

[9] Due to the limited resource base, in addition to the geographical difficulties to expand energy generation from the new renewable sources, METI contemplates maintaining fossil sources in the electricity matrix. According to the Ministry's projections, it is expected that 50% of the electrical energy will continue to be generated through coal and natural gas until 2030 (Japan, 2019).

[10] The first reforms were initiated in 1995, easing entry to the generation segment for interested parties through the introduction of a retail business structure, tariff regulation relaxation, and flexible adjustment of the safety regulations. In 2000, high-voltage (more than 2,000 KW) energy consumers were allowed to freely choose their energy providers. In that year, the reforms allowed third parties to access the distribution lines, divided into ten regional areas throughout the country, which were controlled by the EPCOs at that time (IEA, 2016).

[11] Management of the electricity sources in Japan is organized as follows. Hydroelectric and nuclear energy provide electricity at origin, while coal and LNG are the primary energy sources for medium-load supply. Hydroelectric energy, crude oil and pumped storage respond to the demand peaks and contribute to consistent and stable electricity provision (Genscape, 2019).

As a short-term strategy to meet the grids' connection capacity restriction, the Japanese government adopted the Japanese version of Connect & Manage. The approach consists in integrating as much renewable energy as possible into the existing grid, while simultaneously seeking to minimize the increase in electricity prices and reducing the need for grid upgrades[12]. Secondly, the approach replaces the practice of providing a "steady connection" to renewable generation companies by offering them to connect to and sell the amount of energy that the grid can accommodate (Jensterle & Venjakob, 2019)[13].

To administer intermittence of the new renewable sources, the 2018 strategic plan established flexible use of thermal generators. The plan also proposes the gradual adoption of technologies such as cogeneration, Virtual Power Plants (VPPs), V2H/V2G and stationary Energy Storage Systems (ESSs). Complementarily, in 2015 METI launched a grants program to support the installation process for energy stock devices in solar energy facilities (Watanabe, 2015)[14].

In 2018, METI established funding instruments for expansion and enhancement projects of the transmission and distribution grids, in addition to introducing mechanisms for auctions and proposal submissions among generating companies located in close proximity for accessing specific transmission and distribution lines (Watanabe, 2015; Yamazaki & Ikki, 2018)[15]. In 2020, the Japanese government established that an over-tariff distributed at the national level had to be paid to fund the development of regional interconnection grids (METI, 2020).

In order to generate greater flexibility from the "demand management" perspective, the national government has been promoting the adoption of smart meters since 2016, starting with the largest industrial consumers and gradually extending the measure to residential consumers. It is expected that nearly 80 million units will be installed by 2025 (Jensterle & Venjakob, 2019).

Finally, Strategy 4 includes policy instruments aimed at promoting the country's technological and industrial development by leveraging the transformation of the energy industries[16,17]. These efforts are framed within The Green Growth Strategy, which aims at driving a new economic growth and environmental sustainability cycle by supporting the private sector in transitioning towards a car-

[12] For this purpose, it first uses a method to apply the emergency capacity of the existing grid by the n-1 principle, freeing the technically available transmission capabilities (Jensterle & Venjakob, 2019).

[13] In Japan, distribution companies follow the "First-come, First-served" principle, which prioritizes the connection of generating companies already connected to the grid and guarantees them transmission capacity corresponding to their maximum generation capacity (Jensterle & Venjakob, 2019).

[14] Energy storage with batteries has been incorporated into the grants program for net Zero Energy Houses (ZEH) and in pilot projects for net Zero Energy Buildings (ZEB), initiatives aimed at encouraging the incorporation of storage and energy-saving technologies by providing a fixed grant of 700,000 Yens for each eligible residence (Yamazaki & Ikki, 2018).

[15] These measures were introduced in the scope of the 2020 Plan on Development of Cross-Regional Grids. Through this plan, it is expected that the interconnection capacity between both frequency regions may increase from 1.2 GW to 2.1 GW until March 2021 and to 3 GW up to March 2028. Interconnection projects are also ongoing within the frequency regions (IEA, 2021b).

