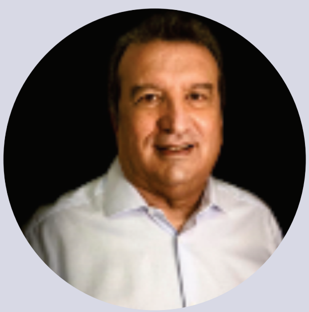
LOGO

Assessment of the innovation level of the brazilian electric sector's (SEB) RD&I program

Avaliação do nível de inovação do programa de PD&I do setor elétrico brasileiro (SEB)



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e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

ABSTRACT

The purpose of this article was to estimate the degree of innovation in SEB's RD&I program, and to assess the current status of the program in terms of the concept of the missing link of innovation or valley of death of innovation. The methodological procedures adopted were qualitative and exploratory, with mixed methods, including bibliographic and documental research and field research applied through a questionnaire in electronic form. Forty-eight questionnaires were answered from a population of 140 R&D managers and researchers from the SEB. The results obtained in the documental research indicate that Brazil is in an uncomfortable position in the Global Innovation Index (GII) ranking. It occupied the 47th position in 2011, and in 2021, it was 57th. It is 4th in the Latin America and Caribbean (LAC) Top 5 and among the BRICS; it is in the last position. The Innovation Efficiency Index (IEI) was 0.92 in 2011 and in 2021 it was 0.55. As for the Innovation Intensity Index, Brazil has only one company from the electricity sector in a ranking with 2,500 organizations. The evaluation of the RD&I maturity of the SEB revealed that it is a grade 3 ecosystem, under development. The estimation of the technological readiness level of the SEB showed that only 12.50% of the surveyed companies evaluate using the Technology Readiness Level (TRL) or Manufacturing Readiness Levels (MRL) scale, 47.92% do not evaluate TRL/MRL, and 39.58% evaluate, but remain in the initial stages. The analysis of the missing link of innovation leads to believe that the vast majority of projects of the RD&I of the SEB are plunging into the valley of death of innovation. It remains as a suggestion for research the formation of research networks in the SEB and the implementation of open innovation with the inclusion of startups.

KEYWORDS

Degree of Innovation; Technological Readiness Level; Electricity; RD&I; TRL.

RESUMO

O objetivo deste artigo foi estimar o grau de inovação do programa de PD&I do SEB, e apreciar o estágio atual do programa quanto ao conceito do elo perdido da inovação ou vale da morte da inovação. Os procedimentos metodológicos adotados foram de cunho qualitativo e exploratório, com métodos mistos, incluindo pesquisa bibliográfica, documental e pesquisa de campo aplicada por meio de questionário em formulário eletrônico. Foram respondidos 48 questionários de uma população de 140 gerentes e pesquisadores de P&D do SEB. Os resultados obtidos na pesquisa documental apontam o Brasil em uma posição desconfortável no ranking do Índice Global de Inovação (IGI), pois ocupava a 47ª posição em 2011, em 2021 foi para a 57ª, é o 4º no Top 5 da América Latina e Caribe (ALC) e entre os BRICS, fica na última posição. O Índice de Eficiência em Inovação (IEI) era 0,92 em 2011 e em 2021 foi de 0,55. Quanto ao Índice de Intensidade de Inovação, o Brasil tem apenas uma empresa do setor elétrico em um ranking com 2.500 organizações. A avaliação de maturidade de PD&I do SEB revelou que se trata de ecossistema grau 3, em desenvolvimento. A estimação do nível de prontidão tecnológica do SEB demonstrou que apenas 12,50% dos pesquisados fazem avaliação utilizando a escala Technology Readiness Level (TRL) ou Manufacturing Readiness Levels (MRL), 47,92% não fazem avaliação TRL/MRL e 39,58% avaliam, mas ficam nos estágios iniciais. A análise do elo perdido da inovação leva a crer que a grande maioria dos projetos do PD&I do SEB estão mergulhando no vale da morte da inovação. Fica como sugestão de pesquisa a formação de redes de pesquisa no SEB e a implementação de inovação aberta com inclusão de Startups.

PALAVRAS-CHAVE

Grau de Inovação; Nível de Maturidade Tecnológica; Eletricidade; PD&I; TRL.

INTRODUCTION

Developing an entrepreneurial and innovative ecosystem requires a set of individual elements, such as leadership, culture, capital markets, and open-minded customers that need to make synergistic combinations in a complex environment (Isenberg, 2010). Isenberg (2010) warns that these elements alone lead to the entrepreneurial path; however, the lack of their integration makes the process unsustainable.

Hence the need for the project of entrepreneurship and innovation to be led by the State, with the participation of academia, organizations, and civil society. This model called 4 helices (quadruple helix), which together can address the 4 elements (leadership, culture, capital markets, and customers), to awaken creativity and innovation, develop the risk appetite and enhance growth in a sustainable manner (Cukierman, Rouach, & Pagani, 2019; Isenberg, 2010; Mazzucato, 2014).

Given this scenario, it is observed that an innovation ecosystem is composed of a set of actors that must work around dimensions that can leverage the innovation process, so that it works as a symphony orchestra in the first moment, and then acquires a mixed-status of a symphony orchestra[1]/philharmonic[2], the State and society start financing innovation (Mazzucato, 2014).

The object of this article is the public innovation policy of the Brazilian electricity sector (SEB), materialized in the Research and Development (R&D) and Energy Efficiency (EE) programs. Together, they form the RD&I of the SEB, which had its results analyzed according to (Marques, Dias, & Vianna, 2021) and, afterward, an impact evaluation of the implementation of the public policy on the average supply tariff (AST) of electricity, according to Marques (2022) was elaborated. Now is the time to move forward in the evaluation process and understand the results obtained over 22 years of the program.

Given this context, the following research problem is proposed: how can the innovation maturity degree and the technological

1 - Symphony Orchestra is financed by the State (SABRA, 2022).
2 - Philharmonic Orchestra is financed by civil society (SABRA, 2022).

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http://doi.org/1026771/e-Revista.LOGO/2022.2.08

readiness level of the SEB's RD&I program contribute to delivering better results for society?

To answer this question it was defined that the objective of this research is to estimate the degree of innovation maturity, as well as the level of technological readiness of the SEB's RD&I program, and to appreciate the current stage of the program regarding the concept of the missing link of innovation or valley of the death of innovation.

The justification for conducting this study was the need to understand the context of the SEB's innovation ecosystem. This was done by evaluating the sector's degree of innovation maturity, which was carried out in 6 dimensions: i) innovation environment; ii) programs and actions; iii) ST&I environment; iv) public policies; v) financing; and vi) governance, to provide an overview of the program's current stage(Cukierman et al., 2019; Isenberg, 2010; Mazzucato, 2014). Another element that is incorporated in the justification of this research is the estimation of the technological readiness level of the SEB, measured in the TRL scale, which contributed to evaluating the quality of the investment made in innovation in the SEB (Gurgel Veras, 2021; Mankins, 2004).

This article was structured in five sections, being: introduction, literature review, methodological procedures, results and discussion, and final considerations.

2 LITERATURE REVIEW

This section proposes to present the precedents of innovation and the Brazilian SEB public policy of innovation, the Global Innovation Index (GII), the Innovation Intensity Index (III) in the world and Brazil, the degree of innovation maturity, and the technological readiness level (TRL) of an innovation program.

2.1 Precedents of Innovation

It is known that innovation is not a recent theme, since Schumpeter (1934) introduced the theme of innovation in the world of science and business when he created the concept of creative destruction. Innovation is divided into three types: a) incremental innovation; b)

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creative innovation; and c) disruptive innovation (OCDE, 2006; OECD/Eurostat, 2018). The first two types were developed by Schumpeter (1934), while the third, disruptive innovation, derives from the second and is used on a large scale today, due to its potential to transform technology, a product or service, in a simple, convenient, accessible and low-cost way (Christensen, 1997; Marques, Dias, & Vianna, 2020).

2.2 Public policies

A Public policy has the function of addressing a public problem and it contains two fundamental elements: a) intentionality and b) response to the public problem. Thus, the motivation to create and implement a public policy is the treatment or resolution of a collective and relevant problem (Marques, 2022; Secchi, 2019).

Given this concept, it is observed that the public policy of innovation of the electricity sector (SEB), in this case, the RD&I program of the SEB, is properly framed in the description of lines "a" and "b". The need to innovate made the Brazilian legislators inspired to manifest the intention to attack a problem that affects the whole society. And in 2000, with the advent of Law No. 9,991/2000, which instituted the CT-Energe, they paved the road for the creation and implementation of the SEB's public policy for innovation (RD&I of the SEB), materialized by the R&D and EE programs, both regulated by ANEEL, as per Brasil (2000) e ANEEL (2020), object of this study.

