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TESE DE DOUTORADO

INOVAÇÃO NO SETOR ELÉTRICO BRASILEIRO NA ERA DAS TECNOLOGIAS DISRUPTIVAS E DAS FONTES RENOVÁVEIS DE ENERGIA: diagnóstico e perspectivas para o Brasil em 2030

Gilmar dos Santos Marques

Brasília-DF
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Orientador: Professor Doutor José Luiz de Andrade Franco

Coorientadora: Professora Doutora Maria Amélia de Paula Dias

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AGRADECIMENTOS

O desafio de concluir um trabalho de tese a esta altura da minha vida, por si só é uma tarefa gigantesca. Quando se acrescenta a isso, o contexto vivido pelo povo brasileiro nos últimos anos (pandemia de Coronavírus COVID-19) e a crise econômica, agravada por um ambiente político conturbado e marcado por uma polarização inepta, o gosto de vitória é imenso e maravilhoso. Outro aspecto que deve ser destacado é o fato de deixar uma contribuição pessoal para a ciência, em um momento muito particular como é o atual, em que ela é atacada em todas as frentes mundo afora e principalmente aqui no Brasil. Mas, é bom destacar que a ciência segue gerando conhecimento, sempre baseada no rigor do método científico, mesmo com recursos cada vez mais escassos, em decorrência da infeliz ideia de se fazer contingenciamento dos recursos do Fundo Nacional de Desenvolvimento Científico e Tecnológico (FNDCT), principal fonte de financiamento da ciência no Brasil.

Nesse contexto, esta pesquisa foi realizada, seguindo o exemplo daqueles que fazem ciência no Brasil. Pesquisar inovação no Setor Elétrico Brasileiro (SEB) foi um grande desafio, mas foi possível graças às companhias agradáveis dos meus colegas de turma de 2017, do Programa de Pós Graduação (PPG) do Centro de Desenvolvimento Sustentável (CDS) da Universidade de Brasília (UnB): Beatriz Soares, Cristiana Dobre, Cristina Pegorin, Daniesse Kasanoski, Emília Faria, Geórgia Jordão, Júlio César, Nelson Bernal e Paula Emília.

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Agradeço muito à minha mãe e ao meu saudoso pai. Agradeço, especialmente, à Tania, minha esposa e companheira de uma vida toda, e à Vívian e à Lílian, minhas filhas, não só por renunciarem ao tempo de convivência, em função da minha dedicação aos estudos, mas também pelas minhas perturbações constantes, pedindo que lessem meus textos, comentassem e, até mesmo, discutissem comigo sobre eles, como se eles fossem algo do interesse delas. Mas, sei que elas fizeram tudo isso com prazer, pois estudo na nossa casa sempre foi um tema de interesse coletivo e compartilhado.

Por último, um agradecimento mais que especial ao professor doutor João Nildo de Souza Vianna (ou simplesmente JN para os seus alunos), que participou ativamente do design desta pesquisa e acompanhou boa parte dela, mas não pôde chegar até aqui porque foi convocado para uma missão maior em outra dimensão.

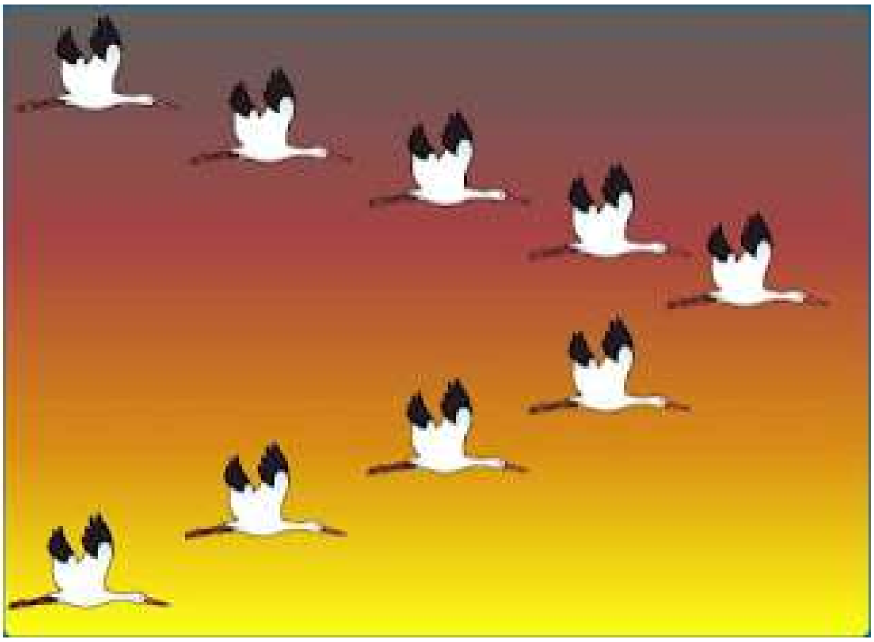
Logo, ao iniciar este agradecimento me veio a seguinte pergunta: por que o professor João Nildo impactou tantas vidas? Então, comecei a pensar na sua agenda de trabalho: CDS UnB, UFAM, Chile, Portugal (REALP), França (Paris), Moçambique e Cabo Verde (REALP) – presença confirmada no mínimo uma vez por ano. Em duas oportunidades, eu acompanhei o professor João Nildo em eventos da Rede de Estudos Ambientais de Países de Língua Portuguesa (REALP), uma em Manaus e outra em Fortaleza. A REALP, instituição da qual foi um dos fundadores e membro atuante até o último minuto de sua vida.

Nesses dois eventos da REALP, em que eu estava na agradável companhia do professor João Nildo, pude entender um pouco dessa pessoa espetacular e, com certeza, é o engenheiro mais humanista que conheci ao longo da minha vida, quase sexagenária. Que liderava os seus orientandos com a leveza do voo de um pássaro, em busca de um destino mais confortável para a próxima estação. Recentemente, li um artigo da Forbes sobre liderança, no LinkedIn, que trazia a seguinte pergunta: por que os pássaros voam em V? O professor João Nildo certamente responderia sem titubear... como um observador da natureza, atento aos detalhes como ele era, responderia com precisão.

O professor João Nildo liderava e influenciava as pessoas a fazerem algo significativo, diariamente. Pensava grande e compreendia que, a partir de ações micro (que se multiplicariam), iria gerar um impacto de grandes proporções na sociedade. O professor João Nildo entendia de gente, queria ver seus orientandos participando dos eventos, com atuações estrategicamente planejadas e ainda dizia mais ou menos assim: vocês devem assumir posições de destaque e o meu papel é viabilizar isso. Atitude de um líder preparando novos líderes.

Mas, como o professor João Nildo responderia à pergunta: por que os pássaros voam em V? Ousado que sou, resolvi escrever algo como se ele estivesse respondendo à pergunta.

Figura: Bando de pássaros voando com formação um V



Fonte: armazemdetexto.blogspot.com (2017

O engenheiro e cientista João Nildo responderia que esse formato em V, proporciona uma melhor aerodinâmica, gera economia de energia, o que é necessário para fazer longas viagens, melhora a comunicação e a coordenação do bando, e ainda amplia a visão do grupo de forma compartilhada (BEHAVIORAL ECOLOGY, 2004).

Certamente, o humanista João Nildo, seguiria explicando, que os mais velhos lideram o grupo e indicam o caminho, e dão o tom da velocidade, pois conhecem bem o percurso. A ordem nessa formação leva em conta a experiência, se é um júnior, pleno, sênior ou master. Mas, o líder sabe a importância do revezamento, uma vez que o efeito da aerodinâmica impacta a condição física, por isso o revezamento é feito ao longo do percurso, mas a liderança caberá sempre aos mais experientes do grupo (BEHAVIORAL ECOLOGY, 2004).

Em algum momento, em particular ele iria dizer: se você implementar essa estratégia conseguirá manter altas velocidades e conseguirá atingir distâncias cada vez maiores...

Assim, eu vi o professor João Nildo, com auxílio da professora Maria Amélia, conduzindo o nosso grupo de pesquisa “CDS - Energia Sustentável” e seus orientandos.

Muito obrigado!

RESUMO

Esta tese tem como problema de pesquisa a seguinte pergunta: em que medida a política pública de inovação do setor elétrico brasileiro (SEB) contribuiu para a redução dos impactos socioambientais do setor, e como ela concorre para que o Brasil possa cumprir os compromissos firmados junto ao Acordo de Paris – Agenda 2030? Para responder a essa pergunta, foi definido como objetivo geral: analisar o impacto da política pública brasileira de inovação do SEB, tanto nos aspectos socioambientais, quanto na premissa do PD&I do SEB de modicidade tarifária e nos compromissos firmados pelo Brasil, em sua NDC e o ODS 7 da Agenda 2030. Contudo, para alcançar esse objetivo geral, foram estabelecidos quatro objetivos específicos, que resultaram em quatro estudos exclusivos. Assim, este trabalho foi composto por seis capítulos, sendo que o primeiro traz a introdução do assunto, com a contextualização, o problema central, o objetivo geral, os objetivos específicos, a justificativa e procedimentos metodológicos (estrutura). O segundo, o terceiro, o quarto e o quinto capítulos apresentam a contextualização, os resultados e as considerações finais dos artigos 1, 2, 3 e 4, respectivamente. O sexto capítulo exibe a conclusão integradora. O artigo 1 abriu o horizonte dos impactos da inovação no setor elétrico e confirmou os problemas que passaram a delinear esta pesquisa, a partir do artigo 2, tais como os compromissos do Brasil com a Agenda 2030, mais especificamente o ODS 7 – Meta 7.1 e a modicidade tarifária. Os resultados do artigo 2 foram divididos entre o programa de P&D e o programa de Eficiência Energética (PEE). O P&D apresentou pouca evolução no quesito qualidade dos serviços das distribuidoras. Praticamente não há projetos com abordagem de impacto socioambiental, incluindo redução de emissões de gases de efeito estufa (GEE). Houve avanços no conceito de tríplice hélice: notou-se um elevado nível de engajamento das Universidades e dos Institutos de Ciência e Tecnologia (ICT) no programa governamental. O PEE apresentou resultados animadores, tais como: investimento evitado em geração de energia elétrica (IEGE), energia economizada (EECO), demanda retirada da ponta (DRP), todos com grande potencial de impacto positivo tridimensional: redução de emissões de CO_2e no SEB, redução de impactos socioambientais e financeiros de projetos de Usinas Hidrelétricas (UHE) de grande porte. O artigo 3 complementa a resposta da pergunta de pesquisa central, ao demonstrar que ficaram evidenciados fortes indícios de que a tarifa média de fornecimento (TMF) foi majorada logo após a implementação do PD&I do SEB. Na sequência, o estudo propôs a criação de um índice de poder de compra de energia elétrica (iPCEE), que confirmou uma perda de poder aquisitivo do consumidor, considerando a evolução da renda do brasileiro versus evolução do preço do MWh, no período entre 2000 e 2022. Diante da ausência de resultados consistentes no PD&I do SEB, restou um novo questionamento: por que uma política pública que tem recursos e tem atores supostamente engajados não gera resultados alinhados com as metas do Estado brasileiro? A resposta veio no artigo 4, que concluiu que o PD&I do SEB possui grau de maturidade 3 (em escala de 1 a 5), que equivale ao estágio de ecossistema em desenvolvimento, portanto, ainda incapaz de gerar benefícios consistentes e duradouros. Trata-se de um programa de inovação com indícios de que pode cair no denominado elo perdido da inovação ou vale da morte da inovação. Por fim, conclui-se que o PD&I do SEB deve avançar e acelerar rumo a um ecossistema maduro (grau 5), com inovação aberta, em rede, incluindo Startups, para gerar energia limpa e de baixo custo. Dessa forma, o SEB poderá passar pela disrupção necessária e entregar benefícios à sociedade.

Palavras-chave: Política Pública de Inovação; Setor Elétrico; PD&I; Brasil; Agenda 2030.

ABSTRACT

This thesis has as its research problem the following question: to what extent has the public innovation policy of the Brazilian electricity sector (SEB) contributed to the reduction of the sector's socio-environmental impacts, and how does it contribute so that Brazil can fulfill the commitments made with the Paris Agreement - Agenda 2030? To answer this question, the general objective was defined as: to analyze the impact of the Brazilian public policy of innovation in the SEB, both in socio-environmental aspects and in the premise of the RD&I of the SEB of tariff moderation and the commitments made by Brazil, in its NDC and SDG 7 of Agenda 2030. However, to achieve this general objective, four specific objectives were established, which resulted in four exclusive studies. Thus, this work was composed of six chapters, the first of which brings the introduction of the subject, with the contextualization, the central problem, the general objective, the specific objectives, the justification, and the methodological procedures (structure). The second, third, fourth, and fifth chapters present the contextualization, results, and final considerations of articles 1, 2, 3, and 4, respectively. The sixth chapter displays the integrative conclusion. Article 1 opened the horizon of the impacts of innovation in the electricity sector and confirmed the issues that started outlining this research, starting from article 2, such as Brazil's commitments to Agenda 2030, more specifically SDG 7 - Target 7.1 and tariff moderation. The results of article 2 were divided between the R&D program and the Energy Efficiency Program (EEP). The R&D presented little evolution in the quality of services of the distributors. There are practically no projects with a socio-environmental impact approach, including the reduction of greenhouse gas emissions (GHG). There was progress in the triple helix concept: a high level of engagement of Universities and Institutes of Science and Technology (IST) in the government program was noted. The EEP presented encouraging results, such as avoided investment in electricity generation (IEGE), saved energy (EECO), and off-peak demand (OPD), all with great potential for positive three-dimensional impact: reduction of CO_2e emissions in the SEB, reduction of socio-environmental and financial impacts of large Hydroelectric Power Plant (HPP) projects. Article 3 complements the answer to the central research question by demonstrating that strong evidence that the average supply tariff (AST) was increased soon after the implementation of the RD&I of the SEB. Next, the study proposed the creation of an Electricity purchasing Power index (EPPi), which confirmed a loss of purchasing power of the consumer, considering the evolution of the Brazilians' income versus the evolution of the MWh price, in the period between 2000 and 2022. Given the absence of consistent results in the RD&I of the SEB, a new question remained: why does a public policy that has resources and supposedly engaged actors not generate results aligned with the goals of the Brazilian State? The answer came in article 4, which concluded that the RD&I of SEB has maturity level 3 (on a scale of 1 to 5), which is equivalent to the stage of a developing ecosystem, therefore, still unable to generate consistent and lasting benefits. It is an innovation program with indications that it may fall into the so-called missing link of innovation or valley of death of innovation. Finally, it is concluded that the RD&I of the SEB should advance and accelerate towards a mature ecosystem (grade 5), with open innovation, in a network, including startups, to generate clean and low-cost energy. In this way, the SEB will be able to undergo the necessary disruption and deliver benefits to society.

Keywords: Public Innovation Policy; Electric Sector; RD&I; Brazil; Agenda 2030.

LISTA DE SIGLAS

ABRADEE	Associação Brasileira de Distribuidores de Energia Elétrica
ACL	Ambiente de Contratação Livre
ACR	Ambiente de Contratação Regulado
AFC	Análise Fatorial por Correspondências
ANA	Agência Nacional de Águas
ANEEL	Agência Nacional de Energia Elétrica
ANP	Agência Nacional de Petróleo
ASEAN	Associação das Nações do Sudeste Asiático
BID	Banco Interamericano de Desenvolvimento
C	Comercialização
CEEE	Companhia Estadual de Energia Elétrica
CELG	Companhia Energética de Goiás
CELPE	Companhia de Eletricidade de Pernambuco
CEMIG	Companhia Energética de Minas Gerais
CEPEL	Centro de Pesquisas de Energia Elétrica
CGEE	Centro de Gestão e Estudos Estratégicos
CHD	Classificação Hierárquica Descendente
CMSE	Comitê de Monitoramento do Setor Elétrico
CN	Congresso Nacional
CNPE	Conselho Nacional de Política Energética
CONAMA	Conselho Nacional de Meio Ambiente
ContribInova	Contribuição de Inovação
COP21	21ª Conferência das Partes
COPEL	Companhia Paranaense de Energia
CO_2e	Equivalência em Dióxido de Carbono
CPFL	Companhia Paulista de Força e Luz
CQNUMC	Convenção-Quadro das Nações Unidas sobre a Mudança do Clima
CTEnerg	Fundo Setorial de Energia
D	Distribuição
DRP	Demanda Retirada da Ponta
ECON	Energia Conservada
EECO	Environment and Energy Conference
ELETROPAULO	Eletropaulo Metropolitana Eletricidade de São Paulo
ENEL	Ente Nazionale per L'energia Elétrica
EPE	Empresa Brasileira de Pesquisa Energética
FBMC	Fórum Brasileiro para Mudança do Clima
FINEP	Financiadora de Estudos e Projetos
FIRJAN	Federação das Indústrias do Estado do Rio de Janeiro
FMI	Fundo Monetário Internacional
FNDCT	Fundo Nacional de Desenvolvimento Científico e Tecnológico

FV	Valor Futuro
G	Geração
GD	Geração Distribuída
GEE	Gases de Efeito Estufa
GTD	Geração, Transmissão e Distribuição
GTDC	Geração, Transmissão, Distribuição e Comercialização
IASC	Índice ANEEL de Satisfação do Cliente
IBGE	Instituto Brasileiro de Geografia e Estatística
IEGE	Investimento Evitado em Geração de Energia
IPCA	Índice de Preços ao Consumidor Amplo
iPCEE	Índice de Poder de Compra de Energia Elétrica
IPEA	Instituto de Pesquisa Econômica Aplicada
ITGCC	The development of integrated tar gasification combined cycle plants
LIGHT	Light Serviços de Eletricidade S. A.
MCTIC	Ministério da Ciência, Tecnologia, Inovação e Comunicações
MMA	Matriz Metodológica de Amarração
MMA	Ministério do Meio Ambiente
MME	Ministério das Minas e Energia
MME/EPE	Ministério de Minas e Energia/Empresa de Pesquisa Energética
MME/SPE/EPE	Ministério de Minas e Energia/Secretaria de Planejamento e Desenvolvimento Energético/Empresa de Pesquisa Energética
MQO	Mínimos Quadrados Ordinários
NDC	Contribuição Nacionalmente Determinada
OCDE	Organização para Cooperação e Desenvolvimento Econômico
ODS	Objetivos de Desenvolvimento Sustentável da ONU
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares
NOS	Operador Nacional do Sistema Elétrico
ONU	Organização das Nações Unidas
PCEE	Poder de Compra de Energia Elétrica
PCEERMbIBGE	Poder de Compra de Energia Elétrica com base na RMbIBGE
PCEESMCBDIEESE	Poder de Compra de Energia Elétrica calculado com base no SMCBDIEESE
PCEESMN	Poder de Compra de Energia Elétrica calculado pelo Salário Mínimo Nacional
PD&I	Pesquisa, Desenvolvimento e Inovação
PDE	Plano Decenal de Expansão de Energia
PEE	Programa de Eficiência Energética
PIB	Produto Interno Bruto
PNEf	Plano Nacional de Eficiência Energética
PP&D	Programa de Pesquisa e Desenvolvimento
PPG-CDS	Programa de Pós-Graduação em Desenvolvimento Sustentável
PPU	Políticas Públicas

PR	Presidência da República Federativa do Brasil
PROCEL	Programa Nacional de Conservação de Energia Elétrica
PROPEE	Procedimentos do Programa de Eficiência Energética
QTI	Quarta Revolução Industrial
$RECO_2$	Redução de Emissões de CO_2
RED	Recursos Energéticos Distribuídos
RI	Revoluções Industriais
RMbIBGE	Renda Média do Brasileiro calculada pelo IBGE
ROL	Receita Operacional Líquida
SEB	Setor Elétrico Brasileiro
SGP&D	Sistema de Gestão de Projetos
SIN	Sistema Interligado Nacional
SMART	Specific, Measurable, Attainable, Relevant and Time Bound
SMCBDIEEESE	Salário Mínimo Cesta Básica do DIEESE
SMN	Salário Mínimo Nacional
SNI	Sistema Nacional de Inovação
SNRH	Secretaria Nacional de Recursos Hídricos
ST	Segmentos de Texto
T	Transmissão
TD	Tecnologias Disruptivas
TIC	Tecnologia da Informação e Comunicações
TMF	Tarifa Média de Fornecimento
UF	Unidades de Federação
UnB	Universidade de Brasília
VF	Valor Futuro
VP	Valor Presente

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1 INTRODUÇÃO GERAL

1.1 Contexto

A inovação no setor elétrico no mundo começou a ganhar força na última década do século XX, diante da necessidade de reduzir o impacto ambiental na geração de eletricidade produzida por meio de combustíveis fósseis (Gulli, 1995). O setor elétrico global seguiu o modelo de inovação setorial que passou de produto para processo, chegou às empresas, instituições, órgãos reguladores. Hoje, ele inclui fontes renováveis de energia (solar fotovoltaica, eólica, dentre outras), combinadas com as novas tecnologias disruptivas e os recursos energéticos distribuídos, operados por organizações de diferentes portes, podendo ser empresa local, regional, nacional ou até mesmo corporações que atuam em diferentes países (FGV EAESP GVces, 2015; Marques, Dias & Vianna, 2020; MME/SPE/EPE, 2018).

Nesse mesmo período, o Brasil vem implementando mudanças no setor elétrico brasileiro (SEB), composto por geração, transmissão e distribuição (GTD), que era puramente estatal, mas que no último quarto de século tem avançado com privatizações, principalmente no segmento de distribuição. Os segmentos de geração e transmissão ainda têm uma parcela significativa sob a responsabilidade de empresas estatais. Trata-se de um setor altamente regulado e está sob a supervisão da Agência Nacional de Energia Elétrica (ANEEL), o que se faz necessário, pois o SEB ainda é monopólio na maioria das Unidades de Federação (UF). Em algumas UF como São Paulo e Rio de Janeiro é um oligopólio com características de monopólio, uma vez que o consumidor não tem a liberdade de comprar energia elétrica da companhia de sua preferência, sendo obrigado a comprar daquela que o Estado autorizou a operar no endereço dele (Castro; Brandão, 2019; Mankiw, 2001; MME/EPE, 2018; Tirole, 2020).

O SEB possui algumas vantagens em relação aos sistemas elétricos de outros países e duas delas merecem destaque: a) a geração de energia elétrica de fontes hídricas em escala nacional; e b) o Sistema Interligado Nacional (SIN). A primeira vantagem possibilita que o Brasil tenha uma matriz elétrica limpa, em consonância com a Agenda 2030. A segunda viabiliza o transporte de energia elétrica gerada em uma região e consumida em outra, mesmo em um país com dimensões continentais, como é o caso do Brasil, e permite que o Operador

Nacional do Sistema[1] (ONS) faça uma gestão equilibrada da oferta e demanda nas diferentes regiões do território nacional (ANEEL, 2018).

O SIN foi uma inovação no setor elétrico, quando criado em 1998 por meio da Resolução 351/98 do Ministério das Minas e Energia (MME), em conformidade com a Lei 9.648/98 e o Decreto 2.655/98, de acordo com ANEEL (1998), visto que países como os EUA e regiões como a União Europeia hoje caminham na construção de seus sistemas elétricos interligados, tanto intra país como entre nações, como é o projeto europeu com previsão de conclusão para 2030 (Cambini, Caviggioli & Scellato, 2016).

Para acelerar a inovação do SEB, foi criada uma política pública de inovação para o setor por meio da Lei 9.991/2000, que se tornou o marco legal do programa de desenvolvimento e inovação (PD&I) do SEB, concentrando os programas de pesquisa e desenvolvimento (P&D) e o programa de eficiência energética (PEE) (ANEEL, 2020b; Brasil, 2000). Na primeira e na segunda fase do programa regulado pela ANEEL, adotou-se um modelo de inovação de perspectiva linear, nos períodos compreendidos entre 2000 e 2007 e de 2008 a 2015. Mas, a partir de 2016, em sua terceira fase, o PD&I do SEB buscou uma evolução do modelo de inovação, adotando um modelo de visão sistêmica, alinhado com um Sistema Nacional de Inovação (SNI), que se baseia no aprendizado interativo como fator de competitividade sustentada (Bin et al, 2015; Castro; Brandão, 2019; Castro et al, 2017; ANEEL, 2020).

A evolução detectada nesta pesquisa foi confirmada pela alteração da Lei 9.991/2000, no Art. 3º, § 4º, no que se refere ao P&D, que passou a ter a seguinte redação: "Nos programas e projetos de pesquisa e inovação tecnológica do setor de energia elétrica, deverá ser priorizada a obtenção de resultados de aplicação prática, com foco na criação e no aperfeiçoamento de produtos, processos, metodologias e técnicas" (Brasil, 2015). Em 2021, a mesma lei teve uma alteração no Art. 5º, inciso IV, § 1º, sobre o PEE, cuja redação ficou assim: "Os investimentos em eficiência energética de que trata o art. 1º desta Lei deverão priorizar iniciativas, serviços e produtos de empresas nacionais, bem como a inovação e a pesquisa produzidas no País, conforme regulamento a ser editado pela Aneel" (Brasil, 2021). Foi nesse sentido, que esta tese passou a denominar os programas de P&D e EE, regulados pela ANEEL, de PD&I do SEB.

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[1] O Operador Nacional do Sistema (ONS) é uma entidade brasileira de direito privado sem fins lucrativos que é responsável pela coordenação e controle da operação das instalações de geração e transmissão de energia elétrica no SIN e pelo planejamento da operação dos sistemas isolados do país, sob a fiscalização e regulação da ANEEL (ONS, 2022).

O Sistema Nacional de Inovação segue o preconizado pelo Manual de Oslo. Este diz que inovação é a criação de um produto (bem ou serviço) novo ou significamente melhorado, ou um processo, ou um novo método financeiro ou comercial, ou um novo processo organizacional e novas práticas de negócio, seja na organização do local de trabalho ou nas relações externas (OECD/Eurostat, 2018). Deve-se esclarecer que melhoramentos significativos são: especificações técnicas, componentes e materiais, softwares incorporados, facilidade de uso ou outras características funcionais associadas (OECD/Eurostat, 2018). A inovação de processo ocorre a partir da implementação de um método de produção ou distribuição novo ou significativamente melhorado (OECD/Eurostat, 2018). Embora a inovação de produto e processos seja mais frequente, pode haver inovações nas dimensões de marketing e de estrutura organizacional (Marques, Dias & Vianna, 2021).

Diante disso, observa-se que, em seu terceiro ciclo, o PD&I do SEB procurou alinhar-se ao Manual de Oslo, no que diz respeito às boas práticas de inovação. Mas, a implementação ou até mesmo a reformulação de um programa de inovação passa, necessariamente, por escolhas metodológicas que envolvem a definição de modelos ou formas de inovar, o que depende de uma avaliação criteriosa do grau de maturidade da inovação do setor, bem como do estágio atual de desenvolvimento do mercado em que a organização atua (Christensen, 1997; Christensen, 2019; Marques, Dias & Vianna, 2021).

Quanto à escolha do modelo de implementação de um programa de inovação, têm-se a inovação incremental e a inovação radical ou disruptiva. Normalmente, se a organização opera em um mercado estável e maduro, ela segue o modelo de inovação incremental. Mas, se a empresa opera em um ambiente volátil e precisa introduzir rapidamente novos produtos ou serviços, novas tecnologias e novos modelos organizacionais, ela deve adotar o modelo de inovação radical ou disruptiva (Christensen, 1997; Christensen, 2019; Marques, Dias & Vianna, 2021).

Cabanes *et al.* (2016) estudou o modelo de inovação da indústria de semicondutores, em pesquisa realizada na STMicroelectronics na França, onde afirmou que, mesmo em mercados estáveis, mas que passam por grandes mudanças tecnológicas, é recomendável a adoção da inovação radical ou disruptiva. Este parece ser o modelo recomendável para o setor elétrico brasileiro, na era das energias de fontes renováveis, recursos energéticos distribuídos e tecnologias disruptivas.

Partindo dessas premissas, uma política pública de inovação, alinhada com o conceito de um Sistema Nacional de Inovação, mesmo que seja setorial, deve promover a cultura da inovação no setor elétrico brasileiro, por meio do desenvolvimento de novos equipamentos, do aprimoramento da prestação de serviços, contribuir para a segurança energética, a modicidade tarifária e a redução do impacto socioambiental do setor (ANEEL, 2020; Marques, Dias & Vianna, 2021).

Em 2016, o governo brasileiro ratificou o Acordo de Paris, o que de certa forma, ampliou os compromissos do setor elétrico brasileiro, uma vez que as premissas estabelecidas no programa de PD&I do SEB, parágrafo anterior, foram reforçadas ou até mesmo ampliadas, tanto na NDC do Brasil quanto na Agenda 2030, que se trata de um compromisso global com os 17 Objetivos de Desenvolvimento Sustentável (ODS) e 169 metas (BID, 2017; IPEA, 2019; BRASIL, 2016).

As metas acordadas e fixadas no âmbito do Acordo de Paris foram as seguintes: a) na NDC do Brasil – i) expandir o uso de fontes renováveis, além da energia hídrica, na matriz total de energia para uma participação de 28% a 33% até 2030; ii) aumentar o uso das fontes de energia não fóssil, ampliando a parcela de energias renováveis (eólica, biomassa e solar), além da energia hídrica, na matriz de energia elétrica para ao menos 23% até 2030; e iii) atingir 10% de ganhos de eficiência no setor elétrico até 2030; b) na Agenda 2030 – i) assegurar o acesso confiável, sustentável, moderno e a preço acessível da energia para todos, conforme previsto no ODS 7 - energia acessível e limpa e, por correlação, auxiliar na indústria, inovação e infraestrutura (ODS 9) e como ação contra a mudança global do clima (ODS 13). (BRASIL, 2016; BID, 2017; IPEA, 2019; Marques; Dias & Vianna, 2021).

1.2 Problema Central

Diante do contexto apresentado, percebe-se que a política pública de inovação do SEB, notadamente o programa de PD&I do SEB, tem potencial para gerar benefícios para a sociedade brasileira, tais como: i) cultura de inovação; ii) desenvolvimento de novos produtos; iii) melhoria de qualidade dos serviços prestados; iv) segurança energética; v) modicidade tarifária; e vi) redução de impactos ambientais. Lembrando que este último tem repercussão global por meio da redução de emissões de Gases de Efeito Estufa (GEE).

Dessa forma, esta tese tem como problema de pesquisa a seguinte pergunta: em que medida a política pública de inovação do setor elétrico brasileiro (SEB) contribuiu para a redução dos impactos socioambientais do setor, e como ela concorre para que o Brasil possa cumprir os compromissos firmados junto ao Acordo de Paris – Agenda 2030?

A resposta da pergunta central da tese foi elaborada a partir de questões solucionadas em cada um dos estudos, que foram apresentados em forma de artigo, respondendo suas respectivas perguntas de pesquisa, relacionadas a seguir:

i) qual é o estado da arte da literatura do tema inovação no setor elétrico e quais são as tendências tecnológicas para o setor? - Estudo 1, Artigo 1, Apêndice A;

ii) como as políticas públicas brasileiras para inovação do SEB, desenvolvidas por meio dos Programas de Pesquisa e Desenvolvimento (P&D) e de Eficiência Energética (EE), regulados pela ANEEL, impactarão os compromissos do Brasil para a Agenda 2030? - Estudo 2, Artigo 2, Apêndice B;

iii) qual foi o impacto da implementação da política pública de PD&I do SEB, por meio dos programas de P&D e de EE, na política de modicidade tarifária prevista no programa e nas metas da Agenda 2030? - Estudo 3, Artigo 3, Apêndice C;

iv) como o grau de maturidade de inovação e o nível de prontidão tecnológica do programa de PD&I do SEB podem contribuir para entregar melhores resultados para a sociedade? - Estudo 4, Artigo 4, Apêndice D.

1.3 Objetivo Geral

Para responder à pergunta de pesquisa central desta tese, foi definido como objetivo geral: analisar o impacto da política pública brasileira de inovação do SEB, tanto nos aspectos socioambientais, quanto na premissa do PD&I do SEB de modicidade tarifária e nos compromissos firmados pelo Brasil, em sua NDC e o ODS 7 da Agenda 2030.

1.3.1 Objetivos específicos

Para a consecução do objetivo geral desta tese, foram propostos 4 objetivos específicos, sendo que cada um deles foi o objetivo norteador de cada um dos 4 estudos realizados. São eles:

i) identificar, descrever e analisar o estado da arte da literatura sobre inovação no setor elétrico, na era das tecnologias disruptivas, por meio de um estudo bibliométrico, incluindo a evolução das pesquisas no período de 1991 a 2019 - objetivo geral do Estudo 1, Artigo 1, Apêndice A;

ii) analisar se as políticas públicas brasileiras, materializadas no PP&D e PEE do SEB, concorrem para que o governo brasileiro possa cumprir os compromissos firmados com a Agenda 2030 e as metas da NDC, junto ao Acordo de Paris, em relação ao ODS 7 - objetivo geral do Estudo 2, Artigo 2, Apêndice B;

iii) avaliar o impacto da política pública brasileira de inovação do SEB, sobre a tarifa média de fornecimento (TMF), visto que uma das premissas do PD&I é a modicidade tarifária, que se alinha com o ODS 7 da Agenda 2030, desde a sua implementação no ano de 2000 até 2020 - objetivo geral do Estudo 3, Artigo 3, Apêndice C;

iv) estimar o grau de maturidade de inovação, bem como o nível de prontidão tecnológica 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 - objetivo geral do Estudo 4, Artigo 4, Apêndice D.

1.4 Justificativa

A justificativa para a realização desta tese parte da necessidade de avaliar o impacto da política pública de inovação do setor elétrico brasileiro, o PD&I do SEB, visto que se trata de uma política pública com mais de 20 anos de existência. Ela foi criada e implementada no momento em que o mundo vem passando por mudanças marcadas por inovações disruptivas em todas as áreas, e o setor de eletricidade precisa avançar para suprir a demanda com energia limpa, a preços acessíveis e de forma segura, em um momento que a sociedade já fala em justiça energética[2] (Ribas & Simões, 2020).

A principal contribuição desta tese foi reunir, em documento único, quatro estudos descritos no item 1.3.1, e detalhados nos itens 1.5.2 e 1.5.3, que devem abrir caminhos para se fazer uma reflexão sobre a política pública brasileira de inovação para o setor elétrico brasileiro ou PD&I do SEB à época de sua concepção em 1998. Estudos que ganharam novos contornos com o advento do Acordo de Paris de 2015, ratificado pelo governo brasileiro em 2016, e com a Agenda 2030, composta por 17 Objetivos de Desenvolvimento Sustentável, que é um compromisso assumido pelos 193 Estados-membros da ONU, incluindo o Brasil, e se tornou referência para a formulação de políticas públicas para os governos em âmbito mundial (EAI-DF, 2021).

Considerando que o mundo e o Brasil vivem em plena era da indústria 4.0, onde as mudanças acontecem em escala exponencial e a inovação do presente não serve para o futuro,

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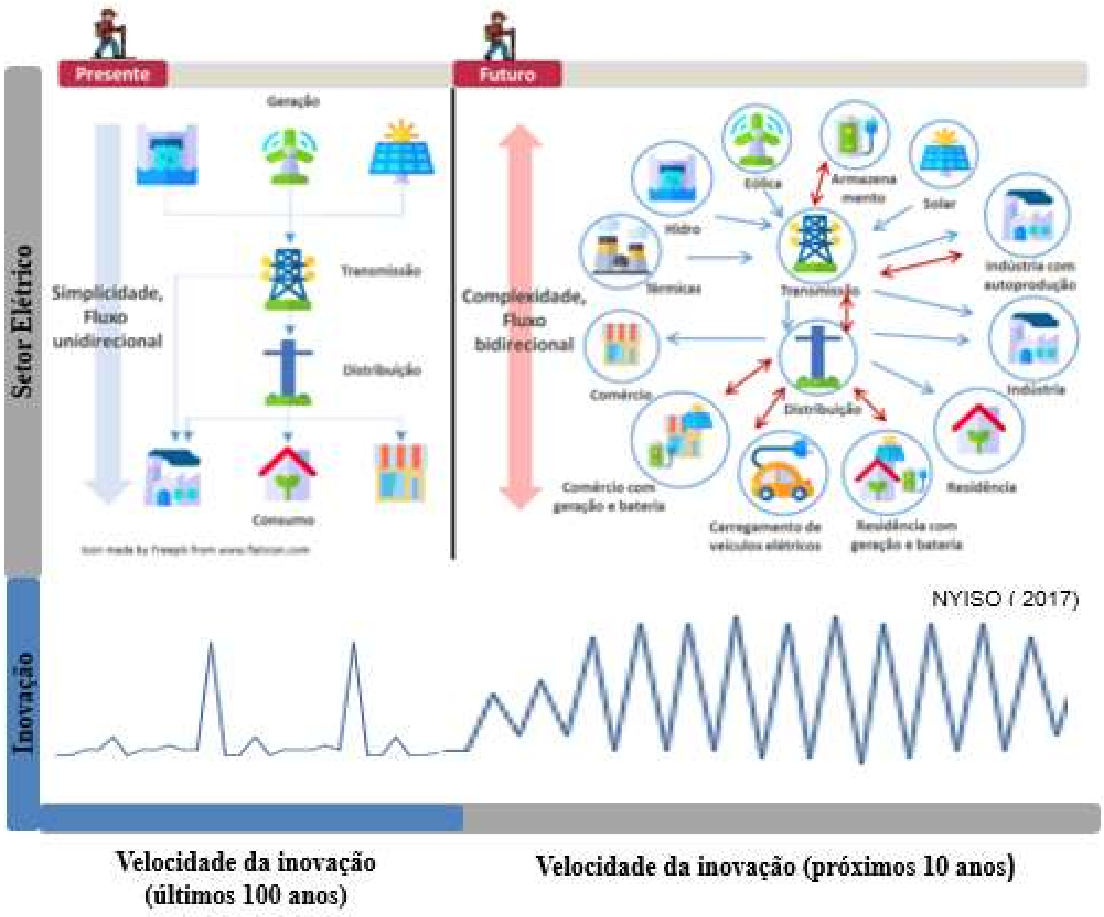
[2] Justiça energética deve incorporar oito princípios: disponibilidade, acessibilidade (financeira), devido processo legal, transferência e prestação de contas, sustentabilidade, equidade intergeracional e responsabilidade de acordo com Ribas et. al. (2020, p. 57).

verifica-se que é preciso acelerar o programa de PD&I do SEB (P&D e EE), de forma que as empresas do SEB possam atuar com inovação no limite da fronteira do conhecimento das organizações mais inovadoras do mercado.

A crescente participação das fontes renováveis de energia na matriz elétrica no mundo tem forçado uma mudança estrutural na operação do setor elétrico, pois atualmente o modelo é relativamente simples, com fluxo unidirecional. A nova modelagem do setor atuará em um ambiente cada vez mais complexo, e operando com fluxo bidirecional, para atender novos atores que passaram a fazer parte do sistema, conforme mostra a Figura 1.

Figura 1 – Velocidade da inovação: presente *versus* futuro



Fonte: elaborado pelos autores, adaptado de NYISO (2016).

1.5 Estrutura da Tese

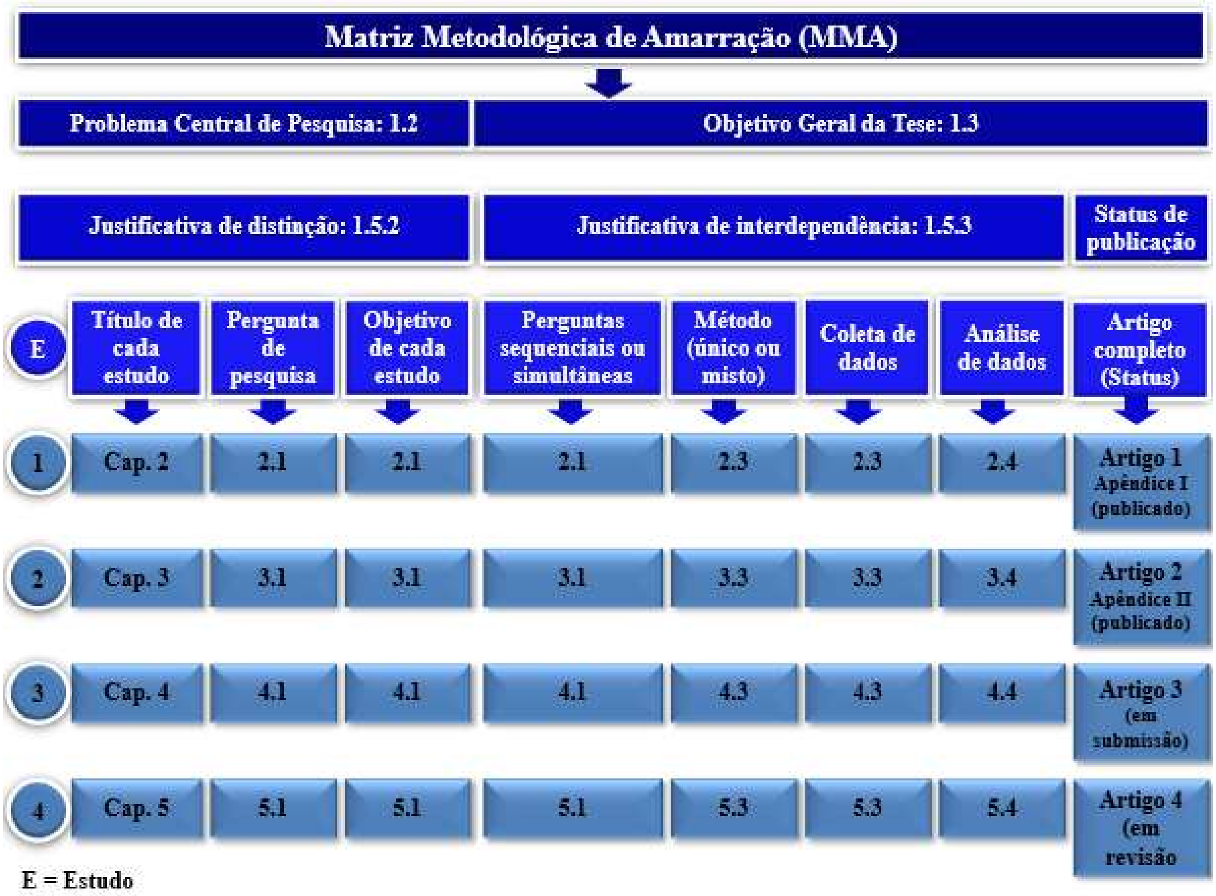
Para atingir o objetivo geral, os objetivos específicos e responder às questões de pesquisa, esta tese foi dividida em 6 capítulos: Capítulo 1 – Introdução; Capítulo 2 – Estudo

1; Capítulo 3 – Estudo 2; Capítulo 4 – Estudo 3; Capítulo 5 – Estudo 4, que serão apresentados na matriz metodológica de amarração (MMA) e Capítulo 6 – Conclusão Integradora, conforme Figura 2. Fazem parte desta tese os seguintes documentos: Apêndice A – Artigo 1; Apêndice B – Artigo 2; Apêndice C – Artigo 3; Apêndice D – Artigo 4; e Apêndice E – Formulário de pesquisa.

1.5.1 Matriz metodológica de amarração (MMA)

A MMA foi elaborada de forma que demonstrasse a consistência metodológica dos estudos realizados, com vistas a atender o objetivo geral da tese, bem como seus objetivos específicos (Da Costa, Ramos, & Pedron, 2019). Em decorrência disso, a MMA contém a justificativa de distinção de estudos, incluindo o título, a pergunta de pesquisa e o objetivo geral, de cada estudo, bem como a justificativa de interdependência, envolvendo o tipo e a sequência ou simultaneidade das pesquisas realizadas, os procedimentos metodológicos contendo coleta e análise de dados, conforme Figura 2 (Da Costa et al., 2019).

Figura 2 – Matriz Metodológica de Amarração (MMA)



Fonte: elaborada pelos autores, com base em modelo de Costa, Ramos & Pedron (2019)

1.5.2 Justificativa de distinção dos estudos

Os quatro estudos realizados para atender aos propósitos desta pesquisa foram constituídos pelos objetivos específicos, listados no item 1.3.1, e decorrem do objetivo geral desta tese, conforme item 1.3.

A justificativa para que os quatro estudos sejam distintos é o fato de que, para avaliar uma política pública, é preciso partir de sua concepção, incluindo um período antes da sua criação e um período após a sua implementação. Isso envolve pesquisa e recursos metodológicos que possam viabilizar um conjunto de resultados isolados, mas que sejam capazes de compor um resultado que represente a sinergia gerada pelos estudos individualizados.

1.5.3 Justificativa de interdependência dos estudos

A justificativa de interdependência dos quatro estudos realizados é provada pelo fato de atender aos propósitos desta pesquisa, como objetivos específicos, listados no item 1.3.1, que são decorrentes do objetivo geral desta tese, conforme item 1.3.

Diante da exposição de cada estudo, que mostrou como cada pergunta de pesquisa foi respondida, com a devida descrição do conjunto de métodos utilizados (mistos), envolvendo coleta e análise de dados e discussão de resultados, bem como a sequência, ficou demonstrada a interdependência dos estudos para responder à questão geral de pesquisa desta tese.

Os quatro problemas analisados e os objetivos específicos, alicerces desta tese, foram apresentados como estudos individualizados sob a forma de artigos, que se encontram nos seguintes estágios:

Apêndice A – Artigo 1 - Status: publicado no International Journal of Advanced Engineering Research and Science, em fevereiro de 2020. Qualis CAPES A2. NAAS Score: 3,18. Disponível em: https://ijaers.com/detail/innovation-in-the-electricity-sector-in-the-age-of-disruptive-technologies-and-renewable-energy-sources-a-bibliometric-study-from-1991-to-2019/

Apêndice B – Artigo 2 - Status: publicado no International Journal of Advanced Engineering Research and Science, em julho de 2021. Qualis CAPES A2. NAAS Score: 3,18. Disponível em https://ijaers.com/detail/the-brazilian-public-policies-for-rd-i-in-the-brazilian-electrical-system-seb-in-light-of-the-commitments-of-the-agenda-2030/

Apêndice C – Artigo 3 - Status: Aceito na The 3rd SDEWES LA Conference will be held in São Paulo, Brazil (24-28 de julho de 2022);

Apêndice D – Artigo 4 - Status: Aceito na The 3rd SDEWES LA Conference will be held in São Paulo, Brazil (24-28 de julho de 2022).

2 ESTUDO 1 – ARTIGO 1

O Estudo 1 teve como título: Inovação no setor elétrico na era das tecnologias disruptivas e das fontes renováveis de energia: um estudo bibliométrico de 1991 a 2019.

2.1 Contextualização

O primeiro estudo buscou responder a seguinte pergunta: qual é o estado da arte da literatura do tema inovação no setor elétrico e quais são as tendências tecnológicas para o setor?

A resposta a esta pergunta foi viabilizada por meio do seguinte objetivo: identificar, descrever e analisar o estado da arte da literatura sobre inovação no setor elétrico, na era das tecnologias disruptivas, por meio um estudo bibliométrico, incluindo a evolução das pesquisas no período de 1991 a 2019.