[16] Japan has experience in implementing ST&I policies in the energy sector. The Sunshine Project, the Moonlight Project and the New Sunshine Project stand out among them (Japan, 2019).

[17] Japan has also been part of the Mission Innovation initiative since 2015 (IEA, 2016).

bon-neutral society. The strategy includes five cross-sectional policy instruments (support measures) and action plans in 14 sectors to be continuously updated (METI, 2021).

The following can be mentioned among the options contemplated in the strategy:

(i) Incentives to incremental innovation in solar and eolic energy;

(ii) Energy grids, by introducing batteries for electricity storage, integration of the electricity systems and solutions to balance offer and demand;

(iii) Hydrogen;

(iv) Ammonium-derived fuels;

(v) CCUS technologies;

(vi) New-generation nuclear energy (METI, 2021).

Among the policy instruments, the governmental plan includes funding of research activities and development and demonstration of prospected technology options[18]. For this, the Japanese government considers 2 trillion Yens in funds until the end of the decade and expects to encourage private investments of around 15 trillion Yens during the same period (METI, 2021).

The plan proposes to adopt tax incentives to encourage private investments for 1.7 trillions in the next decade. Additionally, it contemplates guidelines about funding policies and definition of long-term funds with subsidized interests to attract sustainable investments. It also proposes reforms in the regulatory framework in several sectors, such hydrogen, offshore eolic energy and mobility. Among the reforms, the strategy proposes changes in the regulation of public purchases, aiming to encourage the demand for certain products and services and to enable their introduction into commercial channels. Finally, deepening of international cooperation is contemplated, as well as in the development of innovation projects, standardization and development of norms (METI, 2021).

5. Comparative analysis

After mapping the main policy instruments implemented and examining the policy guidelines for driving the low-carbon energy transition, it is possible to perform a comparative analysis of the paths defined by both countries based on the analysis criteria established in section 2 (Tables 3 and 4).

Analyzing the evolution of the share of fossil fuels in the electricity mix in 2009 and 2019, as shown in Table 3, it was identified that in the German case there was a 5% reduction, whereas the Japanese case presented a 10% increase. The slow reduction in the share of fossil fuels in the German electricity mix can be attributed to the country's decision to shut down all its nuclear power plants by 2022. This led to compensating for the loss of this generating capacity by relying on fossil sources, even delaying the decommissioning of coal-fired thermoelectric power plants, which is projected to continue until 2038 (IEA, 2020c). In the case of Japan, it was due to the need to compensate for the reduction in the electricity generation capacity after the Fukushima nuclear accident and the complete shutdown of the national nuclear fleet (IEA, 2021b).

[18] In 2019, public investments reached the amount of USD 2.88 billions, a relatively low figure compared to the beginning of the decade, due to the impacts of the Fukushima accident and a reduction in funding for nuclear energy research (IEA, 2021a).

TABLE 3 – Share of fossil sources in the German and Japanese electricity matrices and decarbonization targets.

Analysis criteria	**Germany**		**Japan**	
	2009	**2019**	**2009**	**2019**
Proportion of fossil fuels in the electricity matrix	56.5%	51,5% (2018)	63%	73.1%
Share of the electricity generated from renewable sources	18.5%	36% (2018)	10%	20,5% (2019)
Share of the electricity produced based on nuclear energy	25%	12% (2018)	27%	6,4% (2019)
Electrical energy generation targets from renewable sources until 2030		65%		22%-24%
Electrical energy generation targets from nuclear sources until 2030		0%		20%-22%
Scope of the governmental plans from the perspective of the decarbonization targets	**Accelerated**		**Gradual**	

SOURCE: prepared by the authors.

TABLE 4 – Guidelines from the governmental policies to drive the low-carbon energy transition in Germany and Japan.