2.3 Global Innovation Index

Before evaluating a public policy, it is necessary to know and understand the global scenario of innovation and the positioning of the country that hosts the public policy under evaluation, to understand the context in which it is inserted. It was in this context that the study sought to understand the Global Innovation Index (GII), developed jointly by Johnson Cornell University, World Intellectual Property Organization (WIPO), and The Business School for the World (INSEAD), in 2007 (Amon-Há, de Arruda, Bezerra, & Leitão, 2019).

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
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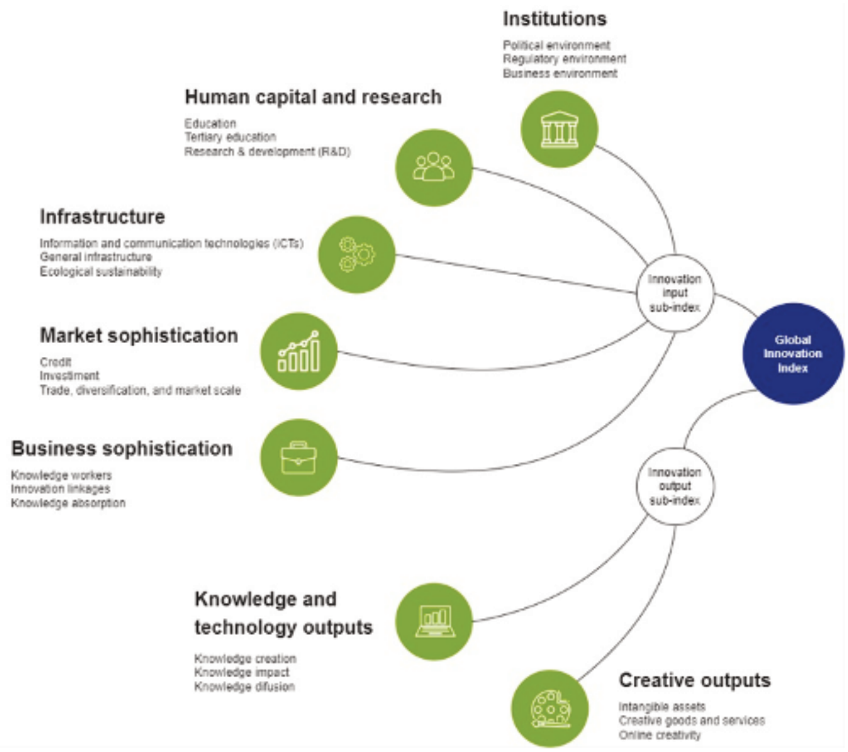
Understanding the structure of the GII construction is fundamental to understanding the results of this index so that public policies can be designed for innovation that generates results in favor of society. The GII is composed of Inputs and Outputs dimensions, which are divided as follows, according to CNI, WIPO, & OMPI (2020):

a) innovation inputs: i) institutions; ii) human capital and research; iii) infrastructure; iv) market sophistication; v) business sophistication; and,

b) innovation outputs: i) knowledge and technology products; ii) creative products.

Figure 1 shows how these dimensions operate within an ecosystem, and how they generate inputs for GII and IEI assessment, according to (CNI et al., 2020).

Figure 1: Schematic structure of the Global Innovation Index



Source: elaborated by the authors (WIPO, 2021).

2.2.1 Innovation Efficiency Index (IEI)

The IEI is a consequence of how the country manages its innovation inputs, investing in the structuring of strong institutions, in the training of human capital, researchers, and infrastructure (schools and laboratories), and in the sophistication of efficient and effective organizational processes, which are fundamental to raise the quality of the innovation inputs (CNI et al., 2020).

From good management of innovation inputs, there are innovation outputs, which are the results of the inputs, translated into knowledge products, new technologies, and creative products. The IEI is the ratio between innovation outputs and innovation inputs (CNI et al., 2020).

2.2.1 Innovation Intensity Index

The Innovation Intensity Index (III) is an indicator that measures investments in innovation, called R&D intensity or Innovation Intensity, calculated by the 2017 EU Industrial R&D Investment Scoreboard published by the Industrial Research and Innovation Monitoring and Analysis (IRIMA), which publishes a ranking of 2,500 companies, based around the world, with the innovation intensity index (European Union, 2017). This index indicates the percentage that represents the organization's investment in innovation concerning its Net Operating Income (NOI).

In Brazil, IBGE's Industrial Survey of Technological Innovation (PINTEC) has advanced the Innovation Intensity Index or RD&I Expenditure survey and published results in 2011, then in the following two trienniums: 2012-2014 and 2015-2017. The results were by sectors of the economy, using the same metric as the European Union (EU) (2017), that is investment in innovation, concerning its NOI, as a percentage result (IBGE, 2020; PINTEC, 2017).

2.2.1 Innovation maturity and technology readiness level

The evolution of an innovation ecosystem should be evaluated so that the actors have a vision of the results that can be expected. For

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

this, two techniques were decided upon: i) innovation maturity assessment of a program or ecosystem; and ii) technology readiness level estimation of an innovation program, using the TRL scale.

2.2.4 Innovation maturity assessment

The evaluation of the degree of maturity of an innovation ecosystem is fundamental to guide the decision-making process of the actors involved, concerning the future of innovation. A public or private organization that wants to innovate must look systemically at a set of dimensions. Most studies work with six dimensions and others go up to 12 dimensions, and they usually demonstrate the degree in a radar chart, which allows the view of all dimensions in the same plan (Bosma et al., 2020; Cunha, Carvalho, & Bartone, 2015).

Six dimensions were defined to evaluate the maturity level, varying on a scale from 1 to 5: i) innovation environment; ii) programs and actions; iii) ST&I environment; iv) public policies; v) financing; and vi) governance.

2.2.5 Estimating the level of technological readiness: TRL scale

The estimation of the Technology Readiness Level (TRL) or Manufacturing Readiness Levels (MRL) of a product, process, or service, is a methodology proposed by Mankins (2004) and is employed in the private and public sector, as is the case with VINNOVA, the Innovation Agency of Sweden, one of the most innovative countries in the world for decades (Gurgel Veras, 2021).

The TRL/MRL scale ranges from 1 to 9 and can be grouped into 6 or 3 dimensions, depending on the interest of who is using it, as shown in Table 1.

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

Table 1: Technology Readiness Level: TRL/MRL Scale

LEVEL	DESCRIPTION OF THE TECHNOLOGICAL READINESS LEVEL
TRL/MRL 1	Research ideas are being initiated and these early indications of feasibility are being translated into further research and development.
TRL/MRL 2	The basic principles have been defined and there are results with practical applications that point to the confirmation of the initial idea.
TRL/MRL 3	In general, analytical and/or laboratory studies are needed at this level to see if a technology is viable and ready to proceed to the development process. In this case, a proof-of-concept model is often built.
TRL/MRL 4	The proof of concept is put into practice, consisting of its application in an environment similar to the real one, which can be laboratory-scale tests.
TRL/MRL 5	The technology must undergo more rigorous testing than technology that is only at TRL 4, i.e. validation in a relevant component environment or experimental arrangements, with final physical configurations. Ability to produce a prototype of the product component.
TRL/MRL 6	The technology constitutes a fully functional prototype or representational model and is demonstrated in an operational environment (relevant environment in the case of key enabling technologies).
TRL/MRL 7	The prototype is demonstrated and validated in an operational environment (relevant environment in the case of key enabling technologies).
TRL/MRL 8	The technology has been tested and qualified for the real-world environment and is ready to be implemented in an existing system or technology.
TRL/MRL 9	The technology is proven in an operational environment (competitive manufacturing in the case of key enabling technologies), as it has already been tested, validated, and proven under all conditions, with its use in its full range and quantity. Established manufacturing.

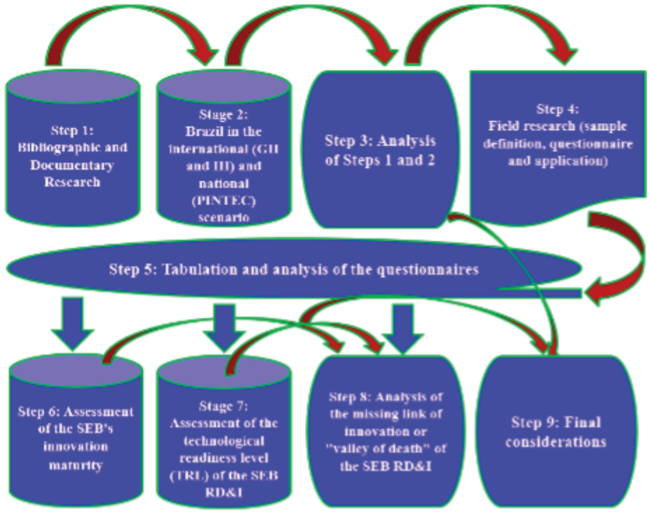
Source: Diniz (2021), adapted by the authors.