Os procedimentos metodológicos para coleta de dados deste estudo foram os seguintes: criou-se os argumentos de busca, com a definição das palavras-chave para a pesquisa em consonância com o tema da tese “setor elétrico”, “inovação” e “tecnologias disruptivas”; definiu-se a estratégia de busca nas bases de dados; realizou-se o ajuste fino da pesquisa: a) Scopus e Web of Science; b) exportação dos resultados da pesquisa das duas bases; fez-se o tratamento dos arquivos em planilhas Excel, de acordo com o interesse da pesquisa: 242 artigos baixados; selecionou-se os artigos para exclusão de duplicidades (71 artigos) e aqueles que estavam fora do escopo da pesquisa (12 artigos): 83 artigos excluídos; realizou-se o download dos artigos definidos como de interesse da pesquisa: 159 artigos. Em seguida, fez-se a leitura dos resumos de todos os artigos.

O tratamento de dados envolveu aspectos qualitativos, quantitativos e estatístico e foi realizado para analisar os 159 textos selecionados, utilizando o Iramuteq (Interface de R pour les Analyses Multidimensionneles de Textes et de Questionnaires), software específico que possibilita identificar o contexto em que as palavras ocorrem, utilizando a plataforma estatística do software R (Camargo & Justo, 2013; Salviati, 2017).

O estudo bibliométrico realizado avançou na análise de conteúdo, em busca de verificar o que a literatura estudada apresenta como resultados do tema inovação no setor elétrico no mundo.

2.2 Resultados

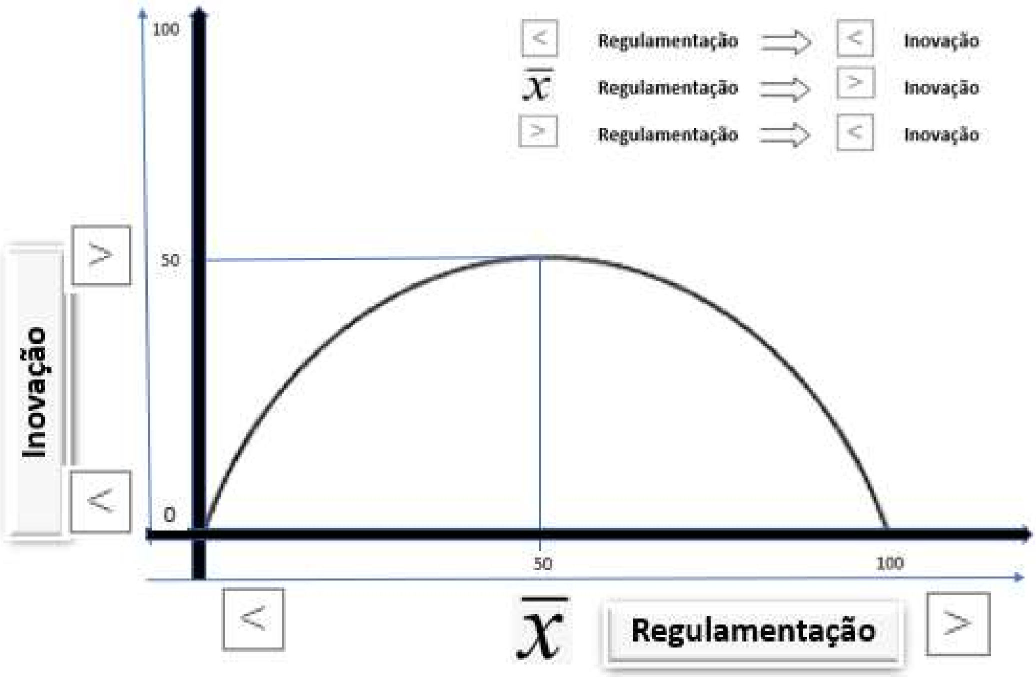
Este estudo possibilitou identificar a evolução da literatura sobre inovação no setor elétrico com resultados animadores no que se refere aos aspectos socioambientais (redução de emissões) e de redução de custos do sistema elétrico como um todo (Wiersma, 1991; Gulli, 1995; Fischer & Newell, 2008; Jusoh, 2017; Zhu et al., 2018). Deve-se registrar ainda que foi identificado na literatura um alerta de que há impactos negativos dos aspectos regulatórios do setor elétrico nos programas de inovação que, inclusive, impedem que resultados cheguem ao consumidor (Jamasb & Pollitt, 2008b; Jamasb & Pollitt, 2008, 2015; Marino, Parrotta, & Valletta, 2019).

Os principais resultados do estudo bibliométrico apontam para inovações que vêm ocorrendo nos EUA, Europa e China, que combinam evolução tecnológica e redução de emissões de CO_2e. Apontam ainda para um aumento considerável da participação das fontes renováveis na matriz de eletricidade na Ásia, liderada pela China.

No que se refere à inovação no setor elétrico, estudos realizados no Reino Unido e em 31 países da OCDE e países que adotaram políticas semelhantes aos países daquele bloco, como é o caso Brasil, há uma barreira a ser considerada, quando se trata de setor altamente regulado como é o setor elétrico no mundo, que é o denominado efeito U-invertido. Este efeito indica que a regulação ajuda potencializar a inovação até determinado ponto (considerado ótimo) e a partir daí, quando aumenta a regulação, ela impacta nos resultados positivos da inovação e estes começam a anular os benefícios da inovação (Apêndice A – Artigo 1, item 4.3.1).

O efeito U-invertido pode impedir que os benefícios das novas tecnologias da indústria 4.0 cheguem ao setor elétrico, impedindo o surgimento de novos modelos de negócios que utilizam tecnologias disruptivas, baseados em fontes renováveis de energia, redes inteligentes e que tenham o prossumidor como o principal novo ator desse ecossistema. Veja como funciona o efeito U-invertido, conforme Apêndice A – Artigo 1, item 4.3.1 e na Figura 3, a seguir:

Figura 3 – Representação gráfica da forma U invertido da relação regulamentação e inovação



Fonte: Elaborado pelos autores, conforme Apêndice A – Artigo 1, item 4.3.1.

2.3 Considerações Finais

Este estudo contribuiu para a demonstrar o avanço do conhecimento, por meio de um estudo bibliométrico que compreendeu o período de 1991 a julho de 2019, que registrou o impacto da inovação no setor elétrico global e no Brasil, e identificou os avanços e os gargalos da inovação no setor.

As limitações do Estudo 1 foram não aprofundar em fontes bibliográficas que tratam especificamente dos avanços do setor elétrico nos EUA, na Europa e na China, para fazer comparações com o Brasil.

Fica como proposta para estudos futuros identificar pesquisas que avaliem o impacto da regulação na inovação do setor elétrico em outros países e no Brasil.

3 ESTUDO 2 - ARTIGO 2

O Estudo 2 teve como título: As políticas públicas brasileiras de PD&I do setor elétrico brasileiro (SEB), frente aos compromissos da agenda 2030.

3.1 Contextualização

Este estudo teve como pergunta de pesquisa: como a política pública brasileira de inovação do SEB, desenvolvidas por meio do PD&I do SEB, no Programa de P&D e no Programa de Eficiência Energética (PEE), regulados pela ANEEL, impactarão os compromissos do Brasil para a Agenda 2030?

A resposta a essa pergunta foi viabilizada por meio do seguinte objetivo: analisar se as políticas públicas brasileiras, materializadas no PD&I do SEB (P&D e PEE), concorrem para que o governo brasileiro possa cumprir os compromissos firmados com a Agenda 2030 e as metas da NDC, junto ao Acordo de Paris, em relação ao ODS 7.

Os procedimentos metodológicos utilizados neste estudo consistem em uma combinação de métodos e instrumentos (misto), em decorrência das diferentes demandas de análise. Incialmente, buscou-se o apoio do referencial teórico (pesquisa bibliográfica e documental) para identificar dados que pudessem contribuir para responder à pergunta de pesquisa. O conceito e o tipo de inovação, objeto de estudo deste artigo, tiveram como base o Manual de Oslo (Marques et al., 2021; OECD/Eurostat, 2018; Roesch, 2006). A coleta e a análise de dados, bem como as metas para comparação, observaram as diretrizes do Quadro 1 a seguir e Apêndice B – Artigo 2, item 3.3.

Quadro 1 – Diretrizes para coleta e análise de dados e comparação com metas da Agenda 2030

O que?	Como? Análise e resultados	Metas Agenda 2030
1) Promover a cultura da inovação, estimulando o PD&I no SEB (PP&D).	Referencial teórico e a PPU de inovação do SEB (PP&D). Invest./Resultados/Patentes	ODS 7 – Meta 7.a, em correlação com o ODS 9.
2) Criar/desenvolver novos equipamentos e diminuir a dependência tecnológica do país.	Referencial teórico e quantidade de patentes requeridas (PP&D).	ODS 7 – Meta 7.a, em correlação com o ODS 9.
3) Aprimorar a prestação de serviços e contribuir para a segurança energética.	Índice de ANEEL de Satisfação do Consumidor (IASC).	ODS 7 – Meta 7.1, em correlação com o ODS 9.

4) Energia economizada.	Quantidade em TWh.	ODS 7 – Meta 7.3, correlacionado com o ODS 9.
5) Demanda retirada da ponta.	Quantidade em GW.	ODS 7 – Meta 7.3, correlacionado com o ODS 9.
6) Investimento evitado em geração de energia.	Em R$ no período de vigência do PD&I da ANEEL.	ODS 7 – Meta 7.3, correlacionado com o ODS 9.
7) Reduzir o impacto ambiental do SEB.	Redução de emissões de CO_2e.	ODS 7, por correlação com os ODS 9 e 13.
8) Energia conservada.	Em % da energia consumida, conforme PNEE.	ODS 7 – Meta 7.3 e NDC (meta de 10,0%).
9) Aumentar a oferta de energia renovável (solar, eólica e biomassa).	Em % da matriz elétrica brasileira.	ODS 7 – Meta 7.2 e NDC (meta de 23,0%).

Fonte: Marques *et al*. (2021), conforme Apêndice B – Artigo 2, item 3.3.

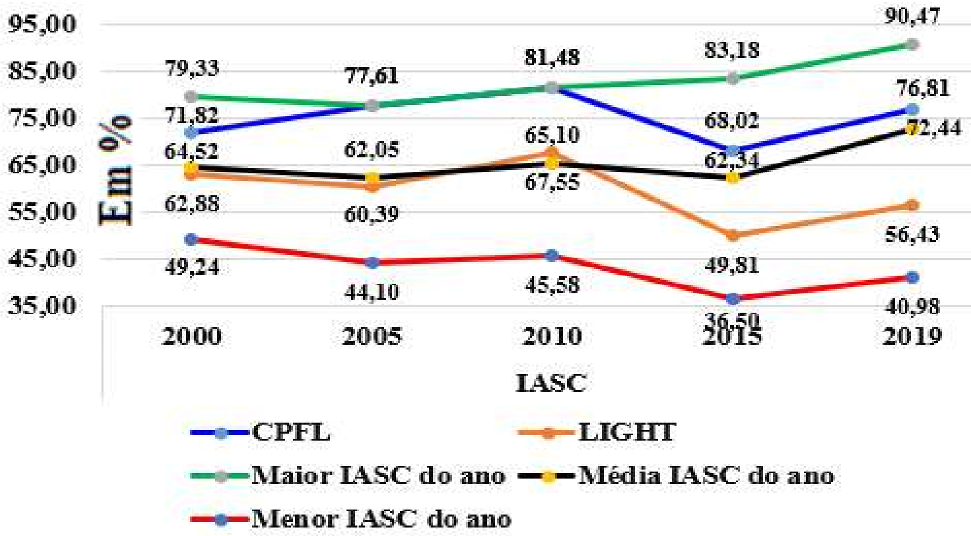
3.2 Resultados

Para melhorar a compreensão, os resultados deste estudo foram divididos em dois segmentos de programas: Pesquisa e Desenvolvimento (P&D) e de Eficiência Energética (EE), conforme a seguir.

Os resultados do P&D foram apurados e subdivididos da seguinte forma: a) evolução da qualidade dos serviços prestados aos consumidores de energia elétrica, por meio da elaboração da evolução do índice de satisfação do consumidor (IASC) de acordo com dados da (ANEEL, 2020a), para o período de 2000-2019; b) como é a integração dos atores no PD&I do SEB no conceito da tríplice hélice; c) tipos de projetos apresentados e desenvolvidos no programa; e d) evolução dos resultados no indicador de patentes.

Quanto ao índice de satisfação do consumidor (IASC), que mede a evolução da qualidade dos serviços prestados pelas concessionárias aos consumidores de energia elétrica, detectou-se a seguinte evolução: saiu de 64,52% para 72,44%, melhorando apenas 7,92% (p.p.), ao longo de 19 anos (de 2000 e 2019). Isso, representa um incremento na melhoria do índice da ordem de 0,4%a.a., o que é muito pouco quando se observa que o ponto de partida era muito baixo, situava-se em torno de 65,0%, demonstrando que, mesmo após 19 anos de programa, o IASC deve ser considerado regular, conforme Apêndice B – Artigo 2, item 4.1.3 e Figura 4 a seguir.

Figura 4 – Evolução do índice ANEEL de satisfação do consumidor (IASC), escala: de 0 a 100



Fonte: Elaborado pelos autores com base em dados da ANEEL (2020) , conforme Apêndice B – Artigo 2, item 4.1.3.

No que se refere à integração dos atores, constatou-se que houve uma evolução no conceito de tríplice hélice (academia, governo e empresas) no PD&I do SEB, em especial no P&D, por meio da ampliação do programa nas Universidades e Institutos de Ciência e Tecnologia (ICT).

Quanto aos tipos de projetos apresentados, há uma mudança de perfil, quando comparados os períodos de 2000 a 2016 e de 2017 a 2019. Os projetos com abordagem do desenvolvimento de Conceito ou Metodologia, Sistema ou Software representavam 53,54% do total, no primeiro ciclo, enquanto no último ciclo passaram para 76,67%, mudança esta que pode ser decorrente de uma presença maior da Universidade no programa. Apesar de o aumento da participação da Academia nos projetos representar um avanço, percebe-se que há uma grande concentração em pesquisa básica e aplicada, cujos projetos seguem no máximo à fase de prototipação, não gerando um produto que seja disponibilizado no mercado. Os projetos com desenvolvimento de software concentram em soluções empresariais muito personalizadas, sem possibilidades de gerar produtos ou até mesmo novos negócios escaláveis no mercado.

O indicador de patentes apresenta uma melhora significativa, pois no período de 1998 a 2007 era de 2,00% e, quando analisado o período de 2000 a 2019, o percentual foi para 7,65%. Em que pese este indicador ser muito criticado por pesquisadores e futurólogos, visto estar em um ambiente de mercado onde deverá imperar a economia colaborativa, de acordo com Schwab (2018) e Rifkin (2012), ainda é um indicador relevante para determinar a classificação de um país no Índice Global de Inovação (CNI, WIPO, & OMPI, 2020). Estes e outros resultados podem ser observados de forma detalhada no Apêndice B – Artigo 2, itens 4.1.1 e na Tabela 1.

Tabela 1 – Dados do P&D: 1998-2030

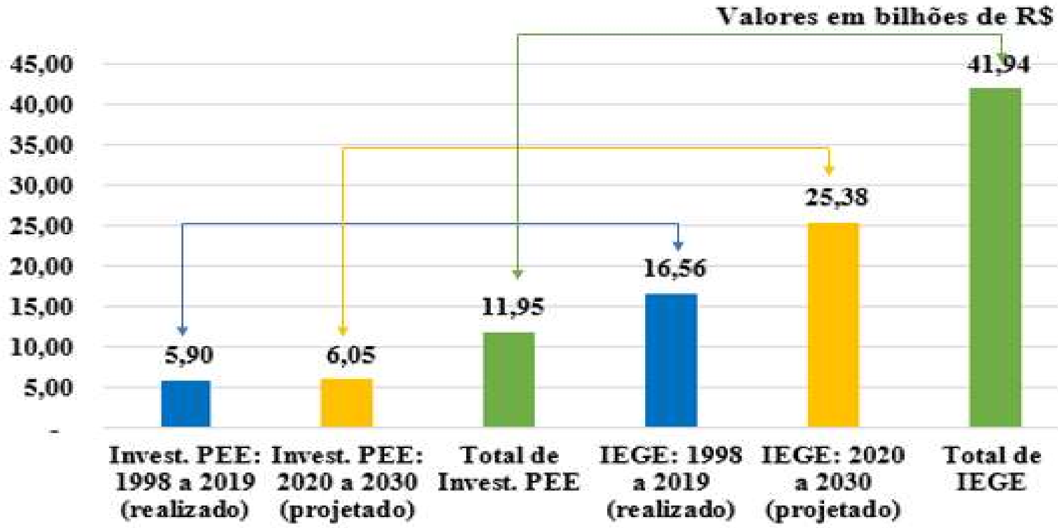
Valor de Investimento no PP&D: 1998 a 2030	**Valores em bilhões de R$**
Investimento no período: 1998 a 2019 (realizado)	7,60
Investimento no período: 2020 a 2030 (projetado)	6,05
Total de Investimento (realizado + projetado)	**13,65**
Outros dados do PP&D: realizado de 1998 a 2019	**Em Unidades**
Projetos apresentados	6.061
Projetos aprovados	4.247
Patentes e Licenças	325
Pesquisadores atuantes	1.200
Artigos publicados	3.900

Fonte: Elaborado pelos autores com base em dados da ANEEL (2020), período realizado (1998-2019). Projeções elaborada pelos autores de forma linear (2020-2030) , conforme Apêndice B – Artigo 2, item 4.1.1.

Em seguida, são apresentados os resultados do Programa de EE, da seguinte forma: a) investimento evitado em geração de energia (IEGE) elétrica entre 2000 e 2030 (realizado de 2000-2019 e a realizar 2020-2030); b) quantidade de energia elétrica economizada (EECO); c) demanda retirada da ponta (DRP); d) estimativas de energia conservada (EEC) por meio do plano nacional de eficiência energética (PNEf) até 2030, pelo programa de eficiência energética (EE) (MME, 2011). Os resultados das alíneas "a", "b", "c" e "d" foram apurados entre 2000 e 2019 e projetados para o período de 2020 a 2030.

O valor do investimento evitado em geração de energia (IEGE), no período de 2000 a 2019, foi da ordem de 16,56 bilhões de reais – cada R$ 1,00 investido em eficiência energética, neste período, gerou R$ 2,80 de IEGE, neste período. Quando projetado para o ano de 2030, acrescenta-se mais 25,38 bilhões de reais, perfazendo um total de R$ 41,94 bilhões de reais, para o período de 2000 a 2030, ampliando a relação custo *versus* benefício de R$ 1,00 investido em EE gera IEGE de R$ 3,50, em média. O IEGE é um indicador relevante pois além de evitar desembolsos do Tesouro com novos empreendimentos de grande porte de geração de energia elétrica, como é o caso das Usinas Hidrelétrica (UHE), contribui para evitar impactos socioambientais decorrentes desses empreendimentos. Os resultados detalhados estão no Apêndice B – Artigo 2, itens 4.2.1 e na Figura 5.

Figura 5 – Valores de investimento no PEE *versus* IEGE pelo PEE: 1998 a 2030



Fonte: Elaborado pelos autores com base em dados da ANEEL (2020) e projeções elaborada pelos autores, conforme Apêndice B – Artigo 2, item 4.2.1.

Há mais dois indicadores gerados por meio da análise dos projetos do Programa de EE, que são: a quantidade de energia elétrica economizada (EECO) até 2019 foi de 63 TWh/ano, e de 2020 a 2030 projetou-se uma economia de 4,39 TWh/ano, totalizando 67,39 TWh/ano de EECO, para todo o período; e a quantidade de demanda retirada da ponta (DRP) até 2019 foi de 2,80 GW, e o projetado para o período de 2020 a 2030 foi de 1,07 GW, totalizando 3,87 GW no período estudado. Ambos os indicadores podem ser conferidos no Apêndice B – Artigo 2, itens 4.2.2, e na Tabela 2 a seguir.

Tabela 2 – Energia economizada pelo PEE: 1998-2030[3] (realizado e projetado)

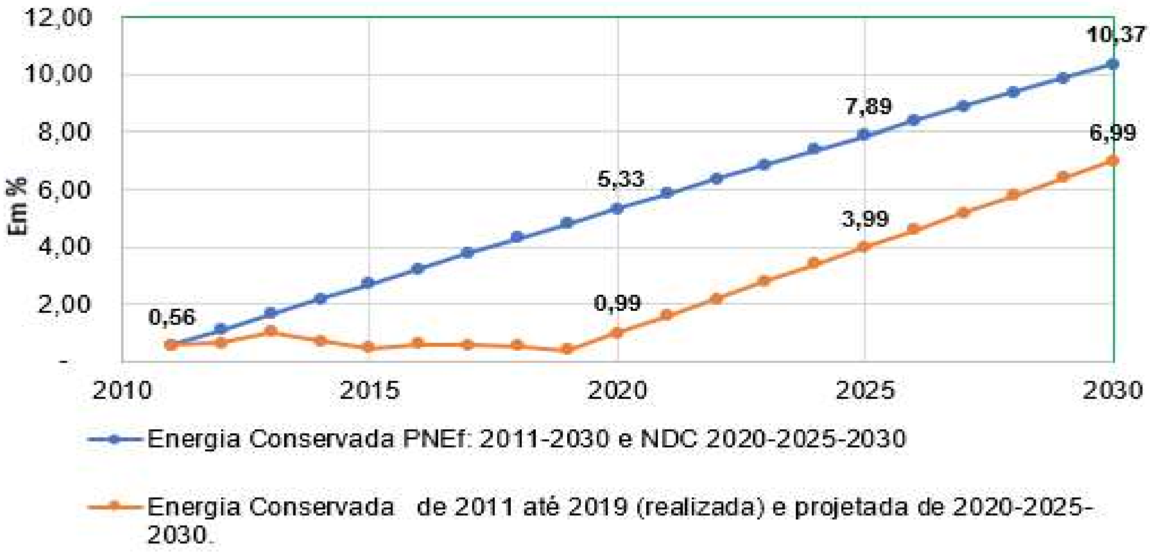
Energia Economizada (EECO)	**Qtde. (em TWh)**
EECO – realizado de 1998 a 2019 (em TWh/ano)	63,00
EECO – projetado de 2020 a 2030 (em TWh/ano)	4,39
Total de EECO (realizada + projetada) em TWh/ano	**67,39**
Demanda Retirada da Ponta (DRP)	**Qtde. (em GW)**
DRP no período de 1998 a 2019 (realizado)	2,80
DRP no período de 2020 a 2030 (projetado)	1,07
Total de DRP (realizado + projetado) em GW	**3,87**

Fonte: Elaborado pelos autores com base em dados da ANEEL (2020) e projeções elaborada pelos autores, conforme Apêndice B – Artigo 2, item 4.2.2.

3 Análise envolve o período de 1998-2030, sendo que de 1998-2019 utilizou-se os dados divulgados pela ANEEL (2020). De 2020-2030 os dados foram projetados pelos autores de forma linear.

Ainda na linha de Eficiência Energética, as estimativas de energia conservada (EEC), por meio do plano nacional de eficiência energética (PNEf) até 2030, estão aquém do comprometido na NDC do Brasil que seria 10,00% e deve ficar em torno de 7,00%, aproximadamente, conforme Apêndice B – Artigo 2, itens 4.3 e na Figura 6.

Figura 6 – Conservação de energia elétrica: meta da NDC *versus* realizado/projetado

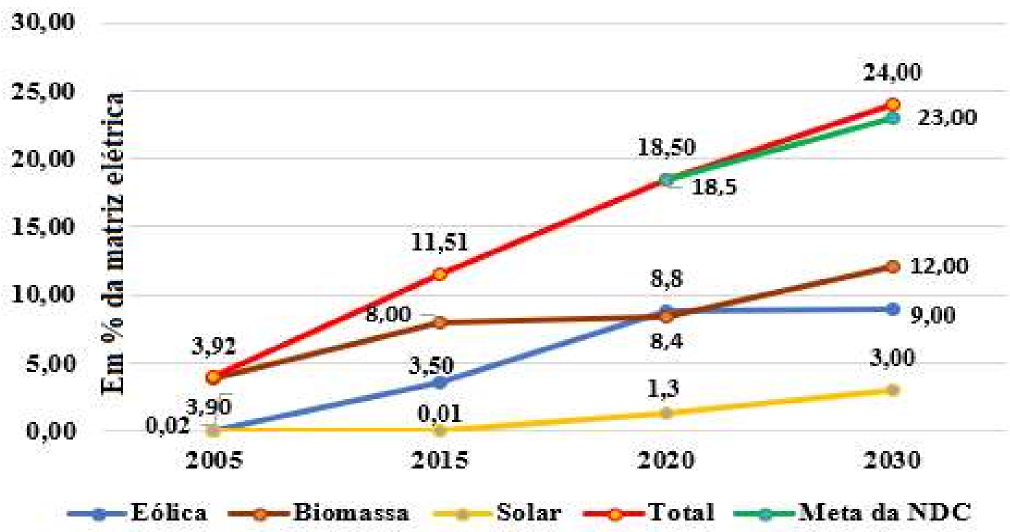


Fonte: Elaborado pelos autores com base no PNEf (MME, 2011), dados do PDE (MME/EPE, 2020) e projeções elaboradas pelos autores com base no PDE 2030 (MME/EPE, 2020) , conforme Apêndice B – Artigo 2, item 4.3.

No que se refere às metas fixadas na NDC, para fontes renováveis que são: a) expandir o uso de fontes renováveis, além da energia hídrica, na matriz total de energia para uma participação de 28% a 33% até 2030; b) aumentar o uso das fontes de energia não fóssil, ampliando a parcela de energias renováveis (eólica, biomassa e solar), além da energia hídrica, na matriz de energia elétrica para ao menos 23% até 2030, de acordo com BID (2017) e Brasil (2016), os resultados obtidos estão no Apêndice B – Artigo 2, itens 4.4, na Figura 7.

Os resultados projetados para o ano de 2030 indicam que a meta estabelecida na NDC do Brasil, para energia renovável (eólica, biomassa e solar), deve ser atingida, caso o ritmo de investimentos seja mantido.

Figura 7 – Meta da NDC para energia renovável (eólica, biomassa e solar) para 2030



Fonte: Elaborado pelos autores com base na NDC (Brasil, 2016) e BIRD (2017) e MME/EPE (2020) , conforme Apêndice B, Artigo 2, item 4.4.

Para finalizar, outro resultado importante apesentado neste estudo é a redução de emissões de CO_2e verificada no programa de EE, em que pese não estar explícita como um de seus objetivos, deve ser vista como uma externalidade positiva do programa e que está alinhada com energia limpa (ODS 7), inovação (ODS 9) e combate às mudanças climáticas e seus impactos (ODS 13), por correlação (IPEA, 2019). A meta de mitigação da ordem de 2,33 $MtCO_2e$ é factível, de acordo com as estimativas apresentadas no Apêndice B – Artigo 2, item 4.5 e na Tabela 3.

Tabela 3 – Estimativa de emissões de CO_2e evitadas com o PEE - realizado: 1998-2019 e projetado: 2030

		Períodos	Qtde. Estimada (em tCO2e)	Estimativa Total (em MtCO2e)
CENÁRIOS	**Pessimista**	1998-2019 2020-2030	1.512.000 105.369	1,617369
	Pessimista – Eficiência	1998-2019 2020-2030	1.701.000 118.540	1,819540
	Referência	1998-2019 2020-2030	3.276.000 228.299	3,504299
	Referência – Eficiência	1998-2019 2020-2030	1.764.000 122.930	1,886930
	Otimista	1998-2019 2020-2030	4.536.000 316.106	4,852106
	Otimista – Eficiência	1998-2019 2020-2030	2.079.000 144.882	2,223882

Fonte: Elaborada pelos autores com base em dados na ANEEL (2020) – realizado, e projeções dos autores com base nas expectativas do PEE da ANEEL, para o período de 2020 e 2030, conforme Apêndice B – Artigo 2, item 4.5.

3.3 Considerações Finais

As considerações finais do Estudo 2 partiram de uma análise dos resultados encontrados na pesquisa e se estes respondem à pergunta de pesquisa: como a política pública brasileira de inovação do SEB, desenvolvidas por meio do PD&I do SEB, no Programa de P&D e no Programa de Eficiência Energética (PEE), regulados pela ANEEL, impactarão os compromissos do Brasil para a Agenda 2030?

Observou-se que o PD&I do SEB, ao longo de 19 anos (2000 a 2019), notadamente o programa de P&D, apresentou uma pequena evolução no índice de satisfação do consumidor (IASC), que mede a evolução da qualidade dos serviços prestados pelas concessionárias aos consumidores de energia elétrica. Neste período, o IASC saiu de 64,52% para 72,44%, melhorando apenas 7,92% (p.p.), o que é muito pouco pois representa menos de 0,50% a.a. de taxa de melhoria.

Foi detectada uma mudança no perfil dos projetos de P&D do SEB, quando comparado o período de 2000 a 2016 com o período de 2017 a 2019. Os projetos com abordagem do desenvolvimento de Conceito ou Metodologia, Sistema ou Software representavam 53,54% do total, no primeiro ciclo, enquanto no último ciclo passaram para 76,67%, mudança esta que pode ser decorrente de uma presença maior da Universidade no programa. Mas, não foram detectadas mudanças que pudessem indicar uma guinada a um modelo de inovação alinhado com os conceitos de desenvolvimento sustentável.

Quanto a patentes, observou-se que houve uma melhora significativa, pois no período de 1998 a 2007 apenas 2,00% dos projetos resultavam em requerimento de patente. Quando analisado o período de 2000 a 2019, o percentual subiu para 7,65%, e é um indicador utilizado para avaliar o desempenho no ODS 9 e Agenda 2030.

O programa de EE do PD&I do SEB apresentou resultados positivos em diversos indicadores, tais como: investimento evitado em geração de energia (IEGE), que no período de 2000 a 2030 (realizado até 2019 e projetado até 2030) soma aproximadamente R$ 41,94 bilhões de reais, e a relação custo *versus* benefício é positiva, pois cada R$ 1,00 investido em EE gera IEGE de R$ 3,50, em média. No mesmo período, a quantidade de energia elétrica economizada (EECO) deve totalizar 67,39 TWh/ano, e a quantidade de demanda de energia elétrica retirada da ponta (DRP) totalizará 3,87 GW. Estes resultados contribuem para que o Brasil possa alinhar-se com os ODS 7, ODS 9 e ODS 13 da Agenda 2030, mas são insuficientes para o cumprimento de metas, pois apenas melhora a qualidade da energia entregue à sociedade (energia limpa), inovando na Geração, Transmissão e Distribuição (GTD) e na redução do impacto socioambiental do SEB.

Outro indicador importante dentre os compromissos assumidos na NDC do Brasil é a estimativa de energia conservada (EEC), prevista no bojo do plano nacional de eficiência energética (PNEf) até 2030, que foi revisado neste estudo e apresentou projeções nada animadoras, visto que prevê que a EEC deve ficar em torno de 7,00% aproximadamente, enquanto o compromisso firmado pelo Brasil na NDC é de 10,00%.

Percebe-se que a contribuição deste estudo foi gerar dados do programa de PD&I do SEB (P&D e PEE), para possibilitar a realização de comparações com os compromissos assumidas pelo Brasil, tanto na NDC, quanto na Agenda 2030. As suas limitações foram não aprofundar em questões como: a) a premissa de modicidade tarifária do SEB; e b) a meta 7.1 do ODS 7 de assegurar o acesso universal, confiável, moderno e a preços acessíveis a serviços de energia. Mas, cabe destacar que estas limitações foram abordadas no Estudo 3, como parte desta tese.

Fica como proposta para estudos futuros analisar formas de utilizar o PD&I do SEB para: a) ampliar a geração elétrica centralizada de fontes renováveis; b) como ampliar a geração distribuída; c) como ampliar a capacidade de armazenamento de energia; d) como investir na repotenciação de hidrelétrica; e e) como expandir a geração de energias renováveis em localidades isoladas.

4 ESTUDO 3 – ARTIGO 3

O Estudo 3 recebeu o título: Avaliação de impacto da política pública de inovação do setor elétrico brasileiro (SEB) na tarifa de energia elétrica paga pelo consumidor.

4.1 Contextualização

O terceiro estudo teve como pergunta de pesquisa: qual é o impacto da implementação da PPU de PD&I do SEB, por meio dos programas de P&D e do EE, na política de modicidade tarifária prevista no programa e nas metas da Agenda 2030?

A resposta foi viabilizada por meio do seguinte objetivo: avaliar o impacto da política pública brasileira de inovação do SEB, desde a sua implementação no ano de 2000 até 2020, sobre a tarifa média de fornecimento (TMF), visto que uma das premissas do PD&I é a modicidade tarifária, que se alinha com o ODS 7 da Agenda 2030. Como consequência da análise da TMF foi proposto um indicador do poder de compra de energia elétrica.

Os procedimentos metodológicos utilizados no presente estudo consistem em uma combinação de métodos de pesquisa bibliográfica, documental e experimental. Na pesquisa bibliográfica, buscou-se entender os resultados de estudos publicados sobre avaliação de política pública de inovação do SEB. Na pesquisa documental, identificou-se os dados referentes às tarifas de energia elétrica de 1994 a 2020, o valor da contribuição para o programa de inovação do SEB na base de dados da ANEEL, no período de 2000 a 2020, assim como o objetivo de modicidade tarifária do SEB (ANEEL, 2017, 2020b; Roesch, 2006). A pesquisa experimental foi desenvolvida para testar a hipótese de que criar a política pública e adicionar a obrigatoriedade de uma contribuição para financiar o programa de inovação trariam ganhos de eficiência para as empresas e para o sistema, de forma a beneficiar os consumidores via redução de tarifas (Maldonado & Severino, 2019).

A análise e o levantamento de dados foram realizados com base no desempenho do valor real da TMF/MWh ao longo do período de 1994 a 2022[4], por meio de uma amostra de 7 grandes distribuidoras de energia elétrica, em um total de 111, correspondendo a 6,30% do total de distribuidoras em operação em 2021, mas que juntas comercializam 38,55% da energia elétrica consumida, respondem por 39,26% da receita do setor (sem impostos) e

[4] Para efeito de projeção de valor nominal da TMF, este trabalho optou por adotar os dados projetados para 2021 e 2022, visto que eles foram divulgados pela ANEEL.

atingem 38,73% dos consumidores do território nacional, em todas as classes de consumo (ANEEL, 2021).

A análise de regressão linear possui "um conjunto de ferramentas cujo foco é a realização de inferências, na maior parte das vezes, causais", a partir de evidências encontradas para uma amostra, que permitem "realizar generalizações de resultados para a população", conforme (Chein, 2019, p. 7).

A ferramenta utilizada para a realização desta pesquisa experimental foi a análise de regressão. Em geral, a análise de regressão busca estimar o valor médio da variável dependente de uma população com base em valores conhecidos da amostra. Neste estudo, busca-se estimar efeitos das variáveis exploratórias, especialmente da *dummy* de contribuição (variável independente), na variável dependente, a tarifa média de fornecimento (TMF) de energia elétrica. É importante destacar que, embora a análise de regressão lide com a dependência de uma variável em relação a outras, isso não implica necessariamente em causação. Nas palavras de Kendall e Stuart, "uma relação estatística, por mais forte e sugestiva que seja, nunca pode estabelecer uma conexão causal: nossas ideias de causação devem vir de fora da estatística, em última análise de alguma teoria" (Gujarti & Porter, 2011).

Em relação aos tipos de dados disponíveis, têm-se dados em formato de painel, observações de "preços" de várias empresas, ao longo do tempo, ambas variáveis quantificáveis. Porém, é comum que outras variáveis do tipo qualitativas afetem a variável dependente assim como as variáveis quantitativas. Para isso, é comum que se construa uma variável binária, também conhecida como *dummy*. Tais variáveis assumem valores "0" e "1", em que "1" indica a presença do atributo e "0" a ausência (Gujarti & Porter, 2011).

Em seguida, aplicou-se o modelo "Antes e Depois da Tarifa Real", por meio de uma estimação em Mínimos Quadrados Ordinários (MQO ou OLS, em inglês), para identificar se houve mudança nos preços médios das TMF/MWh após o estabelecimento da obrigatoriedade da ContribInova utilizando quatro modelos de regressão (Peixoto et al., 2012). As fórmulas e a aplicação do método estão descritas no Estudo 3.

Na sequência, este estudo propôs um conjunto de 3 indicadores e 1 índice de poder de compra de energia. Os indicadores Poder de Compra de Energia Elétrica (PCEE) foram elaborados da seguinte forma: o primeiro, com base no Salário Mínimo Nacional (SMN); o segundo, no Salário Mínimo Cesta Básica do DIEESE (SMCBDIEESE); e o terceiro, pela Renda Média do brasileiro, calculada pelo IBGE (RMbIBGE). A seguir, têm-se os indicadores propostos, que foram calculados de 1994 a 2020, exceto o PCEERmbIBGE, que iniciou em 2012 e foi até 2020.

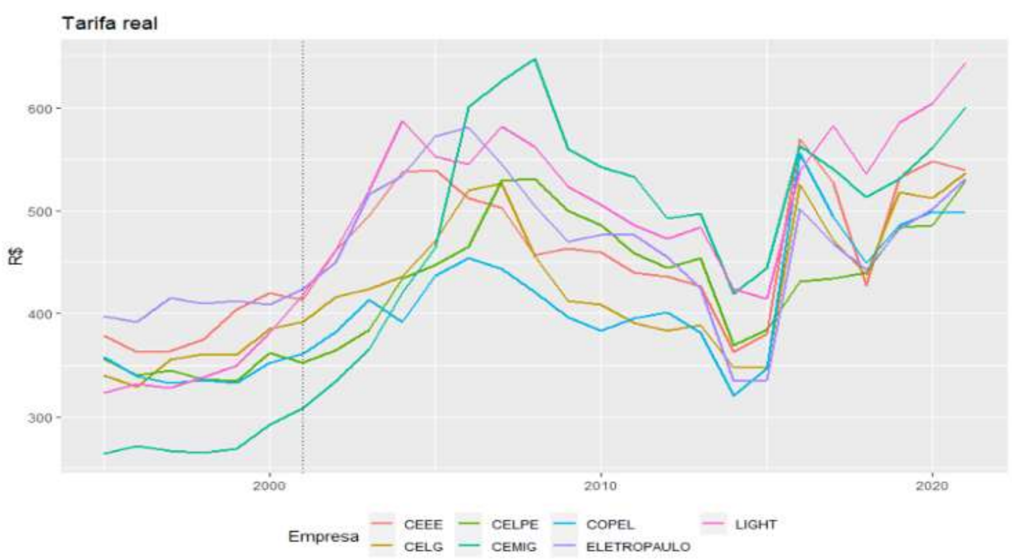
Em seguida, procedeu-se ao cálculo do índice de Poder de Compra de Energia Elétrica (iPCEE), utilizado neste estudo, a partir da $\overline{X_p}$ dos 3 indicadores $PCEESMN\ em\ MWh,$ $PCEESMCBDieese\ em\ MWh\ e\ \ PCEERmbIBGE\ em\ MWh.$ Uma vez obtida a $\overline{X_p}$ dos 3 indicadores, foi calculada a evolução da $\overline{X_p}$ dos indicadores, em percentual com base 100.

4.2 Resultados

Os resultados deste estudo foram divididos em três etapas, conforme apresentado a seguir. Na primeira etapa, foi avaliado o impacto da política pública de inovação do SEB, o programa de PD&I do SEB (P&D e PEE), na tarifa média de fornecimento (TMF) de energia elétrica, ocorrido logo após a implementação da política pública no ano de 2000.

Nesta etapa do Estudo 3 foi demonstrado que a política pública de inovação do SEB, o programa de PD&I do SEB (P&D e PEE), ao criar a Contribuição de Inovação (ContribInova) para financiar o programa, impactou o valor da TMF paga pelo consumidor de energia elétrica, conforme Apêndice C – Artigo 3, itens 4.3 e na Figura 8.

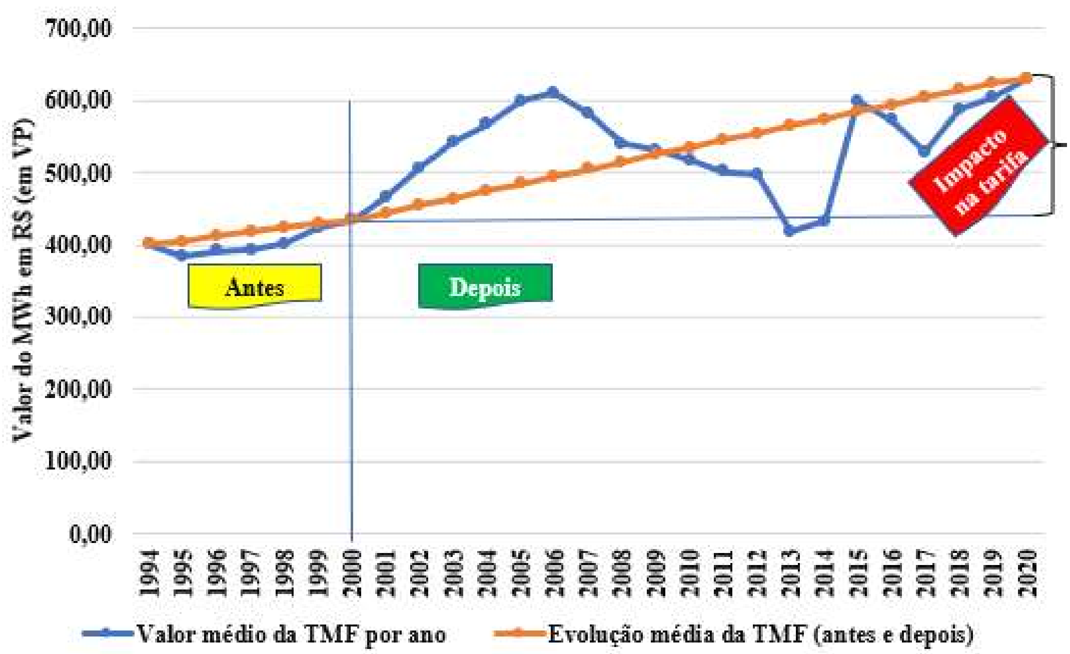
Figura 8 – Tarifa de energia elétrica (TMF) real (em R$ 1,00) de 1994 a 2020 em MWh



Fonte: elaborado pelos autores com base na TMF/MWh Real (1994-2020), a partir de dados da ANEEL (2021), atualizada pelo IPCA (IBGE, 2021), calculado no software R, , conforme Apêndice C – Artigo 3, item 4.3.

A estimação foi realizada pelo método *Antes* e *Depois* e compreendeu o período de 1994 a 2020, sendo que de 1994 a 1999 foi denominado *Antes* e o período de 2000 a 2020 foi denominado *Depois*, cujo impacto foi da ordem de 60,95%, o que implica em dizer que gerou um aumento real no valor da TMF desta ordem. Deve-se destacar que este impacto deve ser tratado como indício, uma vez que não foram investigadas outras possíveis causas, dentre elas o efeito do câmbio sobre a cadeia de fornecimento do setor elétrico que é internacionalizada, conforme Apêndice C – Artigo 3, item 4.3 e na Figura 9, que demonstra a variação da TMF em reais.

Figura 9 – Evolução da TMF real de 1994 a 2020 – Valor do MWh em R$ (em VP)

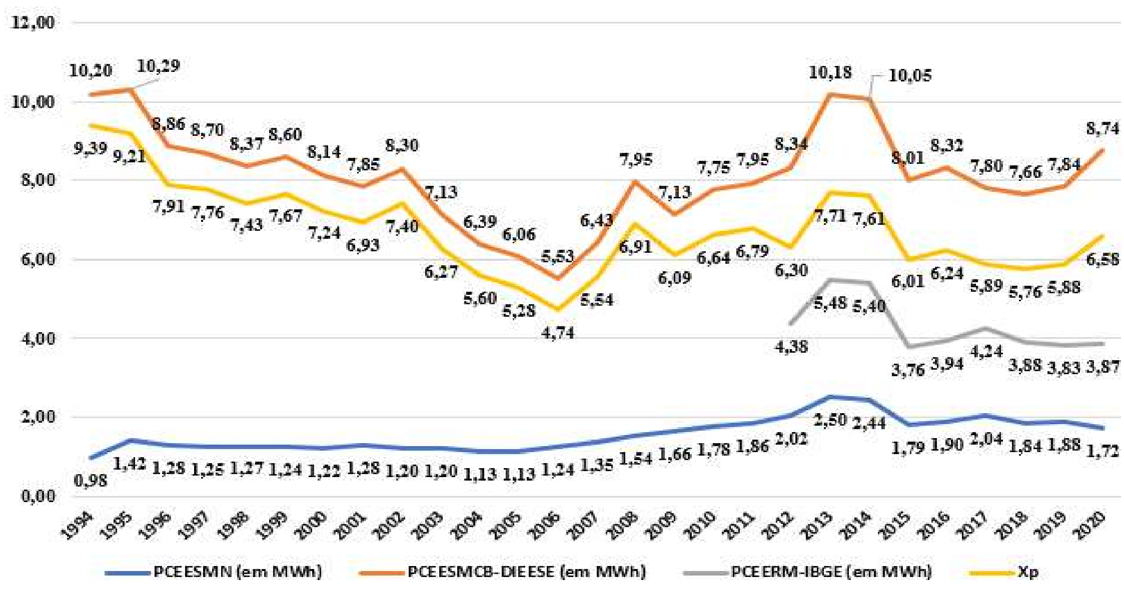


Fonte: elaborado pelos autores com base na TMF/MWh Real (média anual), a partir de dados da ANEEL (2021) e VP calculado pelo IPCA (IBGE, 2021), , conforme Apêndice C – Artigo 3, item 4.3.

Na segunda etapa deste estudo, foi proposta a criação do índice de poder de compra de energia elétrica (iPCEE), composto por três indicadores: a) Poder de compra de energia elétrica com base no salário mínimo nacional (PCEESMN); b) Poder de compra de energia elétrica com base no salário mínimo cesta básica do DIEESE (PCEESMCB-DIEESE); e c) Poder de compra de energia elétrica com base na renda médio do IBGE (PCEERM-IBGE). Em seguida, efetuou os cálculos dos indicadores e do iPCEE, que confirmou o alto custo da TMF da energia elétrica nos últimos 21 anos, de 2000 a 2021, e projetou o índice para o ano de 2022, confirmando a tendência de aumento no valor da energia elétrica.

Os dados apresentados pelos indicadores desenvolvidos neste estudo, na série histórica de 1995 a 2020, evidenciaram que houve perda de poder aquisitivo do brasileiro, quando se compara a relação renda versus valor da TMF/MWh, exceto para o indicador PCEESMN que tem como base o salário mínimo nacional, que passou um bom período apresentando ganho real (2003 a 2014). A média aritmética ponderada dos três indicadores também reflete a perda no poder aquisitivo, demonstrando mais uma vez a dificuldade do Brasil em cumprir o pactuado na Agenda 2030 que é ofertar energia elétrica a preços acessíveis, conforme Apêndice C – Artigo 3, item 4.5 e na Figura 10.