Analysis criteria	**Germany**	**Japan**
Scope of the governmental plans from the perspective of the economic transformation objectives	Accelerated Transition + Productive Capacity Development + Technological Capacity Development	Gradual Transition + Productive Capacity Development + Technological Capacity Development
Main technological options adopted	Onshore eolic, offshore eolic, solar photovoltaic, bioenergy, hydrogen.	Solar photovoltaic, onshore eolic, geothermal, nuclear, hydrogen.
Main public policy instruments to promote the incorporation of renewable energy sources	Feed-in tariffs, guaranteeing connection to the grid, Feed-in premium tariffs, auctions.	Feed-in tariffs, Feed-in premium tariffs, auctions.
Main policy instruments adopted to adapt the electricity system to the dynamics inherent to the variable renewable sources	Regulations and obligations (market competition, reserve capacity), auctions, charges, loans (sector coupling), tax reductions, demand-side response measures.	Regulations and obligations (market competition, load-at-origin market, balance capacity), charges, auctions, tax incentives, grants and demand-side response measures.
Main technological options adopted to adapt the electricity system to the dynamics inherent to the renewable sources	Cogeneration technologies, smart meters, batteries, IoT, AI, natural gas, coal, biogas.	Smart meters, IoT, AI, batteries, cogeneration technologies, natural gas.
Technological options prospected to be commercially introduced	Solar and eolic energy, hydrogen, batteries, ocean energy, nuclear energy, carbon-based technologies, digital and information technologies.	Solar and eolic energy, hydrogen, ammonium, CCUS, batteries, new nuclear energy generation, digital and information technologies.
Main instruments to promote industrial and ST/I development	Public funding for basic research, applied research, development and demonstration, policies to promote collaboration, policies to promote networking, entrepreneurship promotion policies, technological prospection, loans.	Public funding for basic research, applied research, development and demonstration, policies to support collaboration, policies to promote networking, entrepreneurship promotion policies, incentives for private investment, public purchases, tax incentives.

SOURCE: prepared by the authors.

The high share of fossil fuels also allows identifying the scope inherent to the challenge of decarbonizing the electricity matrix. In the German case, the government plans aim at increasing electricity generation from renewable sources, excluding nuclear, from 36% in 2018 to 65% of the electricity mix by 2030. This would qualify within the "accelerated transition" category, understanding that the increase in generation capacity from these sources should be almost doubled by the end of the decade. However, in the case of Japan, the targets outlined in the government plans can be categorized as a "gradual transition", as they do not envision the electricity mix being dominated by low-carbon sources by 2030.

In relation to the scope of the governmental policies, the official documents reveal that both countries seek to leverage the low-carbon energy transition process to boost national economic development by building new productive and technological capacities. In this context, the government policies in both countries aim at creating conditions for their business sectors to excel in developing technologies and products related to the new socio-technical regime emerging from the energy transformation process (Table 4).

In relation to the promotion of electrical energy generation from new renewable sources, it can be observed that despite the difference in timing of their implementation, both countries adopted similar policy guidelines and instruments. In a first stage, both countries adopted policy instruments targeted at making introduction of these sources economically viable; Feed-in tariffs and the obligation to connect these sources to the grid.

Subsequently, in both cases, the guidelines from the governmental policies continued to seek an increase in installed generation capacity from variable renewable sources, although introducing instruments targeted at achieving greater cost efficiency to be passed on to end consumers. For this purpose, both cases transitioned to the introduction of other instruments, such as Feed-in premium tariffs and auction mechanisms. This was encouraged by the need to reduce the high electricity tariffs (the electricity tariffs in both countries are among the highest ones in OECD countries) and the impact of incremental technological innovations in lowering the production costs of devices and generation from renewable sources over the last decade (IEA, 2021b; IRENA, 2019).

There are important differences regarding the technological options adopted by the countries. Germany chose to promote the variable sources and deactivate all nuclear power plants by 2021, whereas Japan decided to continue maintaining nuclear power as one of the low-carbon options in its energy transition. The countries' cases also presented differences in the pace with which the technological options adopted were disseminated. Despite being the same ones, eolic energy dissemination progressed faster than solar energy, which also presented growth, although not at the same speed. In the Japanese case, the technological option that presented remarkable growth was solar energy. In the case of eolic energy, the country did not show substantial results[19].

[19] Although not analyzed more in depth in this paper, several reasons explain the solar energy dissemination speed in Japan and for eolic energy in Germany. They are related to issues such as geographical conditions and to public policies to promote the creation of productive and technological capacities since the second half of the 20th century. See Wieczorek (2019) for more details.