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

3 METHODOLOGICAL PROCEDURES

The methodological procedures used in this article are qualitative and exploratory in nature and seek to adopt mixed methods, combining bibliographic, documentary, and field research, to survey a group of people composed of RD&I managers, researchers, and employees of the RD&I in the Brazilian electricity sector (SEB) (Da Costa, Ramos, & Pedron, 2019). The structure of the method is represented in Figure 2 below.

Figure 2: Graphic representation of the method



Source: elaborated by the authors.

In the first stage, scientific articles and technical reports dealing with entrepreneurship and innovation were selected, with a focus on innovation ecosystem development according to (Marques et al., 2020).

In step two, a survey of WIPO's General Innovation Index (GII) publications was conducted (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021), which conducts a global survey and publishes the GII per country, annually. Next, a publication from the European Union was identified, called European Union (EU) (2017), with an Innovation Intensity Index (III) ranking of 2,500 companies worldwide. In the GII ranking, it was verified Brazil's position in the ranking from 2011 to 2021, in the group of Top 10 countries in the world, Top 5 in Latin America and the Caribbean, as well as the ranking in the BRICS group.

In the III ranking, companies in the electricity sector that disclose their innovation intensity were identified, to compare with Brazilian companies and the index calculated by IBGE (2017, 2020), by business segments, with an emphasis on the Brazilian electrical sector.

The third step comprises an analysis of the indicators of the global innovation index and the innovation intensity index both globally and locally. The analysis goes through the dismemberment of the indicators of innovation inputs and innovation outputs, to understand the innovation efficiency index and compare with BRICS countries, based on WIPO data (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021).

In the fourth stage, the planning and execution of the field research were developed, involving the following actions: a) definition of the sample: the mailing from ANEEL contained 453 R&D managers, excluding 246 repeated names (people that represented one or more companies), which resulted in 207 R&D managers. When making the contact confirmation test, 67 did not respond, so they were excluded, leaving a total of 140 active contacts, which was defined as the target population of the research; b) as it is a small population with a certain difficulty of access, we chose sampling by judgment, since the target audience is grouped around the theme of the research (Stevenson, 1981); c) In the first round of the digital questionnaire, 32 answers were received, which corresponds to 22.86% of the population, close to the average for this resource, which is around 25.00%, according to (Vieira, Castro, & Shuch Junior, 2010); d) even though there was no obligation to reach a percentage of the population, a search was conducted through the professional relationship platform LinkedIn, identifying professionals (researchers, R&D collaborators linked to the R&D managers surveyed, and public managers linked to the program), inviting them to answer the survey, and with this, 48 questionnaires were answered. It should be noted that the idealization of the questionnaire took into account a combination of dimensions used to assess the maturity of innovation ecosystems advocated by different specialists (Fundação CERTI, 2021; Isidro, 2020; Montezano & Isidro, 2020; Isenberg, 2010).

In the fifth step, the data was tabulated and grouped by dimensions in a table to generate different types of analysis (mainly two), the focus of this study: assessment of the degree of innovation maturity of the SEB and assessment of the technological readiness level of the SEB, by the TRL scale (Fundação CERTI, 2021; Gurgel Veras, 2021; Mankins, 2004).

In step six, we proceeded to analyze the maturity level of innovation in the SEB, based on the answers to the questionnaire, grouping the answers into six dimensions: a) innovation environment; b) programs and actions; c) ST&I environment; d) public policies; e) financing; and f) governance. The dimensions were presented in a radar chart, to provide a dimensional view of the innovation ecosystem of the SEB (Fundação CERTI, 2021).

In the seventh stage, the focus was to estimate the technological readiness level (TRL) of the RD&I of the SEB, elaborating the classification in TRL levels, ranging from 1 to 9, divided into six dimensions: i) Basic research of the technology; ii) Research to prove feasibility; iii) Technology under development; iv) Technological demonstration; v) Process development (system); vi) Product or service testing, operation and launch on a commercial scale (Gurgel Veras, 2021; Mankins, 2004).

In step eight, the current stage of the SEB's RD&I was analyzed, regarding the concept of the missing link of innovation or the valley of death of innovation, using the TRL level of technological readiness of innovation of Mankins (2004), the innovation resource requirement curve of ABGi Brasil (2022) and the supply of resources in RD&I.

The results of each of these eight steps have been presented in detail in the results and discussion section below.

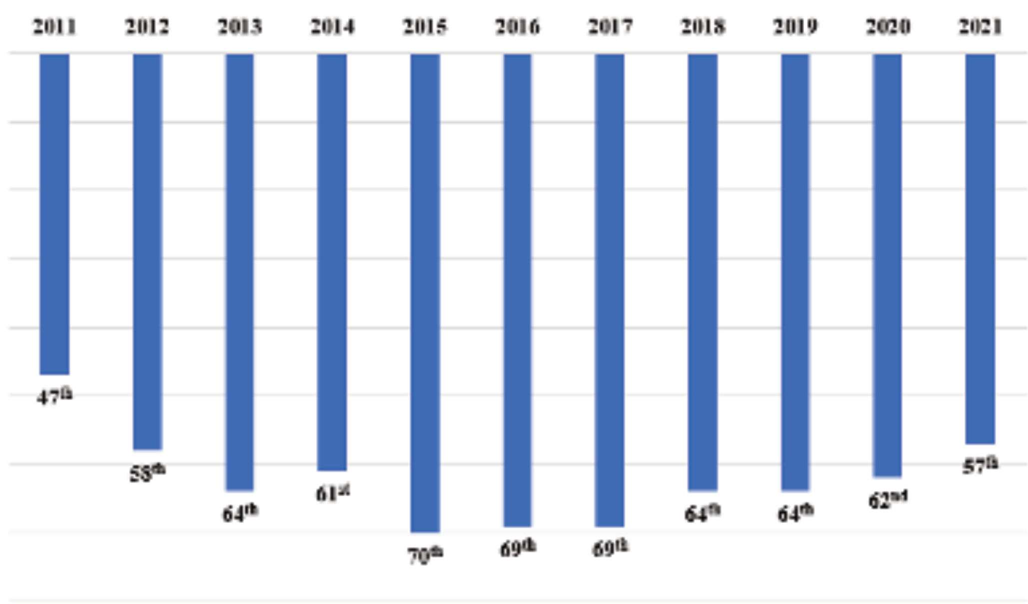
4 RESULTS AND DISCUSSION

This section presents the results obtained by Brazil, regarding the theme innovation, which are published by the World Intellectual Property Organization (WIPO), from an analysis of the Global Innovation Index (GII) and its developments. Next, are the results of the Industrial Survey of Technological Innovation (PINTEC) conducted by the Brazilian Institute of Geography and Statistics (IBGE), highlighting the results of the electricity sector, the focus of this study. Finally, the results of the evaluation of the RD&I maturity stage of the Brazilian electric sector (SEB) are presented (Amon-Há et al., 2019; CNI et al., 2020; IBGE, 2017, 2020; WIPO, 2019, 2021).

4.1 Brazil in the global innovation ranking: GII from 2011 to 2021

In the last decade, Brazil has had bad results in the GII assessment, starting the cycle in 2011 in the 47th position of the global ranking, which was uncomfortable for a nation that was between the 7th and 8th economy in the world. At last, what was already bad became worse over time, as in 2015 it reached 70th place, closing 2021 in 57th place in the ranking (among 132 countries), 10 positions behind the result obtained in 2011, according to data from (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021). Figure 3 presents the evolution of Brazil in the GII from 2011 to 2021.