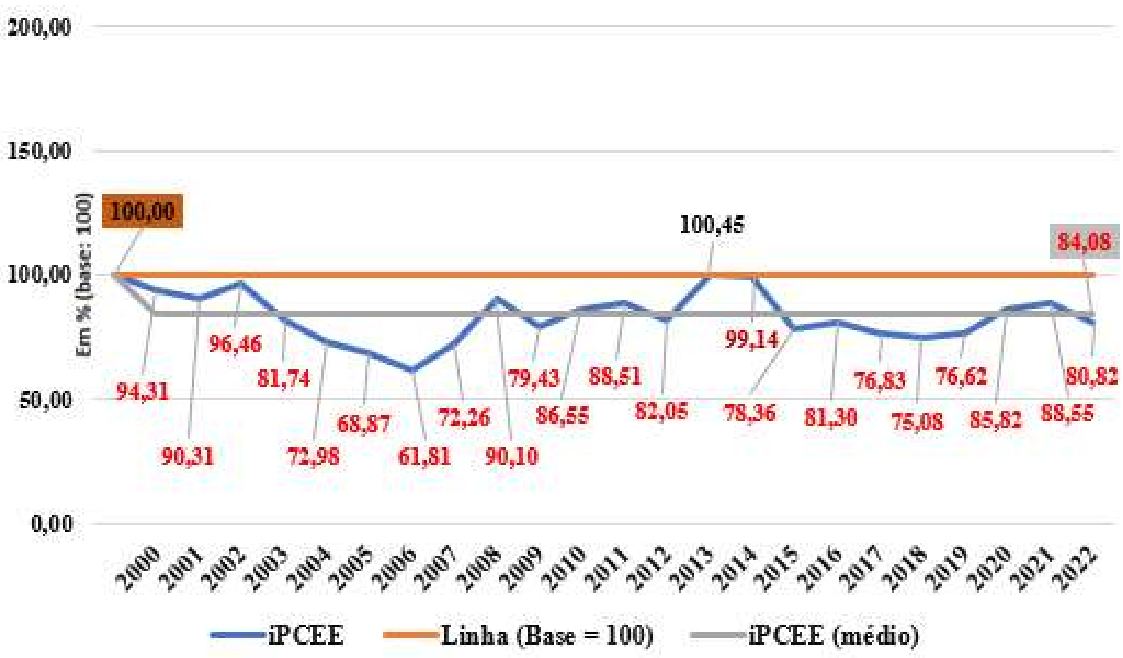
Figura 10 – Evolução dos indicadores do poder de compra de energia elétrica (1994-2020)



Fonte: elaborado pelos autores com base em dados IBGE (2021), IPEA (2021) e DIEESE (2021), , conforme Apêndice C – Artigo 3, item 4.5.

O iPCEE é um índice de base 100, que iniciou em 1999 com 100,00%, logo no ano seguinte caiu para 94,31%, chegou em 2006 com 61,86%, fechou 2021 com 88,52% e fechará 2022 com 80,82%. Somente no ano de 2013 o iPCEE fechou em 100,45% (ano em que teve um corte de 30% no preço da energia elétrica). A média do iPCEE de 2000 a 2020 foi 84,08%, considerando que, se a média fosse de 100,00%, poder-se-ia afirmar que nesse período o consumidor teria perdido poder de comprar em relação ao valor pago por MWh, em aproximadamente 16,00% (100,00 – 88,08 = 15,92%), conforme demonstrado no Apêndice C – Artigo 3, item 4.6 e na Figura 11.

Figura 11 – Evolução do iPCEE de 2000 a 2020 e projetado para 2021 e 2022



Fonte: elaborado pelos autores com base nos três indicadores de PCEE, conforme Apêndice C – Artigo 3, item 4.6.

4.3 Considerações Finais

Este estudo contribuiu para avaliar o impacto da política pública brasileira de inovação do SEB, desde a sua implementação no ano de 2000 até 2020, sobre a tarifa média de fornecimento (TMF), tendo como premissas a modicidade tarifária e ODS 7 da Agenda 2030, inclusive criando o iPCEE (de 2000 a 2022), que é um índice que mede o poder de compra de energia elétrica do brasileiro, a partir de três indicadores de poder de compra de energia elétrica.

O estudo apresentou evidências de que a política pública de inovação do SEB, o PD&I do SEB, financiada por meio de uma contribuição de 1,0% que incide sobre a Receita Operacional Líquida (ROL) das empresas do SEB, provocou um impacto no valor da TMF para maior (aumento), da ordem de 60,45% ao longo do período analisado.

O iPCEE calculado em todo o período de 2000 a 2022, demonstrou que o brasileiro perdeu poder de compra de energia elétrica ao logo de todo o período estudado, exceto no ano de 2013, cujo ganho foi de 0,45%. Nos outros 21 anos analisados, o consumidor teve que assimilar perdas relevantes.

Para fechar as considerações finais, deve-se destacar que o resultado da estimação do impacto da cobrança da ContribInova no preço da TMF de energia é corroborado pelo resultado do iPCEE, que demonstra perda no poder de compra de energia elétrica do consumidor em relação ao valor da TMF de energia elétrica.

A maior contribuição deste estudo foi gerar insumos para fazer comparações entre o estágio atual da política pública de inovação do SEB e os compromissos com a modicidade tarifária e as metas da Agenda 2030.

Deve-se destacar que uma limitação deste estudo foi não investigar outras possíveis causas do aumento da TMF de energia elétrica no período estudado, tais como o efeito do câmbio na tarifa de energia elétrica, da carga tributária e das bandeiras tarifárias em função da crise hídrica, que ficam como proposta para estudos futuros.

5 ESTUDO 4 – ARTIGO 4

Ao Estudo 4 foi dado o título: Avaliação do grau de maturidade e do nível de prontidão tecnológica do programa de PD&I do setor elétrico brasileiro (SEB).

5.1 Contextualização

O quarto e último estudo procurou responder a seguinte pergunta: como o grau de maturidade de inovação e o nível de prontidão tecnológica do programa de PD&I do SEB podem contribuir para entregar resultados melhores para a sociedade?

Para responder à pergunta proposta neste estudo, foi fixado o seguinte objetivo: estimar o grau de maturidade de inovação, bem como o nível de prontidão tecnológica 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 deste estudo foram divididos em oito etapas, que envolvem a busca de dados bibliográficos e documental, pesquisa de campo, com tabulação e análise, conforme descrito a seguir.

Na primeira etapa, foram selecionados artigos científicos e relatórios técnicos que tratam de empreendedorismo e inovação, com foco em desenvolvimento de ecossistema de inovação, segundo (Marques et al., 2020).

Na etapa dois, realizou-se um levantamento das publicações do Índice Geral de Inovação (IGI) da WIPO que faz uma pesquisa em âmbito global e da publicidade do IGI por país, anualmente (WIPO, 2021; CNI, WIPO & OMPI, 2020; WIPO, 2019). Na sequência, identificou-se uma publicação da União Europeia, denominada (European Union (EU), 2017), com um ranking do Índice de Intensidade de Inovação (III) de 2.500 empresas em âmbito mundial. No ranking do IGI, verificou-se a posição do Brasil no ranking de 2011 a 2021, o grupo de países Top 10 no mundo, Top 5 na América Latina e Caribe, bem como o ranking no grupo dos BRICS. No ranking do Índice de Intensidade de Inovação, identificou-se empresas do setor elétrico que divulgam a sua intensidade de inovação, para comparar com empresas brasileiras e o índice apurado pelo IBGE/PINTEC, por segmentos de negócio, com destaque para o setor de eletricidade (IBGE, 2017, 2020; PINTEC, 2017).

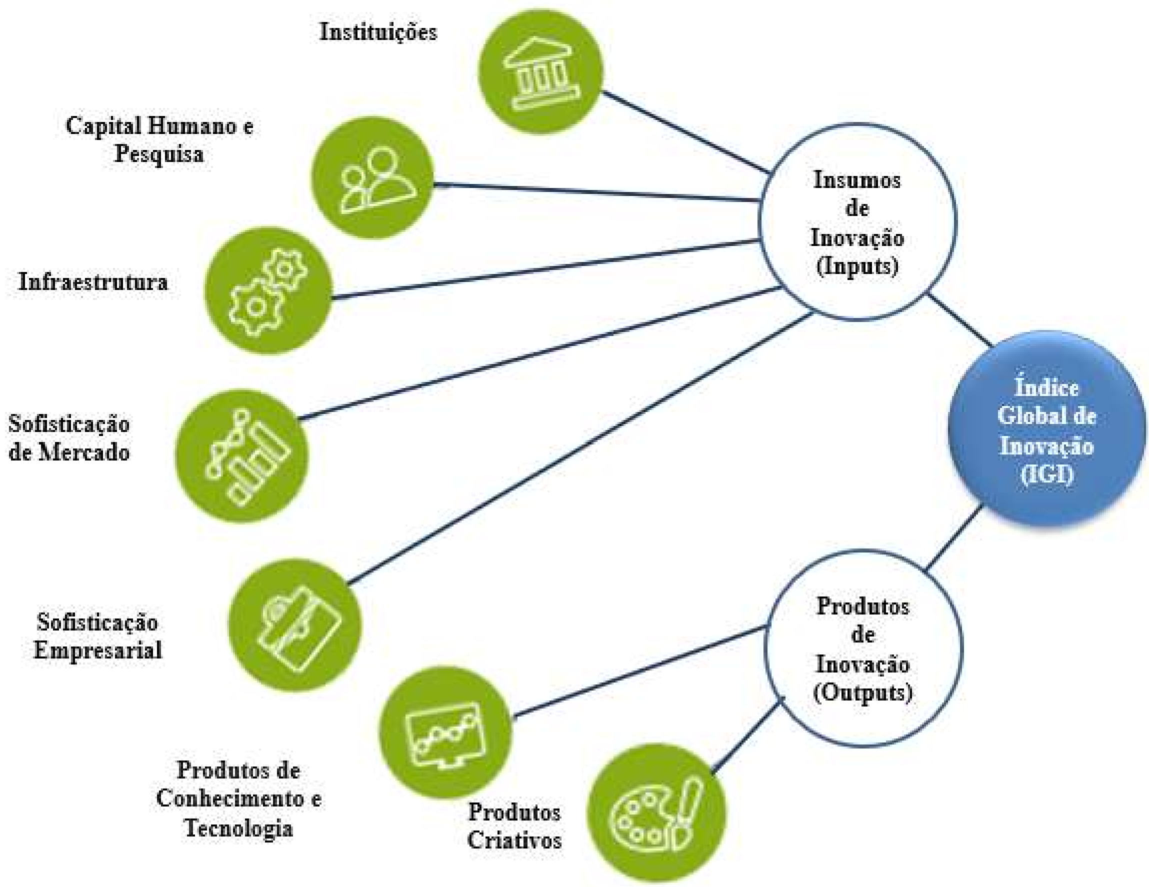
A terceira etapa compreende uma análise dos indicadores do índice global de inovação, do índice de intensidade de inovação tanto em âmbito global, como local. A análise passa pelo desmembramento dos indicadores de insumos de inovação e produtos de inovação, para entender o índice de eficiência de inovação (IEI) e comparar com países dos BRICS, a partir de dados da WIPO (WIPO, 2021; CNI, WIPO & OMPI, 2020; WIPO, 2019). O IGI é composto por dimensões de Inputs e Outputs, que se dividem da seguinte forma, conforme (CNI, WIPO & OMPI, 2020):

a) insumos de inovação: i) instituições; ii) capital humano e pesquisa; iii) infraestrutura; iv) sofisticação de mercado; v) sofisticação empresarial; e,

b) produtos de inovação: i) produtos de conhecimento e tecnologia; e ii) produtos criativos.

A seguir, têm-se uma mostra de como essas dimensões operam dentro de um ecossistema e como geram insumos para avaliação do IGI e IEI, conforme Apêndice D – Artigo 4, item 2.3 e na Figura 12.

Figura 12 – Estrutura esquemática do Índice Global de Inovação



Fonte: WIPO (2020, adaptado pelos autores, conforme Apêndice D – Artigo 4, item 2.3.

Na quarta etapa, elaborou-se o planejamento e a execução da pesquisa de campo, envolvendo as seguintes ações: a) definição da amostra: o mailing da ANEEL continha 453 gerentes de P&D, excluídos 246 nomes repetidos (devido uma pessoa representar uma ou mais empresas, resultou em 207 gerentes de P&D. Ao fazer o teste de contato, 67 contatos não responderam, logo, foram excluídos, ficando um total de 140 contatos ativos, que foram definidos como a população objeto da pesquisa; b) como se trata de uma população pequena e com uma certa dificuldade de acesso, optou-se pela amostragem por julgamento, visto que o público-alvo é agrupado em torno do tema da pesquisa (Stevenson, 1981); c) Na primeira rodada de aplicação do questionário em meio digital, foram recebidas 32 respostas, o que corresponde a 22,86% da população, próximo à média deste recurso que é da ordem de 25,00%, conforme (Vieira, Castro & Shuch Junior, 2010); d) mesmo não tendo a obrigação de atingir um percentual da população, foi realizada uma busca por meio da plataforma de relacionamento profissional *LinkedIn*, identificando profissionais (pesquisadores, colaboradores do P&D ligados aos gerentes de P&D pesquisados e gestores públicos ligados ao programa), convidando-os a responder a pesquisa e, com isso, chegou-se a 48 questionários respondidos. Deve-se destacar que a idealização do questionário levou em conta uma combinação de dimensões utilizadas para avaliação de grau de maturidade de ecossistemas de inovação defendida por diferentes especialistas (Fundação CERTI, 2021; Isidro, 2020; Montezano & Isidro, 2020; Isenberg, 2010).

Na quinta etapa, efetuou-se a tabulação dos dados, que foram agrupados por dimensões em uma tabela, de forma que ela pudesse gerar diferentes tipos de análises, principalmente duas, consideradas focos deste estudo: avaliação de grau de maturidade de inovação do SEB e avaliação de nível de maturidade tecnológica do SEB, pela escala TRL (Fundação CERTI, 2021; Gurgel Veras, 2021; Mankins, 2004).

Na etapa seis, procedeu-se à análise do grau de maturidade de inovação do SEB, com base nas respostas do questionário, agrupando as respostas em seis dimensões: a) ambiente de inovação; b) programas e ações; c) ambiente de CT&I; d) políticas públicas; e) financiamento; e f) governança. As dimensões foram apresentadas em gráfico radar, para proporcionar uma visão dimensional do ecossistema de inovação do SEB (Fundação CERTI, 2021).

Na sétima etapa, o foco foi estimar o nível de maturidade tecnológica (TRL) do PD&I do SEB, elaborando a classificação em níveis de TRL, que varia de 1 a 9, dividido em seis dimensões: i) pesquisa básica da tecnologia; ii) pesquisa para provar viabilidade; iii) tecnologia em desenvolvimento; iv) demonstração tecnológica; v) desenvolvimento de processos (sistema); vi) teste do produto ou serviços, operação e lançamento em escala comercial (Gurgel Veras, 2021; Mankins, 2004). A escala TRL/MRL varia de 1 a 9, conforme Apêndice D – Artigo 4, item 2.3.5 e no Quadro 2.

Quadro 2 – Nível prontidão tecnológica: escala TRL/MRL

NÍVEL	DESCRIÇÃO DO NIVEL DE PRONTIDÃO TECNOLÓGICO
TRL/MRL 1	Ideia da pesquisa que está sendo iniciada e esses primeiros indícios de viabilidade estão sendo traduzidos em pesquisa e desenvolvimento futuros.
TRL/MRL 2	Os princípios básicos foram definidos e há resultados com aplicações práticas que apontam para a confirmação da ideia inicial.
TRL/MRL 3	Em geral, estudos analíticos e/ou laboratoriais são necessários nesse nível para ver se uma tecnologia é viável e pronta para prosseguir para o processo de desenvolvimento. Nesse caso, muitas vezes, é construído um modelo de prova de conceito.
TRL/MRL 4	Coloca-se em prática a prova de conceito, que consiste em sua aplicação em ambiente similar ao real, podendo constituir testes em escala de laboratório.
TRL/MRL 5	A tecnologia deve passar por testes mais rigorosos do que a tecnologia que está apenas na TRL 4, ou seja, validação em ambiente relevante de componentes ou arranjos experimentais, com configurações físicas finais. Capacidade de produzir protótipo do componente do produto.
TRL/MRL 6	A tecnologia constitui um protótipo totalmente funcional ou modelo representacional, sendo demonstrado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras).
TRL/MRL 7	O protótipo está demonstrado e validado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras).
TRL/MRL 8	A tecnologia foi testada e qualificada para ambiente real, estando pronta para ser implementada em um sistema ou tecnologia já existente.
TRL/MRL 9	A tecnologia está comprovada em ambiente operacional (fabricação competitiva no caso das principais tecnologias facilitadoras), uma vez que já foi testada, validada e comprovada em todas as condições, com seu uso em todo seu alcance e quantidade. Produção estabelecida.

Fonte: Diniz (2021), adaptado pelos autores, conforme Apêndice D – Artigo 4, item 2.3.5.

Na etapa oito, analisou-se o estágio atual do PD&I do SEB, quanto ao conceito de elo perdido da inovação ou vale da morte da inovação, usando o nível de prontidão tecnológica da inovação TRL de Mankins (2004), a curva de necessidade de recursos de inovação da ABGi Brasil (2022) e a oferta de recursos no PD&I do SEB.

5.2 Resultados

A partir dos resultados gerados pelas etapas anteriores, o quarto e último estudo levantou o posicionamento do Brasil em âmbito global por meio do índice global de inovação (IGI), comparou com a lista de países Top 10 no mundo, Top 5 na América Latina e Caribe, e nos BRICS – analisou-se ainda a evolução dos insumos de inovação e produtos de inovação, bem como o índice de eficiência de inovação do Brasil, comparando o desempenho Brasil versus China de 2011 a 2021.

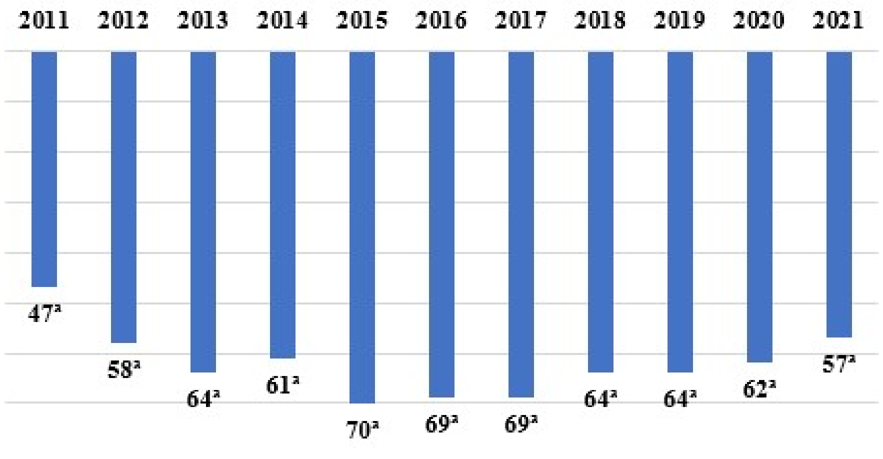
Em seguida, verificou-se a evolução dos gastos de inovação do Brasil e no mundo e foi realizada a avaliação do grau de maturidade da política pública brasileira de inovação ou do programa de PD&I do SEB, seguindo os ensinamentos de Cukerman, Rouach, & Pagani (2019); de Mazzucato (2014); e de Isenberg (2010).

Na sequência, estimou-se o nível de maturidade tecnológica ou nível de prontidão tecnológica do PD&I do SEB, utilizando a metodologia *Technology Readiness Level* (TRL) ou *Manufacturing Readiness Levels* (MRL) de Mankins (2004). Para finalizar, realizou-se uma análise do ciclo de vida do projeto de PD&I do SEB, com a identificação do elo perdido da inovação ou vale da morte da inovação. Veja os resultados detalhados a seguir.

Os principais resultados do Estudo 4 mostram o baixo desempenho do Brasil no ranking do Índice Global de Inovação (IGI), pois estava na 47ª posição em 2011, em 2015 chegou à 70ª e em 2021 fechou na 57ª posição, conforme Apêndice D – Artigo 4, item 4.1 e a Figura 13.

Figura 13 – Evolução da posição do Brasil no índice global de inovação (IGI) - de 2011 a 2021 (0-100)

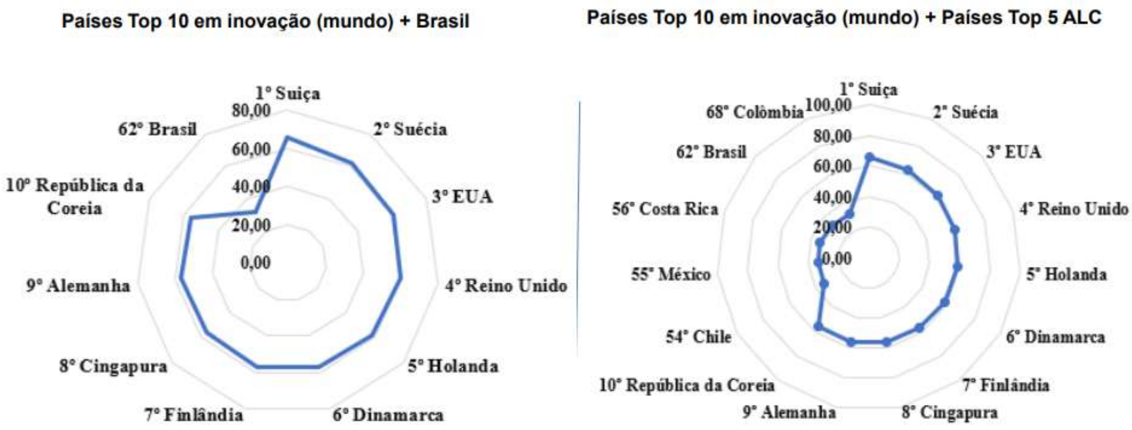
(Ranking com 132 países)



Fonte: elaborado pelos autores (WIPO, 2019; 2020; 2021), conforme Apêndice D – Artigo 4, item 4.1.

No ranking regional (América Latina e Caribe), o Brasil ocupa a 4ª posição, ficando atrás de Chile, México e Costa Rica. Quando a comparação é feita entre os países dos BRICS, o Brasil amarga a última posição entre os 5 componentes, conforme Apêndice D – Artigo 4, item 4.1 e a Figura 14.

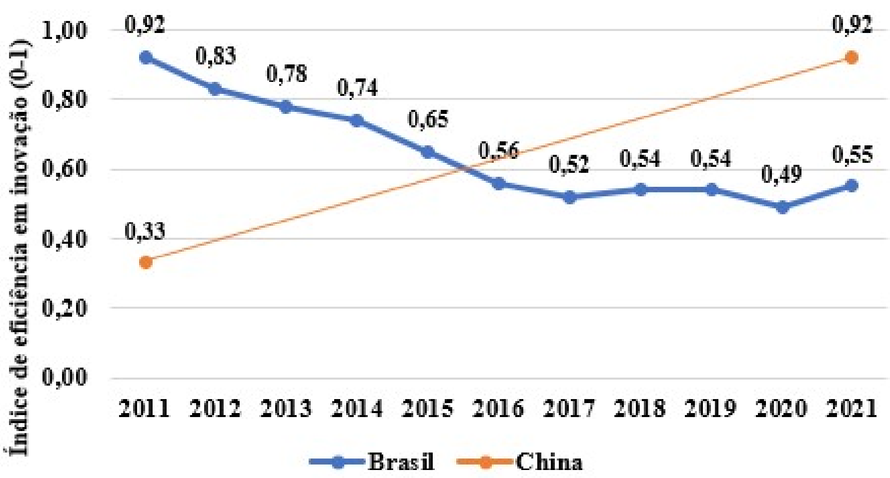
Figura 14 – Índice global de inovação (IGI) - ranking de 2020 (0-100)



Fonte: elaborado pelos autores (WIPO, 2020; 2021), conforme Apêndice D – Artigo 4, item 4.1.

No índice de eficiência de inovação (IEI) (que varia de “0” a “1”), o Brasil obteve em 2011 o índice de 0,92, mas em 2021 chegou a 0,55 portanto, em queda livre no período analisado. Comparando no âmbito dos BRICS, o índice chinês em 2011 era de 0,33, chegou em 2021 com 0,92, praticamente, fez o inverso do Brasil em um indicador que mede quão bem ou mal o país gasta os seus recursos com inovação, conforme Apêndice D – Artigo 4, item 4.2 e a Figura 15.

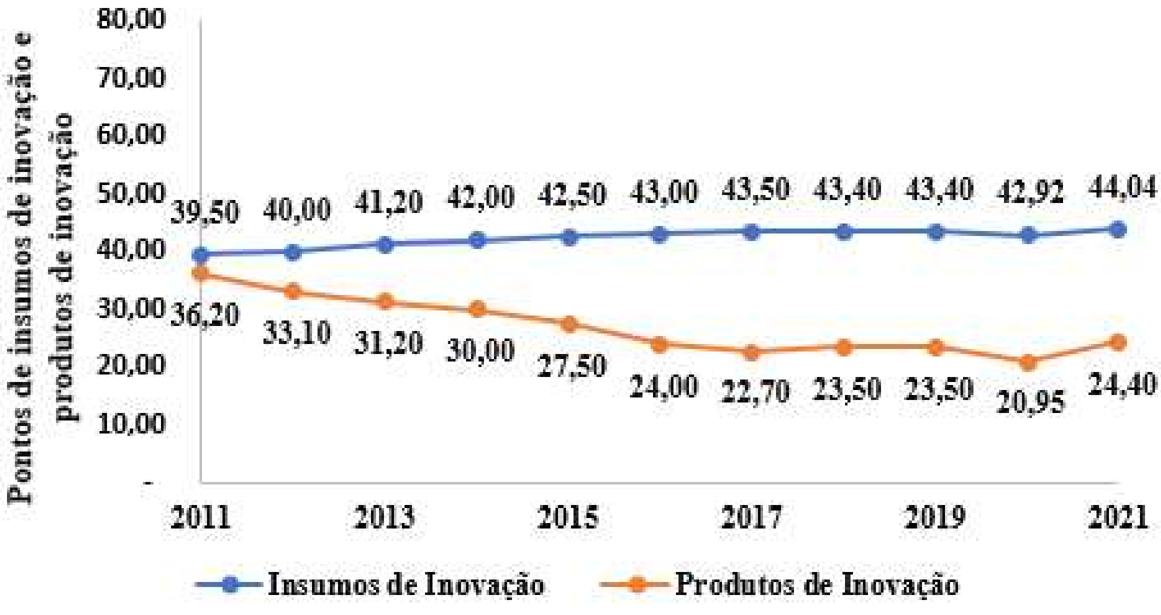
Figura 15 – Evolução do índice de eficiência de inovação do Brasil – de 2011 a 2021



Fonte: elaborado pelos autores (WIPO, 2108; 2019; 2020; 2021), conforme Apêndice D – Artigo 4, item 4.2.

Quanto aos insumos de inovação (Instituições, Capital Humano e Pesquisa, Infraestrutura, Sofisticação de Mercado e Sofisticação Empresarial), pode-se dizer que em 2011 a pontuação obtida estava em 39,50, chegou em 2021 com 44,04 pontos, enquanto para os produtos de inovação (Produtos de Conhecimento e Tecnologia e Produtos Criativos) a pontuação em 2011 era de 36,20, mas em 2021 atingiu 24,40 pontos, ou seja, o indicador encontra-se em queda, o que provoca a queda no nível de eficiência dos gastos com inovação no país, conforme Apêndice D – Artigo 4, item 4.2 e a Figura 16.

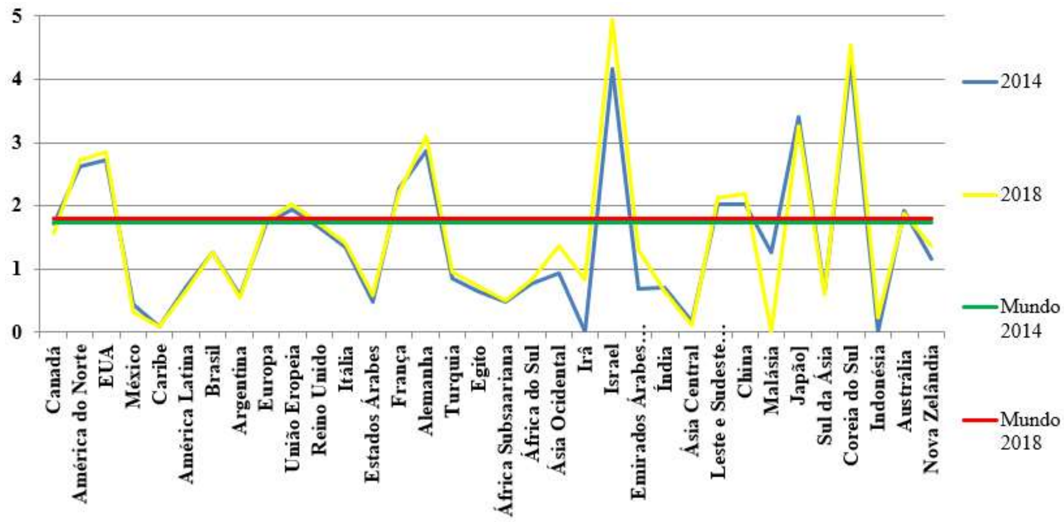
Figura 16 – Evolução da pontuação do Brasil em insumos de inovação e produtos de inovação: 2011 a 2021



Fonte: elaborado pelos autores (WIPO, 2108; 2019; 2020; 2021), conforme Apêndice D – Artigo 4, item 4.2.

Um indicador de referência para investimentos em inovação de um país é o percentual do PIB que é destinado para inovação. O Brasil investiu em média nos últimos anos algo em torno de 1,2% do PIB Nacional, o que representa 50% dos investimentos de países como EUA e Alemanha, e aproximadamente, 1/3 de países como Coreia do Sul, China, Japão e Israel. Este indicador pode ser um indício para explicar o declínio nos rankings de inovação e perda de competitividade no mercado internacional, conforme Apêndice D – Artigo 4, item 4.4.1 e a Figura 17.

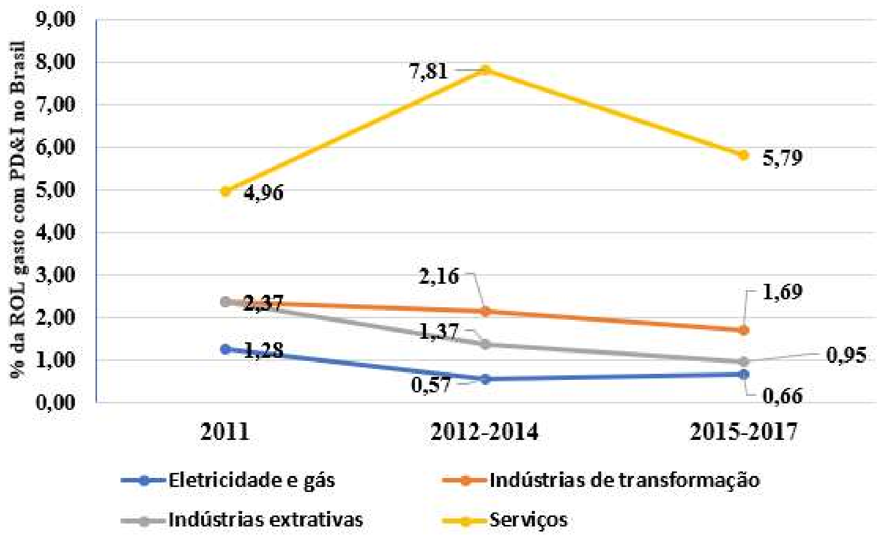
Figura 17 – Gasto com investimento em inovação por país e região em % do PIB



Fonte: elaborado pelos autores (UNESCO, 2021), conforme Apêndice D – Artigo 4, item 4.4.1.

Outro dado que contribui para o baixo desempenho nos indicadores de inovação do Brasil são os gastos com PD&I no Brasil por organizações, cuja medida é o percentual da Receita Operacional Líquida (ROL) da empresa que é investido em inovação. O setor de eletricidade e gás, objeto deste estudo, gastou 1,28% da sua ROL em PD&I em 2011, reduziu para 0,57% entre 2012-2014 e voltou a subir no triênio 2015-2017, quando registrou 0,66% da ROL, aproximadamente a metade do triênio 2009-2011, conforme Apêndice D – Artigo 4, item 4.3 e a Figura 18.

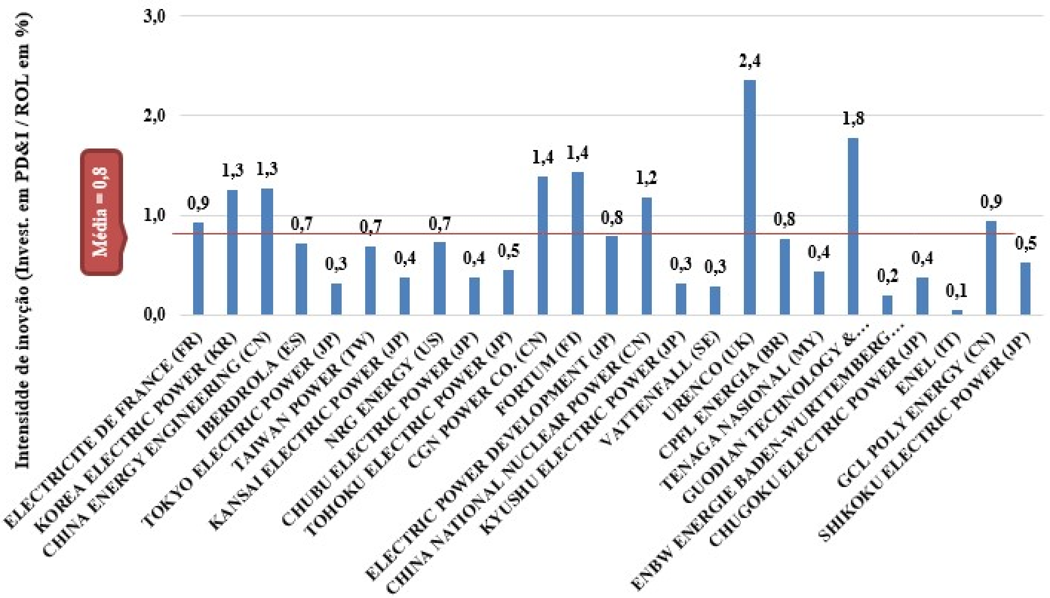
Figura 18 – Evolução dos gastos com PD&I no Brasil – de 2011 a 2017



Fonte: elaborado pelos autores (IBGE/PINTEC 2017, 2020), conforme Apêndice D – Artigo 4, item 4.3.

Quando a análise desce ao nível de corporações do setor elétrico global, a única empresa brasileira do setor elétrico brasileiro (SEB), que aparece no ranking global é a CPFL Energia, com índice de intensidade de inovação igual a 0,8%, o que corresponde exatamente ao índice médio das empresas que estão naquele ranking, e acima de 0,7% que o índice do setor no Brasil. Isso não gera nenhum conforto ao Brasil, pois de um total de 25 empresas desse ranking, 10 estão acima da média, por conseguinte à frente do Brasil, sendo que algumas registram até 3 vezes o índice brasileiro, conforme Apêndice D – Artigo 4, item 4.4.2 e a Figura 19.

Figura 19 – Intensidade de inovação de empresas de eletricidade no mundo



Fonte: elaborado pelos autores (European Union/Scoreboard, 2017), conforme Apêndice D – Artigo 4, item 4.4.2

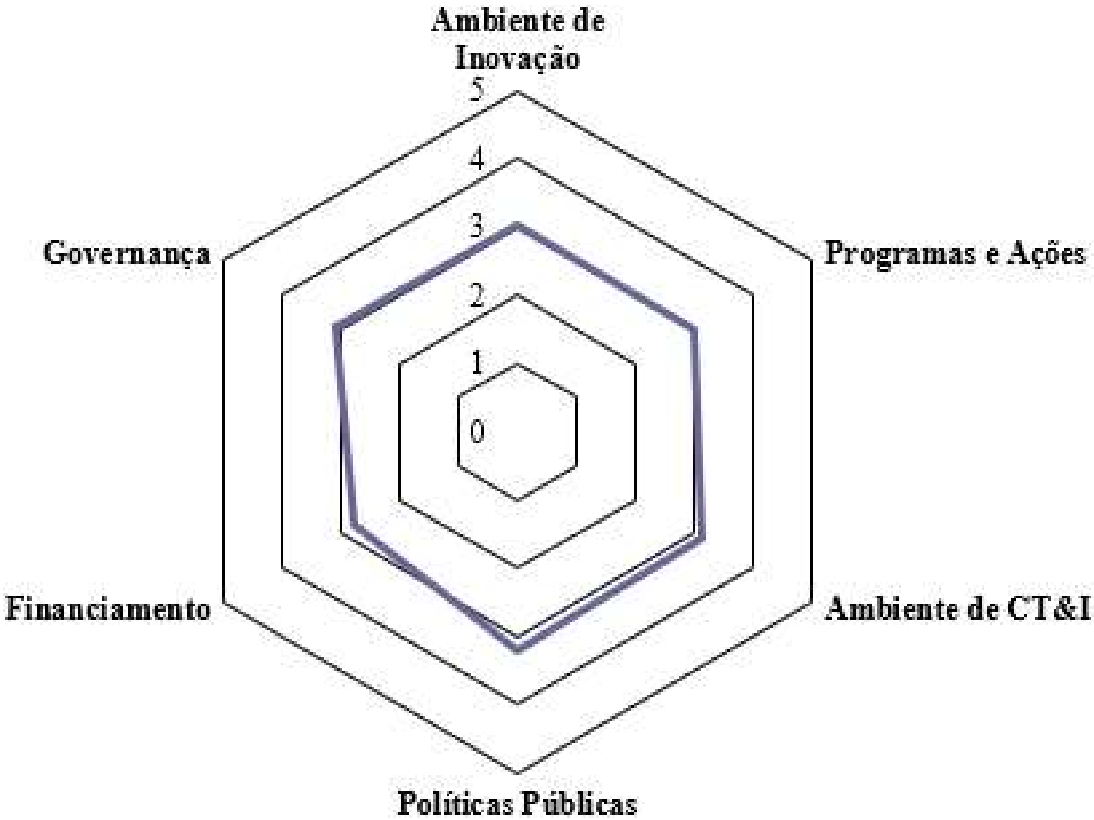
Outros resultados que este estudo trouxe foram a avaliação do grau de maturidade da inovação do PD&I do SEB, que atingiu grau 3, conforme Apêndice D – Artigo 4, item 4.5 e a Figura 20.

Figura 20 – Grau de maturidade de inovação do PD&I do SEB

Fonte: adaptado pelos autores (Fundação CERTI, 2021), conforme Apêndice D – Artigo 4, item 4.5.

A avaliação do grau de maturidade do SEB é analisada em 6 dimensões: ambiente de inovação; programas e ações; ambiente de CT&I; políticas públicas; financiamento e governança, conforme Apêndice D – Artigo 4, item 4.5 e a Figura 21.

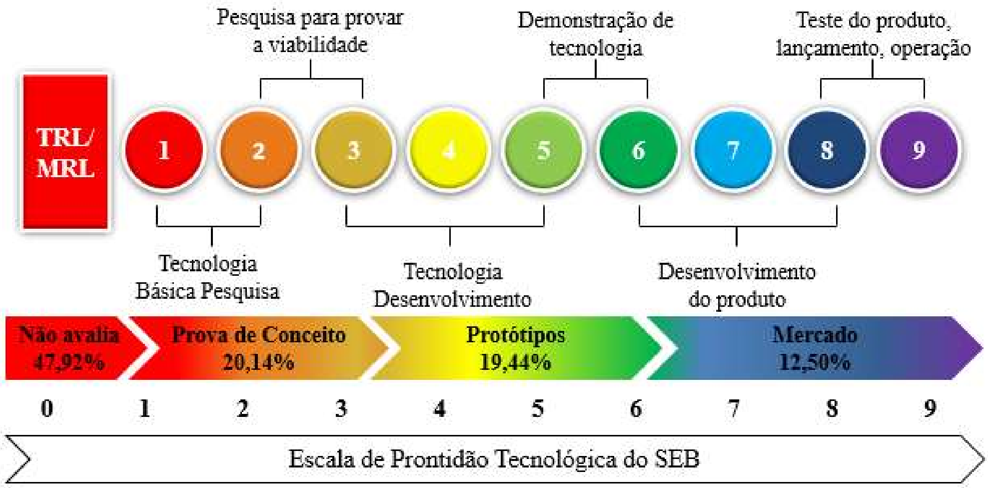
Figura 21 – Grau de maturidade de inovação do PD&I do SEB: radar da inovação no SEB



Fonte: elaborado pelos autores, conforme Apêndice D – Artigo 4, item 4.5.

A estimação do nível de maturidade tecnológico do PD&I do SEB, que indicou que 47,92% dos pesquisados responderam que fazem a avaliação dos projetos utilizando a escala TRL/MRL, 20,14% deles responderam que fazem avaliação até a prova de conceito (primeiro estágio da escala TRL), 19,44% chegam à prototipação e apenas 12,50% atingem o estágio final que é o desenvolvimento de mercado, conforme Apêndice D – Artigo 4, item 4.6 e a Figura 22.

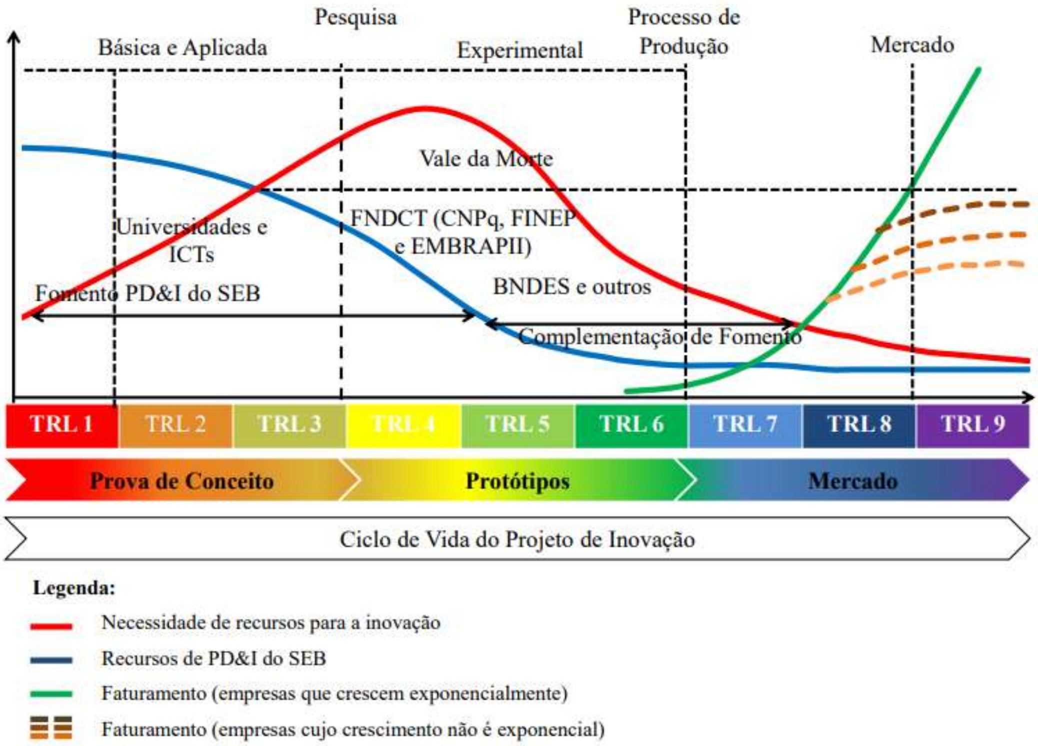
Figura 22 – Escala de prontidão tecnológica no SEB: escala TRL/MRL



Fonte: elaborado pelos autores, conforme Apêndice D – Artigo 4, item 4.6.

Para finalizar, com a avaliação do grau de maturidade de inovação e a estimação do nível de prontidão tecnológica do SEB, foi possível analisar o estágio atual do programa de PD&I do SEB e o elo perdido da inovação ou vale da morte da inovação, cuja conclusão é que a permanência neste estágio implica em resultados que comprometem o futuro do programa, conforme Apêndice D – Artigo 4, item 4.7 e a Figura 23.

Figura 23 – Ciclo de vida do projeto de PD&I do SEB: da pesquisa básica ao mercado



Fonte: elaborado pelos autores, conforme Apêndice D – Artigo 4, item 4.7.

5.3 Considerações Finais

Após fazer a contextualização do quarto e último estudo, em que foram apresentados objetivo da pesquisa, conceitos que fundamentaram o artigo, a descrição resumida dos procedimentos metodológicos e os resultados da investigação, chegou o momento de averiguar se a pesquisa contribuiu para responder à pergunta: como o grau de maturidade de inovação e o nível de prontidão tecnológica do programa de PD&I do SEB podem contribuir para entregar resultados melhores para a sociedade?

O estudo concluiu que o ecossistema de inovação do SEB está em desenvolvimento e encontra-se em grau 3 (em uma escala que varia de 1 a 5), conforme Apêndice D – Artigo 4, item 4.5. Deve-se destacar que um ecossistema de grau 3 não consegue gerar benefícios que possam ser repassados à sociedade, pois está em fase de formação e não consegue gerar efeitos sinérgicos entre os diversos atores.

Na estimação do grau de maturidade tecnológica do SEB, identificou-se que 47,92% das empresas do PD&I do SEB não fazem avaliação dos projetos de P&D utilizando a escala TRL/MRL ou qualquer outra ferramenta que possa avaliar o grau de maturidade dos projetos de inovação do SEB. 39,58% das empresas avaliam os projetos na escala TRL/MRL, sendo que mais ou menos a metade dos projetos dessas empresas ficam no primeiro estágio, até a prova de conceito, e a outra metade chega à fase de protótipo. Apenas 12,50% completam o ciclo final levando produto ou serviço ao mercado.

Ressalta-se que, ao optar por não avaliar o projeto utilizando a escala TRL/MRL, o PD&I do SEB assume o risco de fomentar projetos que não representam inovação ou, no mínimo, aumentam enormemente a margem de erro nos investimentos feitos em inovação. Espera-se que estes resultados sejam capazes de provocar uma reflexão sobre o estágio atual do programa de PD&I do SEB e que leve a uma análise profunda do modelo, bem como a busca para as eventuais saídas que podem tirar 87,50% dos projetos do estágio do elo perdido da inovação ou vale da morte da inovação.