5. Conclusions

Throughout this paper, the intention was to identify the review process of the national energy policies, as a result of seeking results that allow an energy matrix transformation through the reduction of fossil fuels. In this sense, the role of the State in this review process is crucial. From the conceptual framework of Policy Mixes, the need to articulate and coordinate, differently from the past, a series of new public policy instruments is made evident. Thus, it was possible to highlight that, in generic terms, the Policy Mix design emerges from the interest in achieving general objectives through specific public policy instruments that are incorporated into the mix to coexist with previously adopted ones. The search to achieve general objectives is the result of the interaction, alignment and aggregation of interests among political actors within the State's institutional political arrangement, as well as of their prioritization in the governmental agendas.

This conceptual framework has been extremely valuable for studies about transitions of socio-technical regimes and that test public policy packages. In the case under consideration in this paper, similarities and differences were identified in the scope of the reviews of governmental policies in Germany and Japan to adapt their electricity systems to the dynamics of variable renewable sources. In the German case, this is directly related to the need to integrate variable renewable sources into the system, whereas in Japan, the integration of renewable sources is part of a broader safety view, aimed at reducing the country's vulnerabilities to environmental disasters.

Among the elements in common, the governmental policies in both countries share the guideline to transition to liberalized energy systems and seeking that the pricing mechanisms respond to market signals. Among the solutions to ensure safety in supply and the transition to more flexible systems, the countries also present similarities in the alternatives adopted. Both countries coincide in the need to improve and expand their electricity transmission and distribution grids, as well as to enhance integration between regions to achieve better balance conditions. In order to deal with the intermittence inherent to the variable sources, the countries are promoting the installation of energy cogeneration and storage systems.

In the scope of the technological options considered, the countries also present similarities. Both contemplate adopting natural gas as a backup source to deal with the intermittence inherent to the renewable sources. Similarly, the governmental plans established the adoption of cogeneration and battery storage technologies to deal with intermittence, as well as the introduction of digital technologies to improve the electricity system management capacity and as part of demand-side management measures.

In terms of policies to promote industrial and ST&I development, the governmental plans show certain direction to increasing efforts in terms of public policy to complement the promotion of low-carbon sources and the energy systems' adaptation to the new dynamics of these energy sources. They also aim at placing the local companies in the technological frontier and, as countries, to continue preserving their position as economies that export high-technology products and services.

In both cases, it can be observed that the incentives for technological development go beyond the policy instruments directly aimed at promoting

R&D and demonstration activities. In both policy mixes, it can be observed that the other strategies also fit as incentives for the demand of specific technologies and for generating incremental innovations aimed at reducing generation costs, improving transmission and distribution grids, and enhancing the efficiency of the technological options to address the intermittence inherent to variable sources.

Among the instruments adopted, the mapping stood out for public funding of basic research, applied research, development and demonstration activities (Table 2). In both cases, the governmental plans show an interest in accelerating the times in line with the commercial introduction of new products and services. Complementarily, the official documents show a broad range of public policy instruments, many of them targeted at specific topics. Among the most prominent instruments, those targeted at promoting collaboration among stakeholders, establishing interaction networks, and instruments focused on fostering entrepreneurship within the scientific community were found.

However, among the differences, the Japanese Policy Mix case presents a greater State intervention scope than the German one. In addition to funding for capacity expansion and the adoption of technological options, instruments that are present in both countries, the Japanese Green Growth Strategy includes more aggressive instruments in terms of State intervention, such as the explicit use of the State's purchasing power.

Finally, in relation to the technological options, both countries coincide in the need to continue encouraging the creation of incremental innovations in the variable renewable sources. Another point in common is continuity of the incentives for the development of hydrogen-based technologies. Both countries also show similarities in relation to searching technological solutions in terms of transmission grids, battery energy storage systems, cogeneration systems and digital technologies to enhance system operation capabilities and demand-side management actions. Likewise, both countries pointed out the intention to develop technological capacity in terms of CCUS.

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