Figure 3: Evolution of Brazil's position in the global innovation index (GII) - 2011 to 2021 (0-100) (Ranking of 132 countries)



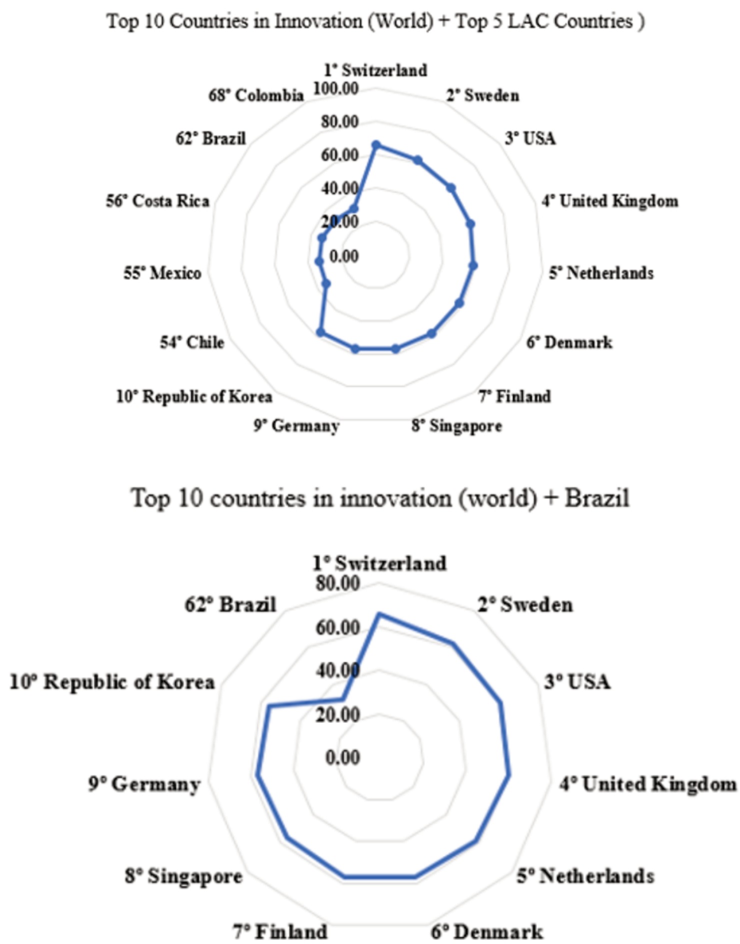
Source: elaborated by the authors (WIPO, 2018; 2019; 2020; 2021)

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

In 2020, when Brazil ranked 62nd in the GII ranking when compared to the countries listed as Top 10 in the GII, one finds its fragility. It obtained 31.94 points and ranked 62nd, against 56.11 points of the Republic of Korea in 10th place and 66.08 points of Switzerland the number 1 in the ranking that year, according to Figure 4 (left side) (CNI et al., 2020; WIPO, 2019, 2021).

On the right side of Figure 4, Brazil is in the Top 5 list, ranking 4th among Latin American and Caribbean countries (LAC) and 62nd in the world. Chile ranks 1st in LAC (54th in the world), Mexico 2nd in LAC (55th in the world), Costa Rica 3rd in LAC (56th in the world), and Colombia 5th in LAC (68th in the world). Therefore, even excluding the North American countries (the USA and Canada), Brazil still ranks fourth in the LAC region (CNI et al., 2020; WIPO, 2019, 2021)

Figure 4: Global Innovation Index (GII) - 2020 ranking (0-100)



Source: elaborated by the authors (WIPO, 2018; 2019; 2020; 2021)

It should be noted that in 2020, the American continent had only one country in the Top 10 list, which was the USA with 60.56 points, on a scale of zero to one hundred, where the first place was Switzerland with 66.08 points (CNI et al., 2020).

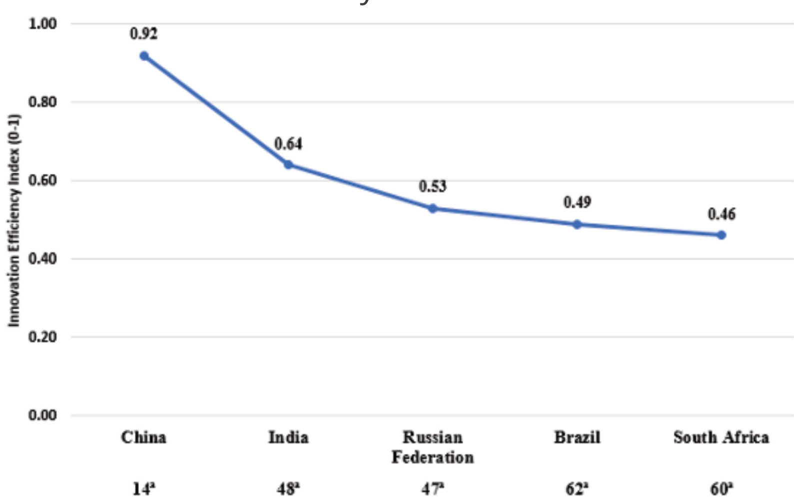
Thus, it can be observed that Brazil's situation in the GII ranking, both globally and regionally (LAC) is well below the potential of its economy in terms of GDP and export volume.

After analyzing the situation of innovation in Brazil, the world, the American continent, and especially in a regional stratum in LAC, next, it was verified the country's situation in the group of nations composed of Brazil, Russia, India, China, and South Africa, called BRICS, which are ranked 62nd, 47th, 48th, 14th, and 60th in the GII ranking, respectively. Even in a bloc of five countries, Brazil is in 5th and last place (as is the case of the BRICS) (CNI et al., 2020).

Considering that the BRICS countries are not well placed in the GII ranking, except for China, this study sought to analyze another very important indicator in the process of innovation management, whose function is to measure the efficiency of spending on innovation in a country, called the innovation efficiency index, as shown in Figure 5.

In this regard, the ranking in the BRICS is as follows: China, in 1st place with an index of 0.92; India, in 2nd place with an index of 0.64; Russian Federation, in 3rd place with an index of 0.53; Brazil, in 4th place with an index of 0.49; and South Africa, in 5th place with an index of 0.46 (CNI et al., 2020; WIPO, 2021).

Figure 5: Innovation efficiency index of the BRICS countries (0-1) - in 2020



Source: elaborated by the authors (WIPO, 2020)

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

Another point to highlight in the innovation efficiency index in BRICS countries is the big difference between China and the other countries since it shows that Chinese investment is efficient (0.92 out of 1.00), India and Russian Federation operate at 0.64 and 0.53 out of 1.00, respectively. While Brazil and South Africa have an efficiency index below 0.50 (0.49 and 0.46 out of 1.00), which indicates that these two countries have work to be implemented that can generate improvement in the innovation efficiency index (CNI et al., 2020; WIPO, 2021).

4.2 Innovation in Brazil: a look from the GII inputs

To better understand the results of innovation in Brazil, it is necessary to stratify the composition of the general innovation index (GII). Following this line, this article sought to analyze the components of the GII, which are:

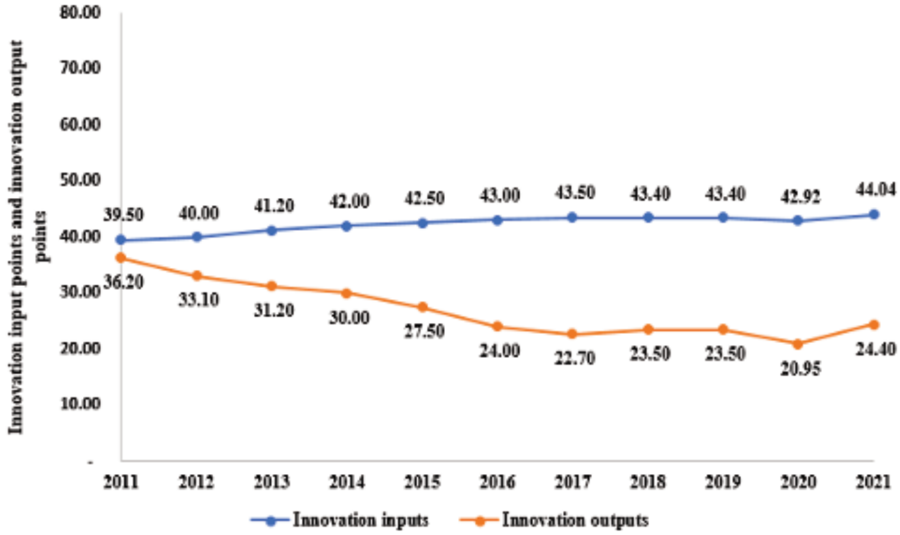
a) innovation inputs: i) institutions; ii) human capital and research; iii) infrastructure; iv) market sophistication; and iv) business sophistication;

b) innovation outputs: i) knowledge and technology products; and ii) creative products.

Figure 6 shows the score of each of the components that generate the innovation efficiency index of a country, which in this case is Brazil. The innovation inputs, which are the inputs of the innovation process, recorded 39.50 points in 2011 and 44.04 points in 2021, therefore they grew by 4.54 points an 11.49% growth rate in a decade. Innovation products or outputs of the innovation process that were 36.20 points in 2011, reached 2021 with 24.40, decreasing 11.80 points or -32.60% over ten years . (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021).