Considerando que o PD&I do SEB é uma política pública, entendeu-se que analisar o desempenho do Brasil no ranking global do IGI seria pertinente. Ao fazer esta análise este estudo concluiu que o Brasil teve baixo desempenho no ranking global do IGI, na última década, pois estava na 47ª posição em 2011, e chegou em 2021 na 57ª posição, entre 132 países. No ranking regional (América Latina e Caribe), ocupa a 4ª posição, ficando atrás de Chile, México e Costa Rica. Nos BRICS, o Brasil amarga a última posição entre as 5 nações que compõem estre grupo.

Constatou ainda que o Brasil gastou com inovação em 2014, aproximadamente 1,27% do PIB, e 1,26% em 2018. No mesmo período os EUA investiram 2,72% e 2,84%, a Alemanha gastou 2,87% e 3,09%, Israel: 4,17% e 4,95%; Coréia do Sul: 4,29% e 4,53%, Japão: 3,40% e 3,26% e China: 2,03% e 2,19%, respectivamente. Estes dados permitem inferir que o Brasil investe pouco em inovação, quando comparado com países inovadores ou até mesmo economia de porte semelhante em PIB, como é o caso de Alemanha e Reino Unido.

Outra questão relevante está na piora do Índice de Eficiência em Inovação (IEI) pois, há uma década (2011), o Brasil contabilizou o índice 0,92, mas chegou em 2021 com 0,55. Quando comparado com a China, verificou-se que ocorreu exatamente o contrário, pois a economia chinesa tinha em 2011, IEI de 0,33, e em 2021 atingiu 0,92. A grande diferença que deve ser registrada é que a China investe em torno de 2,20% do PIB enquanto o Brasil investe cerca de 1,30% e com baixo nível de eficiência.

A limitação deste estudo foi não realizar análises de casos que pudessem gerar comparações entre empresas, sobre como cada uma delas faz a gestão da inovação, desde o nível estratégico até o nível operacional.

Fica como proposta para estudos futuros: a) como desenvolver uma rede nacional de PD&I do SEB; b) acompanhar os editais de inovação aberta, que já é realidade em algumas empresas; c) como implementar a avaliação de projetos na escala TRL/MRL, definindo o valor do fomento de acordo com a escala de prontidão tecnológica.

6 CONCLUSÃO INTEGRADORA

Os resultados dos Estudos 1, 2, 3 e 4, apresentados nos capítulos 2, 3, 4 e 5, desta tese, têm como função precípua responder à pergunta de pesquisa central: em que medida a política pública de inovação do setor elétrico brasileiro (SEB) contribuiu para a redução dos impactos socioambientais do setor e como ela concorre para que o Brasil possa cumprir os compromissos firmados junto ao Acordo de Paris – Agenda 2030?

O Estudo 1 abriu os horizontes do impacto da inovação no setor elétrico, mas também indicou problemas que passaram a delinear toda esta pesquisa, a partir do Estudo 2, tais como: a) compromissos do Brasil com a Agenda 2030, mais especificamente o ODS 7 – Meta 7.1 que visa assegurar a serviços de energia o acesso universal, confiável, moderno, e ODS 13, que objetiva implantar medidas urgentes para reduzir o impacto ambiental; e b) a modicidade tarifária.

A partir desse fio condutor, a investigação seguiu na linha de averiguar como a política pública brasileira de inovação, por meio do PD&I do SEB estaria gerando resultados alinhados ou não com os compromissos citados nas alíneas "a" e "b" do parágrafo anterior.

Analisando os resultados do Estudo 2, ficou evidente que o programa de PD&I do SEB está desalinhado com essas duas premissas norteadoras da pesquisa, pois o programa de P&D não apresenta resultados adequados ao padrão esperado nos ODS 7 e 13, tanto no aspecto de modernidade do sistema, quanto na modicidade tarifária, bem como nos seus impactos ambientais.

Apesar de o indicador de geração de patentes ter melhorado de 2008 para 2019, os produtos não chegam ao mercado de forma que possam se transformar em benefício para a sociedade. Há uma melhora considerável no desenvolvimento de tríplice hélice por meio da integração da academia, com empresas e governo, com potencial de dar uma reviravolta no programa e colocar o PD&I do SEB no patamar superior dos programas de P&D de inovação orientados para a sustentabilidade.

Já o PEE apresentou resultados animadores, tais como: investimento evitado em geração de energia elétrica, energia economizada, demanda retirada da ponta, com grande potencial de impacto positivo nas finanças públicas ao evitar novos investimentos em geração de energia elétrica, com potencial de redução de impactos socioambientais tridimensional: redução de emissões de CO_2e no SEB, redução de impacto ambiental de projetos de Usinas Hidrelétricas e redução de impacto social de grandes empreendimentos. Os resultados sistêmicos do PEE foram potencializados pela elevada relação custo *versus* benefício, pois cada R$ 1,00 investido evitou novos investimentos em geração de energia elétrica entre R$ 3,50 a R$ 4,90, dependendo do período analisado.

O Estudo 3 completa a resposta da pergunta de pesquisa central, uma vez que responde à questão da modicidade tarifária, por meio da avaliação de impacto da política pública de inovação do SEB, o PD&I do SEB, financiada por meio da ContribInova, onde verificou-se que houve aumento da TMF de energia elétrica, após a implementação da política pública.

Este mesmo estudo propôs a criação de um índice de poder de compra de energia elétrica (iPCEE), para verificar como foi o desempenho do poder de compra do consumidor de energia elétrica, analisando renda do brasileiro *versus* preço do MWh – este índice demonstrou que no período de 2000 a 2022, o poder de compra do consumidor foi superior ao aumento da energia apenas no de 2013, exatamente porque ocorreu uma excepcionalidade, pois o governo determinou uma redução nos preços finais de energia da ordem de 30,0%. Mas, logo no ano seguinte as altas retomaram e seguem, inclusive, nas projeções para 2022. O iPCEE constatou que houve perda do poder de compra de energia elétrica, por parte do consumidor, em 21 dos 22 anos analisados.

Diante desse quadro, restou uma pergunta: por que uma política pública que tem recursos e tem atores supostamente engajados não gera resultados alinhados com as metas do Estado brasileiro? Para responder a esta pergunta realizou-se o Estudo 4, que fez a avaliação do grau de maturidade da inovação do PD&I do SEB, e concluiu que se trata de um ecossistema de inovação grau 3, em desenvolvimento, portanto, incapaz de gerar benefícios consistentes e duradouros. Trata-se de um modelo de inovação com indícios de que pode cair no denominado elo perdido da inovação ou vale da morte da inovação.

Por fim, o PD&I do SEB deve agir rápido, pois é preciso avançar para um ecossistema de inovação maduro (grau 5), com inovação aberta, em rede e gerador de benefícios para a sociedade, ofertando energia limpa e de baixo custo. Somente a inovação aberta, com a inclusão de Startups poderá gerar a disrupção necessária, para que os benefícios cheguem à sociedade. É preciso transformar o PD&I do SEB em um programa de inovação orientado para sustentabilidade!

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APÊNDICE A – ARTIGO 1

Innovation in the electricity sector in the age of Disruptive Technologies and renewable Energy Sources: A Bibliometric study from 1991 to 2019

Inovação no setor elétrico na era das tecnologias disruptivas e das fontes renováveis de energia: um estudo bibliométrico de 1991 a 2019

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Innovation in the electricity sector in the age of Disruptive Technologies and renewable Energy Sources: A Bibliometric study from 1991 to 2019

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Abstract *— This article aims to elaborate a bibliometric study about innovation in the electricity sector, in the era of disruptive technologies and renewable energy sources, to describe, quantify and analyze the studied themes, including their evolution, from 1991 to 2019. The following methodological procedures were used: a) definition of keywords and research in the Scopus and Web of Science databases; b) analysis of 159 selected texts, using Iramuteq with the R software statistical interface, for qualitative, quantitative and statistical data processing. As a result, it was possible to observe that innovation in the electricity sector in the world is incipient. In the USA, UK, Australia, China and 31 OECD countries including Brazil, renewable energy sources and technological innovation have found difficulties to make progress. In tightly regulated markets, regulation has yet to find the point and balance that can foster an enabling environment for sectoral technological innovation. The Brazilian electricity sector (SEB) also finds difficulty to innovate, as indicated in the studied literature. It was found that the research gap, which was the absence of bibliometric studies on innovation in the electricity sector in the world and in Brazil, was satisfactorily met.*

Keywords ***— electricity sector; innovation; disruptive technologies.***

I. INTRODUCTION

The study of innovation in the electricity sector began to draw attention in the last decade of the twentieth century, when a study on the technological reconversion of the oil refining industry was published, by gasification of heavy refinery waste with electricity generation, generating product and process innovation for both the oil and electricity sectors (Gulli, 1995).

From 1991 to 2010, the publication of literature on the subject remained relatively low, but from 2011 to 2019, scientific production accelerated and advanced rapidly.

In the same period (1991-2019), sector innovation shifted from product and process to companies, institutions, regulation and, more recently, to disruptive technologies, renewable energy sources such as solar photovoltaics, and Distributed Energy Resources (DER). (GVces, 2015; MME/SPE/EPE, 2018).

The type of innovation adopted, albeit incrementally, has shown that investing in new technologies has generated a combination of useful results or directed to both business and the environment. Business has been accounting for economic and financial gains and image improvement with the consumer (Wiersma, 1991; Gulli, 1995; Fischer & Newell, 2008; Jusoh, 2017; Zhu *et al.*, 2018).

When a product and process innovation occurs in the electric sector, which implies a reduction in the use of fossil fuels for electricity generation, the environment receives a certain relief due to the reduction of greenhouse gas (GHG) emissions, since that GHG is one of the villains of global warming, which is one of the greatest challenges facing humanity today. However, this GHG reduction is still far from the ideal level (Gulli, 1995; Fischer & Newell, 2008; Jusoh, 2017; Zhu *et al.*, 2018).

Faced with the challenge of writing a thesis, whose theme is innovation in the Brazilian electricity sector in the era of disruptive technologies and renewable sources of energy, arose the need for a study that would understand the evolution of the theme in the world over time. After readings and discussions, the convenience of a systematic literature review through a bibliometric research was identified.

The bibliometric study is a quantitative and statistical technique used to measure the production and dissemination of scientific knowledge that can also be a way of measuring the written communication patterns of the authors of these works. This type of study is recommended when the researcher is facing a large amount of bibliographic material published about the object of his research, as is the case shown (Araújo, 2006; Quevedo-Silva et al., 2016).

Thus, the aim of this paper is to elaborate a bibliometric study about innovation in the electricity sector in the age of disruptive technologies, to describe, quantify and analyze the studied themes, including their evolution from 1991 to 2019.

The justification for the application of bibliometric research in this article is the fact that this method is the most appropriate to present the vast published scientific production, in a summarized and systematized way, over a long period (Quevedo-Silva et al., 2016). The databases defined for this research were: Scopus and Web of Science, from 1991 to 2019, more specifically until June 2019. The choice of these two databases is due to their privileged position in the rankings of scientific publications in the world. The motivation for choosing the period is based on the fact that the 1990s (20th century) was a milestone in the study of business innovation in the world, and in 1991 the first publication (identified by this research) about innovation in the electricity sector occurred.

The contribution of this study is to structure the academic-scientific knowledge, on a global scale, on innovation in the electricity sector in the age of disruptive technologies, published in the Scopus and Web of Science databases, from 1991 to June 2019.

This article is structured in five parts, the first being this brief introduction. The second section presents a literature review involving the main concepts of the study. The third section describes the methodological procedures step by step. The fourth shows the results and the discussion of the bibliometric study. The fifth and last one describes the final considerations about the study accomplished.

II. LITERATURE REVIEW

The literature review presents the concepts of innovation, business model innovation, disruptive technologies (DT) of industry 4.0 (I.4.0), Brazilian electricity sector (BES) and technological innovation.

2.1 Concepts

The main concepts that guided this study are presented.

2.1.1 Innovation

The concept of innovation for the purpose of this study followed the Oslo Manual, which is a proposal for guidelines for the collection and interpretation of data on technological innovation in the scope of countries that are part of the 1997 Organization for Economic Cooperation and Development (OECD). In 2004, the innovation standard advocated by the Oslo Manual was adopted by Brazil as the benchmark for evaluating the technological innovation model at the national level, through an initiative of the Ministry of Science, Technology, Innovation and Communications (MCTIC) and the Financier of Studies and Projects (FINEP) (BRASIL, 2004; OCDE, 2004).

Currently, innovation is divided into three types: a) incremental innovation; b) creative destruction; and c) disruptive innovation.

The first two types were developed by Schumpeter in 1934 and are in the Oslo Manual. In it, incremental innovations are described as those that continually fill the process of change, while radical innovations bring about major changes in the world, the latter being responsible for the concept of creative destruction, coined by the same author (BRASIL, 2004; OCDE, 2004).

The third type of innovation is disruptive innovation, inspired by the concept of creative destruction, disruptive innovation means the transformation of a technology, product or service into something new, simpler, more convenient and affordable, that is, easily accessible and inexpensive (Christensen, 1997).

While disruptive innovation has emerged more than 20 years ago, it has started to build on the literature and the marketplace over the past 10 years, with the advent of start-up businesses in Silicon Valley, California, and within a new conception of business models, companies such as UBER, Netflix and others won over the world.

2.1.2 Innovation in business models

As there is no uniqueness as to the concept of business model, a broader search was necessary, since defining a business model implies on meeting complex organizational structures, that include internal (organizational) and external aspects. External aspects include the sector competitive environment, with potential for value creation for stakeholders, which can be translated into competitive advantage (Chesbrough, 2010; Gambardella & Mcgahan, 2010; Ostenwalder & Pigneur, 2009; Teece, 2010; Zott, Amit, & Massa, 2011).

Faced with a tangle of concepts that use similar terms, a concept for the theme arrived when Vils *et al*. (2008, p. 315) defined that Business Model "is an instrument by which companies make resources available, using internal and external structures and processes, aiming to create value propositions that solve their clients' existing problems or work".

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From the concept of Business Model, the search for what would be New Business Models began. It was concluded that it was the enterprises that were born using TD from the I.4.0's, some of them based on the sharing of goods and services supported by Information and Communications Technology (ICTs), but that fundamentally alter the traditional business configuration (Prause, 2015; Rifkin, 2012).

2.1.3 Disruptive Technologies (DT) and Industry 4.0 (I.4.0)

Industry 4.0 (I.4.0) is the combination of intelligent machines, production, processes, and systems that form a sophisticated interconnected network that emphasizes the idea of coherence, digitalization, and connection of all productive units in an economy, creating the virtualization of the real world in a large information system (Palma et al., 2017; Prause, 2015).

The first three industrial revolutions (IR) were responsible for mass production, assembly lines, electricity and ICTs, providing economic development never before seen in human history, increasing incomes and technological competition (Rifkin, 2012).

The fourth industrial revolution (FIR) is expected to have an even greater impact on an exponential scale, as it is supported by a set of technologies that allow the fusion of the physical, digital and biological world (ABDI, 2018; Schwab, 2018).

The combination of these technologies led to the transformation of existing products, services and even businesses into something newer, simpler and more affordable, modified by disruptive innovation, which required new business models. This change has reached the electricity sector in various places around the world and now it arrives at the Brazilian electricity sector (SEB).

2.1.4 Structure of the Brazilian Electricity Sector (SEB) and technological innovation

The strategic management of the Brazilian electricity sector is the responsibility of the National Energy Policy Council (CNPE). The Ministry of Mines and Energy (MME) is responsible for implementing the public policies of the sector. The Brazilian Energy Research Office (EPE) elaborates the system expansion planning, while the Electricity Sector Monitoring Committee (CMSE) takes care of the safety of the segment (BRASIL.MME, 2018).

The sector is regulated by the Brazilian Electricity Regulatory Agency (ANEEL), with the participation of the National Water Agency (ANA) and National Agency for Petroleum, Natural Gas and Biofuels (ANP), due to the overlap caused by the resources involved (BRASIL.MME, 2018).

The technical operation of the electric system, as well as the coordination and control of the electricity generation and transmission facilities in the National Interconnected System (SIN), along with the planning of the operation of the isolated systems in the country, is performed by the Electric System National Operator (ONS), under the supervision and regulation of ANEEL (ONS, 2018).

The actors, agents in the electric system, are those involved in the generation, transmission, distribution, commercialization of energy, free consumers, importers or exporters of energy.

For several decades, the Brazilian electricity sector was dominated by power generation from water sources and maintained a traditional modeling, which highlighted the generation, transmission, distribution and commercialization (ANEEL, 2018).

However, there are signs that the current model has been changing configuration, as shown in the 2027 Ten-Year Energy Expansion Plan (PDE 2027). It predicts that technological advances are impacting the current market structure, which is beginning to change as new players or agents are included in this market segment, which are the independent producers or the energy prosumers[1], through Distributed Generation (DG), focusing on renewable energy sources, mainly solar photovoltaic (MME/EPE, 2018; MME/SPE/EPE, 2018).

The ramifications of these technological advances, together with the prospects for investment in SEB, show a change in the profile of the evolution of each source of electricity from 2018 to 2027, according to PDE 2027, Figure 1.

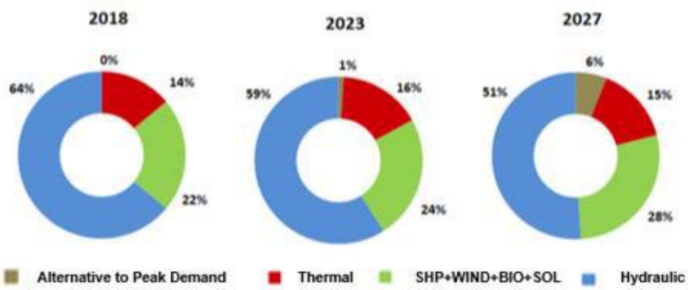

Fig.1: Evolution of the share of electricity sources PDE 2027

Source: Made by the author, based on data from MME/EPE, 2018.

It is noteworthy that, even with the significant drop in the share of water source, the forecast for the participation

[1] Prosumer is a neologism that comes from the combination of producer + consumer or professional + consumer (Rifkin, 2012).

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of 80% of clean energy sources in the national electricity matrix is maintained, which is in line with the commitment of the Nationally Determined Contribution (NDC) signed by Brazil for 2030, under the Paris Agreement (MME/EPE, 2018).

Technological innovation in SEB is guided by the Energy Research, Development & Deployment, regulated by ANEEL, which determines that Generation, Transmission and Distribution (GTD) companies should invest at least 1.0% of their Net Operating Revenue (NOR) in the two programs: the R&D Program (R&D) and the Energy Efficiency Program (PEE) (ANEEL, 2018; De Castro *et al*., 2015).

The R&D program aims to allocate appropriately human and financial resources to projects that demonstrate the originality, applicability, relevance and economic viability of products and services in the processes and end uses of energy. The aim of the PEE is to promote the efficient use of electricity in all sectors of the economy through projects that demonstrate the importance and economic viability of improving the energy efficiency of machines, processes and energy end uses (ANEEL, 2016, 2017).

The implementation of R&D, instituted by Law No. 9.991/2000, is divided into two phases. The first phase was based on Normative Resolutions 502/2001, 219/2006, which regulated the project cycles from 1999 to 2007. In this phase, R$ 1.536 billion were invested in 4,555 projects, the main results of which were products (model/methodology and software/system), i.e. incremental process innovations accounted for 71% of what was generated, product/prototypes 9% and only 2% of the projects generated patents (Guedes, 2012).

Also in the first phase, these R&D projects also resulted in academic degrees of specialization, master and doctorate, in relation to the projects, in the order of 7%, 33% and 24%, respectively (Guedes, 2012).

The second phase of R&D, which covers the 2008-2017 cycle, regulated by Normative Resolutions 316/2008, 504/2012 and 754/2016, invested R$ 4.070 billion in 1,643 projects. The PEE regulated by Normative Resolutions 556/2013 and 830/2018, generated 891 projects, with investments of R$ 4.588 billion, according to ANEEL's project audit report (ANEEL, 2016, 2017). Therefore, the investment values of the two programs in this cycle amount to R$ 8.658 billion.

III. METHODOLOGICAL PROCEDURES

To achieve the proposed objective, the following methodological procedures were established: definition of the research strategy and download of articles, according to items “i” to “vii” (described below); qualitative, quantitative and statistical treatment of data using “R” and Iramuteq software, as recommended for bibliometric studies (Quevedo-Silva *et al*., 2016; Camargo & Justo, 2013).

3.1 Database research, download and data processing

The research in the databases, including search, download and process of the articles obtained, used the following steps:

i) search arguments: the definition of the keywords for the research was in line with the doctoral thesis project presented to the qualification board, at UnB's CDS: “electricity sector”; “innovation” and “disruptive technologies”;

ii) database search strategy: the words were translated into English for query purposes: {[(“electricity sector”) AND (“innovation”)] OR (“disruptive technolog?)}”;

iii) refining search adjustment: a) Scopus = “TITLE-ABS-KEY” and Web of Science = “TOPIC”; v) export of the research results of the two databases in extension “.csv”; “.ris” and “.doc”;

iv) handling of files in Excel sheets, according to the research interest: 242 articles downloaded;

v) selection of articles to exclude duplicates (71 articles) and those outside the research scope (12 articles): 83 articles excluded;

vi) research and download of articles defined as research interest: 159 articles;

vii) inclusion of 159 articles in the Mendeley software;

viii) reading of the abstracts of all articles.

3.2 Data processing: qualitative, quantitative and statistical

To analyze the 159 selected texts, Iramuteq (*Interface de R pour les Analyses Multidimensionneles de Textes et de Questionnaires* – in french), a specific software that enables the identification of the context in which the words occur, was used, applying the R software statistical platform. In recent years, Iramuteq has been used as a data processing tool in scientific works and textual materials obtained in various ways, including articles published in journals, because it is free and effective in its results (Camargo & Justo, 2013; Salviati, 2017).

Initially, a database was prepared in Word, called “Corpus Geral”, with 159 texts, originated from the abstract of each article under analysis. In accordance with the Iramuteq method, each article abstract was identified with a title beginning with four asterisks, one space,

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another asterisk. Then, the letter A (initial of the word Article) was placed, underline, AUTHOR'S NAME, underline, year of publication of the article. Example: **** *A_MOORE_2004 (Camargo & Justo, 2013; Salviati, 2017).

The article abstracts were copied and pasted into a Notepad, and all blank lines between the title and abstract or between paragraphs of the abstract were deleted, leaving only one space line separating one abstract from the other. A folder named "Corpus_teste" was created and the file was saved in * .txt format with the encoding: UTF-8 (Salviati, 2017; Camargo & Justo, 2018).

Next, the Iramuteq application was used, which processed the data and presented the description of the corpus[2]. From it, we proceeded to Text Analysis, involving the following parts: Statistics; Specifics and AFC; Classification - Reinert Method; Similarity Analysis; and Word Cloud (Salviati, 2017; Camargo & Justo, 2018).

It was requested a generation of a statistic by selecting definitions "lemmatization", the key properties "1 – active", for adjectives and nouns; "2 – supplementary" for supplementary adjectives and supplementary nouns; and "0 – eliminate" for the other word classes; and "indexing". Based on this statistic, only active forms (nouns and adjectives) were analyzed and 40 forms were selected, with at least 42 occurrences (Camargo & Justo, 2018).

The next moment, the word cloud was made, the similarity analysis was performed, and the text was categorized into three classes by the Reinert method and the study of the Specificities and Correspondence Factor Analysis (CFA) in Iramuteq.

The word cloud analysis shows a set of words that are grouped, organized, and structured in a cloud form. These words are presented in different sizes, and the larger words are those that are most important and appear most frequently in the textual corpus. Although it is a simple lexical analysis, it is quite interesting because it allows quick identification of the keywords of a corpus (Salviati, 2017).

The Similarity analysis is based on the theory of graphs whose results help in studying the relationships between objects of a mathematical model. It shows a graph representing the link between words in the textual corpus. From this analysis, it is possible to infer the structure of text construction and the themes of relative importance, from the co-occurrence between the words (Salviati, 2017).

Reinert's method proposes a descending hierarchical classification and aims to obtain classes of Text Segments (TS) that, at the same time, present similar vocabulary and different vocabulary from other classes. Its analysis is based on lexical proximity and the idea that words used in similar context are associated with the same lexical world and are part of specific mental worlds or systems of representation (Salviati, 2017).

The Specificity analysis associates texts with variables and enables the analysis of textual production as a function of characterization variables. The corpus is associated with variables that the researcher wants to analyze, so that the database is divided according to the selected variable (Salviati, 2017).

The use of Iramuteq made it possible to obtain the number of texts in the corpus, number of text segments, total number of words occurrence, number of different words, and number of words that appeared only once in the corpus. It was also possible to elaborate a relation with the active words, to understand the specificities, associating the texts with the variables used, calculating their frequencies and the chi-square relation of each corpus word.

This tool showed the words in different sizes, according to the frequency with which they occur in the textual corpus, grouped in a cloud format and facilitated the presentation of the link between the words in the textual corpus, making the similarity analysis.

In addition, it made it possible to perform descending hierarchical classification (DHC) with Reinert's method for grouping words into thematic classes. In DHC, Iramuteq performed the chi-square test (X^2) to measure the association between words and their respective class. According to Souza *et al.* (2008), the association will be confirmed when the value of X^2 is greater than 3.84 and the value of p, which identifies the lowest level of significance in which the null hypothesis of the association of the word with the grammatical class would be rejected, is less than 5% ($p < 0.05$) and a minimum use of 70.00% of the ST. In the sequence, the correspondence factor analysis (CFA) was performed (Camargo & Justo, 2013; Camargo & Justo, 2018).

The results obtained with the support of Iramuteq were analyzed in order to establish the connection between the scientific production from 1991 to 2019 as a way of explaining to what extent published articles can contribute to the study of innovation in the electricity sector.

IV. RESULTS AND DISCUSSION

The analysis of the results was divided into quantitative and qualitative with content analysis using Iramuteq/R. Class analysis from DHC and CFA results.

[2] Corpus is a set of texts constructed by the researcher that form the object of analysis (Salviati, 2017).

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4.1 Quantitative analysis: publications and citations from 1991 to 2019.

In both databases, 242 articles were obtained, in which 127 were in Scopus and 115 in Web of Science. Of these 242, 83 were excluded (71 because they were in duplicate and 12 because they were outside the scope of the research). This left 159 works of the search that performed properly related in an Excel sheet, with the following data: Publishing base; author or authors; title; year; periodic; DOI; total of citations; average of citations per year, distribution of citations from 1991 to 2019[3], as shown in Figure 2.

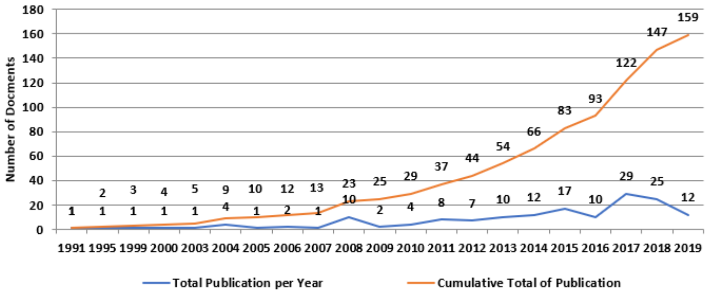

Fig.2: Number of articles published per year and accumulated in the period (1991-2019)
Source: Made by the authors.

The 159 articles generated 3,261 citations, whose annual and cumulative distribution can be analyzed in Figure 3. It should be clarified that the counting of citations started only in 2004, retroactive to 2002. Therefore, the period of citations registration ranges from 2002 to 2019 and the survey was conducted until June of this last year.

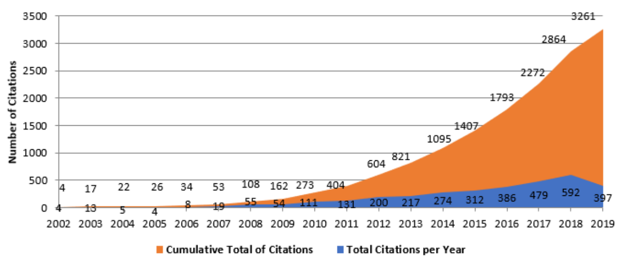

Fig.3: Number of citations of articles per year and accumulated in the period (2002-2019)
Source: Made by the authors.

Of these 3,261 citations, a single work contributed with 734 citations or 22.5% of identified citations. Another aspect verified is that there is a direct relationship between the growth of publications and citations in the analyzed period, which demonstrates the dissemination of knowledge via publications in digital media, over the last two decades, enhanced by access via the Internet, as shown in Figures 2 and 3.

4.2 Content analysis of texts using "Iramuteq/R"

4.2.1 Statistical analysis of texts

The study was conducted through a General Corpus, consisting of 159 texts, separated into 861 text segments (TS). From it, 30,681 occurrences arose (words or forms), being 4,131 different words and 1,802 words with a single occurrence.

After defining the corpus, a statistic was generated, selecting as active properties only adjectives and nouns and using the lemmatization and indexation of these words. From this statistic, the following result was obtained: a) the number of forms that appeared only once was 1,303, which corresponds to 40.18% of the number of forms (3,243) and 4,25% of the number of occurrences (30,681); b) the 3,243 selected forms appeared on average 192.96 times per text, considering the number of 30,681 occurrences and the number of 159 texts.

Next, the 40 forms with more than 42 occurrences were selected, eliminating the forms "paper" and "study", and a word cloud was formed on the theme under study, whose strongest word is "energy", which appears highlighted in the central part. As can be seen in Figure 4, the twenty most frequently occurring words are: energy (298 occurrences), policy (186), innovation (177), technology (161), model (115), development (110), market (109), system (109), power (102), renewable (101), sector (98), transition (91), research (82), change (77), grid (76), project (74), carbon (71), process (69), emission (67) and business (61).

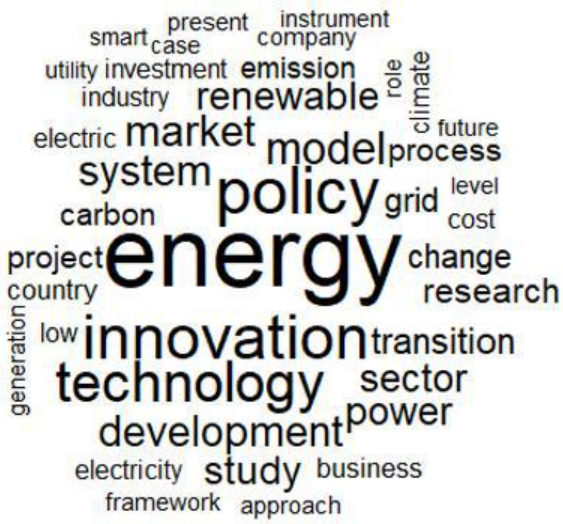

Fig.4: Word cloud of the general corpus of 159 texts
Source: Made by the authors, generated by Iramuteq.

[3] Data extracted from the Scopus and Web Of Science databases refer to the period 1991 to June 2019.

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4.2.2 Similarity Analysis

The Similarity analysis resulted in Figure 5, which resembles the roots of a tree, forming branches between the words that stand out as they appear closer to each other throughout the analyzed texts. From a central core formed by the word "energy", it is possible to observe branches that form communities with "innovation", "development", "model", "power" and "policy". The stronger the root that connects the nucleus to communities, the greater and more frequent the relationship between them (Camargo & Justo, 2013; Camargo & Justo, 2018).

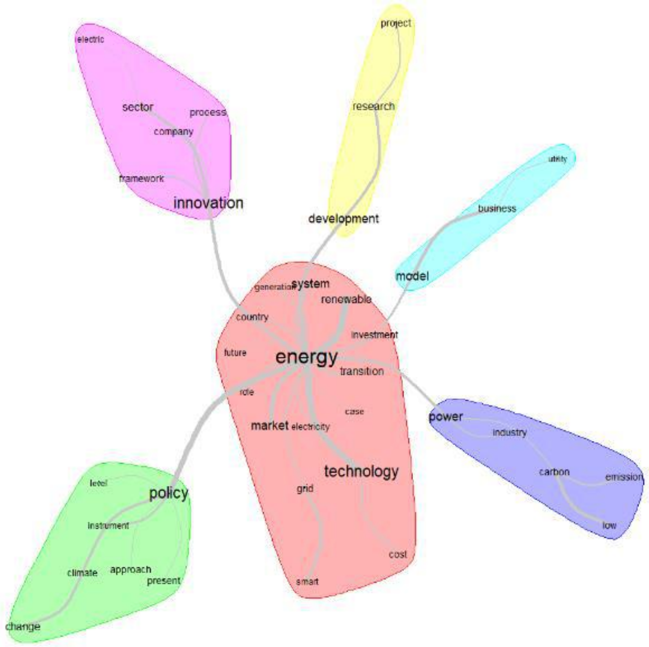

Fig.5: Keyword similarity and co-occurrence analysis - community and halo (1991-2019)

Source: Made by the authors, generated by "Iramuteq/R".

Three of these communities form attention-grabbing nodes, such as: "policy", with three branches, the most important being that consisting of "instrument", "climate" and "change"; a second led by "power", whose node is in "carbon", distributing to "emission" and "low"; the last community is "innovation", which has a node with "process", "company", "sector" and "electric". This indicates that the analyzed literature addresses the relationship between these words in each community, by the proximity with which they appear in the texts, as well as by the frequency (Camargo & Justo, 2013; Camargo & Justo, 2018).

4.2.3 Descending Hierarchical Analysis (DHC)

The DHC is the most important analysis of texts or discourses performed by Iramuteq, because in it the TS are correlated, forming the hierarchical scheme of vocabulary classes (Camargo & Justo, 2018).

The analysis used the Reinert Method, where of the 861 TS found, 685 were classified, which means that 79.56% of the existing TS were classified, thus above the established minimum for the model to be validated, which is 70% (Camargo & Justo, 2013; Camargo & Justo, 2018).

Figure 6 shows the content analyzed and categorized into three classes: Class 1 with 255 TS (37.23%): Class 2 with 142 TS (20.73%) and Class 3 with 288 TS (42.04%).

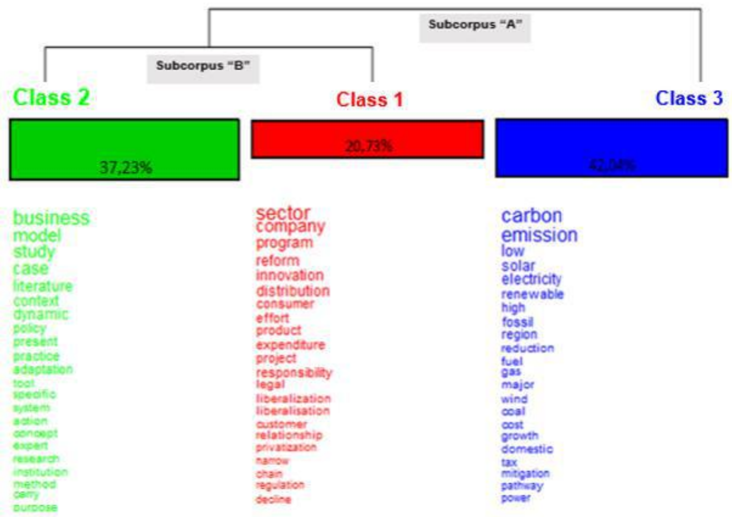

Fig.6: DHC classification of TS by Reinert's method categorized into classes (1991-2019)

Source: Made by the authors, generated by "Iramuteq/R".

These three word classes are divided into two branches: A and B of the total corpus under analysis.

Subcorpus "A" has formed class 3 ("emission, carbon, low, solar and electricity"), called "Carbon", which includes studies on CO_2 emissions from electrical power generation from fossil fuel, mitigation or emission reduction of CO_2 in the electricity sector, renewable sources of energy, with emphasis on solar energy as a source of low carbon electricity generation.

Subcorpus "B" has been divided into two classes: The first, "Sector", contains the class 1 discourses ("innovation, sector, distribution and company"), that addresses innovation in the electricity sector, both in generation and distribution companies, and that demonstrates a new chain that focuses on the customer. The second, "Business", composed by the words of class 2 ("business, model, policy and adaptation"), refers to the conception of new business models in the electricity sector, as well as the need for companies and institutions to adapt to this new market trend, with impacts on planning, management and regulation.

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4.2.4 Specificity Study and Correspondence Factor Analysis (CFA)

To perform the study of specificities and CFA, 40 forms were selected and the variables chosen were: a) used forms: active; b) selected by: modalities (all modalities were selected); and c) minimum frequency: 42, according to the DHC analysis standard, Figure 6.

Figure 7 presented graphically the result of the analysis and formed three clusters in green, blue and red, which associates the words with the studied theme. The colors green and blue have groupings of terms closer than red, and red is well dispersed.

It should be noted that in the interpretation of clusters, font size is related to the frequency of the term, and the proximity between terms is a measure of how much they appear together. The results of the chi-square test ($\chi 2$) and the value of "p" indicate that there was an association of each word with the respective class, since X^2 presented a result higher than 3.84, a "p" value of < 0, 05 and of the 861 TS, 685 were used, that is, 79.56% of the total, when the minimum acceptable is 70%, therefore, within the parameters indicated by Camargo & Justo (2018).

The groupings formed in the study of specificities and CFA are shown graphically in Figure 7, indicating to which class each group belongs, as defined by the DHC analysis.

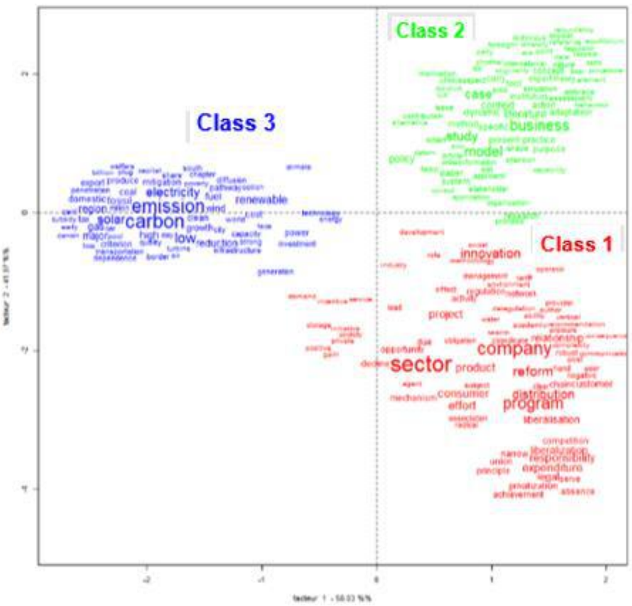

Fig.7: Study of Specificities and Correspondence Factor Analysis (CFA) (1991-2019)

Source: Made by the authors, generated by "Iramuteq/R".

The green grouping has an intermediate density level when compared to the blue and red ones. The highlighted terms are: "business", "model", "case" and "study", and a little further from the core of the grouping "policy", "adaptation" and "system" appear. Thus, the terms of the green grouping indicate the relevance of the study on innovation and disruptive technologies in the electricity sector on business models in the sector.

The blue color grouping has a greater density of the terms "emission" and "carbon", followed by "electricity", "low" and "solar", around this core are "reduction", "renewable", "power", "fossil", "mitigation", and more on the periphery "technology", "energy" and "climate" appear. This demonstrates that these studies focus on carbon emissions, electricity and solar energy.

The content analysis of the texts showed that the thickening of terms in green and blue colors indicates that there is a high correlation, both in frequency and in proximity to them, with the keywords used in the search for articles on innovation, electricity sector and disruptive technologies.

The terms grouped in red, whose densification has a higher degree of dispersion, show that "sector, company, program and distribution" appear in the same frequency and proximity, while "innovation" appears more in the periphery of the group, which indicates a low correlation. However, they are well aligned with the study of innovation and disruptive technologies in the electricity sector, staying between class 1 "sector" and class 2 "business".

4.3 DHC and CFA analysis by classes: 1 - *innovation*, 2 - *business* and 3 - *carbon*

Next, an analysis of the results of DHC and CFA was performed, divided into three classes: class 1 - innovation, class 2 - business and class 3 - carbon.

4.3.1 Class 1 - *Innovation*

By analyzing the effect of public policies and market mechanisms for class 1, from the DHC and specificity analysis and CFA, "innovation", on the electricity sector, including companies and institutions, Jamasb & Pollitt (2015), updated previous studies on the UK electricity sector, admitting that the effects of both liberalization and privatization time are not known.

In recent years, it has re-evaluated the sector and realized that energy innovation efforts were not performing as expected, but acknowledged that there is a new effort to create a sectoral technology and innovation policy that could properly calibrate the institutional structure and promote long term progress in the UK (Jamasb & Pollitt, 2008a, 2008b, 2011, 2015).

Other studies looked at the effect of deregulation on innovation in the electricity sector, but one in particular, one that used a sample of 31 OECD countries or countries that adopt international regulation standards in the electricity sector, like Brazil, and their findings suggest that a decrease in regulatory intensity after significant reform has a negative impact on innovation. The main factor of this force seems to be the degree of contestability of the market. This shows that there is an inverted U-relationship between regulation and innovation, as represented by Figure 8 (Marino, Parrotta & Valletta, 2019).

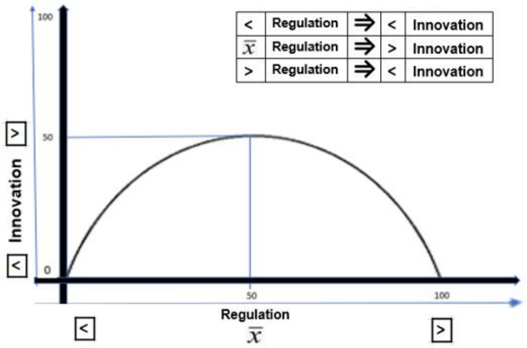

Fig.8: Graphical representation of the inverted U-shape of the regulation and innovation relationship
Source: Prepared by the authors.

The studies by Jamasb & Pollitt (2008b, 2015), conducted in the United Kingdom in 2008 and revisited in 2015, have shown that technological innovation has found difficulty to advance even in ultra-liberal markets such as the United Kingdom, where market mechanisms have failed to solve the problem. According to Marino, Parrotta & Valletta (2019), who studied 31 OECD countries or who use the OECD regulatory standard, where markets are regulated following international standards, regulation also could not find a break-even point that could account for advances in technology development and innovation in the electricity sector.

4.3.2 Class 2 - *business*

Regarding the studies done in DHC analysis and CFA classifications as class 2, renamed to "business", with emphasis on the words ("model and policy"), there was a convergence of the authors as the possible impacts that disruptive technologies and renewable sources of energy will trigger in business models and public policies in the electricity sector on a global level (Fischer & Newell, 2008; Newell, Marsh & Sharma, 2011; Pereira & Soule, 2018; Pereira *et al*., 2018).

It is noted that there is a growing concern with integrated resource management and a close look at the climate-energy-water nexus in countries such as Brazil and Australia, which increasingly requires a systemic and multidisciplinary view on the subject (Fischer, Newell & Preonas, 2014; Nascimento *et al*., 2017).

Smart grids can dramatically change the electricity sector by stimulating customer participation and allowing new players to enter as well as the admission of ICT companies. A critical analysis of existing smart grid studies assesses the consequences on the elements of the business model: value creation, value delivery and value capture, on which many uncertainties weigh, although there is reason to believe that electricity companies can innovate its business model and create the adequate conditions to operate with energy in a sustainable way (Shomali & Pinkse, 2016; Ausrød, Sinha & Widding, 2017).

As the same doubts also arise about the involvement of consumers and the support of governments and new players in this technological evolution, work must be done to reduce uncertainties so that innovation in business models in the electricity sector happens faster, since harnessing disruptive potential depends on quick decision-making for targeted and safe adaptation (Shomali & Pinkse, 2016; Pereira *et al*., 2018; Pereira *et al*., 2018).

4.3.3 Class 3 - *Carbon*

The scientific production submitted to DHC and specificity analysis and CFA, classified in Class 3, titled carbon (emission, electricity, renewable, solar), shows a very uniform positioning of the different authors, when considering that the generation of electricity is one of the most important sources when it comes to total CO_2 emissions, which is directly related to global warming. They also agree that large-scale implementation of innovative renewable energy technologies is key to reducing carbon emissions (Fuss & Szolgayová, 2010; Zhang, 2014).

China and the countries from the Association of Southeast Asian Nations (ASEAN) have a great potential for growth in renewable energy supply while at the same time holding even greater potential for reducing emissions by opting for a cleaner electricity matrix (Jusoh, 2017; Zhu *et al*., 2018).

Published studies show that innovation in the electricity sector can deliver benefits to society by reducing CO_2 emissions, but all will depend on new business models in the sector, the increased use of renewable energy sources and the evolution on regulatory standards.

V. CONCLUSION

This bibliometric study on innovation in the electricity sector in the age of disruptive technologies and renewable energy sources, conducted with 159 articles published in journals in the Scopus and Web of Science databases, covering the period from 1991 to July 2019, demonstrated that there are advances in innovation in the sector worldwide and especially in Brazil.

In the USA, studies analyzed the reduction of carbon dioxide emissions, the inclusion of renewable energy sources in the electric matrix, as well as the technological evolution in the electricity sector. These studies concluded that new technologies are impactful as they affect the desirability of ongoing sectoral policies (Fischer & Newell, 2008).

In Europe, innovation in ITGCC plants ("integrated tar gasification combined cycle plants") was a milestone in the competitiveness of the oil industry in terms of cost and environmental impact reduction in electricity generation (Gulli, 1995).

These cases followed the same line as an empirical study carried out in the Netherlands on electricity-producing coal plants, which simulated for the period 1985-2000 and showed that in an evolving technological environment there would be a reduction in costs by reducing sulfur dioxide (SO_2) emissions per unit of electricity produced by these plants (Wiersma, 1991).

In Asia, notably China, there is a great potential for reducing CO_2 emissions by increasing the use of renewable energy sources, making the continent's electricity matrix cleaner (Jusoh, 2017; Zhu *et al.*, 2018).

In Brazil, the authors Bin *et al.* (2015) and Pereira *et al*. (2018) recognize the advances, but point out problems in the PD&I model adopted by SEB, especially regarding the results of the program regulated by ANEEL. Regarding the problems, the authors Bin and Pereira, can be aligned with Jamasb & Pollitt (2008b; 2015) and Marino, Parrotta & Valletta (2019) who identified that the difficulties faced by innovation models in the electricity sector are inherent in tightly regulated sectors.

Given the results of the studies analyzed, it can be concluded that for the society to reap the benefits of these new technologies, innovation must be able of generating new business models, capable of absorbing disruptive technologies and involve the new actors who will work in the electricity sector.

The study shows that new research should focus on new business models based on renewable energy sources, smart grids and consumer behavior, since these are the trends that will dominate the industry in the coming years.

Another barrier to be broken is the U-inverted effect, because the literature indicates that there is a knot to be untied in the regulation and innovation relationship. If regulations are not adequate to encourage innovation, countries that fail to advance in innovation may lose the opportunity to have a more efficient electricity market and also lose the chance to benefit from the potential gains from innovation in three respects: economic, social and environmental.

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APÊNDICE B – ARTIGO 2

The Brazilian Public Policies for Rd & I in the Brazilian Electrical System (SEB), in Light of the Commitments of the Agenda 2030

As políticas públicas brasileiras de PD&I do setor elétrico brasileiro (SEB), frente aos compromissos da agenda 2030

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The Brazilian Public Policies for Rd & I in the Brazilian Electrical System (SEB), in Light of the Commitments of the Agenda 2030

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***Keywords*— public innovation policies, Brazilian electric sector, RD&I, Agenda 2030.**

Abstract*— The purpose of this article is to analyze whether the Brazilian public policies (PP), materialized in the innovation program (RD&I) of the SEB through the R&DP and EEP, contribute or not to the Brazilian government's fulfillment of the commitments made with Agenda 2030 and the NDC goals, together with the Paris Agreement, concerning SDG 7.The methodological procedures adopted were bibliographic and documental research, involving the legislation that guides the RD&I regulated by ANEEL, as well as the analysis of 30 R&DP projects and 1,026 EEP projects. The R&DP has proven not to be aligned with the goals of Agenda 2030, especially with regard to the development of a culture of innovation in the SEB, besides being disconnected from the rest of the world in terms of the type and model adopted for innovation, patent generation, and continuous improvement.It showed improvement only in the profile of human resources used in the program. The EEP presented results aligned with Agenda 2030 and SDG 7 and Brazil's NDC, through the following indicators: i) investment avoided in energy generation; ii) energy saved; iii) demand withdrawn from the peak; iv) energy conserved.In addition, there are results in line with SDG 9 and 13 such as an increase in the supply of renewable energy and reduction of CO_2e emissions in the system. The R&DP and the EEP together contribute R$ 1.1 billion per year in innovation in the SEB, making an expected value of around R$ 12.1 billion from 2020 to 2030.

[a] In memoriam

I. INTRODUCTION

Implemented two decades ago and regulated by the Brazilian National Electric Energy Agency (ANEEL), the Research and Development Program (R&DP)[b]and the Energy Efficiency Program (EEP)[c]have been consolidated as a Public Policy (PP) of innovation for the Brazilian Electric Sector (SEB).

[b] The Research and Development Program (R&DP) is regulated by ANEEL, according to Law 9.991/2000.

[c]The Energy Efficiency Program (EEP) is regulated by ANEEL, according to Law 9.991/2000.

The SEB is in a structural transition process that started in the 1990s (Castro; Brandão, 2019). The electricity sector is an economic activity recognized as a natural monopoly, which until the 1980s, in Brazil, was purely state-owned. In the following decade, the privatization process in the SEB began, but without the removal of the monopoly condition, which makes the regulation of the sector essential (Castro; Brandão, 2019).

It is necessary to clarify that the electric power sector is still a monopoly, moving towards oligopoly in some federative units (FU) because it is characterized by the presence of market failures that do not allow the sector to reach an efficient Pareto equilibrium on its own(mankiw, 2001; Tirole, 2020). Regulation emerges as a force to try to reduce or even eliminate these failures when possible. The main characteristics for maintaining a monopoly or oligopoly are the high initial investment required (high infrastructure costs) and low marginal costs, which hinder the interest of more players offering the same good and service. Besides having financial entry barriers (because it is a capital-intensive sector), there are also other types of entry barriers, such as legal and regulatory(Tirole, 2020).

The peculiarities of this new condition led, in 1996, to the creation of ANEEL, which from the beginning of its regulatory activities began to be concerned with the evolution of the SEB companies. In 1999, actions coordinated by the Agency began to implement the R&D program in the sector, which culminated with Law 9.991/2000, the first legal framework for innovation programs in the SEB (ANEEL, 2020b; BRASIL, 1996).

Regulated by ANEEL, the R&DP and the EEP have undergone several evaluations, which identified, for example, that ANEEL adopted a linear perspective model of innovation, at least in what is called the first and second phase of the program: from 2000-2007 and 2008-2015, respectively (ANEEL, 2020; Bin*et al.*, 2015; Castro; Brandão, 2019).In 2016, the technological innovation programs of the SEB, regulated by ANEEL, entered their third phase, in search of an evolution of the innovation model, leaving the linear perspective to the systemic view, which includes an approach of a National Innovation System (NIS)(Castro *et al.*, 2017).

The concept of NIS is based on the systemic approach of knowledge, associated with innovation and "interactive learning as factors of sustained competitiveness"(Castro *et al.*, 2017).Thus, the aim is to promote a culture of innovation, stimulating RD&I in the SEB, through the creation of new equipment and improving the provision of services, in a way that can contribute to energy security, moderation of tariffs, reducing the environmental impact of the sector, and Brazil's commitments to the Paris Agreement, Agenda 2030(ANEEL, 2020b).

With Brazil's adhesion to the Paris Agreement, SEB's innovation PPs must align with the goals of Agenda 2030, according to SDG 7: Affordable and clean energy, SDG 9: Industry, innovation and infrastructure, and SDG 13: Climate action (IPEA, 2018, 2019).

A gap has been identified in the sense of analyzing the Brazilian RD&I PPs of the SEB, in light of the commitments made by Brazil, with the United Nations (UN) Agenda 2030 and in particular, the goals established in the Nationally Determined Contribution (NDC), with the Paris Agreement.

Thus, this study has as its research problem the following question: How will Brazilian public policies for the SEB innovation, developed through the Research and Development Program (R&DP) and the Energy Efficiency Program (EEP), regulated by ANEEL, impact Brazil's commitments to the 2030 Agenda?

To answer the proposed problemit was established as the objective of this article: to analyze whether the Brazilian public policies (PP), materialized in the SEB's R&DP and EEP, contribute or not to the Brazilian government's fulfillment of the commitments made with the 2030 Agenda and the NDC goals, together with the Paris Agreement, concerning SDG 7.

The justification for conducting this study is the fact that the R&DP and the EEP, regulated by ANEEL, are responsible for the dynamics of innovation in the SEB, which aims to constantly seek "the innovations needed to meet the challenges of the electric power sector, either by promoting the efficient and rational use of electricity, associated with actions to combat waste" (ANEEL, 2020b).This is an extremely relevant public policy for the electricity sector, as the two together form the largest innovation program in the SEB.

This paper is structured in five parts, the first being this brief introduction. The second part presents a literature review on the main concepts of the study. The third section describes the methodological procedures step by step. The fourth section presents the results generated by the analysis of the R&DP and EEP projects and their discussion against the literature and the goals of SDG 7 - of Agenda 2030 - and the NDC goals of Brazil, along with the Paris Agreement. The fifth and last section describes the final considerations about the research conducted, according to Figure 1, below:

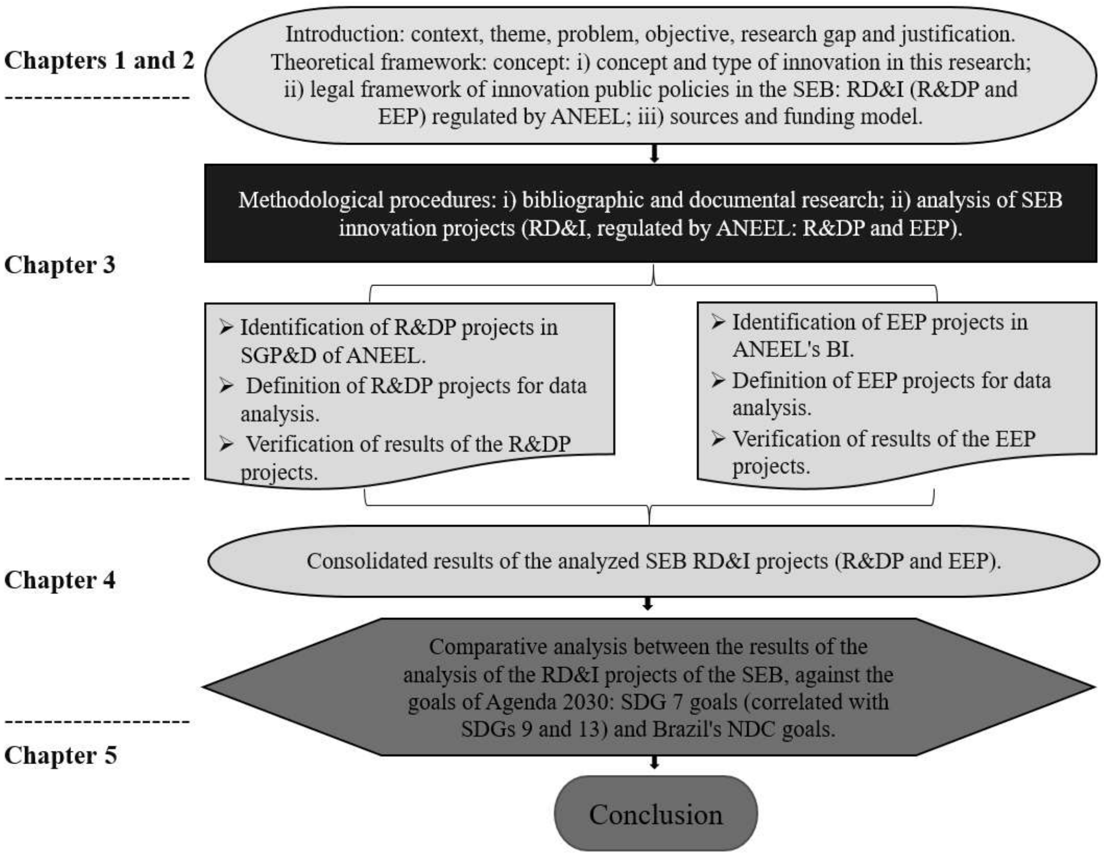

Fig.1: Structure of the method used in this article

Source: Elaborated by the authors.

II. LITERATURE REVIEW

2.1 Innovation: concept, model, and management strategy

The process of organizational change has been accelerating in the last decades, with innovation as the driving force that occurs in the public and private sectors, following a dynamic of conceptual evolution, supported by models or forms of implementation and management strategy of an innovation policy.

2.1.1 Innovation Concept

The concept of innovation in the context of this study follows that advocated by the Oslo Manual for the Organization for Economic Cooperation and Development (OECD), fourth edition, published in 2018, which includes the "requirement of measurability as an essential criterion for selecting concepts, definitions and classifications in this manual"(OECD/Eurostat, 2018, p. 20). According to OECD/Eurostat (2018, p. 20), innovation "is the implementation of a new or significantly improved product (good or service), or a process, or a new financial or business method, or a new organizational method in business practices, in the workplace organization, or external relations."

For it to happen "product innovation must introduce a new or significantly improved good or service concerning its characteristics or intended uses", according to OECD/Eurostat (2018, p. 20).Significant improvements are understood to be: technical specifications, components, and materials, embedded software, ease of use, or other functional characteristics associated (OECD/Eurostat, 2018, p. 20).

The innovation of a process or innovation activity occurs from the “implementation of a new or significantly improved production or distribution method. Significant changes in techniques, equipment and/or software are included” OECD/Eurostat (2018, p. 21).

Besides product and process innovation, which is more frequent, there can still be marketing innovation and organizational innovation. In the former, the "implementation of a new financial or commercial method with significant changes in product design or packaging, product positioning, promotion, or pricing.In the second, the "implementation of a new organizational method in the company's business practices, workplace organization, or external relations" occurs (OECD/Eurostat, 2018, p. 21).

The implementation of innovation programs necessarily involves the definition of models or ways to innovate, which depends on a careful analysis of the maturity stage of the market in which the organization operates (Christensen, 1997;OECD/Eurostat, 2018; Christensen, 2019).

2.1.2 Models or forms of innovation

As for implementation models, innovation can take the form of Schumpeter's creative destruction, incremental innovation, and radical or disruptive innovation (Christensen, 1997; OECD/Eurostat, 2018; Christensen, 2019).

When the form of innovation causes a technical change in the organization, it entails a redistribution of resources, including labor, across sectors and firms, which can generate creative destruction (OECD/Eurostat, 2018).

If the company operates in a stable and mature market, changes can happen continuously, following the rhythm of the market segment and moving in the incremental innovation model(OECD/Eurostat, 2018).

However, when the company operates in a volatile market environment, it needs to quickly introduce new products, new technologies, new processes, and new organizational models, and for this, it needs a form of radical or disruptive innovation (Christensen, 1997; Christensen, 2019).Even in stable markets that undergo major technological change, radical or disruptive innovation is recommended (Cabanes*et al.*, 2016).

After defining the model or form of innovation, the organization must adopt a strategy to manage the implemented innovation model.

2.1.3 Innovation management strategy

For the organization to be successful with its innovation program, besides defining models and forms appropriate to the stage of maturity of the market in which it operates, it is necessary to make important strategic choices for the management of the program. There are two possible options for innovation management strategies: closed innovation and open innovation (Chesbrough, 2003, 2010).

By adopting the closed innovation strategy, the organization minimizes the potential for results, because the closed model is based on the view that innovation is developed internally, without interactions with the environment, which is practically impossible. Open innovation assumes that firms can and should use external as well as internal ideas and pathways as they seek to advance their innovation process, using knowledge input and output flows intentionally to accelerate internal innovation and expand markets for external use (Chesbrough, 2003; 2010).

As this article deals with innovation in the electric sector, more specifically in the SEB, it is necessary to investigate what are the trends of changes that have been occurring in the sector worldwide and transport them to Brazil, so that the Brazilian society can enjoy the benefits generated by these innovations. They are a) reduction of disbursements with investments in energy generation, increased efficiency in distribution and lower costs for the final consumer, which can be provided by energy efficiency; b) flexibility of regulatory standards to encourage distributed generation;c) encourage RD&I for the development of fuel cells (hydrogen from ethanol and natural gas) that can increase the efficiency of renewable sources of solar and wind energy making them deployable[d]on a 24/7 or twenty-four hours a day, seven days a week basis (MME/SPE/EPE, 2018; Castro,Brandão, 2019;Miranda, 2019).

2.2 Institutional Structure of SEB

The SEB has an institutional structure, which is divided into the following segments: policies, regulation and supervision, institutional operation agents, and market agents, as shown in figure 2:

[d]Power plant dispatch is the set of instructions, actions, and control done by ONS in the processes of planning and scheduling, real-time operation, and post-operation (ENERGÊS, 2021). Available at: https://energes.com.br/

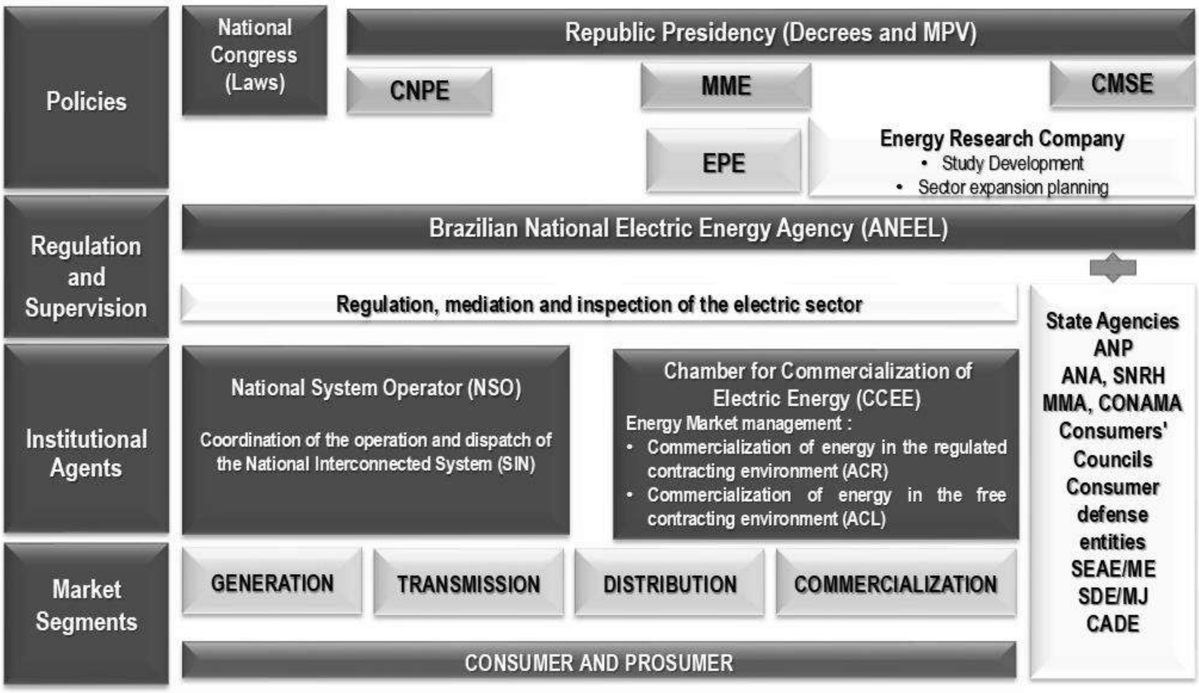

Fig.2: Institutional structure of the SEB

Source: elaborated by the authors, based on Brazil (1991; 2016) and ANEEL (2020).

The policy guidelines may be issued by the Brazilian National Congress (NC), through Laws; by the Presidency of the Federative Republic of Brazil (PR), through Decrees; by the National Energy Policy Council (NEPC), by the Ministry of Mines and Energy (MME),and by the Electric System Monitoring Committee (ESMC), through Resolutions, Ordinances, and Communications, respectively(ANEEL, 2018a).

ANEEL is responsible for the regulation, mediation, and inspection of the SEB, with the support of the National Water Agency (ANA), National Secretary of Water Resources (SNRH), National Petroleum Agency (ANP), Ministry of the Environment (MMA), National Environmental Council (CONAMA), State Electricity Agencies, Consumer Councils and consumer defense entities (ANEEL, 2018a).

The institutional agents of the SEB are the National System Operator (NSO), responsible for coordinating the operation and the dispatch of the National Interconnected System (SIN), and the Chamber for Commercialization of Electric Energy, which manages the energy market: a) energy commercialization in the regulated contracting environment (ACR); and b) energy commercialization in the free contracting environment (ACL)(ANEEL, 2018a).

The market agents are composed of the Generation (G), Transmission (T), Distribution (D), and Commercialization (C) or (GTDC) companies and the consumers and prosumers of electricity (ANEEL, 2018a).

2.3 Public policies of innovation in the Brazilian electricity sector

The background of science and technology in Brazil is recent, since the university system is relatively new, having been consolidated during the first half of the 20th century. Brazilian public policies on innovation are even more recent and date from the end of the 20th century. For this study, only the PPs related to the electricity sector, this focus of this paper, will be analyzed.

2.3.1 Innovation in the Brazilian Electric Sector (SEB)

The innovation in the SEB had as its initial milestone the creation of the Center for Electric Energy Research (CEPEL), which was "established by Public Deed, published on 01.21.74, and entered into by Eletrobras, Chesf, Furnas, Eletronorte, and Eletrosul", with an allocation of around 0.5% of Eletrobras' capital stock (CEPEL, 2017).

According to the bylaws, updated in 2017, the CEPEL (2017)"has as its main and permanent objective to preserve the capacity in research, development, innovation, qualification, and training in the area of electrical systems and related disciplines [...]".

With the privatization program of companies in the power sector that began in the 1990s, the need arose to create ANEEL to deal with the scenario that began to be drawn in the market, where private companies were providing public service through concessions (BRASIL, 1996).

From the regulation of the market, there was a need to raise the level of efficiency of the companies that operated in the sector, both those controlled by the public sector and those whose capital had been transferred to the private sector, but which operated in the Generation, Transmission, and Distribution (GTD) of electricity.

In this context, a new regulatory framework for R&D in the SEB emerged, with Law No. 9.991 of July 24, 2000, which established the Energy Sector Fund (CTEnerg) and created the R&D Program (R&DP) and the Energy Efficiency Program (EEP) (ANEEL, 2017). The same law established the resources to finance the programs, according to Figure 3.

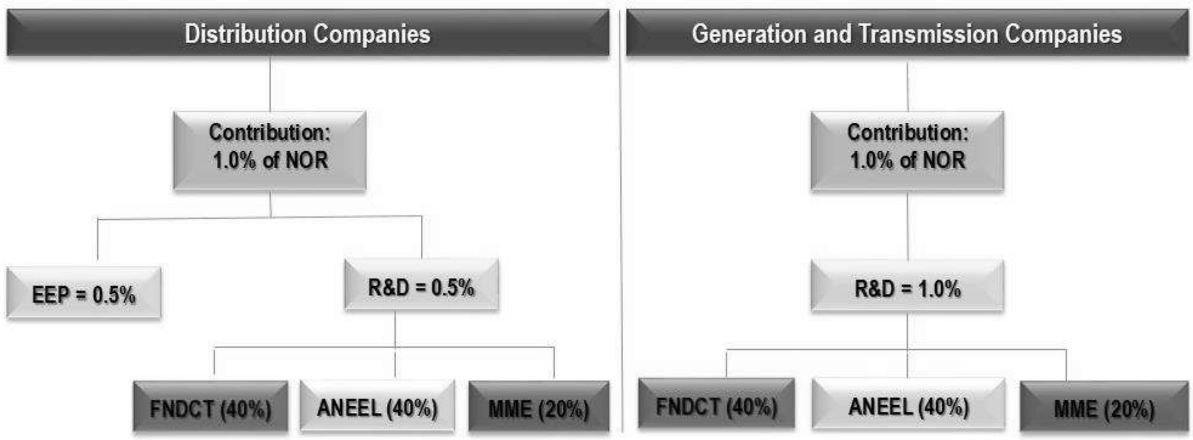

Fig.3: Origin and destination of resources to finance the SEB PP&D and EEP programs: contribution of the GTD segment companies

Source: elaborated by the authors, based on Brazil (1991; 2016) and ANEEL (2020).

As shown in figure 3, the Distribution companies contribute 1% of their Net Operating Revenue (NOR), being 0.5% for R&DP and 0.5% for the EEP. The companies in the Generation and Transmission segments contribute1% to the R&DP of this niche market of G and T (BRASIL, 1991; 2016).

2.3.2Research and Development Program (R&DP)

The objective of R&DP, regulated by ANEEL, "is to adequately allocate human and financial resources to projects that demonstrate the originality, applicability, relevance and economic viability of products and services, in the processes, and end uses of energy" (ANEEL, 2020b).

The program seeks to promote a culture of innovation, stimulating research and development in the SEB, through the creation of new equipment and the improvement of services provision, in such a way as to contribute to energy security, tariff moderateness, the reduction in the sector's environmental impact and the country's technological dependence (ANEEL, 2020b).It should be noted that Law 9,991/2000 has been amended over time to meet the demands for updating R&DP, regulated by ANEEL. This can be seen in Table 1.

Table 1 – Minimum percentages of NOR that the SEB companies must invest in R&DP

Segment of operation	Legal framework - defines % of NOR for R&DP investment				
	Law No. 9.991/00[e]	MPV No. 144/03[f]	Law No. 10.848/04[g]	Law No. 10.848/04[h]	Laws[i] No. 11.465/07, 12.212/10, 13.203/15 and 13.279/16
Generation	0.50%	0.25%	0.40%	0.40%	0.40%
Transmission	0.50%	0.25%	0.40%	0.40%	0.40%
Distribution	0.25%	0.125%	0.30%	0.20%	0.20%

Source: Elaborated by the authors, based on ANEEL (2020).

[e] Percentages in effect from 07/24/2000 to 12/11/2003.
[f] Percentages in effect from 12/12/2003 to 03/14/2004.
[g] Percentages in effect from 03/15/2004 to 12/31/2005.
[h] Percentages in effect from 01/01/2006 to 03/29/2007.
[i] Percentages in effect from 03/30/2007 to 12/31/2022 - the laws change ways of operating the programs, but do not change the percentages of NOR set for investment in the R&DP program.

Currently, as far as the R&DP regulated by ANEEL is concerned, the regulation imposes that the resources be applied as follows: a) 40% of the resources must be collected to the National Fund for Scientific and Technological Development (FNDCT); b) 40% of the resources are destined to the execution of projects presented to R&DP, regulated by ANEEL, which are managed by the contributing companies themselves; and c) the rest of the resources, corresponding to 20%, must be passed on to MME (BRASIL, 1991; 2016).

2.3.3 Energy Efficiency Program (EEP)

According to the Procedures Manual of the Energy Efficiency Program (PROPEE), published by ANEEL, through the normative resolution 830/2018, the objective of the EEP is to "promote the efficient and rational use of electricity in all sectors of the economy through projects that demonstrate the importance and economic viability of actions to combat waste and improve the energy efficiency of equipment, processes, and end uses of energy". This is aligned with the concepts of innovation recommended by the Oslo Manual such as innovation of products, services, and processes (ANEEL, 2018b; OECD/Eurostat, 2018).

In doing so, it "aims to maximize the public benefits of saved energy and avoided demand" under this program (ANEEL, 2018b). The actions of this program seek to implement efficient management of resources, with the "transformation of the electric energy market, stimulating the development of new technologies and the creation of rational habits and practices in the use of electric energy".(ANEEL, 2018b).See in Table 2 the changes in the legal framework of the EEP regulated by ANEEL.

Table 2 – Minimum percentages of NOR that the SEB companies must invest in the EEP

Segment of Operation	Legal framework - defines % of NOR for EEP investment	
	Law No. 9.991/00[j], Law No.11.465/07[k]	Law No.13.280/16[l]
Distribution	0.50%	0.40%

Source: Elaborated by the authors, based on ANEEL (2020).

[j] Percentages in effect from 07/24/2000 to 2006.
[k] Maintains the percentage in effect until April 2016.
[l] Maintains the percentage, but allocates 80% to EEP and 20% to PROCEL.

As of Law 13,280 of May 3, 2016, there was a change in the allocation of resources of the EEP, which remained at 0.50% since its creation until April of that year. As of May of the same year, the Energy Efficiency

Program began to keep 80% of the resource allocation and to pass on the other 20% to the National Electric Energy Conservation Program (PROCEL).

When the company does not make the investment or has project amounts disallowed in the innovation programs regulated by ANEEL, both in R&DP and the EEP, the amounts must be accounted for and kept at the disposal of the programs and subject to the*Selic* rate remuneration (ANEEL, 2020b).

2.5 The Brazilian Electric Sector and the 2030 Agenda - Paris Agreement

To meet the commitments made by Brazil, with Agenda 2030 –The Paris Agreement - the RD&I PP of SEB should meet the following targets set in the NDC of Brazil: i) expand the use of renewable sources other than hydropower in the total energy matrix from a 28% to 33% share by 2030; ii) increase the use of non-fossil energy sources, expanding the share of renewable energy (wind, biomass and solar) other than hydropower in the electricity matrix to at least 23% by 2030; and iii) achieve 10% efficiency gains in the electricity sector by 2030 (BID, 2017; Brasil, 2016).These goals will affect SDG 7 - accessible and clean energy - whose objective is to ensure reliable, sustainable, modern, and affordable energy for all and, by correlation, with SDG 9 - industry, innovation and infrastructure and SDG 13 - action against global climate change, due to the commitments made by Brazil with the 2030 Agenda (IPEA, 2018, 2019).

From this theoretical framework, it was sought to structure a set of methodological procedures to develop the research and reach the proposed goal.

III. METHODOLOGICAL PROCEDURES

The methodological procedures used in this study consist of a combination of methods and instruments, as a result of the different demands of analysis. Initially, support was pursued from the theoretical framework, especially with regard to the concept and type of innovation studied in this article, which has as its base the Oslo Manual (OECD/EUROSTAT, 2018; Marques, Diase Vianna, 2020).Seethe model in Figure 4, below.

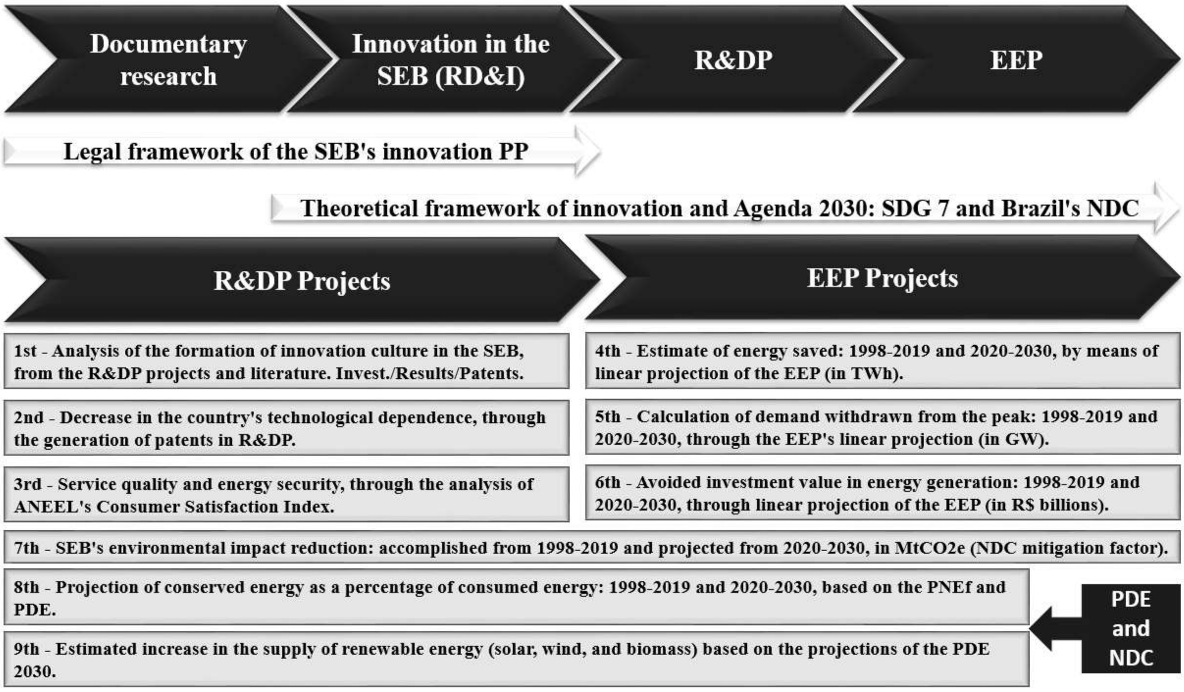

Fig.4: Graphic representation of the method used in the article

Source: elaborated by the authors.

The documental research began with the study of the theoretical framework that regulates innovation in the SEB or in the R&DI of SEB, which is divided into two programs: the R&DP and the EEP regulated by ANEEL, in the period from 1998[m] to 2019[n]. The data survey for the mentioned period was carried out based on documents released by ANEEL.

[m] 1998 is the starting year of the R&DP and EEP Programs, regulated by ANEEL.

The projections of results of the R&DP and EEP of the SEB, from 2020 to 2030, were elaborated based on available literature and documents from the MME, EPE, and ANEEL, notably PDE, PNEf, and data released by ANEEL. The estimates for Energy Savings (ESA), Demand Withdraw from the Peak (DWP), Energy Savings Index (ESI), CO_2 Emission Reduction (RECO2), in megaton of CO_2 equivalent ($MtCO_2e$) and Energy Conserved (ECON), were calculated according to the formulas and calculation memory described in items 3.1 and 3.2, below.

3.1 R&D Program (R&DP) regulated by ANEEL

Documentary analysis[o]was performed of the R&DP, through reports of projects registered in ANEEL's R&D Project Management System (SGP&D), for the period 2008 to 2019. A total of 2,918 projects have been registered, of which 905 are now in completed status. Of this total, 875 projects are from 2008 to 2016, before the ratification of the NDC (aNDC), and 30 projects from 2017 to 2019, after Brazil's ratified the NDC (dNDC). The option to analyze the 30 projects with completed status in SGP&D since they have results registered in the system. The justification for the division into two periods is the fact that Brazil's NDC with the Paris agreement was ratified by the Brazilian National Congress in 2016. Therefore, as of 2017, the RD&I PPs could legally incorporate actions aligned with the goals set in that commitment and that align with the objectives of the SEB innovation PP.

The analysis of the SEB R&DP results followed the analysis model in figure 4, items 1 to 3, as follows:

The first item of the model, which aims to identify whether the R&DP has been able to promote the culture of innovation in the SEB, was analyzed through a survey conducted on the website of 40 companies that account for 99.6% of the electricity supply market, to identify: i) if RD&I is structured in the company; ii) if the company publicizes RD&I on the website; iii) if the company advertises the public announcements of the RD&I editions; iv) if it publicizes the results of RD&I; v) if it announces that RD&I is open to startups. The formation of an organizational culture of innovation depends basically on four factors: whether it has a structured innovation program, whether the program is disclosed on the organization's website, whether the company regularly publishes announcements of the program, and whether it discloses results from previous editions(Bin et al., 2015; CGEE, 2015; Castro et al., 2019). To check if the innovation model is open one should check if the program is open to startups (Cabanes, 2016; Chesbrough, 2003, 2010; C. Christensen, 1997; Christensen, 2019).

The second item of the analysis model, which is to create/develop new equipment and decrease the country's technological dependence, was the identification with the survey of the number of patents applied for the R&DPin the period from 1998 to 2019.

Next, the results of the third, which is to improve the provision of service and contribute to energy security, were calculated through the ANEEL Customer Satisfaction Index (ACSI), identified in the period from 2000 to 2019, released annually by ANEEL.

The survey of the profile of human resources involved in the program was carried out from the analysis of 30 projects, from the period 2017 to 2019, with completed status in ANEEL's SGP&D.

3.2 Energy Efficiency Program (EEP) regulated by ANEEL

The document analysis of the EEP projects was performed from 2008 to 2019 since the data available dates back to this period. This program is properly aligned with the commitments agreed in Brazil's NDC - Agenda 2030. This analysis was done by accessing ANEEL's Microsoft Power BI[p]and a spreadsheet with a list of ANEEL's EEP projects (2020). In both the BI and the spreadsheet, it was possible to filter the information: the number of projects, amounts invested per project and per year, amount of energy saved, and amount of energy withdrawn from the peak, resulting from the implementation of this program. It has been analyzed 1,026 EEP projects, which corresponds to the total number of projects available in the BI of ANEEL's program.

The analysis of the EEP projects contributed to generate data for three items of the analysis model (fourth, fifth, and sixth). The fourth, energy saved (ESA) in TWh, which includes $ESA_{TWh(1998-2019)}$ and $ESA_{TWh(2020-2030)}$was obtained using equation 1:

[n]2019 is the year that ANEEL presents consolidated results of the R&DP and EEP Programs.

[o]The documentary research carried out in the R&DP project reports, where filters were performed in a spreadsheet from ANEEL's SGP&D, for projects with CONCLUDED status, which were separated into two periods: from 2008-2016 bNDC and 2017 to 2019 aNDC.

[p] Microsoft Power BI reports are under construction and may change at any time from June 2020. Available at: https://www.aneel.gov.br/pt/programa-eficiencia-energetica

$$ESA_{TWh(1998-2030)} = ESA_{TWh(1998-2019)} + \sum_{i=2020}^{2030}\left(\frac{VlrTotalInvest_i}{VlrInvest_{R\$/MWh_i}}\right)x\frac{1}{1{,}000{,}000}(1)$$

Where:

$ESA_{TWh(1998-2019)}$ and $ESA_{TWh(2020-2030)}$–is the amount of energy saved (ESA), for the period 1998 to 2019, added with the amount of ESA linearly projected for the period 2020 to 2030, obtained by analyzing the EEP projects (in TWh).

The demand withdrawn from the peak (DWP), which is the fifth analysis item, should be in GW, which includes $DWP_{GW(1998-2019)}$ and $DWP_{GW(2020-2030)}$was obtained through equation 2:

$$DWP_{GW(1998-2030)} = DWP_{GW(1998-2019)} + \sum_{i=2020}^{2030}\left(\frac{VlrTotalInvest_i}{VlrInvest_{R\$/kW_i}}\right)x\frac{1}{1{,}000{,}000}(2)$$

Where:

$DWP_{GW(1998-2019)}$, and $DWP_{GW(2020-2030)}$–is the amount of demand withdrawn from the peak (DWP), annually, for the period 1998 to 2019, added with the linearly projected DWP, for the period 2020 to 2030, using data from the analyzed EEP projects (in GW).

Energy savings, as well as off-peak demand, resulted in the sixth component of the proposed analysis model, investment avoided in energy generation (IAEG) in billions of reais (R$ bi), referring to two periods: $IAEG_{inR\$\ bi\ (1998-2019)}$ and $IAEG_{in\ R\$\ bi\ (2020-2030)}$ according to equation 3:

$$IAEG_{inR\$\ bi(1998-2030)} = IAEG_{inR\$\ bil(1998-2019)} + \sum_{i=2020}^{2030}(DRPinkWxVlrInvestinR\$/kW)\,x\frac{1}{1{,}000{,}000}(3)$$

Where:

$IAEG_{in\ R\$\ bi\ (1998-2019)}$ and $IAEG_{in\ R\$\ bi\ (2020-2030)}$ -is the value of the avoided investment in energy generation (IAEG), in the period from 1998 to 2019, added to the IAEG projected linearly, for the period from 2020 to 2030, based on the data of the analyzed EEP projects (in billions of Reais).

The seventh analysis item is the reduction of SEB's environmental impact and was verified from the reduction of CO_2e emissions that occurred in the period from 1998 to 2019 ($RECO_2e$ in $MtCO_2e_{(1998-2019)}$) and ($RECO_2e$ of $MtCO_2e_{(2020-2030)}$)according to equation 4:

$$RECO2e_{inMtCO2e(1998-2030)} = RECO2e_{inMtCO2e(1998-2019)} + \sum_{i=2020}^{2030}\left(ESAin\frac{MWh}{year}x\ NDC\ Emission\ Factor\ in\ tCO2e/MWh\right)x\frac{1}{1{,}000{,}000}(04)$$

Where:

$RECO_2e$ em $MtCO_2e_{(1998-2019)}$) and ($RECO_2e$ de $MtCO_2e_{(2020-2030)}$ – is the amount of CO_2e emissions avoided in the period 1998 to 2019, added with the amount of CO_2e avoided for the period 2020 to 2030 projected linearly, according to the NDC per emissions scenario.

The eighth item is the amount of conserved energy (ECON), which was calculated for the years 2020, 2025, and 2030 as provided in the NDC, equation 5:

$$ECON_i = \frac{ESA_i}{ECONacum_i}x100(05)$$

Where:

ECON corresponds to the percentage of energy conserved (ECON), obtained from the amount of ESA in the year under analysis, divided by the amount of energy saved accumulated until the year of analysis (ECONacum), multiplied by 100 (in GWh), in period i= 2020, 2025 and 2030.

At last, the new goal, which foresees an increase in the supply of renewable energy, will be analyzed against what was projected in the 2029 PDE, with added projections based on the premises of the 2030 PDE, since this document has not been released yet.

3.3 Analysis of R&DP and EEP results versus Literature, Agenda 2030 (SDG 7) and Brazil's NDC with the Paris Agreement

The data from the two programs (RD&P and EEP) were consolidated in tables, figures (graphics), and charts. This was done to allow a comparative and critical analysis of the results achieved by the projects, with the literature, with the legal framework that regulates the SEB's innovation PPs and, mainly, with the goals set in the NDC, as well as in the 2030 Agenda, especially SDG 7, which is correlated with SDGs 9 and 13. Next is the model for analyzing the results of this article.

The analysis of the results followed the methodological procedures in Figure 4, according to the model proposed in Chart 1, below:

Chart 1 - Analysis model: SEB's RD&I PP results versus Agenda 2030 - Paris Agreement

What?	**How? Analysisandresults**	**Goals: Agenda 2030**
1) Promote a culture of innovation, stimulating RD&I in the SEB (R&DP).	Theoretical framework and the SEB innovation PP (R&DP). Invest./Results/Patents	SDG 7 - Target 7.a, in correlation with SDG 9.
2) Create/develop new equipment and decrease the country's technological dependence.	Theoretical framework and quantity of patents applied for (R&DP).	SDG 7 - Target 7.a, in correlation with SDG 9.
3) Improve service provision and contribute to energy security.	ANEEL's Consumer Satisfaction Index (ACSI)	SDG 7 - Target 7.1, in correlation with SDG 9.
4) Energy Saved.	Quantity in TWh.	SDG 7 - Target 7.3, correlated with SDG 9
5) Demand withdrawn from the peak.	Quantity in GW.	SDG 7 - Target 7.3, correlated with SDG 9.
6) Avoided investment in energy generation.	In R$ in the period of ANEEL's RD&I.	SDG 7 - Target 7.3, correlated with SDG 9.
7) ReduceSEB'senvironmentalimpact	Reduction of emissions of CO_2e.	SDG 7, by correlation with SDGs 9 and 13.
8) Conserved Energy.	As % of the energy consumed, according to PNEE.	SDG 7 - Target 7.3 and NDC (10.0% target).
9) Increase the supply of renewable energy (solar, wind, and biomass).	As % of the Brazilian electric matrix.	SDG 7 - Target 7.2 and NDC (23.0% target).

Source: elaborated by the authors.

Therefore, the method and the analysis model are properly aligned with answering the problem situation and the objective of this article.

IV. RESULTS AND DISCUSSION

The results and discussion were conducted in such a way that the problem issue, which guides this article, was answered during the analysis of the results of the SEB's innovation PP, through the RD&I program regulated by ANELL (RD&P and EEP). All this with regard to the literature and the goals of Agenda 2030, notably SDG 7 - Affordable and Clean Energy. Its goal is to "ensure reliable, sustainable, modern and affordable access to energy for all" and its five targets are the three finalists[q]: 7.1, 7.2. 7.3and two implementation[r]:7.a and 7.b(IPEA, 2018, 2019). It also includes the NDC targets for energy conservation and increasing non-renewable energy sources (solar, wind, and biomass) (BID, 2017).

In this context, the correlation between SDG 7 and Brazil's NDC goals with the Paris Agreement, SDG 9 - Industry, Innovation and Infrastructure, and SDG 13 - Action Against Global Climate Change should be emphasized. Therefore, the results that impact these goals were highlighted in the analysis, but without addressing a specific goal (IPEA, 2018, 2019).

4.1 Results of the RD&P regulated by ANEEL and the goals of Agenda 2030

The analysis of SEB RD&P projects, regulated by ANEEL, was carried out in two periods: from 2008 to 2016 before the NDC (bNDC) and from 2017 to 2019 after the NDC (aNDC), given the goals of Agenda 2030 of the Paris Agreement.

4.1.1 RD&P Investments: Performed from 1998 to 2019 and Projected from 2020 to 2030

The data generated by RD&P is of great relevance to the innovation PP of the SEB, since in the period from

[q] According to the Agenda 2030, the final goals are those whose object relates directly (immediately) to the achievement of the specific SDG (IPEA, 2018).

[r] Implementation targets, in the 2030 Agenda document, the implementation targets refer to human, financial, technological, and governance resources (institutional arrangement and tools: legislation, plans, public policies, programs, etc.) needed to achieve the SDGs.

1998 to 2019 the data was- investment to the tune of R$ 7.60 billion, in 4,247 projects that were approved by ANEEL, out of 6,061 (equivalent to 70.07% of the projects submitted).From 2020-2030, the investment forecast is R$ 550.00 million per year or R$ 6.05 billion for the projected period (ANEEL, 2020b), as shown in Table 3, below.

Table 3 – R&DP data: 1998-2030[s]

Consolidated R&DP data: 1998-2030	
R&DP Investment Value: 1998 to 2030	**Values in billions of R$**
Investment in the period: 1998 to 2019 (accomplished)	7,60
Investment in the period: 2020 to 2030 (projected)	6,05
Total Investment (accomplished + projected)	**13,65**
Other R&DP data: performed from 1998 to 2019	**Qty in Units**
Presented projects	6 061
Approved Projects	4 247
Patents and Licenses	325
Active Researchers	1 200
Published Articles	3 900

Source: Developed by the authors based on data from ANEEL (2020), accomplished period (1998-2019). Projections elaborated by the authors in linear form (2020-2030).

[s] 1998 is the starting year of the R&DP - Between 1998 and 2019: period considered fulfilled. From 2020 to 2030 - data were projected by the authors in a linear fashion.

The RD&P also involved 1,200 researchers and generated 3,900 articles that were published over the period 1998 to 2019(ANEEL, 2020b).

Patents and Licenses area very relevant aspect in practically all RD&I programs, which would be no different in the RD&P regulated by ANEEL, but shows relatively shy results, with 325 patents and licenses, in the analyzed period from 1998 to 2019. This figure indicates that 7.65% of the projects generated this benefit, which presents an advance concerning the results obtained byGuedes (2012)that were 2.00% of patents, for the period 1998-2007.

4.1.2Innovation culture in the SEB and the reduction of the country's technological dependence

Promoting a culture of innovation and reducing the country's technological dependence through RD&I in the SEB is a great challenge for the program, since the Brazilian market has always had low participation of national content. That's because the electrical sector is a business segment known as "supplier follower" where suppliers are directly responsible for innovation in the production chain (Castro*et al.*, 2017a; 2015). A large part of this production chain is developed outside Brazil because most of the supplying companies are globalized.

Brazil's situation regarding innovation in the power sector is quite uncomfortable, according to the 2018 Global Innovation Index: energizing the world with innovation (GII 2018)(Cornell University, INSEAD and OMPI, 2018).In the three rankings: i) Global Innovation Index; ii) Innovation Inputs Sub-Index; and iii) Innovation Outputs Sub-Index, occupying the following positions: 64th, with 33.44 points; 58th, with 43.40 points; 70th with 23.49 points. This ranking is calculated for 126 countries and the scoring scale is from 0.00 to 100.00 (Cornell University, INSEAD and OMPI, 2018).

In the analyzed sample, between 2017 and 2019 aNDC, the percentage of patents stood at 5.95%, below the 7.65% seen between 1998-2019, therefore, it does not show evidence that the SEB innovation PP, concerning the RD&P, is aligned with SDG 9, which aims to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (IPEA, 2018, 2019).

The results of this ranking show that Brazil is far from the indexes of nations with similar economies. A way out of this uncomfortable position is to achieve at least one of the implementation goals of SDG 7, especially 7.a - "by 2030, strengthen international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency [...] and promote investment in energy infrastructure and clean energy technologies”(IPEA, 2018, 2019).

Although there are paths to follow, this study shows that 62.5% of the 40 SEB companies surveyed make no mention of whether or not they adhere to Agenda 2030 or, in particular, to SDGs 7, 9, and 13, either on their website or in their socio-environmental report. On the other hand, 37.5% expose on their website and in their socio-environmental report their corporate commitment to the UN-led Global Agenda. It is noticeable that even five years after the conclusion of the Paris Agreement, some Brazilian corporations have not yet realized that they are part of a signatory country of this global pact, with 17 Sustainable Development Goals.

Brazil may experiment with other types and models of innovation in the SEB, such as open, radical, or disruptive innovation (Christensen, 1997; OECD/Eurostat, 2018; Christensen, 2019; Marques, Dias e Vianna, 2020).For this to happen, it is necessary to examine the research results of this study carefully, because when analyzing data from 40 SEB companies, which account for 99.6% of the electric power supply market, 10.0% do not even announce their RD&I program. Only 15.0% of the 40 companies surveyed inform that their RD&I is open to startups, therefore, they are aligned with the innovation model considered ideal by the literature (Christensen, 2019).90.0% of the companies announce RD&I and publish calls for proposals on the website, which means that the programs are open, but as 85% of them do not inform that their programs are open to startups, it can be concluded that the concept of radical or disruptive innovation does not apply to the innovation model adopted by these companies. This puts them behind other countries and Brazil itself since in 2020, 46% of large companies invested in startups to speed up their innovation programs (MONEYREPORT, 2021).