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

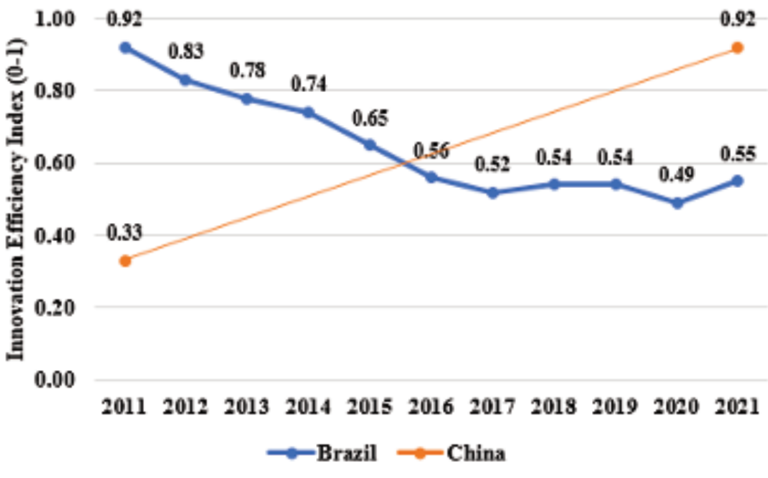
Figure 6: Evolution of Brazil's score in innovation inputs and innovation outputs - 2011 to 2021



Source: elaborated by the authors (WIPO, 2108; 2019; 2020; 2021)

This combination of results - innovation inputs with a low growth rate (11.49%) over ten years, accompanied by decreasing results of innovation outputs, with a negative rate of 32.60% over the same decade, led Brazil to account for a strong loss of efficiency in RD&I investments. The country had an innovation efficiency index of 0.92 in 2011, reached the floor of 0.52 in 2017, and in 2021 reached 0.55, on a scale ranging from 0.00 to 1.00 (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021), as shown in Figure 7.

Figure 7: Evolution of Brazil's innovation efficiency index - from 2011 to 2021



Source: elaborated by the authors (WIPO, 2108; 2019; 2020; 2021)

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

This analysis shows that Brazil goes in the opposite way of China, which is the leading country in innovation in the BRICS and one of the countries that has most evolved in the GII in the last decade. China had an innovation efficiency index of 0.33 in 2011 and reached 0.92 in 2021, demonstrating an evolution in the percentage of 178.79% (Amon-Há et al., 2019; CNI et al., 2020; WIPO, 2019, 2021). China has a high capacity to generate innovative products from its inputs (in 1.0 point of possible efficiency index, the set of innovation inputs generates 0.92 innovative products, losing only 0.08). Brazil's result is very different, since, for each 1.0 point of possible efficiency index, the set of innovation inputs generates only 0.55 of innovative products, losing around 0.45, that is, it invests to obtain one unit and achieves only half a unit, approximately.

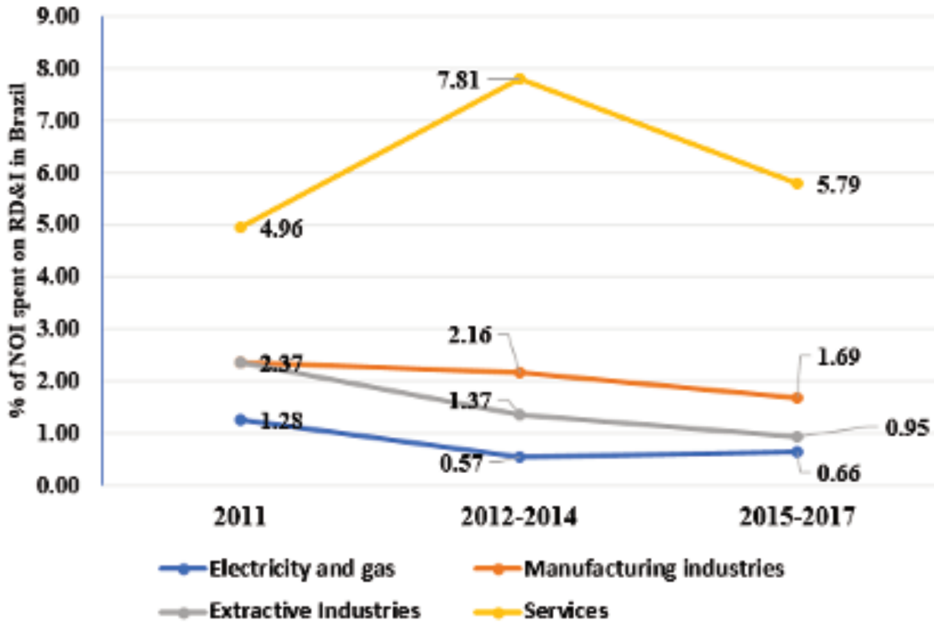
4.3 Expenditure with RD&I by sector of the economy in Brazil - as % of NOI

After finding Brazil occupies an uncomfortable position in the GII ranking, both globally, in the BRICS, and regionally, this research was faced with a dilemma: does Brazil invest little in innovation and therefore reap poor results, or are the poor results in innovative products in Brazil due to low investments in innovation? To face this questioning, this study delved deeper into the search for data that contribute to solving the dilemma in question.

Figure 8 shows the evolution of investments in innovation in Brazil, measured as the percentage of companies' Net Operating Income (NOI) that is spent on innovation, according to data from the Innovation Survey (PINTEC) conducted by the IBGE. Thus, the intensity index of spending on innovation by sector in Brazil in 2011, 2012-2014, and 2015-2017 were: a) electricity and gas: which in 2011 was 1.28, from 2012-2014 fell to 0.57, and in 2015-2017 cycle increased to 0.66; b) services: registered an index of 4.96 in 2011, increased to 7.81 from 2012-2014 and, reduced to 5.79 from 2015-2017 (IBGE, 2017, 2020; PINTEC, 2017).

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

Figure 8: Evolution of RD&I expenses in Brazil - from 2011 to 2017



Source: elaborated by the authors (IBGE/PINTEC 2017, 2020)

Traditional sectors such as extractive industries and manufacturing industries present higher rates than the electricity and gas sector, which leads to indications that the electricity sector has low levels of investment in innovative actions. This is one more reason why this study has adopted as its theme the public innovation policy of the SEB, implemented over 20 years ago and financed through a contribution paid by electricity consumers.

4.4 SEB's RD&I and innovation management best practices

Among the good practices of innovation in the world, there is the rate of spending on innovation as a percentage of GDP that is measured by country, conducted by WIPO. Another important indicator is the rate of investment in innovation made per company and usually grouped by sector, as recommended by the Oslo Manual of the Organization for Economic Cooperation and Development (OECD), which conducts the study globally (OECD/Eurostat, 2018). In Brazil, this survey is carried out by the IBGE and is called PINTEC, which evaluates the investments in innovation, by business segments, as a percentage of the Net Operational Revenue (ROI) (IBGE, 2017, 2020; WIPO, 2021).

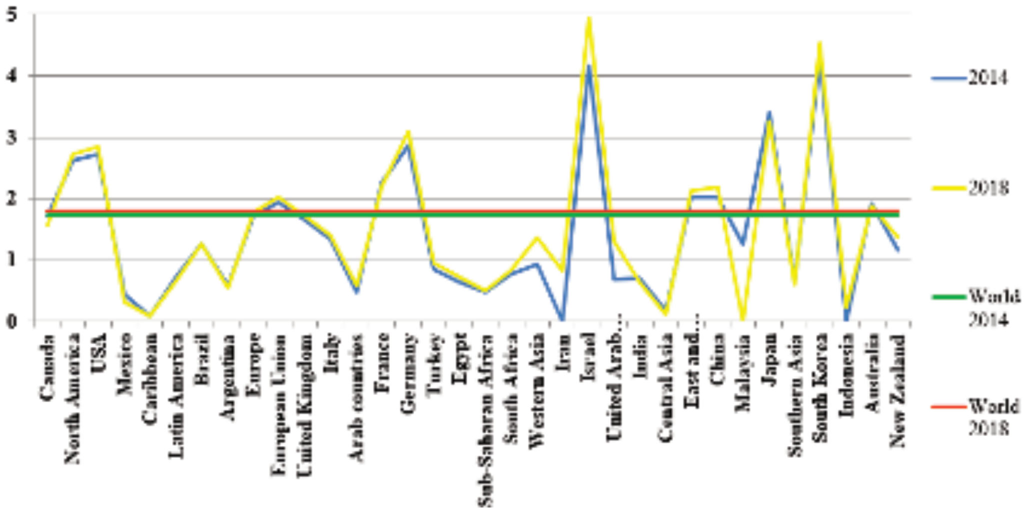
4.4.1 Brazil in relation to the world scenario regarding innovation expenditures (in % of GDP)

The best practices in innovation management go through comparisons that should follow the GII ranking. A reference that should be compared is the spending on RD&I per country since investment in innovation is the main input to generate innovation outputs. In this aspect, it was found that Brazil accounted for spending on innovation the amount of 1.27% of GDP in 2014 and, 1.26% in 2018, whereas in the U.S., in the same period, the spending was 2.72% and 2.84%, while in the European Union spending was 1.94% and 2.02%, with a highlight for Germany that invested 2.87% and 3.09%. The Asian countries have strong investments, both in 2014 and 2018, being: Israel: 4.17% and 4.95%; South Korea: 4.29% and 4.53%, Japan: 3.40% and 3.26% and China: 2.03% and 2.19%. In this small sample, Brazil appears in last place when the subject is the percentage that each country spends on innovation to its GDP (UNESCODOC, 2021).