4.1.3 Quality of services and energy security of the SEB

The ANEEL Customer Satisfaction Index (ACSI), created in 2000 by the regulator body to evaluate the performance of SEB companies, is composed of five variables, which are: i) perceived quality; ii) perceived value (cost-benefit ratio); iii) overall satisfaction; iv) trust in the supplier; and v) loyalty(ANEEL, 2020a).The data in figure 5 show there is nothing to celebrate, since over 19 years there has been practically no evolution.

In the two examples chosen: the company CPFL[t], which operates in the state of São Paulo, including part of the São Paulo megalopolis, in 2000 stood at 71.72 and in 2019 reached 76.81, improving only 4.99% over this period. LIGHT[u]inaugurated the ACSI in 2000, with 62.88 and, closed 2019 with 56.43, representing a drop of 6.45% from end to end, in the period analyzed and, staying below the ACSI Average over half the time of the index's existence. The choice of the companies CPFL and LIGHT, third and fifth in the ranking of SEB companies inconsumer’snumbers of 2019[v]is justified by the factthat they operate in the two largest metropolises in Brazil (the city of São Paulo and the city of Rio de Janeiro, respectively). The reason for excluding the companies CEMIG, ENEL, COPEL, first, second and fourth in the ranking is the fact that they operate in different environments (capital and countryside).

[t] CPFL is a large concessionaire and was chosen as an example since it is one of the companies that show good evaluation in the historical series from 2000-2019. CPFL is the 3rd largest company in the SEB in the total number of consumers in the 2019 ranking (Top 5).

[u] LIGHT is a large concessionaire and was chosen for this analysis since it is one of the underperforming companies in the assessment in the 2000-2019 historical series. CPFL is the 5th largest company in the SEB in the total number of consumers in the 2019 ranking (Top 5).

[v] Ranking calculated by the authors based on data from the Brazilian Association of Electricity Distributors (ABRADEE), 2019 data (ABRADEE, 2021).

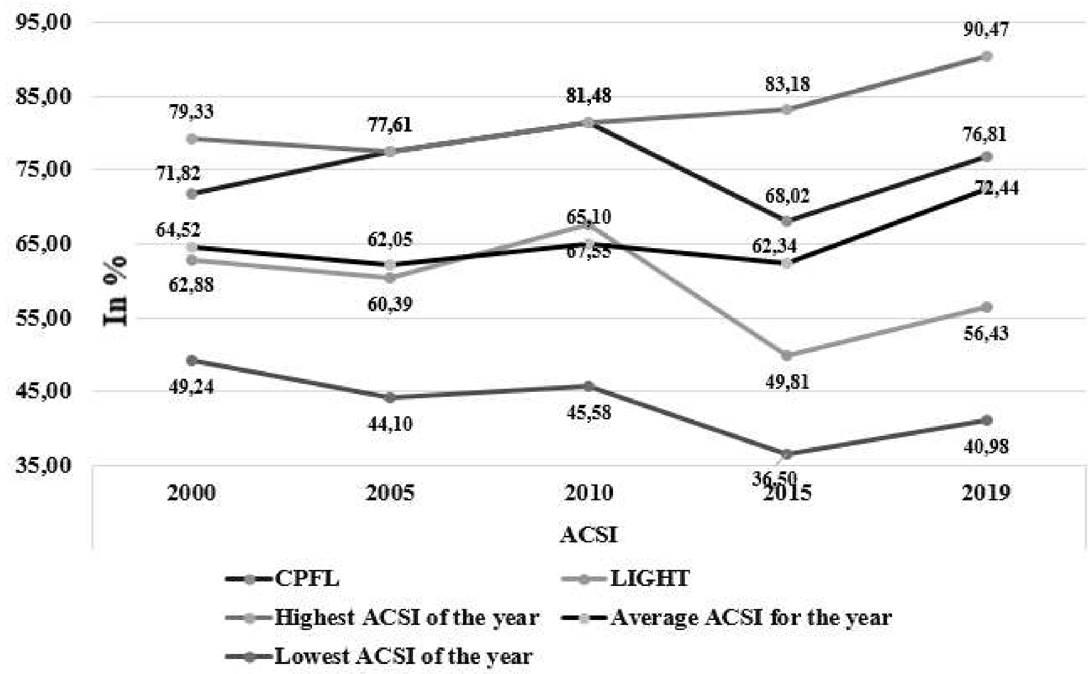

Fig.5: Evolution of ANEEL's consumer satisfaction index (ACSI), scale: from 0 to 100

Source: Elaborated by the authors based on data from ANEEL (2020).

It is also necessary to comment on the largest ACSI in each year since the line is ascending, from 79.33 in 2000 to 90.47 in 2019. Despite being increasing, the companies that occupy the first place in each year are small companies, with very low market share, that is, it is illusory information because the large companies with significant market share are around the score of CPFL (in the upper band) and LIGHT (lower band).

The ACSI results from its inception in 2000 to 2019 show that the SEB lacks a continuous improvement strategy for both service level and system reliability, and aligning with the goals of Agenda 2030 can be an important step towards quality improvement. SDG 7 has both an implementation target and an outcome target on this front: i) the implementation target is 7.b "by 2030, expand the infrastructure and improve the technology for delivering modern and sustainable energy services for all"; ii) the outcome target is 7.1 "by 2030, ensure universal, reliable, modern and [...] access to energy services"(IPEA, 2018, 2019).

4.1.4 Human resources profile and integration with the market and academy

The analysis of the profile of human resources involved in the RD&P, considering the 30 projects analyzed, with completed status in the SGP&D of ANEEL, for the period 2017 to 2019, identified 510 professionals. They are 107 (one hundred and seven) PhDs, 110 (one hundred and ten) masters, 82 (eighty-two) specialists, 157 (one hundred and fifty-seven) higher education level and 54 (fifty-four) technical level, according to Table 4, below:

Table 4: Profile of human resources involved in the 30 projects analyzed from 2017 to 2019

Titration	Quantity	Professionals per project	% bytitration
PhD	107	3.57	20.98
Master	110	3.67	21.57
Specialist	82	2.73	16.08
Higher	157	5.73	30.78
Technical	54	1.80	10.59
Total	**510**	**17.50**	**100.00**

Source: elaborated by the authors, based on a sample taken from the SGP&D of ANEEL (2020)

It should be noted that the 30 (thirty) projects analyzed were executed in partnership with Universities, Federal Institutes, Research Institutes, Foundations, and Consultancies, whose teams are mostly composed of masters and doctors, which account for approximately 60% of the staff.

These results show that there is an ongoing movement towards increased participation of academia in the innovation programs regulated by ANEEL. 100% of the projects in the sample analyzed are linked to academia, contrary to what was detected by the studiesLaplane and Cavalcanti (2015) andCGEE (2015), which indicated low integration between academia and companies in the execution of innovation programs.

However, it should be noted that no international partnership was identified seeking support for R&D in the area of energy, as provided for in SDG 7 - target 7.a - "by 2030, strengthen international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency [...](IPEA, 2018, 2019).To improve the RD&P performance it is necessary to accelerate the transition to the open innovation model, as proposed in the literature(Cabanes, 2016; Chesbrough, 2003, 2010; Christensen, 2019).

4.2 Results of the EEP of the SEB regulated by ANEEL

The results of the EEP, carried out from 1998 to 2019, and the projections of investments to be made from 2020 to 2030, presented below are i) investments in the EEP and investments avoided in energy generation (IAEG) by the EEP and; ii) energy saved (ESA) and demand withdrawn from the peak (DWP).

4.2.1 EEP Investments versus EEP IAEG: 1998 to 2030

The EEP had 4,850 projects executed, where R$ 5.90 billion were invested, in the period from 1998 to 2019, and investments[w]of R$ 6.05 billion are foreseen for the period from 2020 to 2030, which is equivalent to R$ 550.0 million per year, for the next 11 years (ANEEL, 2020b).The values of the two cycles amount to R$11.95 billion.

Investment in energy efficiency (EE) should be a priority for the SEB and Brazilian society since it generates an interesting synergistic effect since it can expand the use of the current installed capacity and avoid new investments in energy generation, as demonstrated in this study (De Castro *et al.*, 2015, 2019).

The values invested in the EEP, in the period from 1998 to 2019 (accomplished) avoided investments in energy generation, of about R$ 1.00 to R$ 2.80, with IAEG in the amount of R$ 16.56 billion.For the period from 2020 to 2030, the projections of this study indicate that the IAEG[x]for the period is of the order of R$ 25.38 billion, raising the cost versus benefit ratio (RCB) to the ratio of R$ 1.00 to R$ 4.19.The IAEG for the period from 1998 to 2030 is R$ 41.94 billion, enough to build an enterprise with an installed capacity of approximately 5,100 kW. See in figure 5 the benefit generated by the EEP by period: investment made in the EEP versus the value of the IAEG by the EEP.

[w] The value of the EEP investment from 2020 to 2030 was projected based on values corrected by the IPCA, referring to 1026 EEP projects analyzed in this study.

[x]The IAEG from 2020 to 2030 was projected based on values corrected by the IPCA, referring to 1026 EEP projects analyzed in this study.

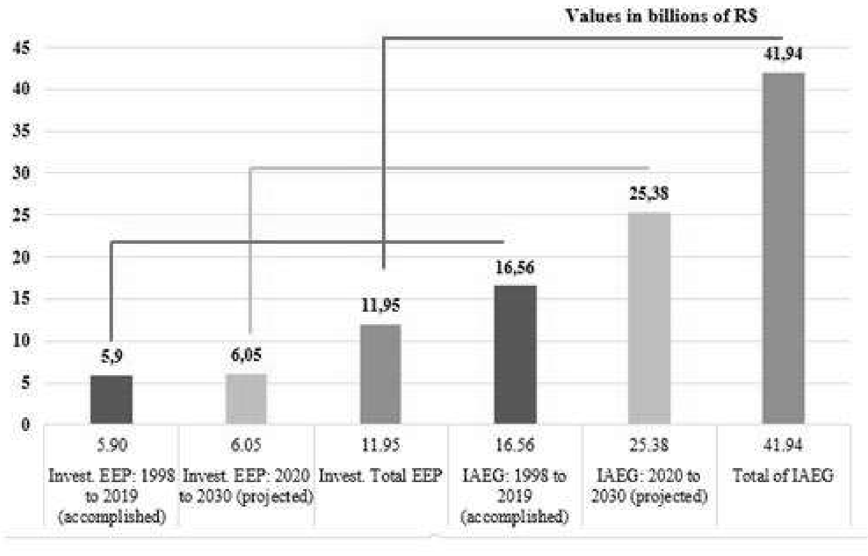

Fig.6: Investment values in the EEP versus IAEG by the EEP: 1998 to 2030

Source: Elaborated by the authors based on data from ANEEL (2020) and projections elaborated by the authors

Since the basis for expanding the production capacity of the SEB is still the HPP model, by avoiding investments in new large undertakings, the EEP is aligned with SDG 13, reducing the environmental impact of the sector.

4.2.2 Energy saved (ESA) and demand withdrawn from the peak (DWP): 1998 to 2030

The EEP is prodigious in generating combined results such as, for example, ESA and DWP. In the period from 1998 to 2019, the ESA is 63.0 TWh and allowed power withdrawal at the peak or DWP of the order of 2.8 GW, which is equivalent to 40% of the power load of the northern region of Brazil or the corresponding to the consumption of 32.4 million households in Brazil for one year (ANEEL, 2020b).The projected ESA for the period 2020 to 2030 was estimated at 4.39 TWh and the DWP 1.07 GW, as the estimates in this study. The total ESA for the period 1998 to 2030 is expected to reach 67.39 TWh and the total DWP is expected to be 3.87 GW. See the data in Table 5.

Table 5 -Energy saved by the EEP: 1998-2030[y](accomplished and projected)

Energy Saved (ESA)	**Qty. (in TWh)**
ESA - accomplished from 1998 to 2019 (in TWh/year)	63,00
ESA - projected from 2020 to 2030 (in TWh/year)	4,39
Total ESA (accomplished + projected) in TWh/year	**67,39**
Demand withdrawn from the peak	**Qty. (in GW)**
DWP in the period 1998 to 2019 (accomplished)	2,80
DWP in the period from 2020 to 2030 (projected)	1,07
Total DWP (accomplished + projected) in GW	**3,87**

Source: Elaborated by the authors based on data from ANEEL (2020) and projections elaborated by the authors.

[y] The Analysis involves the period 1998-2030, and from 1998-2019 the data released by ANEEL (2020) was used. From 2020-2030 the data were projected by the authors in a linear fashion.

EEP results in ESA and DWP meet SDG targets 7 - 7.3 "by 2030, increase the rate of energy efficiency improvement of the Brazilian economy" and 7.1 - "by 2030, strengthen international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency [...] and promote investment in energy infrastructure and clean energy technologies"(IPEA, 2018, 2019).However, one should be aware of the fact that the monitoring of the results forecast for the period from 2020 to 2030 is fundamental to plan for possible course corrections since the projections are linear and any accident along the way can alter the expected results.

4.3 Energy conserved during the PNEf: 2011 to 2030 - achieved and projected

Energy conservation is one of the goals of Brazil's NDC with the Paris Agreement, which is present in the RD&I of the SEB, through the EEP regulated by ANEEL, which by saving energy plays the role of energy conservation. The projections of the 2010 National Program for Energy Efficiency (PNEf), which served as the basis for the NDC, predicted energy consumption of 439,548 GW in 2011, the year of the starting point of the energy conservation program (MME, 2011).

In 2020, the forecast was for consumption without conservation of 674,693 GW, versus consumption with conservation of 638,700 GW. In 2025, consumption without conservation would be 832,775 GW, and consumption with conservation would be 767,067 GW. In the year 2030, energy consumption without conservation would reach 1,027,896 GW, and energy consumption with conservation would reach 921,273 GW, commitments of the NDC for the years 2020, 2025, and 2030 (BID, 2017).

This study verified what occurred in the period from 2011 to 2020 and then made projections for the period from 2020 to 2030, based on the PDEs of the same period, according to Figure 6, below. In the same period, energy consumption with conservation and without conservation was more or less on the same level due to long periods of economic crisis, including recession in the years 2015 and 2016, followed by low growth years between 2017 and 2019, and another recession in 2020 due to the Coronavirus pandemic (COVID-19). Therefore, in 2020, final energy consumption should be around 530,590 GW, practically the consumption level of mid-2014 (MME/EPE, 2018, 2020).

In 2025, projections indicate the energy consumption without conservation would be 642,652 GW, and energy consumption with conservation would be 617,004 GW. In 2030, energy consumption without conservation would reach 770,673 GW, and energy consumption with conservation would reach 716,795 GW. See Figure 7.

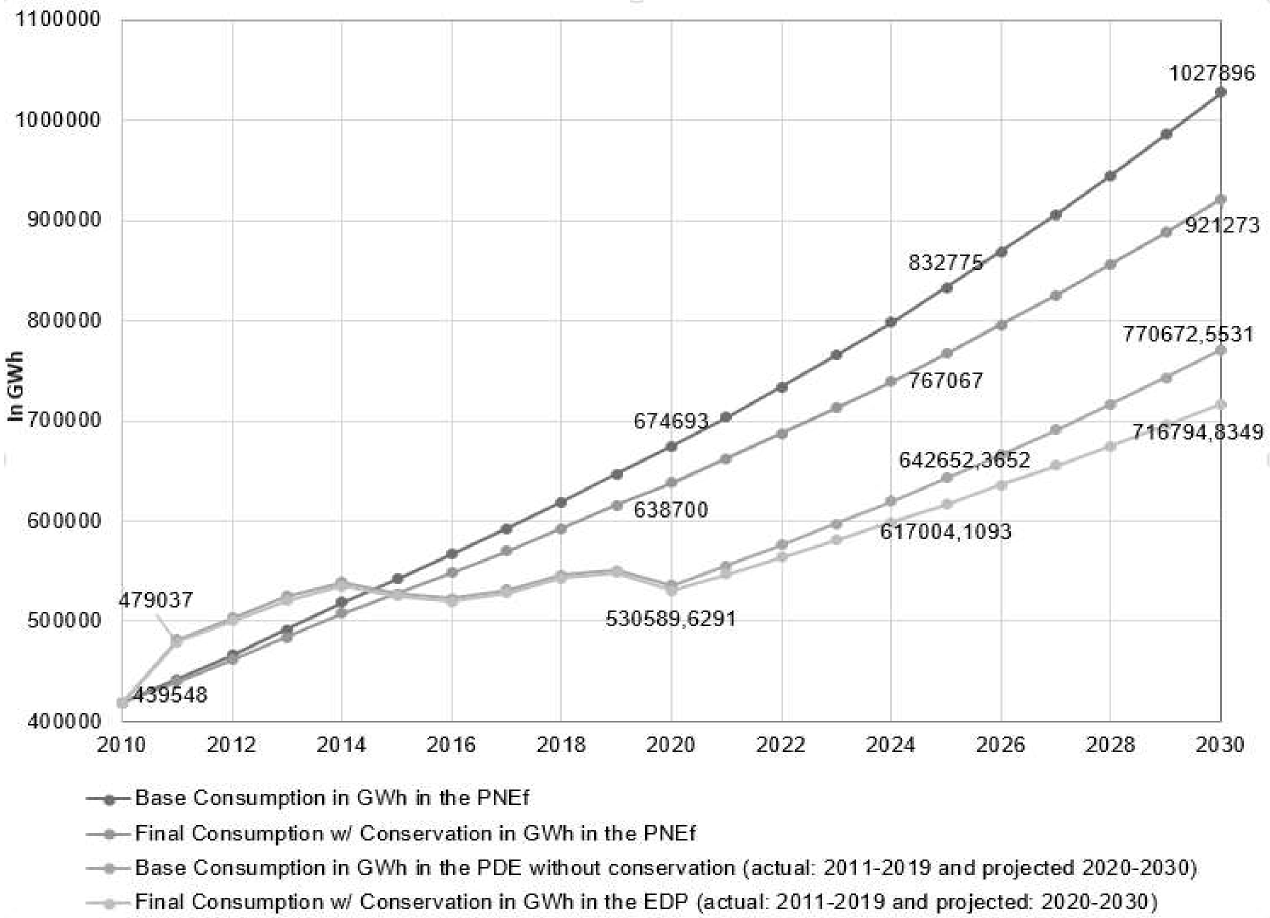

Fig.7: Energy consumption and conservation: 1998 to 2030 - accomplished and projected

Source: Prepared by the authors based on data from the PNEf (2011) and EPE (2020) and projections made by the authors based on the PDE 2030 (EPE, 2020).

The NDC targets for the years 2020, 2025 and 2030 are 4.0%, 8.0% and 10.0%, respectively (BID, 2017).The PNEf forecasted electricity conservation in 2020 of 5.33%, in 2025 of 7.89%, and 2030 of 10.37% (MME, 2011).The goal set in the NDC is compromised because the projections of this study indicate that energy conservation should end 2020 with 0.99%, in 2025 it should reach 3.99%, and in 2030 with 6.99%, compared to the NDC goal: 4.0%, 8.0%, and 10.0%, for the respective years (BID, 2017; MME, 2011)As shown in Figure 8.

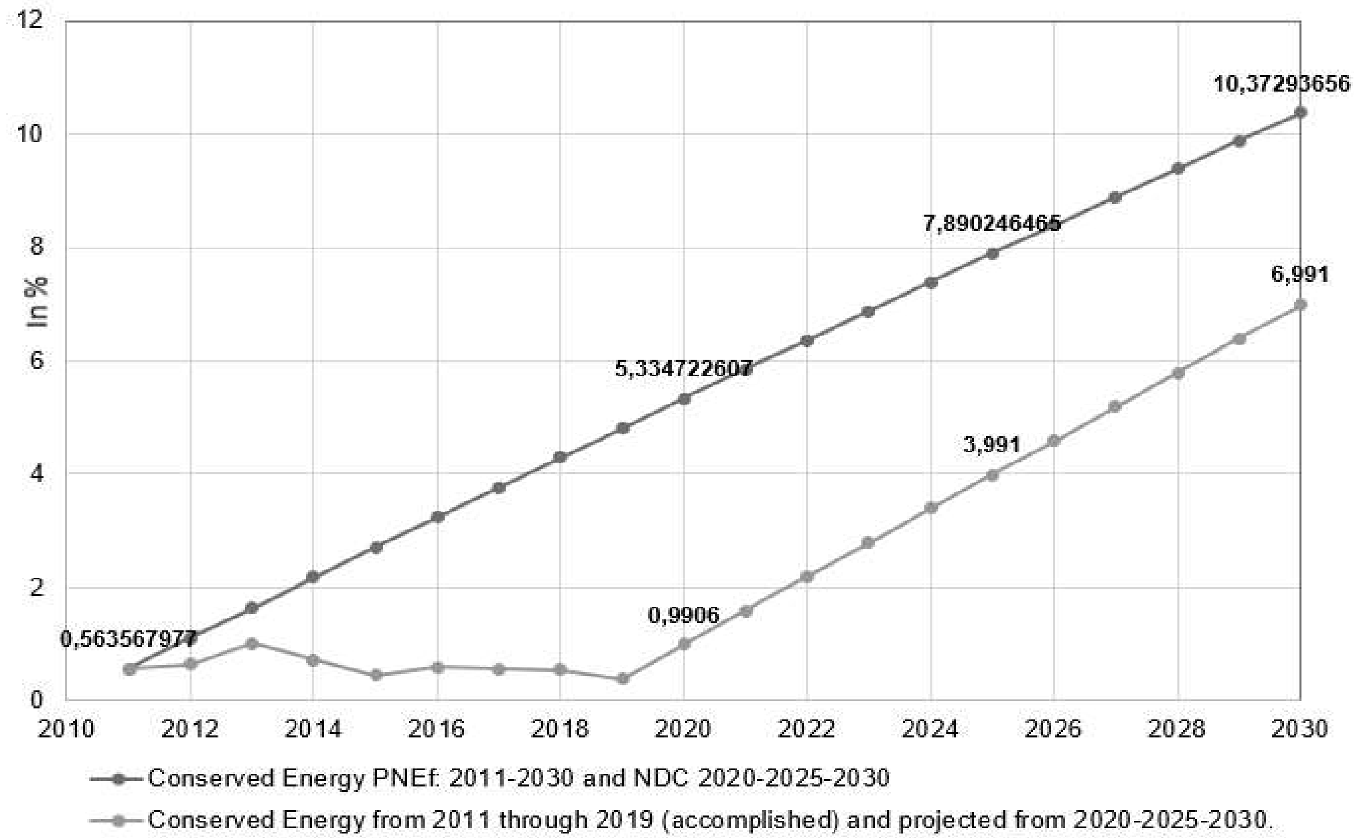

Fig.8: Electricity conservation: NDC target versus accomplished/projected

Source: Prepared by the authors based on the PNEf (MME, 2011), data from the PDE (MME/EPE, 2020) and projections prepared by the authors based on the PDE 2030 (MME/EPE, 2020).

4.4 Increase the supply of renewable energy (solar, wind, and biomass)

The increase in renewable energy supply from solar, wind, and biomass sources is foreseen in the commitments of Agenda 2030, both in the NDC and in SDG 7 - "by 2030, maintain a high share of renewable energy in the national energy matrix"(IPEA, 2019, p. 5). The NDC targets for renewable sources are as follows: i) expand the use of renewable sources other than hydropower in the total energy mix to a 28% to 33% share by 2030; ii) increase the use of non-fossil energy sources by expanding the share of renewable energy (wind, biomass and solar) besides hydropower in the electricity mix to at least 23% by 2030 (BID, 2017; Brasil, 2016).

The projections made based on the PDE 2030 (MME/EPE, 2020) indicate that the participation of renewable energy sources - excluding hydroelectric power, therefore including only wind, biomass, and solar - should reach a total of 24% in 2030, according to a linear projection of the total variable of the Brazilian electricity matrix. This is against 23.00% of variable Brazil's NDC Target with the Paris Agreement, which meets target 7.2 of SDG 7, adjusted for Brazil, which is "by 2030, maintain a high share of renewable energy in the national energy matrix" (IPEA, 2019, p. 5;). See data in Figure 9.

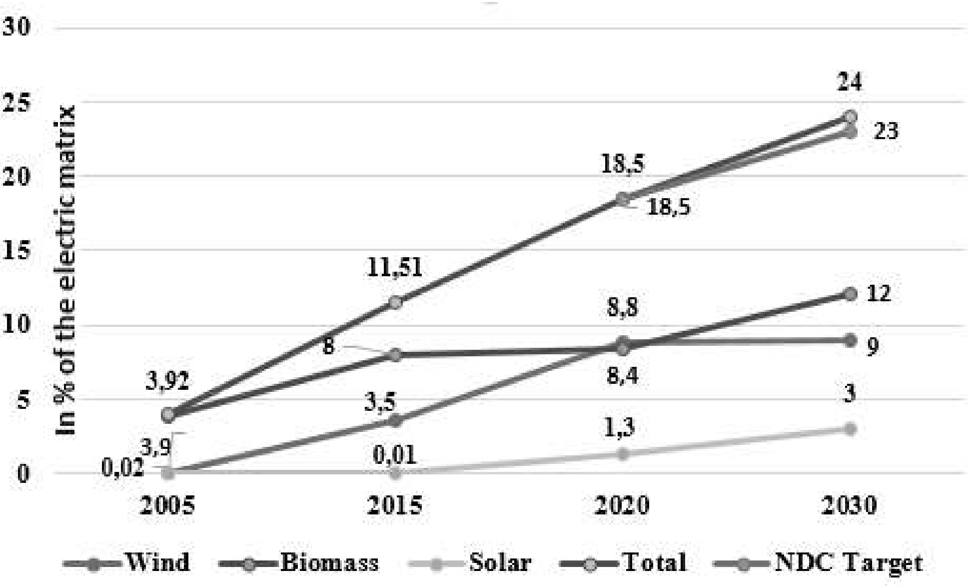

Fig.9: NDC target for renewable energy (wind, biomass, and solar) for 2030

Source: Prepared by the authors based on NDC (Brazil, 2016) and IBRD (2017), and MME/EPE (2020).

Thus, it can be inferred that the target set in the NDC for renewable energy (wind, biomass, and solar) for 2030 should be met if the pace of investment is maintained.

4.5 Reducing the environmental impact of SEB: 1998 to 2030

The reduction of CO_2e emissions verified in the EEP projects, despite not being explicit as one of its objectives, should be seen as a positive externality of the program. That is also aligned with clean energy (SDG 7), to build resilient infrastructure, promote sustainable industrialization, and foster innovation (SDG 9) and take urgent action to combat climate change and its impacts (SDG 13), by correlation (IPEA, 2019).

According to the Brazilian Forum for Climate Change (FBMC), the key role of SEB is to contribute to the "reduction of emissions of the other sectors of the economy", since the sector is a net exporter of GHG emissions for the other business segments of the market (FBMC, 2018, p. 24).

Hence, for the SEB to be able to fulfill its role, it is fundamental that the Brazilian electricity matrix becomes increasingly cleaner and that the participation of solar, wind, and biomass energy increases. That is especially considering the impact of climate change on the capacity to produce energy from hydric sources, due to the alteration of the rainfall regime, which impacts the volume of water in the reservoirs. Table 6 presents the estimates for the periods 1998-2019, as well as the projections of this study for the period from 2020 to 2030 (ANEEL, 2016, 2020b).

The emission reduction estimates of this study showed that in the worst-case scenario - pessimistic - the $RECO_2e$ is 1.617369 $MtCO_2e$ and in the best case scenario - optimistic - is 4.852106 $MtCO_2e$, considering the scenarios and emission factors used in Brazil's NDC (BID, 2017). The FBMC, in 2018, predicted that energy efficiency actions at the consumption end, had a mitigation potential of the order of 2.33 $MtCO_2e$, a value that occupies a midpoint between the worst and best case scenario estimates of this study (FBMC, 2018).

Therefore, it can be said that the SEB is aligned and well-positioned in relation to the rest of the world, when it comes to the global trend of decarbonization of the electricity sector, since the Brazilian electricity matrix has a high share of renewable energy, ending the year 2020 with a share around 85% and should reach 89% in 2030 (MME/EPE, 2020).

Table 6–Estimated CO_2e emissions avoided with the EEP - accomplished: 1998-2019 and projected: 2030

		Periods	Qty.Estimated (in tCO2e)	Total Estimate (in MtCO2e)
S C E N A R I O S	Pessimistic	1998-2019	1.512.000	**1,617369**
		2020-2030	105.369	
	Pessimistic - Efficiency	1998-2019	1.701.000	**1,819540**
		2020-2030	118.540	
	Reference	1998-2019	3.276.000	**3,504299**
		2020-2030	228.299	
	Reference - Efficiency	1998-2019	1.764.000	**1,886930**
		2020-2030	122.930	
	Optimistic	1998-2019	4.536.000	**4,852106**
		2020-2030	316.106	
	Optimistic - Efficiency	1998-2019	2.079.000	**2,223882**
		2020-2030	144.882	

Source: Prepared by the authors based on data at ANEEL (2020) - accomplished, and projections by the authors based on the expectations of ANEEL's EEP, for the period 2020 and 2030.

V. CLOSING REMARKS

The contribution of this article was to analyze the impact of the Brazilian innovation PPs of the SEB, more specifically on the research and development and energy efficiency programs, coordinated by the sector's regulatory agency, in the face of the goals set in Agenda 2030, especially in SDG 7 and Brazil's NDC.

The discussions held from the analysis of the SEB innovation PP - through the RD&I program regulated by ANEEL, which involved RD&P and EEP projects - show that there are considerable advances, with clear results accounted for. Nevertheless, there are also doubts, which fall mainly on the RD&P. For example, it was not identified research with a hydrogen-based fuel cell that is considered the RD&I frontier, capable of potentiating the renewable energy production units (solar and wind).

With regard to technological trends and challenges of the electricity sector in the world: digitalization, decentralization, and decarbonization, Brazil has advanced, but with a certain mismatch. In the first trend, digitalization, the RD&P of the SEB has contributed to the advancement of digital technologies that aim to improve the operational efficiency of the electricity system. This means investing in smart grids and preparing them for a new configuration, which includes the spread of distributed generation and energy efficiency. However, Brazil is still lagging behind the EU and the US (Marques, Dias e Vianna, 2020; ANEEL, 2020b; Castro, N. J.; Brandão, 2019; De Castro et al., 2015).

In the second trend, the decentralization of the electrical systems, the SEB should use it in a complementary way to the SIN, which is considered a model with a good level of efficiency. However, with time the tendency is for integration to increase thanks to technological evolution, to smart grids, which allow bidirectional flows. The change from unidirectional to bidirectional flow facilitates the process of decentralization and makes it possible to add new sources of generation, including renewable ones such as solar and wind, which can be produced close to the final consumer (Castro *et al*., 2017; WORLD ENERGY COUNCIL, 2017; MIT, 2016; NYISO, 2016; Collaço *et al*., 2016;Schwab, 2018;Rifkin, 2012).

The third and last of the global trends, the decarbonization of the electric system, has already been overcome by Brazil, due to the concentration of hydro sources based initially on HPP and SHP. Today, the country is expected to move quickly to other renewable energy sources, such as wind, solar, and biomass, to reduce the dependence on hydroelectric power, due to climate change.

It is also observed that the results of the RD&P, which is in its third cycle - especially in the sample of projects analyzed in this study - are configured in at least three findings: i) the program is not aligned with the 2030 Agenda, especially with the goals of SDG 7, correlated with SDGs 9 and 13 and the NDC goals; ii) the innovation model does not contemplate open innovation, to take better advantage of the innovation potentials in the SEB; iii) the cost-benefit relationship or the impact of the program throughout the 21 years of existence is not proven (ANEEL, 2020b; IPEA, 2019; De Castro *et al*., 2015;Cabanes, 2016; Chesbrough, 2003, 2010).

The EEP presented results aligned with the goals of Agenda 2030, both in the targets of SDG 7, correlated with SDGs 9 and 13, and with the goals of Brazil's NDC, along with the Paris Agreement.

The R&DP projects are concentrated in the products: i) Concept or Methodology; ii) System; and iii) Software, which accounts for 76.67% in the period 2017 to 2019, against 53.54% in the period 2008 to 2016. The products generated in R&DP, when they reach the market and are associated with the supplies made by the international supply chain of inputs for the SEB, contribute to the EEP by providing process innovation, which meets the goals of energy efficiency: reduction of energy consumed, investments and environmental impact of the sector.

As for the financing sources of the SEB's innovation PPs, one can infer that it is one of the few programs with guaranteed resources through the R&DP and EEP since the resources for these programs have not been affected by contingencies from the national treasury (ANEEL, 2016, 2020b). This research has shown that there are other lines of credit available for RD&I in SEB, both at the National Bank for Economic and Social Development (BNDES) and the Study and Project Financing Agency (FINEP), either through non-reimbursable and reimbursable resources(BNDES, 2020; FINEP, 2020).

One of the limitations of this study was not dealing with tariff moderation. This is one of the goals of the RD&I of the SEB, and is aligned with Agenda 2030, SDG 7 - target 7.1 "by 2030, ensure universal, reliable, modern and affordable access to energy services", which due to its extent and importance will be presented in another article in the sequence (IPEA, 2019, p. 5).

It remains as a suggestion for future research the indications made by the FBMC (2018) to the Federal Government so that the SEB could meet the commitments signed in Brazil's NDC. This study did not identify actions in the innovation PPs of the SEB to i) expand centralized electricity generation from renewable sources, both centralized and distributed, in the interconnected system and isolated systems, as well as energy storage capacity; ii) repowering of hydroelectric plants; and iii) expansion of renewable energy in isolated locations (FBMC, 2018). All three indications have the potential to reduce the SEB's environmental impact and thus increase the sector's convergence with the 2030 Agenda.

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APÊNDICE C – ARTIGO 3

Impact evaluation of the public innovation policy of the Brazilian electricity sector (SEB) on the electricity tariff paid by the consumer

Avaliação de impacto da política pública de inovação do setor elétrico brasileiro (SEB) na tarifa de energia elétrica paga pelo consumidor

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Impact evaluation of the public innovation policy of the Brazilian electricity sector (SEB) on the electricity tariff paid by the consumer

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ABSTRACT

The objective of this paper is to evaluate the impact of the SEB public policy of innovation, on the average supply tariff (AST), from its implementation in the year 2000 until 2020, considering the premise of tariff moderation foreseen in the RD&I of the SEB, which is aligned with SDG 7 of Agenda 2030. The methodological procedures used were: (a) a sample consisting of 40% of the market (seven electricity distributors, in a universe of one hundred and eleven) of the market (in consumers and billing) was defined; (b) the "Before and After Real Tariff" model (1994-2020) was applied, through an Ordinary Least Squares (OLS) estimation; c) calculation of the Real AST of the sample, by the present value (PV) method, updated based on the IPCA as indexer; d) calculation of the result of Model 4 "before and after" and the result of AST in PV to verify the impact of the SEB's RD&I public policy on AST. The results obtained from the study showed that the creation of the innovation contribution (ContribInova) impacted the AST value by 60.95% in terms of real increase. Another result to highlight is that three Electricity Purchasing Power (EPP) indicators and the Electricity Purchasing Power Index (EPPi) were proposed and calculated, which aim to track the evolution of the AST with a view to the premise of tariff moderation of the SEB and the Brazilian commitment in Agenda 2030 to ensure access to energy services at affordable prices by 2030.

KEYWORDS

Innovation public policies, SEB RD&I; AST; Agenda 2020 SDG 7.

1 INTRODUCTION

It is expected that policymakers when thinking of investing in a research, development, and innovation (RD&I) program, start from the assumption that such intervention will have a positive impact on the sector. Such as the case of the Research & Development Program (R&DP) and the Energy Efficiency Program (EEP) of the Brazilian electricity sector (SEB), which has tariff moderation as one of its premises. [1] [2] The public policy for innovation in the SEB began with Law No. 9.991 of July 24, 2000, establishing the Energy Sector Fund (CTEnerg) and later implementing the R&DP and EEP regulated by ANEEL [3] [2].

Every public policy must be monitored and evaluated in the course of its existence and this must be foreseen in its design [1]. However, it can be seen that in the case of RD&I of the SEB, which involves R&DP and EEP– regardless of being regulated by ANEEL, which is still a form of monitoring and evaluation - no impact evaluation has been done, despite being a public policy that is more than two decades old.

It should be noted that there are precedents in the literature indicating the need for evaluation of these programs. Examples are the studies of [4] [5] – which indicate that ultraliberal markets, such as the UK, have not been able to solve the problems of innovation in the electricity sector. Also, the study by [6], in 31 countries of the Organization for Economic Cooperation and Development (OECD) - pointing out that the international standard of regulation has not found a point of balance that would allow advances in the development of technology and innovation in the electricity sector [7]. Thus, it is noted that the SEB's RD&I lacks an evaluation to measure the impact of the SEB's public innovation policy.

With the advent of the Paris Agreement, to which Brazil became a party and committed to the 2030 agenda and its 17 Sustainable Development Goals (SDGs), the need to evaluate the program and check the performance of SEB's public policy on innovation and whether it is aligned with the commitments made by Brazil under the United Nations Framework Convention on Climate Change (UNFCCC) at COP21 has increased even more [8].

This study aims to cover a research gap identified in the bibliometric study prepared by [7]. This will be accomplished by conducting the impact assessment of the Brazilian public policy of RD&I of the SEB, concerning the tariff moderation foreseen in the commitments made by Brazil, with the United Nations (UN) Agenda 2030 and in particular with SDG 7 - target 7.1 "by 2030, ensure universal, reliable, modern and affordable access to energy services" [9].

Thus, this article has as its research problem the following question: What is the impact of the implementation of the public policy of RD&I of the SEB, through the R&DP and the EEP, in the policy of tariff moderation foreseen in the program and the goals of Agenda 2030?

To answer the research question proposed in this study, it was set as an objective "to evaluate the impact of the Brazilian public policy of SEB innovation, from its implementation in the year 2000 until 2020, on the average supply tariff (AST), since one of the premises of RD&I is tariff moderation, which aligns with SDG 7 of Agenda 2030."

The justification for conducting this study is the fact that the SEB public policy of innovation, the RD&I regulated by ANEEL, completed 21 years in 2020 and one of its proposals is to promote tariff moderation through innovation. In light of this, it is necessary to conduct an impact evaluation of this public policy to verify whether this objective has been achieved over time and, especially now, with the need to align with the goals of Agenda 2030.

This article was structured in 5 (five) sections: introduction, theoretical framework, methodological procedures, results, and final considerations.

2 THEORETICAL FRAMEWORK

This item will address the basic concepts of public policy, public policy evaluation, regression analysis and regression model with binary variables (dummies), innovation in the SEB and its relationship with the principle of tariff moderation and Brazil's commitments to Agenda 2030, and indicators and purchasing power index of electric power in Brazil.

2.1 Public Policies

A public policy is a guideline designed to address a public problem and it has two fundamental elements: a) intentionality; and b) response to a public problem. Hence, the motivation for creating and implementing a public policy is to treat or solve a collective and relevant problem [10]. According to [11], public policy is "everything that a government decides to do or not to do".

In 2000, the advent of Law 9.991/2000, which instituted the CTEnerge, paved the way for the creation and implementation of the SEB's public policy for innovation (RD&I of the SEB), represented by the R&DP and the EEP regulated by ANEEL according to [3] and [2]. The financing of the initiative was made possible through the contribution for innovation (ContribInova), created to finance this public policy and collected by the SEB companies per segment, as follows: a) Distribution contributes with 1.0% of the Net Operating Income (NOI), being 0.5% for R&DP and 0.5% for the EEP; and b) Generation and Transmission contributes with 1.0% of the NOI, for R&DP [3] [2].

The management of resources for the operationalization of the RD&I of the SEB is carried out following the current legislation, according to [3] and [2], according to the following parameters: (a) National Fund for Scientific and Technological Development (FNDCT) receives 40.0% of the R&DP ContribInova amount; (b) ANEEL receives 40.0% of the R&DP ContribInova amount; and (c) Ministry of Mines and Energy (MME) receives 20.0% of the R&DP ContribInova [3] [2].

Thus, the public policy of innovation of the SEB has the intention to make viable a problem of the sector that is: how to innovate in a complex sector that involves Generation, Transmission and Distribution (GTD) networked as is the case of the electricity sector? Therefore, the action is characterized as a public policy, since it meets the two basic assumptions for such: intentionality and being a relevant public problem, translating purposes into programs and actions [11] [12] [13].

2.2 Public Policy Evaluation

Public policy evaluation is a way of checking the impact of a government's actions in seeking to solve problems that affect society - the evaluation may involve what the government does and what it fails to do [12] [14].

It is common for evaluation to occur before (*ex-ante*) implementation to confirm the correct diagnosis of the problem that gave rise to the creation of public policy, for in this, late detection of formulation and design errors is avoided, which enables the correction of eventual deviations and prevents the waste of public resources, according to [15]. Another way to evaluate a public policy is to conduct an a posteriori (*ex-post*) evaluation, usually at the end of the policy. This is a very important instrument for the decision-making process since it allows the manager to evaluate the results: whether the problem identified was addressed according to the objectives and goals previously established; whether the resources are being allocated correctly; and ultimately, to make the necessary corrections to improve the quality of public spending [16]. In this case, it is necessary to remember that this is an ongoing public policy, with more than 20 years of implementation; therefore, it is necessary to elaborate an impact evaluation that can check its results over time [1]. To meet this type of demand, the same authors suggest estimating the effect of a policy using the before and after evaluation model, since it comprises three important moments of a public policy, program, or project: before, during, and after [1].

2.3 Innovation in the SEB and its relation to the principle of tariff moderation and Brazil's commitments to Agenda 2030

This study compares the results of innovation in the SEB, with the principle of tariff moderation and Brazil's commitments to the 2030 Agenda, derived from the Paris Agreement. To this end, the concept of tariff moderation to be adopted is enshrined in Article 6, §1 of Law No. 8987 of 1995, as follows [17] and interpreted by jurists as follows: [18] states that "[...] having the public service to reach and satisfy the various social groups in the pursuit of the common good, [...] must be consistent with the economic possibilities of the Brazilian people, that is, the lowest possible." [19] goes beyond Marinela when he says that "such modicity, it should be noted, is one of the most important user rights, because, if disrespected, the service itself will end up being unconstitutionally withheld [...]". Therefore, the relevance of the principle of tariff modicity for this study and the Brazilian society is verified.

Considering that Brazil's commitments to Agenda 2030, arising from the Paris Agreement, should be incorporated into public policies, this work has set as a parameter of comparison, goal 7.1 with SDG 7 - Affordable and Clean Energy. Its objective is to "ensure access to affordable, reliable, sustainable and modern energy for all" and its ultimate goal[1], 7.1 - " by 2030 ensure universal access to affordable, reliable, and modern energy services" [20] [9].

2.4 Indicators and purchasing power index

According to [21], it's not possible to manage what you can't measure therefore, building indicators to measure results is important for any management model. "Indicators are measures, that is, they are an assignment of numbers and objects, events or situations according to certain rules" [22].

This research proposes 3 indicators and an index to better manage the principle of tariff moderation and target 7.1 of SDG 7 of Agenda 2030. They are aligned with the SMART concept, which is an acronym for the words: Specific (S), Measurable (M), Attainable (A), Relevant (R), and Time-Bound (T) or in [23]. It is important to point out that these indicators were based on secondary data and one of them, the average income of Brazilians, is highly aggregated. One must remember that indicators are always simplifications of complex realities, even if they do not describe reality exactly, they help to interpret it and contribute to evaluating the evolution of a problem, as warned by [24] and [25].

3 METHODOLOGICAL PROCEDURES

The methodological procedures used in this study consist of a combination of bibliographic, documentary, and experimental research methods. The bibliographical research sought to understand the results of published studies on SEB public policy innovation. In the documental research, were identified the data referring to the electricity tariffs from 1994 to 2020, the value

[1] According to the Agenda 2030, finalist goals are those whose object relates directly (immediately) to the achievement of the specific SDG (IPEA, 2018c).

of the contribution to the innovation program of the SEB in ANEEL's database, in the period from 2000 to 2020, as well as the objective of tariff moderation of the SEB [26] [2]. The experimental research was developed to test the hypothesis that creating the public policy and adding a mandatory contribution to finance the innovation program would bring efficiency gains for the companies and the system, in a way that would benefit consumers via tariff reductions. See in figure 1the structure of the article.

Figure 1. Structure of the article
Source: elaborated by the authors.

3.1 Sample Selection and Data Collection

The analysis and data survey was carried out based on the performance of the real value of the AST/MWh was analyzed over the period from 1994 to 2022[2], employing a sample of 7 large electricity distributors, out of a total of 111. That was corresponding to 6.30% of all distributors in operation in 2021, but which together commercialize 38.55% of the electricity consumed, account for 39.26% of the sector's revenue (without taxes), and reach 38.73% of consumers in the national territory, in all consumption classes.

The justification for this option is the fact that they operate in 4 (four) of the 5 regions of Brazil: a) CEMIG, ELETROPAULO, and LIGHT, from the Southeast region; b) CEEE and COPEL, which operate in the South region; c) CELG from the Mid-West region, and d) CELPE from the Northeast region. Added to this is the fact that these companies have a history that allows the application of the evaluation or comparison model "Before and After", linear regression analysis, utilizing an Ordinary Least Squares (OLS) estimation and also because they represent approximately 40.00% of the national consumption [27].

Figure 2. Application of the analysis models
Source: elaborated by the authors.

3.2 Data Analysis Methods

The linear regression analysis has "a set of tools whose focus is to make inferences, most often causal", from evidence found for a sample, which allows "making generalizations of results to the population", according to [28].

The tool used to conduct this experimental research will be regression analysis. In general, regression analysis seeks to estimate the mean value of the dependent variable of a population-based on known values from the sample. In this study, it seeks to estimate the effects of the

[2] To project the nominal value of the AST, this work opted to adopt the data projected for 2021 and 2022, since they were released by ANEEL.

exploratory variables, especially the contribution dummy (independent variable), on the dependent variable, the energy tariff. It is important to note that while regression analysis deals with the dependence of one variable on others, this does not necessarily imply causation. In the words of Kendall and Stuart, "a statistical relationship, however strong and suggestive, can never establish a causal connection: our ideas of causation must come from outside statistics, ultimately from some theory" [29] [30].

Regarding the types of data available, there are panel data, observations of "prices" from various companies over time, both of which are quantifiable variables. However, it is common for other qualitative variables to affect the dependent variable as well as the quantitative variables, so it is common to construct a binary variable, also known as a dummy variable. These variables take on values "0" and "1", where "1" indicates the presence of the attribute and "0" the absence [29][30].

Next, the "Before and After the Real Tariff" model was applied, through an Ordinary Least Squares (OLS) estimation to identify whether there was a change in the average prices of the AST/MWh after the establishment of the ContribInova obligation, using four regression models [30] [31].

a. Model 1: Simple before-and-after regression, equation 1:

$$\log(RealTariff)_{it} = \alpha + \beta_t \,\mathrm{dummy}(Contribution)_t + \varepsilon_{it} \tag{1}$$

Where:

- $\log(RealTariff)_{it}$ is the value of the logarithm of the Real Tariff of company "i", at time "t" in constant 2020 prices;
- $\mathrm{dummy}(Contribution)_t$ takes on a value of "0" from 1994 to 1999 and "1" in the period from 2000 to 2020, and ε_{it} represents the standard error of the model.

b. Model 2: Before-after regression with time fixed effect

In Model 2 fixed effects were added for the time variable ($data_t$), having a dummy for each of the years analyzed. The idea is to capture movements that may have directly affected the value of the AST/MWh in a specific year. The following equation was used:

$$\log(RealTariff)_{it} = \alpha + \beta_t \,\mathrm{dummy}(Contribution)_t + \theta_t data_t + \varepsilon_{it} \tag{2}$$

Where:

- $\log(RealTariff)_{it}$ is the value of the logarithm of the actual Tariff for company "i", at time "t" in constant 2020 prices;
- $\mathrm{dummy}(Contribution)_t$ takes value equal to "0" from 1994 to 1999 and "1" in the period from 2000 to 2020 and ε_{it} represents the standard error of the model.

c. Model 3: Before-and-after regression with company fixed effect

It is believed that the company may also have specific characteristics that influence its pricing. Thus, in Model 3 fixed effects were added for each one of the companies, to verify if the price levels differ from company to company, according to the following equation:

$$\log(RealTariff)_{it} = \alpha + \beta_t \,\mathrm{dummy}(Contribution)_t + \mu_i company_i + \varepsilon_{it} \tag{3}$$

Where:

- $\log(RealTariff)_{it}$ is the value of the logarithm of the Real Fare for company "i", at time "t" in constant 2020 prices;
- $\mathrm{dummy}(Contribution)_t$ takes value equal to "0" from 1994 to 1999 and "1" in the period from 2000 to 2020 and ε_{it} represents the standard error of the model.

d. Model 4: Before-after regression with time and company fixed effects

Finally, we have Model 4, in which the log of the Real AST/MWh was regressed in function of the temporal dummy that indicates the implementation of the public policy that establishes the

Real Contribution in innovation for SEB companies, considering the presence of time and company fixed effects. Thus, Model 4 estimates specific effects of each of these variables, aiming to identify whether there are differences that reflect in changes in Tariffs based on companies μ_i and in timeθ_t, according to the following equation:

$$\log(RealTariff)_{it} = \alpha + \beta_t \text{dummy}(Contribution)_t + \theta_t + \mu_i + \varepsilon_{it} \quad (4)$$

Where:

- $\log(RealTariff)_{it}$is the value of the logarithm of the Real Tariff of company "i", at time "t" in constant 2020 prices;
- $\text{dummy}(Contribution)_t$ takes value equal to "0" from 1994 to 1999 and "1" in the period from 2000 to 2020 and ε_{it} represents the standard error of the model.

In the application of Model 4, when a positive effect on tariffs is detected after the implementation of the mandatory contributions in innovation, the magnitude of the effect will be verified, which will be obtained through the exponential scale model. To evaluate its magnitude compared to the increase in the AST/MWh per company and percentage, it is necessary to transform the obtained value of the effect in exponential scale (due to the model characteristic) to percentage scale, according to equation 5:

$$effect = (\exp(\beta) - 1) * 100 \quad (5)$$

Where:

- Effect = is the expected result of transforming the exponential scale effect to percentage;
- $\exp(\beta)$ = is the exponential scale effect value.

3.3 Monetary updating of the average electricity supply tariff (AST)

Since the study contemplates a long period, it was chosen to do the monetary updating of the AST/MWh and analyze its evolution in the study period (1994 to 2022), using the present value (PV) method, from the historical value (HP) of the AST/MWh, effective date until the current date, updated by the IPCA variation in the period under analysis, according to [30], with the following equation:

$$FV = PV(1+i)^n \text{ or } FV = PV(1+i)^n \quad (6)$$

Where:

- FV = Future Value;
- PV = Present Value or PV_{AST} = Present Value of AST/MWh;
- i = inflation index (IPCA);
- n = number of periods.

3.4 Comparison of the average supply tariff (AST) with ODS 7

Next, the real increase in the AST/MWh was compared, after the implementation of the SEB innovation public policy from 2000 to 2020[3] with target 7.1 and SDG 7. The comparison was made through the value of AST/MWh (at present value), of a group of electric power distribution companies under study, using the evolution of the Extended National Consumer Price Index (IPCA), calculated by the Brazilian Institute of Geography and Statistics (IBGE), in the analyzed period. This comparison was joined by an indicator that is the positive effect on the AST/MWh, generated by Model 4 - "Before and After", which occurred after the implementation of the ContribInova obligation, created by the SEB public innovation policy.

3.5 Creation of the Electricity Purchasing Power Index (EPPi)

Finally, this study proposed a set of 3 indicators and an energy purchasing power index. The Electricity Purchasing Power (EPP) was prepared as follows: the first, based on the National

[3] Model 4 - Before and After was applied between 1994 and 2020, even though it has data for 2021 and 2022, because it is a regression that is applied to past periods.

Minimum Wage (NMW); the second, on the Minimum Wage Basic Food Basket of DIEESE (MWBFBDIEESE); and the third, by the Average Income of Brazilians, calculated by IBGE (AIbIBGE). Below are the proposed indicators, which were calculated from 1994 to 2020, except the EPPAIbIBGE, which started in 2012 and went until 2020.

The first, Electricity Purchasing Power, calculated based on NMW (EPPNMW) with the following formula:

$$EPPNMW\ in\ MWh = \frac{Value\ of\ NationalMW}{Value\ of\ AST\ in\ MWh} \quad (7)$$

The second, Electricity Purchasing Power Indicator, based on the MWBFBDIEESE (EPPMWBFBDIEESE), obtained with the following formula:

$$EPPMWBFBDieese\ in\ MWh = \frac{Value\ of\ MWBFBDieese}{Value\ of\ AST\ in\ MWh} \quad (8)$$

The third, Electricity Purchasing Power Indicator, based on the AIbIBGE (EPPAIbIBGE), determined from the following formula:

$$EPPAIbIBGE\ in\ MWh = \frac{Value\ of\ AIbIBGE}{Value\ of\ AST\ in\ MWh} \quad (9)$$

Where:

- NMW is the value of the national minimum wage, published by the Federal Government, in effect in December of each year;
- MWBFB is the value of the basic food basket minimum wage, published by DIEESE, in December of each year;
- AIb is the value of the average Brazilian income, released by the IBGE, together with the salary mass study. When not released in the current year, the previous year's will be repeated;
- MWh is the base value of AST/MWh without taxes for each company, in December of each year. The value used for these indicators was the weighted average ($\overline{X_p}$) of the AST/MWh of the 7 concessionaries that make up the study group, for the time of the study.

After obtaining the partial results, the calculation $\overline{X_p}$ of the 3 EPP indicators was performed, to generate a better quality input for the calculation of the Electricity Purchasing Power Index (EPPi). The option for the weighted average is due to the significant variation in AST/MWh among the concessionaires under study, as well as the variation among EPP indicators. See the formula below:

$$\overline{X_p}\ of\ EPP = \frac{\sum_{i=1}^{n} p_i * x_i}{\sum_{i=1}^{n} p_i} \quad (10)$$

Where:

- $\overline{X_p}$ of EPP = weighted average of the Electricity Purchasing Power indicator (EPP)
- $\sum_{i=1}^{n} p_i * x_i$ = sum of the weighted average of the EPPNMW + EPPMWBFB/DIEESE + EPPAIb/IBGE
- $\sum_{i=1}^{n} p_i$ = sum of the weights of EPPNMW + EPPMWBFB/DIEESE + EPPAIb/IBGE

The weighting was done as follows: from 1994 to 2011 with 2 indicators, and from 2012 to 2020 with 3 indicators, after the inclusion of the EPPAIbIBGE indicator, which started to be released in the year 2012.

Then it was calculated the Electricity Purchasing Power Index (EPPi) used in this study, from the $\overline{X_p}$ of the 3 indicators EPPNMW in MWh, EPPMWBFBDieese in MWh, and EPPAIbIBGE in MWh. Once the $\overline{X_p}$ of the 3 indicators was obtained, the evolution of the $\overline{X_p}$ of the indicators was calculated, as a percentage with base 100.

$$EPPi = \left(\frac{\overline{X_p}\ \ Year\ x}{\overline{X_p}\ \ Base\ year}\right) x100 \quad (11)$$

Where:

- $EPPi = Electricity\ Purchasing\ Power\ Index\ (EPPi)$.
- $\overline{X}_p\ \ Year\ x$ = weighted average of the EPP indicators for the year under study.
- $\overline{X}_p\ \ Base\ Year$ = weighted average of the EPP indicators for the year 1999, considering the year on a 100 basis.

The analysis of the EPPi base 100, from 2000 to 2020, considered the year 1999 (the year before ContribInova started to be charged = base year), as base 100, starting in the year 2000 (year x), to calculate the percentage variation from one year to the other. Thus, if the result is equal to 100, it indicates zero effect on the AST/MWh, if the variation is greater than 100, it shows that it is favorable to the consumer, but if it stays below 100, it informs that the consumer is paying more for the electricity bill, therefore losing purchasing power, as per figure 3 below.

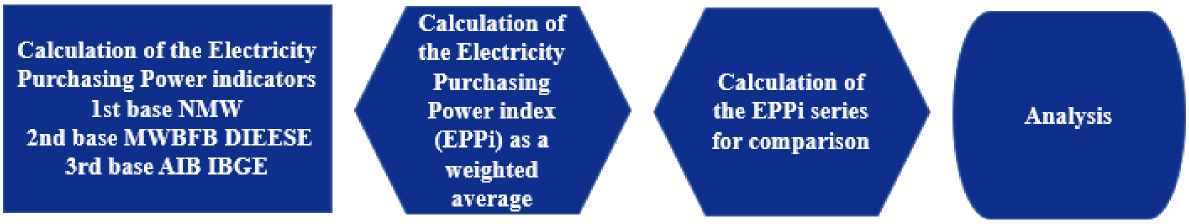

Figure 3. Creation of the Electricity Purchasing Power index (EPPi)
Source: elaborated by the authors.

4 RESULTS AND DISCUSSION

The results and discussion of this study were divided into 5 items for better understanding, as follows:

a) OLS estimation;
b) analysis of the estimation of OLS Model 4;
c) the behavior of the AST/MWh (1994 to 2020), before and after ContribInova;
d) evaluation of the impact of the SEB's RD&I public policy on the AST/MWh, after the creation of ContribInova, including projections for the years 2021 and 2022;
e) comparison of the effects of the SEB's RD&I public policy versus the goals of the 2030 Agenda - SDG 7 - Goal 7.1;
f) development of 3 indicators and 1 index of electric power purchasing capacity.

4.1 OLS estimation in 4 models: models 1, 2, 3 and 4

OLS estimation was performed for each of the four models (Model 1, Model 2, Model 3, and Model 4), as shown in Table 1. It is believed that Model 4 is the best since it presents the treatment for company and date or time fixed effects and has higher explanatory power, where $R^2 = 0{,}77246$ [32].

Table 1. Results of the estimated models

	Model 1	Model 2	Model 3	Model 4
Interceptor	5.80686^{***}	5.79582^{***}	5.84531^{***}	5.83427^{***}
	(0.02296)	(0.04403)	(0.03357)	(0.04311)
Dummy Contrib	0.28620^{***}	0.43296^{***}	0.28620^{***}	0.43296^{***}
	(0.02618)	(0.06227)	(0.02479)	(0.05495)
1995-12-31		-0.01985		-0.01985
		(0.06177)		(0.05433)
1996-12-31		-0.00501		-0.00501
		(0.06177)		(0.05433)

1997-12-31	0.00024		0.00024
	(0.06177)		(0.05433)
1998-12-31	0.01630		0.01630
	(0.06177)		(0.05433)
1999-12-31	0.07451		0.07451
	(0.06177)		(0.05433)
2000-12-31	-0.37595***		-0.37595***
	(0.06177)		(0.05433)
2001-12-31	-0.30397***		-0.30397***
	(0.06177)		(0.05433)
2002-12-31	-0.22382***		-0.22382***
	(0.06177)		(0.05433)
2003-12-31	-0.15582*		-0.15582**
	(0.06177)		(0.05433)
2004-12-31	-0.10882·		-0.10882*
	(0.06177)		(0.05433)
2005-12-31	-0.05453		-0.05453
	(0.06177)		(0.05433)
2006-12-31	-0.03403		-0.03403
	(0.06177)		(0.05433)
2007-12-31	-0.08678		-0.08678
	(0.06177)		(0.05433)
2008-12-31	-0.15682*		-0.15682**
	(0.06177)		(0.05433)
2009-12-31	-0.17602**		-0.17602**
	(0.06177)		(0.05433)
2010-12-31	-0.20035**		-0.20035***
	(0.06177)		(0.05433)
2011-12-31	-0.22853***		-0.22853***
	(0.06177)		(0.05433)
2012-12-31	-0.23873***		-0.23873***
	(0.06177)		(0.05433)
2013-12-31	-0.41018***		-0.41018***
	(0.06177)		(0.05433)
2014-12-31	-0.38041***		-0.38041***
	(0.06177)		(0.05433)
2015-12-31	-0.05154		-0.05154
	(0.06177)		(0.05433)
2016-12-31	-0.09814		-0.09814·
	(0.06177)		(0.05433)
2017-12-31	-0.17820**		-0.17820**
	(0.06177)		(0.05433)
2018-12-31	-0.06815		-0.06815
	(0.06177)		(0.05433)
2019-12-31	-0.04296		-0.04296
	(0.06177)		(0.05433)
CELG		-0.07555·	-0.07555**
		(0.03888)	(0.02766)
CELPE		-0.07264·	-0.07264**
		(0.03888)	(0.02766)
CEMIG		-0.04516	-0.04516
		(0.03888)	(0.02766)
COPEL		-0.11873**	-0.11873***

			(0.03888)	(0.02766)
ELETROPAULO			0.01083	0.01083
			(0.03888)	(0.02766)
R^2	0.40062	0.69456	0.47853	0.77246
Adj. R^2	0.39742	0.64554	0.45836	0.72579
Num. obs.	189	189	189	189
F statistic	124.99126	14.16853	23.72758	16.54994
R^2	0.40062	0.69456	0.47853	0.77246

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\cdot}p < 0.1$

Source: elaborated by the authors, applying the Before and After model, employing Ordinary Least Squares (OLS) estimation, using the software R, with data from the SEB (ANEEL, 2021).

The estimation in OLS, in the Before and After model, presented in 4 models (1, 2, 3, and 4), in Table, 1 makes it possible to analyze the results, considering the "Fixed effect by date" and the "Fixed effect by company", now simulated with the markings: Model 1 (NO and NO); Model 2 (YES and NO); Model 3 (NO and YES) and Model 4 (YES and YES). The purpose of this study is to analyze the results of Model 4, described in Section 4.2, below.

4.2 Analysis of the estimation of Model 4 (OLS)

The analysis of the estimation results performed in Model 4 shows that, when introducing the company fixed effects, the estimation omits some observations due to the existence of perfect multicollinearity. In this case, we have that the company CEEE and the years 1994 and 2018 were omitted, so their effects are captured by the intercept.

The estimated value for the Contribution dummy is statistically significant and positive, indicating that the implementation of the Contribution to Innovation increased AST/MWh values. Thus, it can be seen that the null hypothesis being tested was rejected, actually indicating a loss to consumers after the implementation of the public policy.

The estimated values for the fixed effects show that considering the 5% significance level as the base case for CEEE's 1994 tariffs, CELG, CELPE, and COPEL's tariffs are lower than CEEE's, while CEMIG, ELETROPAULO, and LIGHT's tariffs are statistically equal to CEEE's. In the same model, there is a positive effect on tariffs after the implementation of mandatory contributions in innovation in the magnitude of 0.47592 (exponential scale). As for the time-fixed effects, it can be seen that, in certain periods, 2000 to 2003, 2008 to 2014, and in 2017, there was a reduction in the tariff, as statistically significant and negative values were found. Models 1, 2, and 3 present results that corroborate the positive effect of the need for innovation contribution on the tariff estimated in the model chosen for analysis, Model 4, however, in different magnitudes, according to Table 2.

If the goal is to look only at the effect of the Contribution Dummy and consider the company and time fixed effects only as controls in the model, one can present the results of Table 1 in the format of Table 2.

Table 2. Results of the estimated models

	Model 1	Model 2	Model 3	Model 4
Interceptor	5.84905***	5.83802***	5.88519***	5.87416***
	(0.02325)	(0.04367)	(0.03367)	(0.04247)
Dummy Contrib	0.29471***	0.47592***	0.29471***	0.47592***
	(0.02636)	(0.06177)	(0.02499)	(0.05433)
Fixed effect by date	NO	YES	NO	YES
Fixed effect by company	NO	NO	YES	YES
R^2	0.40062	0.69456	0.47853	0.77246
Adj. R^2	0.39742	0.64554	0.45836	0.72579
Num. obs.	189	189	189	189
F statistic	124.99126	14.16853	23.72758	16.54994

p < 0.001, **p < 0.01, *p < 0.05, ·p < 0.1 (significance level = 0.1% is very strong significance level).

Source: Prepared by the authors, applying the Before and After model, employing an OLS estimation using the R software, with data from SEB (ANEEL, 2021).

4.3 Behavior of AST/MWh (1994 to 2020), before and after ContribInova - Model 4

With the implementation of the SEB RD&I public policy in 2000, it is necessary to verify the evolution of the AST/MWh before and after the creation of ContribInova, which is the financing source of the program. Therefore, this study presented an analysis of the behavior of the AST/MWh, in the period from 1994 to 2020.

The analysis of the Real AST/MWh was elaborated utilizing the Before and After model, being: Before (the period before the implementation of the SEB innovation public policy), from 1994 to 1999; and After (period after the implementation of the SEB innovation public policy), from 2000 to 2020. Therefore, the data analysis in the Before and After model covers the period from 1994 to 2020. The data used were extracted from the [27].

In Figure 2 below, it is possible to observe the performance of the real value of the energy tariff practiced by the 7 electricity distributors in the sample under analysis.
It should be noted that the lowest AST/MWh practiced in the period from 1994 to 2000 is from the company CEMIG, ranging from R$306.10/MWh to R$351.19/MWh, in present value (PV) for 2020, and the second-lowest from LIGHT, whose values ranged from R$374.98 to R$476.25, followed by CELG, CELPE, and COPEL. CEMIG's AST/MWh had a sharp growth between 2001 and 2006 and became the highest value between 2007 and 2016, but lost the position to LIGHT as of 2016. LIGHT continues to lead the ranking of the highest actual AST/MWh in 2020; at R$ 733.45/MWh. CEMIG's AST/MWh closed 2020 with a value of R$ 684.12/MWh, with the second-highest value in the analysis group.

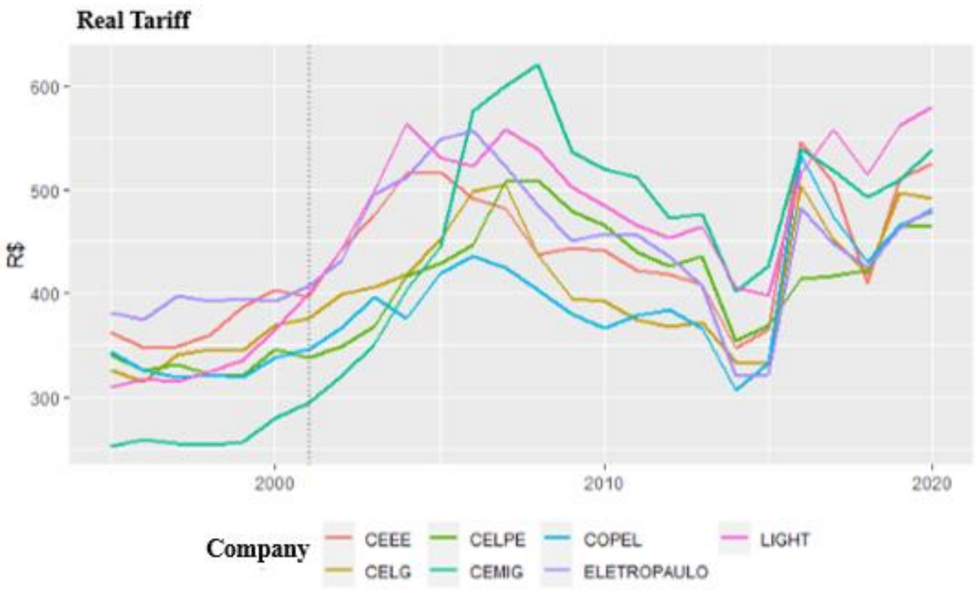

Figure 4. Electricity Tariff (AST) real (in R$ 1.00) from 1994 to 2020 in MWh
Source: elaborated by the authors based on Real AST/MWh (1994-2020), based on data from ANEEL (2021), updated by IPCA (IBGE, 2021), calculated in software R.

It can be observed that, despite ANEEL's efforts to equalize the values of the AST/MWh, a significant difference persists between the lowest and the highest tariffs practiced in the Brazilian electricity market. This difficulty is inherent to the tariffs in regulated companies, as warned by [33] since regulation has difficulty addressing problems involving three important questions: "marginal cost or average cost? Who should cover the fixed costs? The user or the taxpayer?" One school of thought holds that the user should pay the cost of the service they use, but some think differently and argue that the cost should be shared and paid at least in part by third parties who would contribute to a service they do not use [33].

Figure 5 below shows the behavior of the real AST/MWh before and after ContribInova, where it was possible to observe the actual increase in AST/MWh, which already occurred between 1994[4] and 1999 and continued in the following period, after the creation of the public policy.

[4] This work adopted the base date of 1994, therefore applying zero readjustment rate of AST/MWh, for all companies in the analysis group (zero-base). It should be noted that 1994 was the year of the creation of the Real currency and in the month of the implementation of the URV and the new currency (Real), monthly inflation was approximately 85.0% p.m.

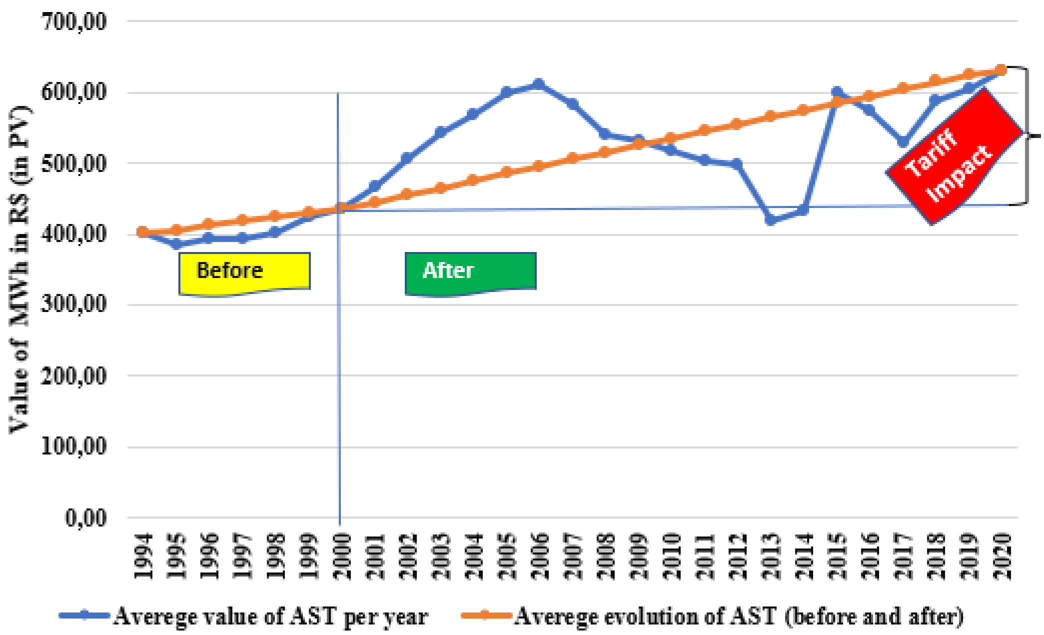

Figure 5. Evolution of the real AST from 1994 to 2020 - Value of MWh in R$ (in PV)

Source: elaborated by the authors based on Real AST/MWh (annual average), from ANEE (2021) data, and PV calculated by IPCA (IBGE, 2021).

It is known that price formation in the global electricity sector is very complex. In Brazil this is no different since it involves a globalized supply chain, therefore, prices are subject to exchange rate variation. Added to these factors are the internal problems of the Brazilian economy (inflation and dependence on an international supply chain) associated with a complex network of Generation, Transmission, and Distribution (GTD), in a country of continental dimensions, where the large power generation projects are far from the large consumer centers [7] [33].

SEB has the National Interconnected System (NIS) and can transport energy from the producing regions to the consuming regions and even import energy from South American countries such as Argentina, Paraguay, and Uruguay and supply the demand of different regions of the national territory. However, it still has difficulties in finding a fair pricing methodology that meets society and the companies that operate in the SEB. This problem is termed by [33] as the regulation of access to the electricity transmission grid, which generates obstacles to the introduction of competition in Brazil and worldwide, including the US and European Union electricity system.

Thus, it is understood that statistical regression analysis modeling, added to the executed AST/MWh projections, based on the IPCA for updating the PV values, provides an adequate level of security to assess the impact of the SEB's RD&I public policy on the tariff moderation policy, which is in line with Agenda 2030 [34] [15] [35] [1][36] [37] [38].

4.4 SEB's RD&I public policy versus Agenda 2030 - SDG 7 - Goal 7.1

The results obtained in the previous items (4.1 to 4.4) have the function of subsidizing the discussions around the objective of this article. That is - evaluate the impact of the Brazilian public policy of RD&I of the SEB, on the average supply tariff (AST) in MWh, since its creation in 1998 and its implementation in 2000 until the present day, since one of the premises of PD&I is tariff moderation, which is aligned with SDG 7, goal 7.1 of Agenda 2030 [20] [9].

To accomplish the comparison of the results of the SEB's RD&I public policy with the objective of this study, an evaluation of the impact of the implementation of the SEB's RD&I public policy was prepared, with ContribInova being levied in the year 2000, using the "Before and After" model, which is one of the most widely used methods for public policy evaluation [37] [1][38].

Additionally, it was decided to prepare a comparison of the AST/MWh to PV. It was considered the entire period from 1994 to 2020, separating them into different moments: a) 1994 to 2020, with the effect presented in Model 4, from 2000 to 2020, focusing on the AST/MWh value in Reais and; b) evaluation of the percentage variation of the AST/MWh, for the same periods: 1994 to 2020 and 2000 to 2020. To calculate the PV of the AST/MWh the historical value was used, duly updated by the IPCA, which is the official inflation index in Brazil, calculated by the IBGE [34] [39] [36].

The results presented in both models detected an increase in the AST/MWh with the implementation of the public policy, suggesting possible contamination of the contribution created by law, which is levied on the Net Operating Income (NOI) of electricity distribution companies, the object of this analysis. Model 4 - Before and After (regression) - detected a positive effect from the implementation of the innovation contribution of a magnitude of 0.47592 (on an exponential scale), in statistical/econometric language, but transformed into market language, this is equivalent to saying that the AST/MWh increased in real terms by about 60.95%, in the period from 2000 to 2020 [40] [35] [41].

A good way to understand the distortion caused by this increase is to visualize the picture of a R$100.00 (one hundred reais) electric bill in 2000. Then, visualize the same bill today, with the same amount of KWh and having to pay for it the amount of R$160.95 (one hundred and sixty reais, ninety-five cents). Thus, it is clear the difference between monetary update of a value and real increase, which is easily explained by basic concepts of finance such as the value of money over time, including actual value and present value [34] [36]).

A finance model was used in a complementary way to provide an alternative comparison with the results of the statistical/econometric model. But it was realized that it also served to confirm that the model applied was correct because it was detected that the AST/MWh had significant increases as a) CEMIG's AST/MWh increased (real increase) 94.80%; b) the companies LIGHT, ELETROPAULO, AND CELPE had AST/MWh increases around 10.0% (9.95%, 10.18%, and 9.25%, respectively); c) in the other companies, there was a small increase in AST/MWh, being: CEEE by 1.32%, COPEL by 2.45% and CELG by 3.71% (Gitman, 1997; Ross; Westerfield & Jaffe, 2002). It should be pointed out that the AST/MWh that increased the most closed the cycle of analysis (2000-2020) with a real increase of 6.671826% p.a., equivalent to 288.19% over 21 years.

It can be observed that the comparison made between the two models corroborates the idea that the creation of the RD&I public policy burdened society, with direct reflection on the MWh price. That was especially in the period from 2000 to 2007, which was incorporated in the formation of the final price of electricity, regardless of there being moments of relief in 2020; prices are already at a high level again.

This has been happening exactly in a period when the International Monetary Fund (IMF) published a study conducted in 195 countries, showing Brazil's economic robustness in terms of nominal GDP in dollars per purchase parity. However, that also exposed important contradictions, because Brazil showed a decrease in GDP per capita, especially when the economic power of the population was analyzed using the same methodology for different regions with different costs of living, a situation that worsens even more in the lower income ranges [42]. In this study, Brazil still holds the position of 8th economy in the world, which, with robust numbers, demonstrates its fragility by ranking 85th and should reach 90th in 2026, considering the GDP per capita in purchasing power parity according to the IMF study cited by [42].

Recently, IPEA published in its "Carta de Conjuntura" a warning about the impact of the increase in the electric bill for the "very low and low income"[5] strata of the population, considering that the accumulated inflation over the last 12 months, for this group of the population, is 10.05%. Whereas, for the "high income[6]" group, the accumulated inflation index is 7.11% for the same period [39][43].

The conclusion this study has reached is that electricity prices are on the rise, at a time when the country is becoming poorer, with decreasing income and rising inflation. All this compromises the public policy of RD&I of the SEB, which has "tariff moderation" as one of its premises and shows that it is not in line with SDG 7 - Goal 7.1 of Agenda 2030.

Given the not very encouraging results, it was decided to present a proposal for the creation of the Electricity Purchasing Power Indicator (EPP), which will be presented in the following item.

4.5 Proposal of Indicators for Electricity Purchasing Power Indicator (EPP)

Electricity is a basic commodity that affects the cost of living of families, the cost of companies - which passes it on to their products and services - and impacts the cost of services provided by the government (Union, States, and Municipalities) to citizens. In short, it is the citizen who ultimately pays the bill, hence the importance of thinking about and proposing the PCEE, which is an indicator of purchasing power of electricity, focusing on the Brazilian's income versus the amount paid in AST/MWh (without taxes).

Figure 8 shows the evolution of the three indicators, where the first two were calculated from 1994 to 2020, but the third was calculated between 2012 and 2020 since the indicator of the average income of Brazilians started to be released only in 2012 [44]. It should be emphasized that the indicators were prepared for a set of seven companies, objects of this study. Considering that 1994 was an atypical year, due to the implementation of the Real Plan when the country lived with a monthly inflation rate of 85.0% p.m. or approximately 1,500% p.a., it was decided to analyze 1995 onwards.

The results presented by the indicators were as follows: (a) EPPNMW started its historical series in 1995 with an index of 1.42 AST/MWh and reached 2020 with 1.72 MWh; (b) EPPMWBFB-DIEESE started in 1995 with 10.29 AST/MWh and arrived in 2020 with 8.74 MWh; c) EPPAIB-IBGE started in 2012, the year in which IBGE released the first version of the "Average income of Brazilians" indicator, with 4.38 MWh and arrived in 2020 at 3.87 AST/MWh and; d) $\overline{X_p}$ of EPP (of the three previous indicators), which opened its historical series, in 1995, with 9.21 AST/MWh and arrived in 2020 with 6.58 AST/MWh.

[5] Income range denomination used by IPEA (DIMAC/IPEA, 2021).
[6] Likewise.

The data presented by the indicators developed in this study, in the historical series from 1995 to 2020, showed that there was a loss in purchasing power of Brazilians. That is when comparing the relation income versus value of the AST/MWh, except for the PCEESMN indicator that is based on the national minimum wage, which went through a good period with real gains (2003 to 2014). The arithmetic average of the three indicators also reflects the loss in purchasing power, demonstrating once again Brazil's difficulty in fulfilling what was agreed in Agenda 2030, which is to offer affordable electricity, according to Figure 6.

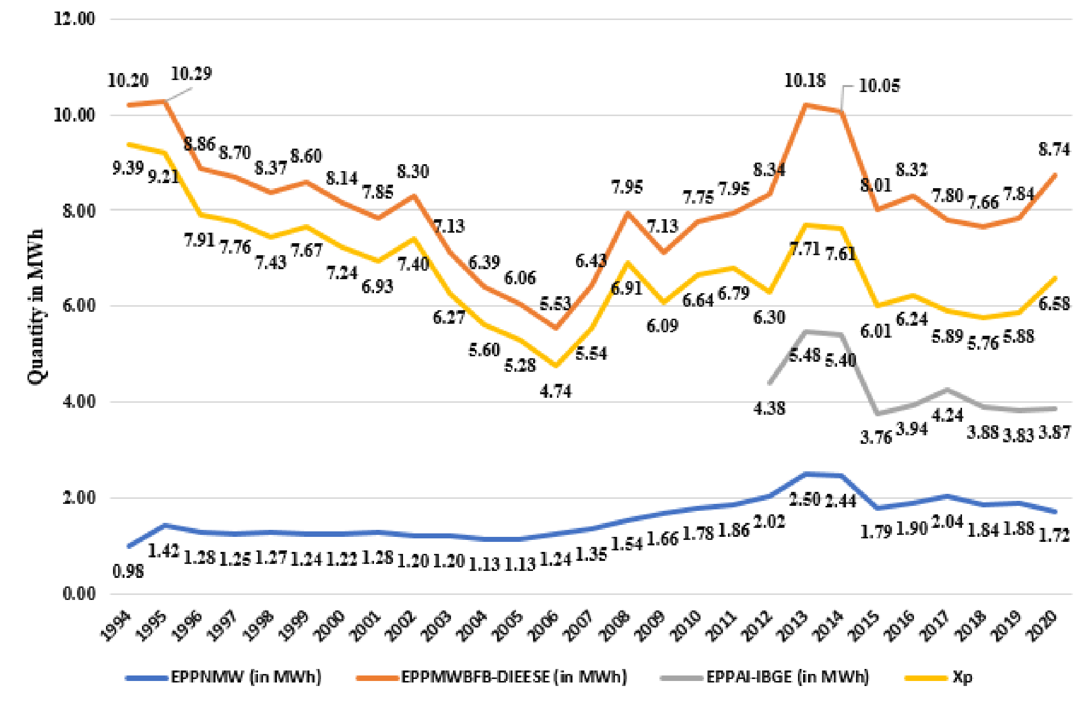

Figure 6. Evolution of the electricity purchasing power indicators (1994-2020)
Source: Prepared by the authors based on IBGE (2021), IPEA (2021) and DIEESE (2021) data.

The indicator denominated $\overline{X_p}$ of EPP in AST/MWh shows the average evolution of the three indicators in AST/MWh, over 1995 to 2020, and generated a database that served to propose and calculate the Electricity Purchasing Power Index (EPPi), which will be presented below.

4.6 Proposed Electricity Purchasing Power Index (EPPi) from 2000 to 2020

Based on the indicators proposed and developed in the previous item, it was decided to calculate the EPPi, from the implementation of the SEB's RD&I public policy, in the year 2000, which makes it possible to follow the tariff adjustment policy implemented in the sector, by ANEEL. The EPPi was calculated from the $\overline{X_p}$ of the three EPP indicators (Xp of the EPP), in percentage, base 100 (in 1999, the year before ContribInova was created). From 2000 on, the percentage variation was calculated, between the previous and the current year, up to the year 2020.

Observing Figure 7, it can be seen that during the period analyzed (2000 to 2020) the increase in AST/MWh was greater than the increase in the Brazilian population income. In the construction of the 3 EPP and EPPi indicators, the year 1999, the year before ContribInova started, was considered equal to 100.00% (the base year for the index), in 2000 the index was 94.31%, in 2006 it reached 61.81%, showing an unequivocal loss of purchasing power of the electric energy consumer of about 38.19% in this period. As of 2007 a period of recovery of the purchasing power of electric energy begins and reaches the year 2013 with EPPi in 100.45%, demonstrating that in this year the consumer had an income slightly higher than the increase of electric energy. But, in 2014 the EPPi starts a new downward movement reaching 75.08% in 2018, but rises again in 2020 to 85.82%, according to Figure 7.

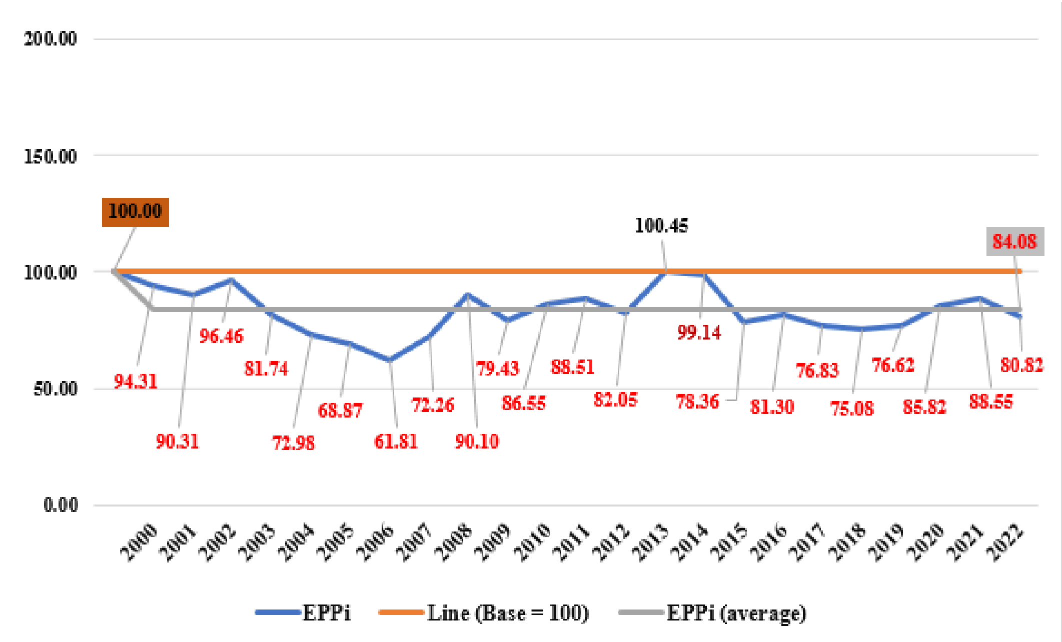

Figure 7. EPPi evolution from 2000 to 2020 and projected for 2021 and 2022
Source: Prepared by the authors based on the three EPP indicators from item 3.6 of this work.

Given that the EPPi showed a constant oscillation during the twenty-two years analyzed (20 elapsed years and 2 projected years), the average EPPi (weighted average) of the period was calculated to verify the average behavior of the index over time. The result was 84.08%, which confirms a loss of purchasing power of electric energy during the cycle between 2000 and 2022.

The tariff management process is very dynamic and very sensitive to periods of crisis, such as inflation, exchange rate policy, and water crisis, especially the latter, since Brazil's electricity matrix is highly dependent on this source of energy generation. In 2021, the Brazilian people faced a crisis of triple origin (inflation, exchange rate, and drought), which has impacted the price of electricity strongly. Considering the increases applied so far in 2021, the AST/MWh has increased around 8.00%, and is expected to triple in 2022, reaching 27.00% [27].

Considering that the present hydroelectric crisis is very strong and can still get worse according to data from [45], this study made projections considering the information already released. Among them is the increase in the AST/MWh by [27], of the IPCA, and the minimum wage by [39], correcting the minimum wage basic basket from DIEESE and maintaining the value of the average Brazilian income from 2020 to 2021 and 2022. With this, we obtained the EPPi of 2021 of 88.55% and 2022 of 80.82%, showing the continuity of the fall in the purchasing power of electricity. The situation tends to be unfavorable to the consumer and could worsen if the water crisis is aggravated within the parameters projected by [45].

This improvement in the EPPi from 2018 to 2020 is explained by the use of a highly aggregated indicator that is the IBGE's AIB, obtained through the IBGE's wage mass study. It shows an apparent improvement, since the crisis generated by COVID-19 increased unemployment in the salary ranges that receive the lowest wages, leaving fewer people employed but receiving higher value wages. Thus, the salary mass decreases, but when divided by a smaller number of workers, it generates a higher average income value.

Finally, it is worth noting that when analyzing the evolution of the EPPi over the implementation period of the RD&I public policy of the SEB (2000-2021), it became evident that this policy had practically no impact on the reduction of prices of electric energy services, despite this being one of its premises.

4.7 Electricity prices in Brazil versus international prices

When comparing the prices charged in Brazil with international standards, the situation is no different. A study by [46] shows that Brazil has the 6th most expensive tariff in the world at R$ 402.30 MWh, second only to the Czech Republic in 5th place with a value of R$ 408.90 MWh. Colombia is in 4th place with R$ 414.10 MWh, Singapore in 3rd with R$ 459.40 MWh, Italy in 2nd place with R$ 536.10 MWh, and India in 1st place with a value of R$ 597.00 MWh. This same study shows that the electricity tariff in Brazil is 46% higher than the international average [46].

In the residential consumer electricity rates comparison rank, Brazil ranks 14th among 28 member countries of the International Energy Agency (IEA), according to a survey by the Brazilian Association of Electricity Distributors (Abradee) [47]. Among the BRICS countries, Brazil has the most expensive residential tariff, according to [48].

From what can be seen, the problem of electricity prices in Brazil comes from far and crosses borders. Hence, the need to pursue one of the goals of the RD&I public policy of the SEB that is tariff moderation, as well as the commitment made under the Paris Agreement, Agenda 2030 that is "by 2030 ensure universal access to affordable, reliable and modern energy services" [20] [9].

4.8 Consequences of high electricity prices in Brazil, combined with crises

The crisis that afflicts the Brazilian people at the moment is a combination of an economic crisis aggravated by the Coronavirus pandemic (COVID-19) and a concomitant hydric crisis, which has impacted the value of the energy bill in Brazil, as per item 4.7 of this article. The successive increases that have been occurring are above the average of recent years, mainly as a result of the introduction of the water scarcity flag. The constant and growing increases have caused an increase in nonpayment, which before the pandemic was around 3.35%, reaching 6.38% between September and December 2021, in the residential segment [49].

ANEEL has taken a socially relevant measure by determining, on 01/04/2022, that 11.3 million families nationwide should be automatically included in the Electricity Social Tariff[7] program (families that are part of the Unified Registry and the Continuous Cash Benefit (BPC)), which added to the current 12.4 million should reach approximately 23 million [50]. This decision will have an impact on nonpayment and will avoid cutting off the supply of electricity to these families.

[7] Law 12.212/2010, the legal framework of the Social Tariff for Electrical Energy, grants a discount on the electricity bill for low-income families.

5 FINAL CONSIDERATIONS

The scope of this study was based on the evaluation of the impact of the implementation of the SEB's RD&I public policy on the tariff moderation policy provided for in the innovation program regulated by ANEEL, in execution for the last 21 years. Additionally, with the advent of the Paris agreement and the creation of the UN Agenda 2030, Brazil has committed to the SDGs - in particular SDG 7, goal 7.1 which aims to ensure universal, reliable, modern, and affordable access to energy services - with the focus of this paper being to specifically analyze the affordability of energy services.

Given this, it should be noted that the article brought relevant contributions to provide an opportunity for reflection in the academic community, companies that operate in the SEB, public managers, and Brazilian society in general, since:

First, it was demonstrated with this study that both the premise of tariff moderation of SEB and the commitment to Agenda 2030 to offer energy and services at affordable prices are not yet a reality for the Brazilian people.

Second, the previous statements are based on two results of this study: a) the introduction of ContribInova to finance the RD&I of the SEB indicates strong evidence of a real increase in the electric energy tariff, soon after the implementation of the public policy, since it generated a real increase of about 60.95%, in the period 2000 to 2020, according to item 4.4 of this article; b) the evolution of the energy purchasing power index (the EPPi base 100), proposed by this study, demonstrated that, in 22 years of RD&I of the SEB, the Brazilian population income (minimum wage, minimum wage from DIEESE and average Brazilian income from IBGE) lost to the AST practically every year, except for the year 2013, and in the average of the period it was 84,08%. Every time the EPPi is below 100, it indicates that income is at a disadvantage concerning the price of electricity, according to item 4.6 of this article.

Third, the results of the comparison of electricity tariff prices in Brazil with those in other countries only confirm that Brazil's position is uncomfortable since the results are as follows: a) it holds the 6th position in the ranking of most expensive electricity; b) as to the residential tariff, Brazil ranks 14th among 28 member countries of the International Energy Agency; and c) among the BRICS, Brazil has the most expensive residential electricity tariff, as per item 4.7.

At last, this study identified an opportunity for research that could have a direct impact on the price of electricity, the tax issue, which was not addressed in this study because it is a very complex topic that should be addressed in a separate study. It is necessary to understand the structure of the Brazilian electricity bill, whose general picture is as follows: taxes represent 42.1% of the bill, the cost of electricity accounts for 39.7%, the companies' remuneration for 15.5%, and 2.7% are the transmission costs. Understanding and proposing alternatives that reduce tax costs, the cost of energy itself, and the services involved are fundamental to reducing the total cost of the electricity bill in Brazil, and thus enable the benefits of innovation to reach the end consumer.

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APÊNDICE D – ARTIGO 4

Assessment of the maturity and technological readiness level of the Brazilian Electric Sector's (SEB) RD&I Program

Avaliação do grau de maturidade e do nível de prontidão tecnológica do programa de PD&I do setor elétrico brasileiro (SEB).

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Assessment of the maturity and technological readiness level of the Brazilian Electric Sector's (SEB) RD&I Program

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ABSTRACT

The objective of this article was to estimate the degree of maturity of innovation, as well as the level of technological readiness of the RD&I program of the SEB, and to assess the current stage of the program regarding 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 Leve; Electricity; RD&I; TRL.

1 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 [1]. [1] 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 [2] [1] [3].

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 [3].

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 [4] and, afterward, an impact evaluation of the implementation of the public policy on the average supply tariff (AST) of electricity, according to [4] 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 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 [2] [1] [3]. 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 [5] [6].

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

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

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) creative innovation; and c) disruptive innovation [7] [8].

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 [9] [10].

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 [11].

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 [12] e [13], 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 [14].

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 [15]:

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 [15].