The average innovation spending in the world in 2014 and 2018 was 1.73 and 1.79, respectively, showing that there was a small growth in spending in 2018 when compared to 2014 (UNESCODOC, 2021).

Figure 9 presents the behavior of countries and regions' innovation spending, as a percentage of the country or region's GDP, compared to the world average, for the years 2014 and 2018 (UNESCODOC, 2021).

Figure 9: Innovation investment spending by country and region in % of GDP



Source: elaborated by the authors (UNESCO, 2021).

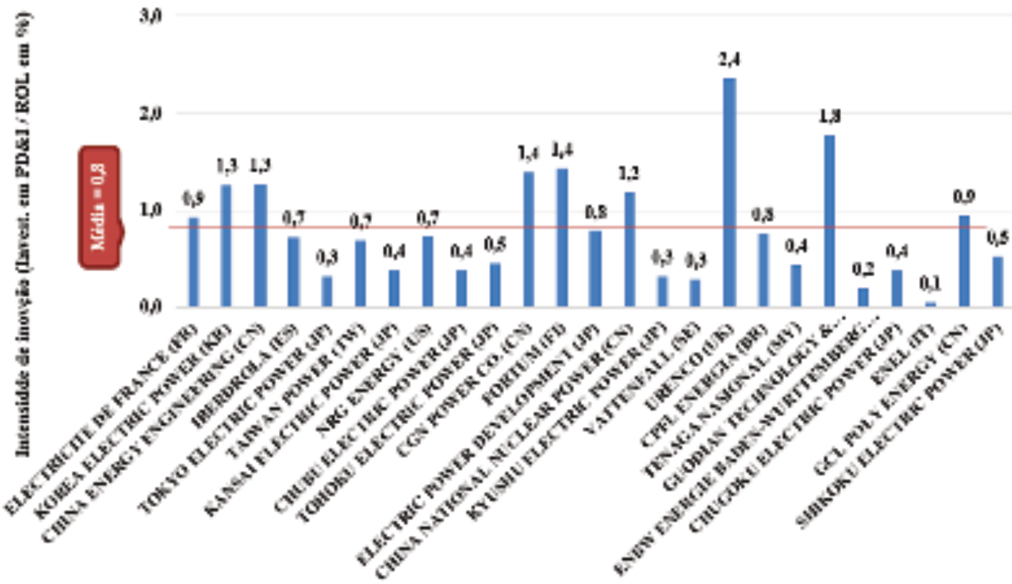
Brazil once again not only failed to follow the world trend of growth in investments in innovation as the leading nations, but also recorded an investment rate below the global average, which in theory would be unimaginable for a nation that ranks among the largest economies in the world.

4.4.2 Spending on innovation in the electricity sector: Brazil versus the world

An IBGE/PINTEC study, conducted in the trienniums 2009-2011, 2012-2014, and 2015-2017, by sampling, evaluated four major sectors of the Brazilian economy (electricity and gas, manufacturing, extractive industries, and services). As the focus of this study is the SEB, only the data of investments in innovation in the electricity and gas sector will be highlighted here, as a percentage of the ROI. They are: in the triennium 2009-2011 the rate was 1.28%, in 2012-2014 it was 0.57% and in 2015-2015 it reached 0.66%, despite having grown again, it is around half of what was recorded between 2009-2011 (IBGE, 2017, 2020; PINTEC, 2017).

There is another indicator that measures investments in innovation, called R&D intensity or Innovation Intensity performed by the 2017 EU Industrial R&D Investment Scoreboard published by Industrial Research and Innovation Monitoring and Analysis (IRIMA). It lists 9 Brazilian companies in a ranking of 2,500 companies, among which CPFL Energia (the only one in SEB), whose innovation intensity index reached 0.8% (European Union, 2017), as shown in Figure 10.

Figure 10: Innovation intensity of electricity companies in the world



Source: elaborated by the authors (European Union/Scoreboard, 2017)

Analyzing the ranking prepared by European Union/Scoreboard (2017), it was found that the only Brazilian company that appears (CPFL Energia) is in the average of the 25 companies, with an innovation intensity of 0.8% (European Union, 2017). Therefore, it is concluded that the average of the electricity sector in Brazil, whose rate of 0.7% according to the IBGE/PINTEC survey (2017; 2020), is close to the world average.

4.5 SEB's RD&I Innovation Maturity Level

An entrepreneurial and innovative ecosystem has essential elements for it to develop and create value for society, according to Isenberg (2010), and this is what RD&I should generate for the Brazilians who have been funding the program for more than 20 years.

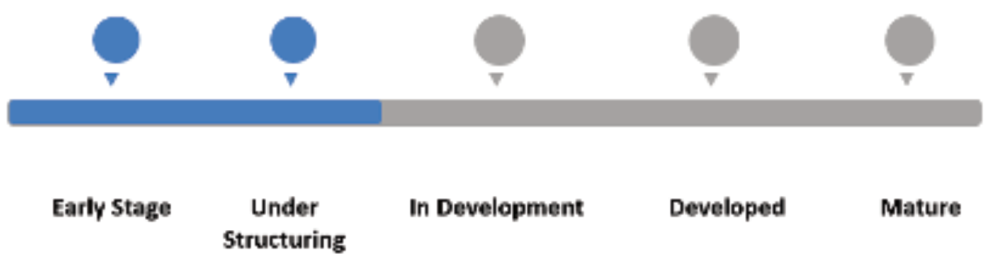
One of the ways to evaluate the performance of an innovation program is to check how mature it is.

Therefore, this work presents the results of this evaluation, which studied the elements that make up the RD&I of SEB, dividing it into six dimensions: a) innovation environment; b) programs and actions; c) ST&I environment; d) public policies; e) financing; and f) governance. It is observed that these dimensions are aligned with the essential needs for the development of an entrepreneurial and innovative ecosystem that follows the principle of the Quadruple Helix, formed by: academia, government, organizations, and civil society (Fundação CERTI, 2021; Cukierman et al., 2019; Mazzucato, 2014; Isenberg, 2010).

These six dimensions were evaluated to identify the maturity level of the SEB's RD&I, on a scale of one to five. This measure aims to indicate how the program is organized around the development of an innovation ecosystem, and whether it can provide actions to stimulate innovation, to transform ideas into innovative products, generating growth and improved competitiveness in the market, resulting in benefits to society.

This scale of one to five indicates that the innovation program is in: a) grade 1: early stage; b) grade 2: in the structuring phase; c) grade 3: in development; d) grade 4: developed (on the way to maturity); 5) mature. See Figure 11.

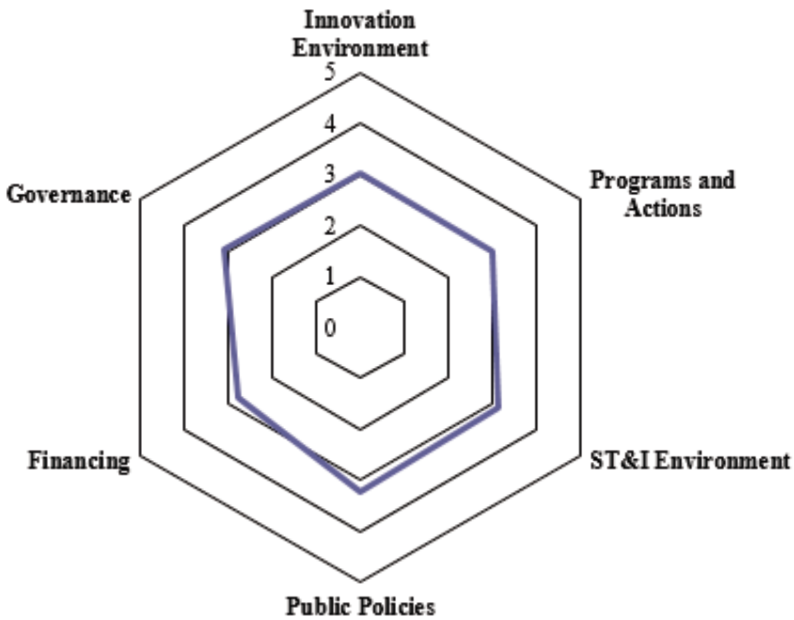
Figure 11: SEB's RD&I innovation maturity level



Source: adapted by the authors (CERTI, 2021).

According to the results of this study, the RD&I of the SEB reached maturity grade 3, indicating that the program is in a stage of development, which seems little for a public policy implemented more than 20 years ago. See the result in Figure 12.

Figure 12: SEB's RD&I innovation maturity degree: innovation radar in the SEB



Source: elaborated by the authors.

Analyzing Figure 12 - innovation radar in the SEB, it can be seen that the dimensions: innovation environment, programs and actions, and governance received similar scores, approximately 3. The dimensions: STI&I environment and public policies received scores slightly higher than 3, which should be seen as important since they are dimensions that drive the innovation process. The financing dimension got a score below three, which in a way is worrisome since it supports the innovation process.

A factor that weighed heavily in the low evaluation of the financing dimension is the fact that 66.67% of those surveyed answered that their company does not allocate its resources for SEB RD&I. This indicates that SEB companies are going against what is recommended by Mazzucato (2014) - actions around innovation should have the

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

presence of the state and the private sector as investors.

Another important issue that impacted the financing dimension is the fact that companies do not seek support for innovation from the National Fund for Scientific and Technological Development (FNDCT). Whether through the Financier of Studies and Projects (FINEP) or the Brazilian Company for Corporate Research and Innovation (EMBRAPII) or even the National Bank for Economic and Social Development (BNDES), which has low-cost financing to support innovation projects in organizations.

4.6 Assessing the level of technological readiness in the SEB

The low degree of maturity of the RD&I of the SEB may be associated with the fact that only half of the professionals who answered this research informed that they evaluate the projects using the TRL/MRL scale. It is known that one of the ways to improve the level of innovation efficiency is to use a methodology to evaluate the technological maturity degree of the sector, which can be applied to projects, products, and materials developed in the innovation ecosystem under analysis.

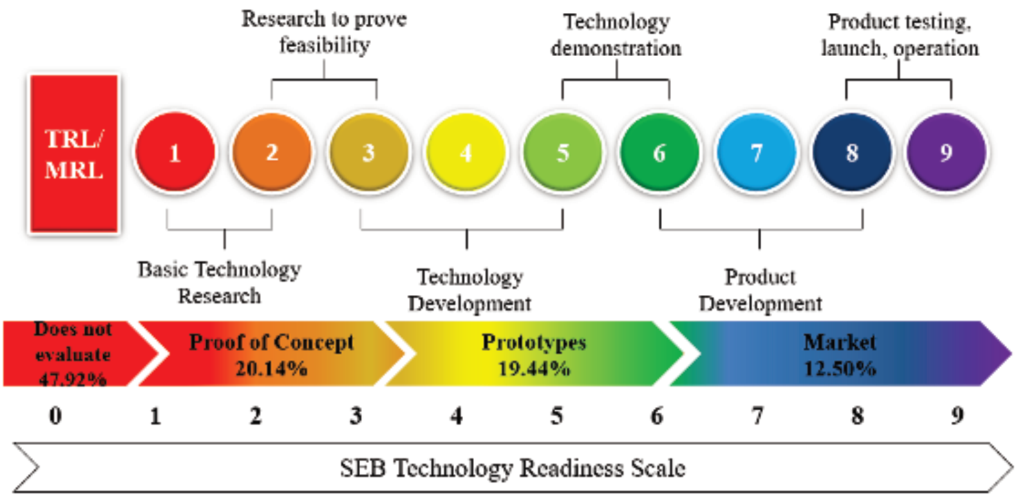
A methodology that is generally used in sectors that employ high technology such as aerospace, warfare, nuclear, energy sector, including electrical, and by space agencies around the world, from an experience of the National Aeronautics and Space Administration (NASA) is the Technology Readiness Level (TRL) or Manufacturing Readiness Levels (MRL) of a product or process. This methodology was proposed by Mankins (2004) and is employed in the private sector and the public sector, as is the case with VINNOVA, the Innovation Agency of Sweden, one of the most innovative countries in the world for decades (Gurgel Veras, 2021; FAPESP, 2019).

In Figure 13, it is possible to check the scale to evaluate the level of technological maturity of the SEB, from the TRL/MRL scale in the survey conducted with the R&D managers and researchers of the SEB companies, and the public managers of the SEB. The results are as follows: 47.92% answered that their company does not evaluate

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

technological readiness; 20.14% confirmed that the projects are evaluated in the first stage, up to the proof of concept; 19.44% reach the prototype and only 12.50% go to the final stage, which is the market.

Figure 13: Technology readiness scale in the SEB: TRL/MRL scale



Source: elaborated by the authors.

The result of this research is worrying, to say the least, since approximately 50% does not evaluate the level of technological maturity, which implies that half of the RD&I projects of the SEB do not know the potential of the research to generate an innovative product. On the other hand, only 12.50% of the projects are evaluated on a TRL/MRL technological readiness scale up to the level of reaching the market.

When it comes to a program that invests around R$ 550 million per year, another possible inference is that 87.50% (100.00% - 12.50%) or R$ 480 million, approximately, might be being allocated to projects with little chance of success. The lack of evaluation affects the quality of innovation projects, generating results lower than potentially projected, thus causing the country's innovation efficiency index to fall.

4.7 SEB's RD&I and the missing link of innovation

Over more than two decades, RD&I has brought important gains to the SEB, especially in the Energy Efficiency Program (EEP), in terms of saved energy, off-peak demand, avoided investment in power generation, conserved energy, and reduced socio-environmental impact throughout the system that involves Generation, Transmission, and Distribution (GTD) (Marques et al., 2021).

However, the current analysis focuses on the Research and Development (R&D) program, based on the results obtained in the evaluation of the maturity of innovation and the evaluation of the technological readiness level of the RD&I of SEB. In the evaluation of the maturity degree, the RD&I of SEB received a score of 3.03 (the maximum score is 5.00), which gives it a grade of 3 and places it as a program under development, despite having more than two decades of existence. The assessment of the level of technological maturity, using the TRL/MRL technology readiness scale, identified that approximately 48.0% of the projects do not go through the technological readiness assessment, and just over 10.0% are assessed on the TRL/MRL scale, at levels 7, 8 and 9.

These distortions set off a warning signal, regarding the purposes of SEB's RD&I to generate benefits for society: one of them is the objective of tariff moderation pursued by the regulator of the Brazilian electricity sector which is ANEEL. See the development flow of an RD&I project of the SEB: how the project receives funding, what is the demand for resources of the RD&I projects and how this should occur to avoid the missing link of innovation or valley of death.

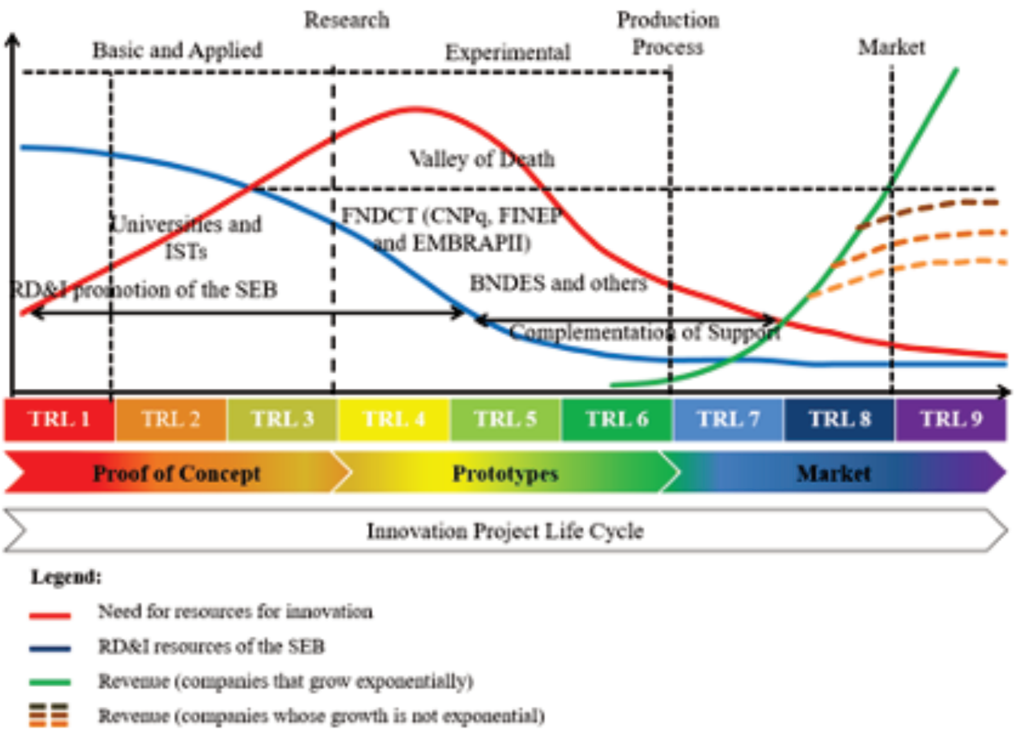
The fact that the innovation program is at grade 3, in a development phase, highlights the need for adjustments that involve all dimensions since all six were evaluated around grade 3. When it reaches grade 5 it becomes a mature innovation ecosystem, forming a nationwide network, with great potential for open innovation, generating startups and innovative and impactful businesses in the SEB (Mazzucato, 2014; Isenberg, 2010).

The non-evaluation of projects on the technological readiness scale (TRL/MRL) allows the entry of projects that are interesting, but that do not represent technological innovation or technological solutions for the market. One result of not evaluating is the fact that practically 90.0% do not reach the final phases TRL 7, 8, and 9, which correspond to technology validation, production process, and market insertion (ABGi Brasil, 2022; Gurgel Veras, 2021; Mankins, 2004; U.S. DOE, 2008).

In Figure 14, it is possible to observe the RD&I project resource need curve, over time and distributed in phases of project development (ABGi Brasil, 2022). It is also possible to observe how the SEB's RD&I resources have been used.

By analyzing Figure 14, one can see that there is a surplus of resources in the initial phases, but then there is a lack of resources in the intermediate phases, and at this point when they run out, the projects are abandoned. It is necessary to have fomentation so that the projects enter the final phases in conditions to raise resources in the market to finance their operations in search of scale gain and even exponential growth.

Figure 14: SEB RD&I project life cycle: from basic research to market



Source: elaborated by the authors.

It can be noticed that there is a mismatch between supply and demand for resources, and this occurs more severely in the second moment, possibly leading the vast majority of projects to the lost link of innovation, better known as the valley of death.

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

5 FINAL CONSIDERATIONS

This study analyzed Brazil's positioning in the Global Innovation Index (GII), evaluated the innovation maturity of RD&I in the Brazilian electricity sector (SEB), and generated the following contributions:

The first identified that Brazil had a low performance in the global GII ranking in the last decade, as it was in the 47th position in 2011, in 2015 it reached the 70th and in 2021 it was in the 57th position. In the regional ranking (Latin America and the Caribbean), it ranks 4th, behind Chile, Mexico, and Costa Rica. When the comparison is made among the BRICS countries, Brazil ranks last among the five components.

After noting these uncomfortable positions for an economy the size of Brazil's, the second contribution of this study was to investigate another indicator to seek other answers. That is when the concern increased since Brazil has been facing a decline in the innovation efficiency index (IEI) (which ranges from "0" to "1") since in 2011, Brazil's index was 0.92 and in 2021 it reached 0.55. Compared within the BRICS, the Chinese index in 2011 was 0.33, arrived in 2021 with 0.92 - the reverse of Brazil in an indicator that measures how well or poorly the country spends its resources on innovation.

Third, Brazil's poor results in the IEI led to further study in search of the causes that provoke low efficiency of innovation spending in a country. In Brazil in the period from 2011 to 2021, a low growth was identified in the score of innovation inputs (Institutions, Human Capital and Research, Infrastructure, Market Sophistication, and Business Sophistication). In 2011 the score obtained was 39.50, arriving in 2021 with 44.04 points, while for the innovation products (Knowledge and Technology Products and Creative Products) the score in 2011 was 36.20, but in 2021 it reached 24.40 points, that is, the indicator is falling (item 5.4.2). The result of innovation inputs and outputs brings a very bad combination, as the former grew by only 4.54 points and the latter decreased by 11.80 points, distancing from innovation inputs. Since IEI is the ratio of Innovation Outputs to Innovation Inputs, therefore, the decrease of Outputs relative to Inputs increases the inefficiency of innovation.

The fourth contribution of this study was to present the results of

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

the PINTEC/IBGE innovation survey. It was conducted in the period between 2011 and 2017, where spending on innovation in Brazil accounted for a drop in three sectors of the economy (Electricity and Gas, Manufacturing Industry and Extractive Industry) and only one sector showed growth in spending - which is the Services sector. The electricity and gas sector, an object of this study, spent in RD&I in 2011, 1.28% of its Net Operating Income (NOI), reduced to 0.57% between 2012 and 2014 and went back up in the triennium 2015-2017 when it recorded 0.66% of the NOI, approximately half of the 2009-2011 triennium.

Given these results presented so far, the study made a fifth contribution by benchmarking the expenditures of the countries that lead the global GII ranking. It was verified that the Brazilian investments that registered 1.26% of GDP represent something around 50% of countries like the USA and Germany and in the range of 1/3 of what Asian countries (South Korea, China, Japan, and Israel) contribute to RD&I. This leads to the conclusion that Brazil invests little and poorly, as indicated by the index and efficiency in innovation.

The sixth contribution of the study was to identify companies that operate in the electricity sector and, for this, it was used the ranking published by the European Union, called Scoreboard (2017). It was verified the presence of a Brazilian company from the Brazilian electricity sector (SEB), CPFL Energia, with an innovation intensity index equal to 0.8%, which corresponds exactly to the average index of the companies that are in that ranking, and above 0.7% the index of the sector in Brazil. Even so, the information does not make Brazil comfortable, because of a total of 25 companies, 10 are above the average, therefore ahead of Brazil, with some registering up to 3 times the Brazilian index.

Another result of this article and the seventh contribution was the evaluation of the maturity degree of the RD&I of SEB, where it was found that the program has grade 3 (on a scale from 1 to 5). This indicates that the innovation ecosystem of SEB is in the development phase, so it will still have a long way to go to become a mature ecosystem. This is very little for a public policy that has been in

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

existence for 21 years and that relies on resources guaranteed in part, annually.

The eighth contribution of this study focused on another assessment (sparked by the SEB's low innovation maturity), which aimed to evaluate the SEB's level of technological maturity, that is, what is produced with innovation in the SEB, which may be combined with the country's low innovation efficiency index. In this evaluation, it was detected that 47.92% of those surveyed (R&D managers of SEB companies) responded that their company does not evaluate the level of technological maturity TRL/MRL, a tool used by practically all innovation ecosystems in the world, to evaluate the technological readiness of what is done and what is purchased. 20.14% evaluate in the first stage (up to proof of concept); 19.44% reach the prototype and only 12.50% reach the final stage, which is market development.

Finally, this article brought an analysis of the life cycle of the RD&I project in the SEB, in the TRL scale. It demonstrated the curve of the need for resources for innovation, the curve of the resources of the RD&I of the SEB, the actors of the ecosystem, and the identification of the lost link of innovation or "valley of death of innovation". It also gave suggestions to avoid the plunge of the RD&I of the SEB in the lost link of innovation or the valley of death, or even to remove it from this uncomfortable position (item 4.7). It is necessary to balance the supply and demand of resources for innovation, according to the demand of each phase and implement the TRL/MRL technology readiness assessment methodology, to improve the efficiency of the public innovation policy of the SEB, and thereby provide benefits to society, such as energy security and tariff reduction, avoiding consequently energy poverty and energy injustice.

To sum up, this study highlights as research opportunities the development of a national network of RD&I of the SEB, with perspectives of internationalization. Another interesting topic would be the promotion of open innovation on a national level, with projects evaluated on the TRL/MRL scale. That would be possible with the definition of the promotion value, depending on the scale of technological readiness of the project and with support for startups, in system management projects using artificial intelligence (AI), as well as in projects that associate solar energy in HPP lakes and the production of fuel cells (green hydrogen).[3]

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3 - Green hydrogen is produced with electricity from clean and renewable energy sources, such as hydroelectric, wind, solar, biogas, and biomass. Green hydrogen is zero carbon: obtained without CO_2 emission (Rifkin, 2012; Schwab, 2016).

e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
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e-Revista LOGO - v. 11, n. 2, 2022 - ISSN 2238-2542
http://doi.org/1026771/e-Revista.LOGO/2022.2.08

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Received on: Fev. 2023
Acceptecd: Fev. 2023