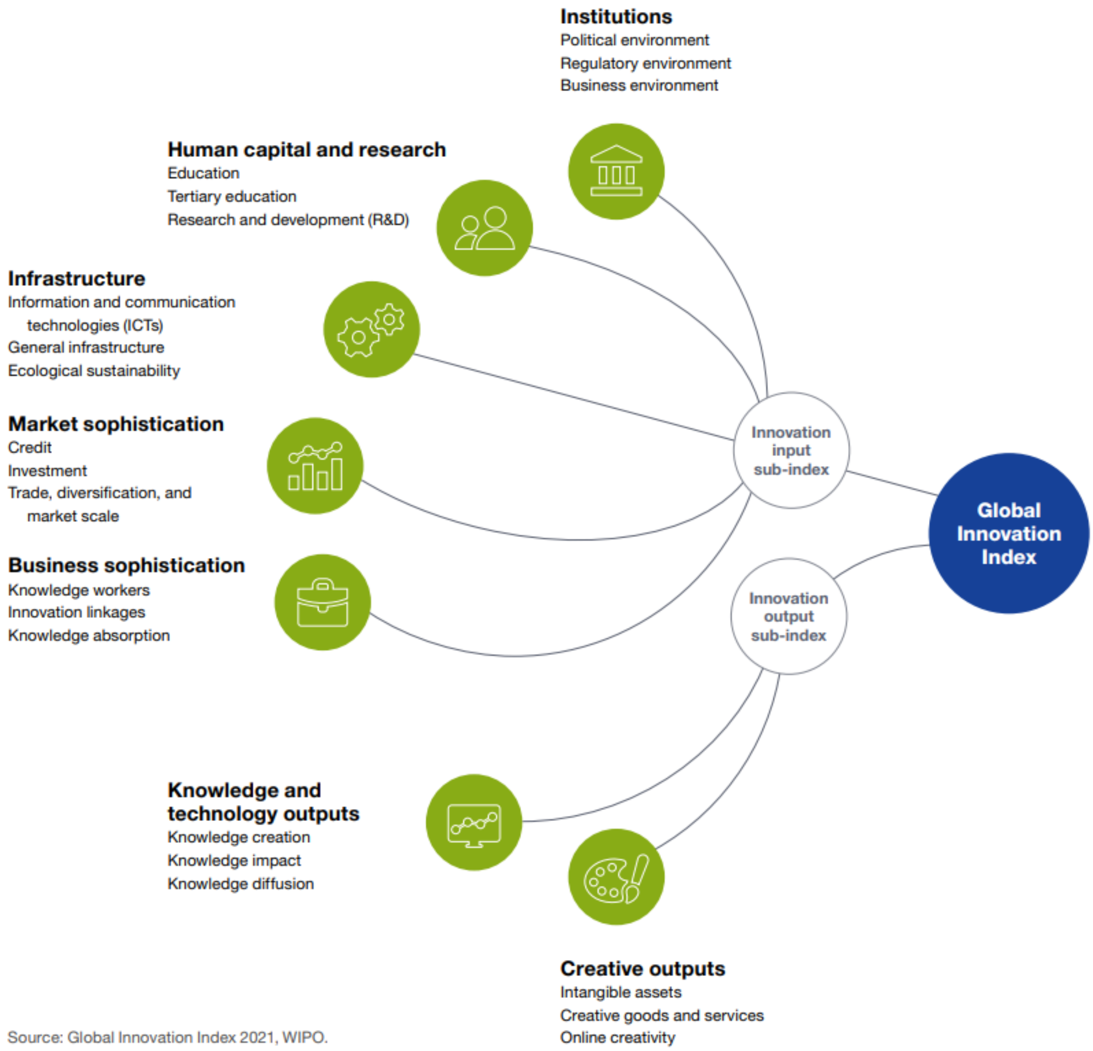

Figure 1. Schematic structure of the Global Innovation Index
Source: WIPO (2021).

2.3.1 *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 [15].

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 [15].

2.3.2 *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 [16]. 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 [16], that is investment in innovation, concerning its NOI, as a percentage result [17] [18].

2.3.3 *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 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.

2.3.4 *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 [19] [20].

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.

2.3.5 *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* [6] 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 [5].

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.

Table 5. 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.

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) [21]. The structure of the method is represented in Figure 2 below.

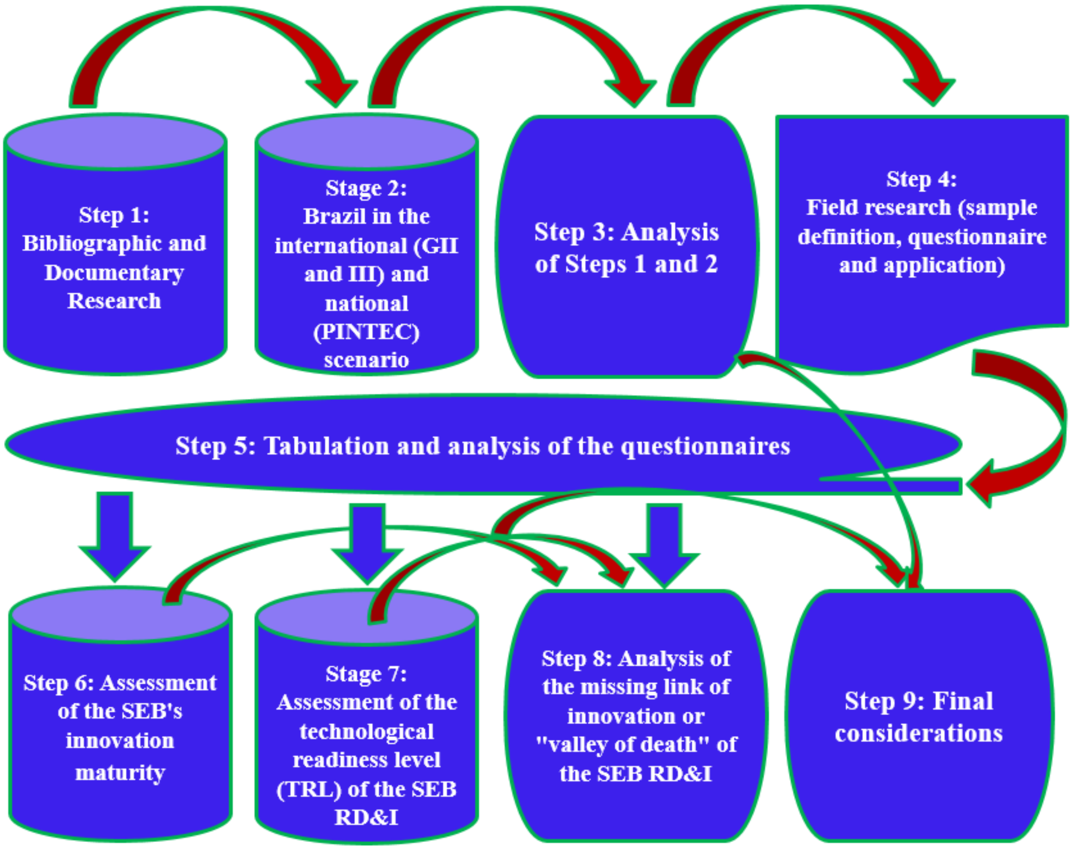

Figure 2. Graphic representation of the method
Source: elaborated by the authors.

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 [10].

In step two, a survey of WIPO's General Innovation Index (GII) publications was conducted [14] [15] [22] [23], which conducts a global survey and publishes the GII per country, annually. Next, a publication from the European Union was identified, called [16], 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 [24] [17], 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 [14] [15] [22] [23].

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 [25]; 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 [26]; 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 [27] [28] [29] [1].

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 [27] [5] [6].

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 [27].
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 [5] [6].

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 [30] 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 [14] [15] [24] [17] [22] [23].

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 [14] [15] [22] [23]. Figure 3 presents the evolution of Brazil in the GII from 2011 to 2021.

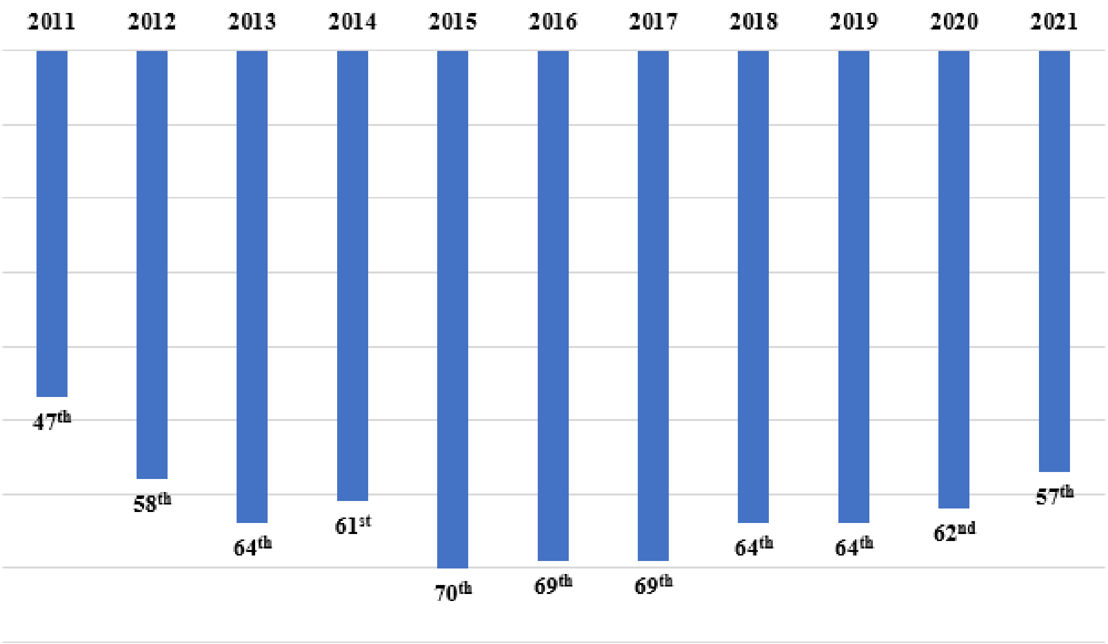

Figure 3. Evolution of Brazil's position in the global innovation index (GII) - 2011 to 2021 (0-100)
Source: elaborated by the authors (WIPO, 2018; 2019; 2020; 2021)

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) [15] [22] [23].

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 [15] [22] [23].

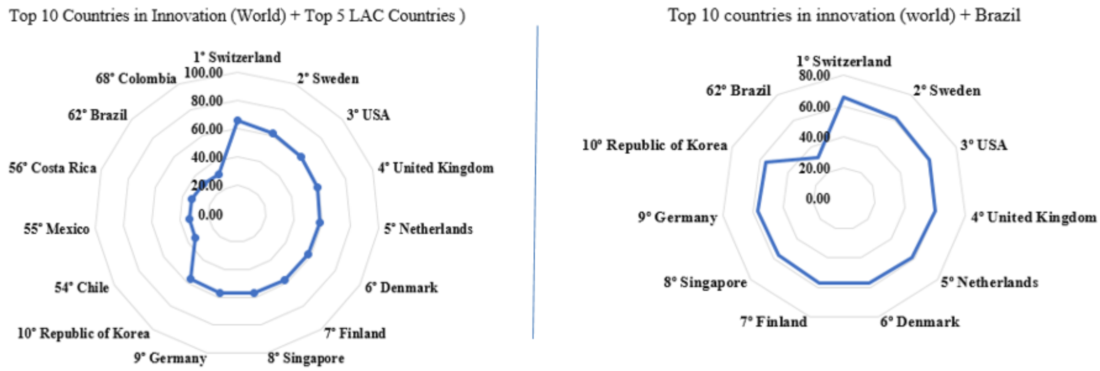

Figure 4. Global Innovation Index (GII) - 2020 ranking (0-100)
Source: elaborated by the authors (WIPO, 2020; 2021)

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 [15].

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) [15].

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 [15] [23].

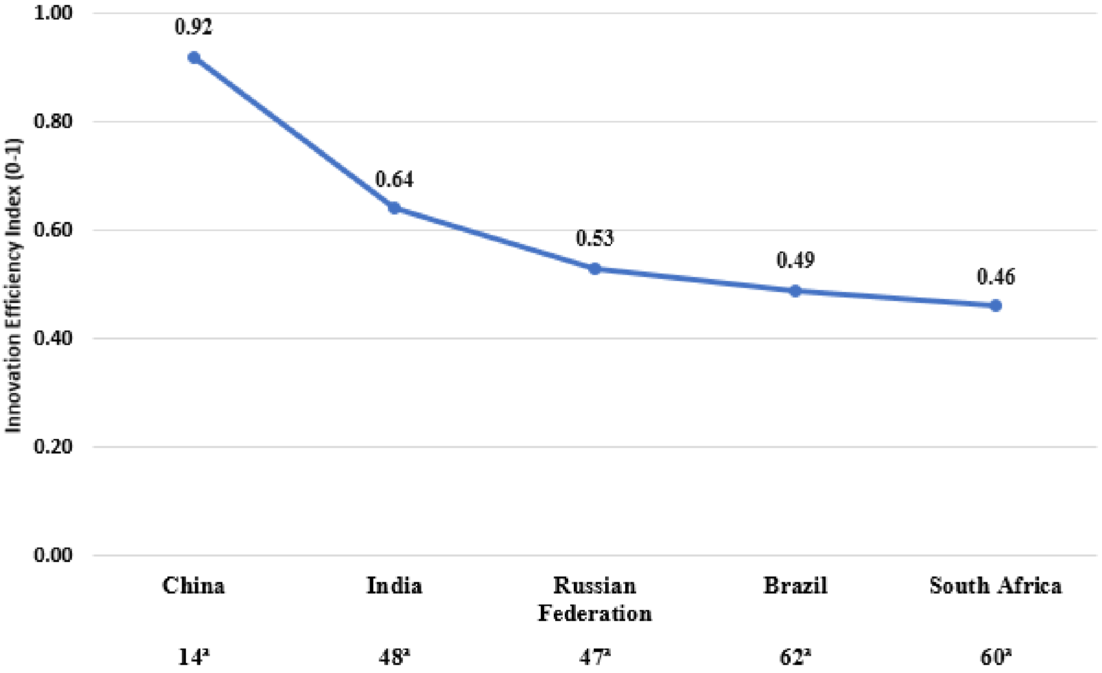

Figure 5. Innovation efficiency index of the BRICS countries (0-1) - in 2020
Source: elaborated by the authors (WIPO, 2020)

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 [15] [23].

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 [14] [15] [22] [23].

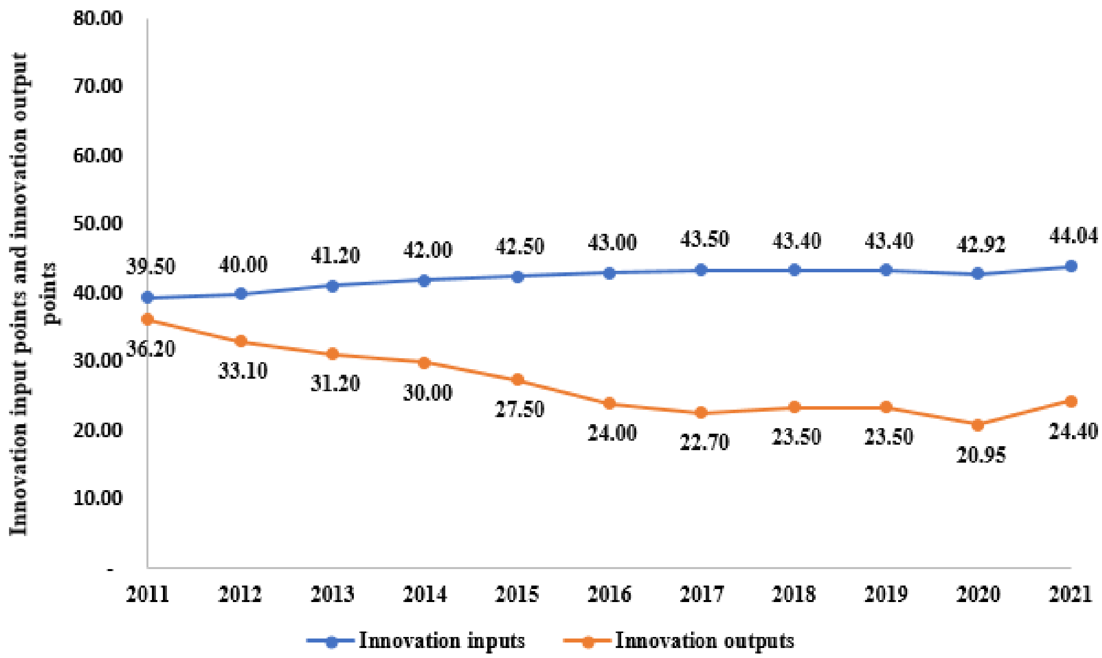

Figure 6. Evolution of Brazil's score in innovation inputs and innovation outputs - 2011 to 2021
Source: elaborated by the authors (WIPO, 2108; 2019; 2020; 2021)

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 [14] [15] [22] [23], as shown in Figure 7.

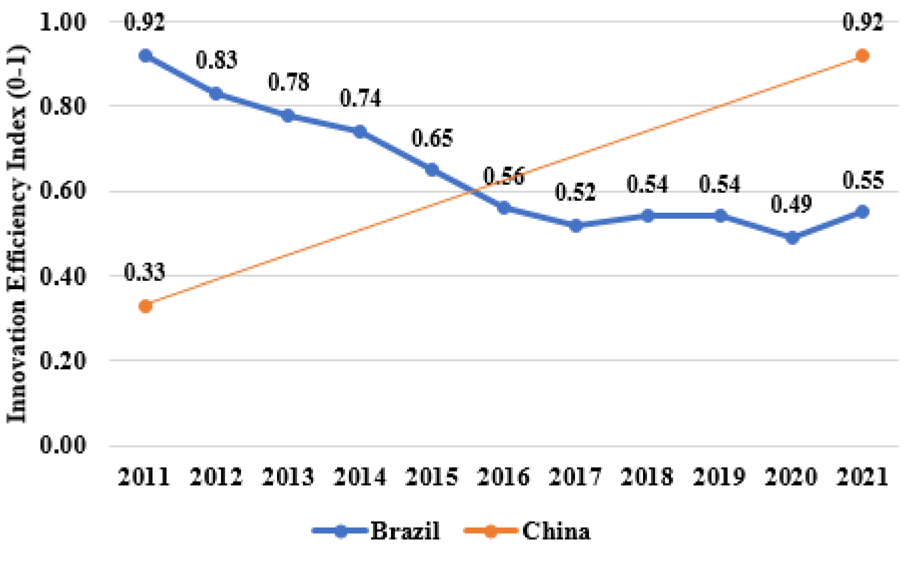

Figure 7. Evolution of Brazil's innovation efficiency index - from 2011 to 2021
Source: elaborated by the authors (WIPO, 2108; 2019; 2020; 2021)

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% [14] [15] [22] [23]. 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 [24] [17] [18].

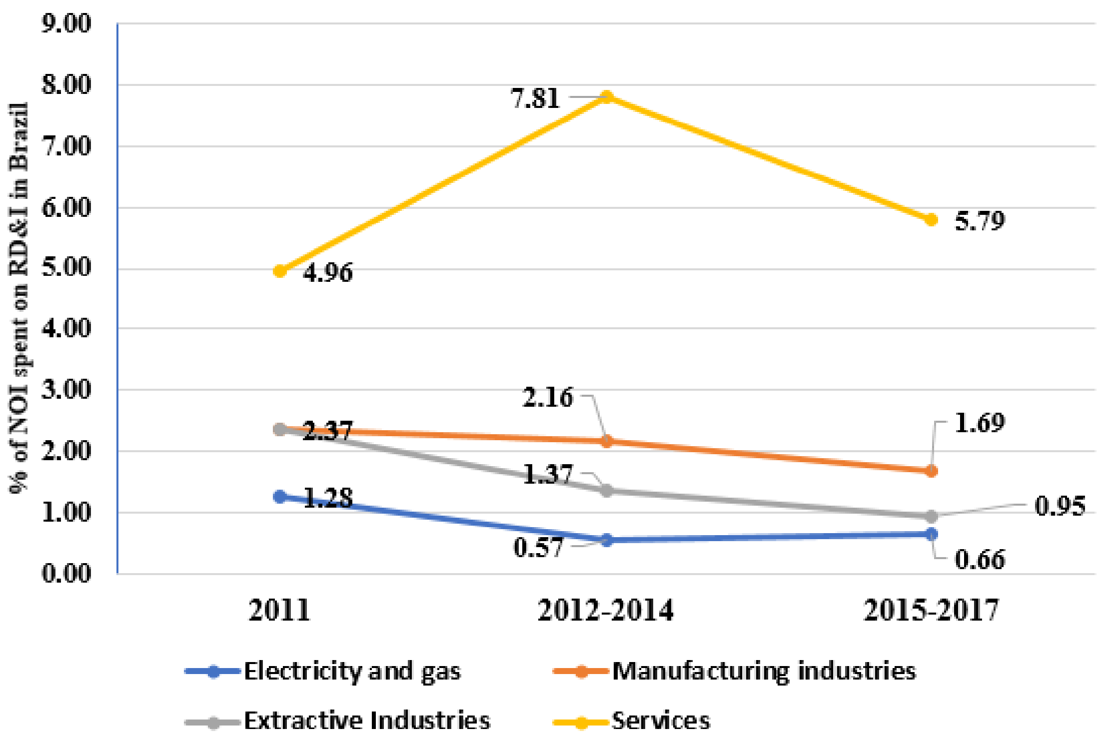

Figure 8. Evolution of RD&I expenses in Brazil - from 2011 to 2017
Source: elaborated by the authors (IBGE/PINTEC 2017, 2020)

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.

Considering that PINTEC/IBGE has been adapting in search of an approximation with the IGI methodology, it would be advisable to align with the generation of a Sustainable Innovation Index, which aims to add greater value to Brazil's performance in the international scenario, and that is in line with the sustainability-oriented innovation proposal by [31] [32].

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 [8]. 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) [24] [17] [23].

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 [33].

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 [33].

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 [33].

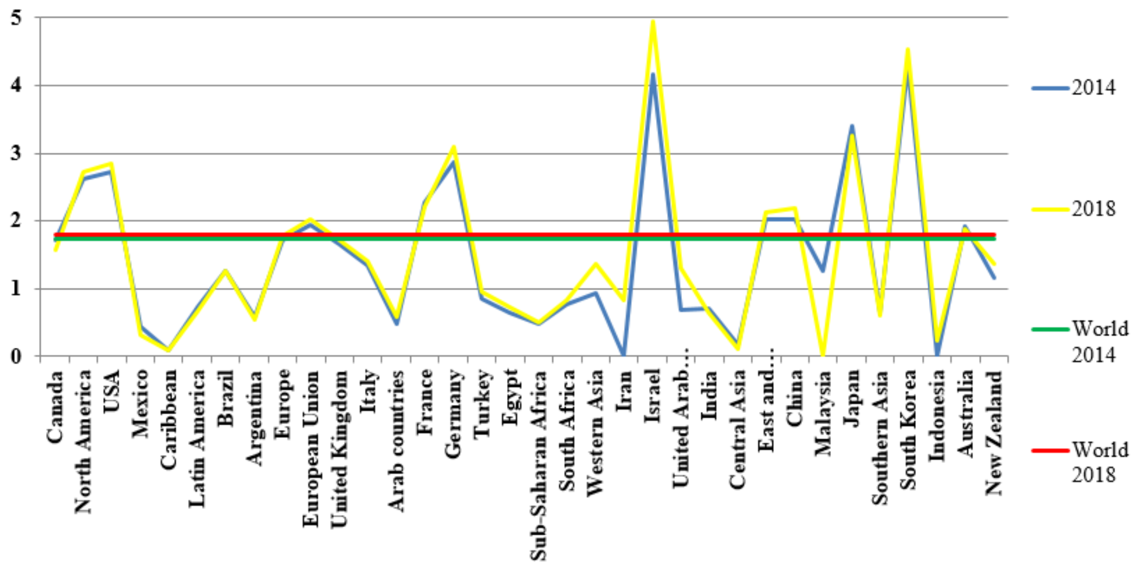

Figure 9. Innovation investment spending by country and region in % of GDP
Source: elaborated by the authors (UNESCO, 2021).

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 [24] [17] [18].

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% [16], as shown in Figure 10.

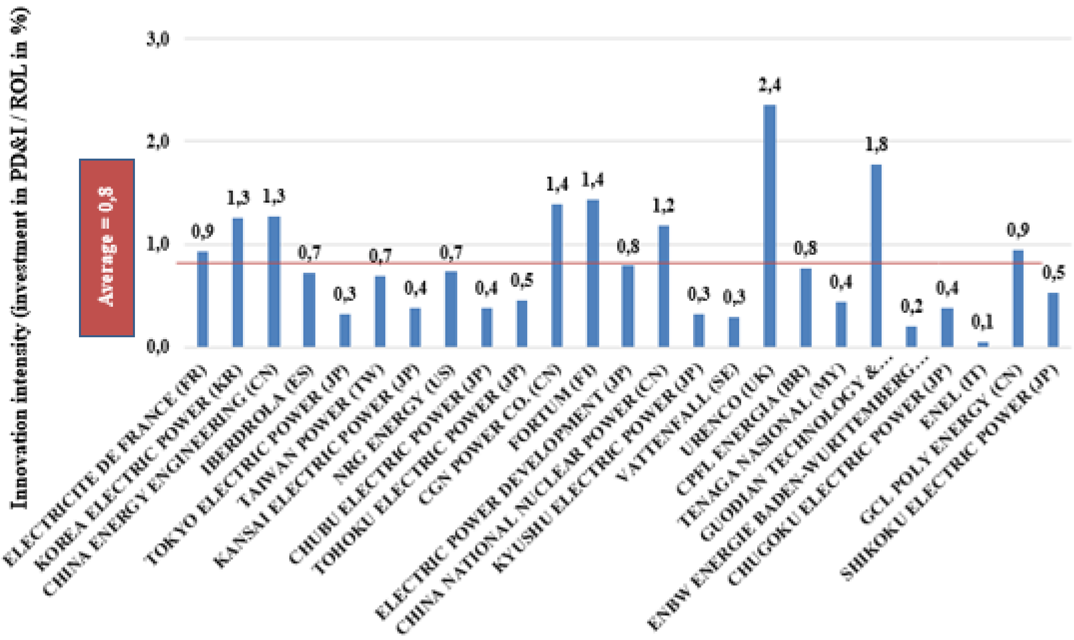

Figure 10. Innovation intensity of electricity companies in the world
Source: elaborated by the authors (European Union/Scoreboard, 2017)

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% [16]. Therefore, it is concluded that the average of the electricity sector in Brazil, whose rate of 0.7% according to the [24] [17], 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 [1], 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 [27] [2] [3] [1].

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.

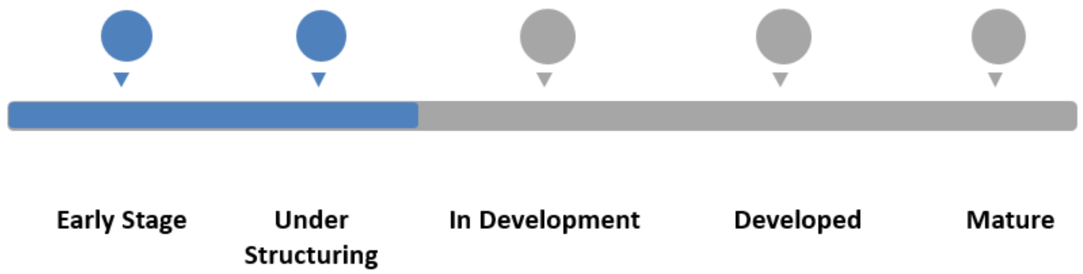

Figure 11. SEB's RD&I innovation maturity level
Source: adapted by the authors (CERTI, 2021).

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.

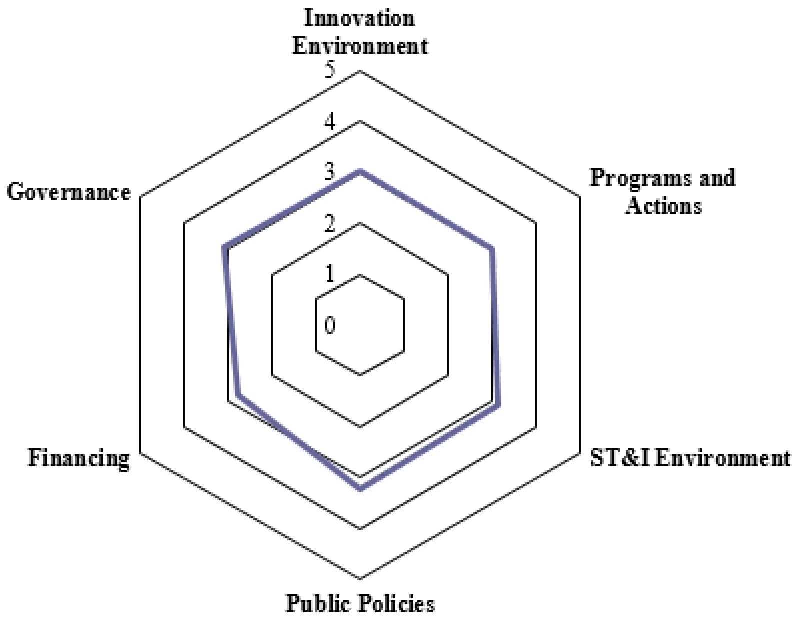

Figure 12. SEB's RD&I innovation maturity degree: innovation radar in the SEB
Source: elaborated by the authors.

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 [3] - actions around innovation should have the 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 [6] 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 [5] [34].

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 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.

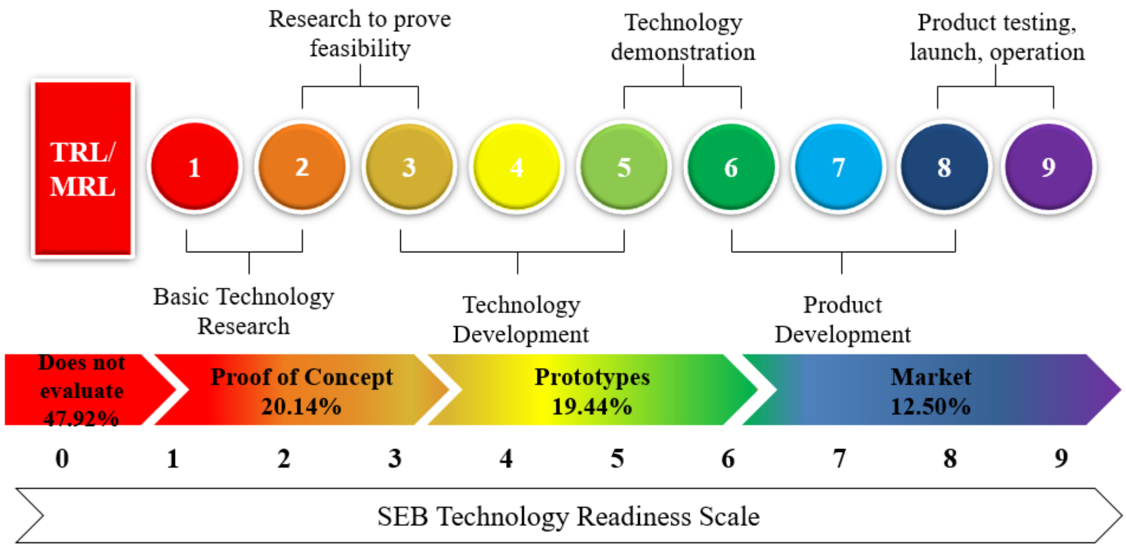

Figure 13. Technology readiness scale in the SEB: TRL/MRL scale
Source: elaborated by the authors.

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) [4].

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 [3] [1].

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 [30] [5] [6] [35].

In Figure 14, it is possible to observe the RD&I project resource need curve, over time and distributed in phases of project development [30]. 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.

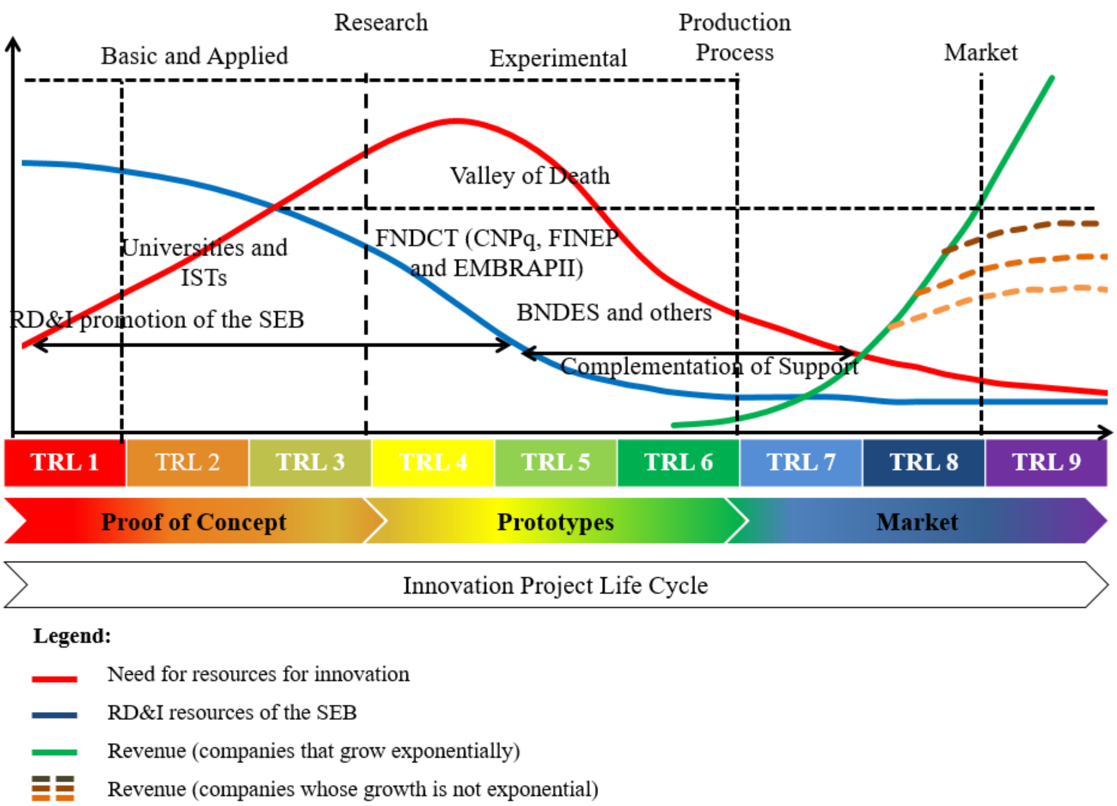

Figure 14. SEB RD&I project life cycle: from basic research to market
Source: elaborated by the authors.

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.

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 (item 4.1).

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 (item 4.1).

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 (item 4.2).

The fourth contribution of this study was to present the results of 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 (item 4.3).

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 (item 4.4.1).

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 (item 4.4.1 and 4.4.2).

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 existence for 21 years and that relies on resources guaranteed in part, annually (item 4.5).

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 (item 4.6).

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]).

[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).

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APÊNDICE E – FORMULÁRIO DE PESQUISA

Pesquisa acadêmica sobre o grau de maturidade da gestão da inovação e o nível de maturidade tecnológica do Setor Elétrico Brasileiro (SEB)

Meio de encaminhamento: Google Formulários

Disponível em: https://lnkd.in/dthgXydM

Pesquisa acadêmica sobre o grau de maturidade da gestão da inovação e o nível de maturidade tecnológica do Setor Elétrico Brasileiro (SEB)

A presente pesquisa visa identificar a sua percepção sobre o grau de maturidade da gestão da inovação e o nível de maturidade tecnológica do Setor Elétrico Brasileiro (SEB) em relação à sua organização. Trata-se de uma pesquisa feita pelo aluno Gilmar dos Santos Marques, matrícula 17/0048764, doutorando pelo Programa de Pós Graduação do Centro de Desenvolvimento Sustentável da Universidade de Brasília (PPGCDSUnB), orientado pelo Professor Doutor José Luiz de Andrade Franco e coorientado pela Professora Doutora Maria Amélia de Paula Dias.

A sua participação é voluntária e anônima. É fundamental que ela reflita fielmente a sua percepção sobre o PD&I do SEB. Os dados serão analisados de forma conjunta, incluindo todos os respondentes, de forma que não há possibilidade de conhecer opiniões individuais.

Os resultados desta pesquisa poderão contribuir com o processo de melhoria contínua de sua organização, no que se refere ao PD&I do SEB e Inovação em geral. A sua participação é muito importante!

Esta pesquisa não captura e nem armazena dados dos participantes, portanto, está em consonância com a Lei Geral de Proteção de Dados (LGPD) - Lei 13.709 de 14/08/2018. Para receber devolutiva, você deverá autorizar e inserir o seu e-mail ao final do questionário, se assim o desejar.

O tempo de resposta deste questionário é estimado em, aproximadamente, 10 minutos.

Agradecemos antecipadamente a sua resposta, colocando-nos à disposição para quaisquer esclarecimentos que se fizerem necessários, pelo e-mail: gilmar.marx@gmail.com ou pelo e-mail: 170048764@aluno.unb.br

Atenciosamente,

Gilmar dos Santos Marques
Aluno do doutorado do PPGCDSUnB, matrícula 17/0048764

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*Obrigatório

1. Você concorda em participar desta pesquisa de forma voluntária? *

Marcar apenas uma oval.

- ( ) Sim.
- ( ) Não.

2. Você faz parte de qual público-alvo da pesquisa?

Marcar apenas uma oval.

- Gerente de PD&I do setor elétrico brasileiro (SEB)
- Pesquisador(a) de PD&I do setor elétrico brasileiro (SEB)
- Colaborador(a) de PD&I do setor elétrico brasileiro (SEB)
- Gestor Público na área de PD&I do setor elétrico brasileiro (SEB)

Antecedentes da Inovação

São apresentadas, a seguir, práticas de gestão dos antecedentes da inovação nas organizações. Por favor, leia atentamente tais itens e, considerando a sua organização atual, escolha a opção que melhor representa sua percepção.

Para responder as perguntas de 1 a 13, entenda os itens que compõem cada um dos questionamento:

=> De Forma Estruturada e Aberta, Engajando Clientes, Usuários e prestadores de serviços: significa que a prática ocorre com a colaboração de clientes, usuários e prestadores de serviços (múltiplos atores) com os quais a organização interage, tais como clientes, usuários e prestadores de serviços (do terceiro setor, setor privado, setor público). É uma atuação colaborativa, ampla e aberta, envolvendo diretamente cidadãos ou usuários de políticas ou serviços públicos nos esforços de inovação - Grau 5.

=> De Forma Estruturada e Colaborativa, Engajando Parceiros (Públicos, Privados e Terceiro Setor): significa que a prática ocorre com a colaboração de atores com os quais a organização mantém relações, tais como parceiros e fornecedores púbicos, privados ou do terceiro setor. É uma atuação colaborativa, mas com alcance limitado, pois não envolve diretamente cidadãos ou usuários de políticas ou serviços públicos nos esforços de inovação - Grau 4.

=> De Forma Estruturada: significa que a prática ocorre de forma estruturada, organizada e planejada, utilizando-se de métodos, técnicas ou processos de trabalho adequados para esforço de inovação - Grau 3.

=> De Forma Reativa: significa que a prática ocorre de forma não estruturada, reativa, caótica, sem uso de métodos, técnicas ou processos de trabalho adequados para esforço de inovação - Grau 2.

=> A prática não ocorre em minha organização - Grau 1 .

Nota: os conceitos utilizados nesta pesquisa (1ª Seção) foram retirados de uma pesquisa de autoria do professor Dr. Antonio Isidro (2021), coordenador do Laboratório de Inovação e Estratégia em Governo da Universidade de Brasília, em parceria com Dra. Lana Montezano do CDT da UnB, e do Planejamento do Ecossistema de Inovação do Distrito Federal elaborado pela Fundação CERTI (2021), adaptados por Gilmar dos Santos Marques, para efeito desta pesquisa.

3. 1. Minha organização busca inovar com os recursos do PD&I do SEB *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

4. 2. Minha organização estabelece os objetivos que pretende alcançar com a inovação *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

5. 3. Minha organização compartilha os objetivos que pretende alcançar com a inovação PD&I do SEB *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

6. 4. Minha organização responde à política pública de inovação (P&D e PEE) do SEB *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

7. 5. Minha organização percebe que a inovação no SEB ocorre *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas limitada pela regulação do programa.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

8. 6. Minha organização entende que a inovação no SEB deveria ser implementada *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

9. 7. Minha organização percebe que o modelo inovação do SEB proporciona oportunidades para geração de novos modelos de negócio no setor de energia elétrica *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

10. 8. Minha organização trabalha a cultura organizacional para a inovação no SEB *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

11. 9. Minha organização utiliza parcerias que integram instituições de pesquisa (Universidades, ICTs, Consultorias e Startups) e recursos (FNDCT, FINEP, BNDES e outros) para favorecer sua intenção de inovar *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

12. 10. Minha organização utiliza programas de treinamento e capacitação para favorecer sua intenção de inovar *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

13. 11. Minha organização disponibiliza infraestrutura (ambiente de ideação, laboratórios para prototipação e validação de piloto) de inovação *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando clientes, usuários, prestadores de serviços e múltiplos atores, operando em rede.
- de forma estruturada e colaborativa, engajando clientes, usuários, prestadores de serviços e múltiplos atores.
- de forma estruturada, organizada ou planejada, mas dentro do padrão preconizado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

14. 12. Minha organização percebe que a governança do programa de inovação do SEB funciona *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando os Stakeholders (organizações do setor, empregados, clientes, usuários, prestadores de serviços e múltiplos atores), organizados em fórum setorial e independente.
- de forma estruturada e colaborativa, engajando os Stakeholders (organizações do setor, empregados, clientes, usuários, prestadores de serviços e múltiplos atores).
- de forma estruturada, organizada ou planejada, mas dentro do padrão liderado pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

15. 13. Minha organização entende que a regulação atua para que o programa de inovação do SEB se desenvolva *

Marcar apenas uma oval.

- de forma estruturada e aberta, engajando os Stakeholders (organizações do setor, empregados, clientes, usuários, prestadores de serviços e múltiplos atores), incluindo fomento com recursos próprios e de parceiros para acelerar a inovação por meio de Startups.
- de forma estruturada e colaborativa, engajando os Stakeholders (organizações do setor, empregados, clientes, usuários, prestadores de serviços e múltiplos atores), construindo alternativas para o financiamento e aceleração da inovação.
- de forma estruturada, organizada ou planejada, mas dentro do padrão estabelecido pelo órgão regulador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

Informações para avaliação de ambiente de inovação: IBGE (PINTEC) e Índice Global de Inovação ou Global Innovation Index (GII).

As informações a serem prestadas para os órgãos que fazem pesquisa sobre inovação nas organizações, seja no Brasil ou até mesmo no mundo (de ordem global), são:
a) no Brasil, o IBGE que elabora a PINTEC;
b) no mundo, a WIPO que é o fórum global para serviços, políticas, informações e cooperação de propriedade intelectual, agência de autofinanciamento da ONU, que elabora o Índice Global de Inovação ou Global Innovation Index (GII).
A PINTEC foi reformulada e hoje busca uma aproximação com a WIPO, de forma que tenhamos mais empresas figurando no GII, mas para esta pesquisa é preciso examinar alguns dados para analisar a evolução das empresas brasileiras, com relação ao GII, tais como:
=> O capital humano à disposição da organização;
=> Inovação é parte da estratégia organizacional;
=> Apuração de receitas oriundas de inovação;
=> Percentual de investimento inovação em relação à Receita Operacional Líquida (ROL);
=> Orçamento para inovação.

Responda as questões 14, 15, 16 e 17 com base nos dados citados anteriormente, que são exigidos na PINTEC e no GII.

16. 14. Minha organização utiliza o capital humano estruturado em carreiras diferentes (carreira de gestor e carreira de pesquisador) para favorecer sua intenção de inovar *

Marcar apenas uma oval.

- de forma estruturada e colaborativa, separando carreiras de gestor e pesquisador e engajando mestres e doutores empreendedores.
- de forma estruturada e colaborativa, mas separa carreira de gestor e de pesquisador estimulando o desenvolvimento de duas carreiras.
- de forma estruturada e colaborativa, mas não separa a carreira de gestor e de pesquisador.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

17. 15. Minha organização trata o tema inovação em âmbito corporativo *

Marcar apenas uma oval.

- de forma estruturada e aberta, tendo o CEO como líder da inovação, engajando todo o corpo funcional criando um ecossistema de inovação internamente.
- de forma estruturada e colaborativa, partindo do nível estratégico mas sem objetivos e metas definidos.
- de forma estruturada, organizada ou planejada, mas nos níveis táticos e operacionais seguindo normas internas.
- de forma reativa e não-estruturada.
- a prática não ocorre em minha organização.

18. 16. Minha organização trata as receitas oriundas de inovação, para avaliar o impacto da inovação sobre a sua ROL *

Marcar apenas uma oval.

- de forma estruturada e aberta, definindo objetivos e metas de receitas de inovação, que são contabilizadas e divulgadas para o mercado.
- de forma estruturada e colaborativa, apurando percentual de receitas de inovação na ROL, por meio de estimativas.
- de forma estruturada, organizada ou planejada, mas sem apurar quanto da ROL tem origem em inovação.
- de forma não-estruturada e não apura a receita oriunda de inovação.
- a prática não ocorre em minha organização.

19. 17. Minha organização destina recursos próprios (além do valor definido em lei) para inovação *

Marcar apenas uma oval.

- de forma estruturada e aberta, destinando o valor a ser investido anualmente, com base em percentual da ROL, associando com fomentos e parcerias que possam agregar valor na cadeia produtiva.
- de forma estruturada e colaborativa, definindo o valor a ser investido com base em um percentual da ROL, sempre olhando para os investimentos do setor em que atua.
- de forma estruturada, organizada ou planejada, definindo o valor a ser investido com base em um percentual da ROL.
- de forma não-estruturada, com base no valor investido no ano anterior.
- a prática não ocorre em minha organização.

Nível de maturidade tecnológica do PD&I do Setor Elétrico Brasileiro (SEB)

Entenda o Nível de Maturidade Tecnológica ou TRL (Technology Readiness Level) ou MRL (Manufacturing Readiness Levels) de um produto ou processo (MANKINS, 1995).

=> TRL/MRL 1: Ideia da pesquisa que está sendo iniciada e esses primeiros indícios de viabilidade estão sendo traduzidos em pesquisa e desenvolvimento futuros.

=> TRL/MRL 2: Os princípios básicos foram definidos e há resultados com aplicações práticas que apontam para a confirmação da ideia inicial.

=> TRL/MRL 3: Em geral, estudos analíticos e/ou laboratoriais são necessários nesse nível para ver se uma tecnologia é viável e pronta para prosseguir para o processo de desenvolvimento. Nesse caso, muitas vezes, é construído um modelo de prova de conceito.

=> TRL/MRL 4: Coloca-se em prática a prova de conceito, que consiste em sua aplicação em ambiente similar ao real, podendo constituir testes em escala de laboratório.

=> TRL/MRL 5: A tecnologia deve passar por testes mais rigorosos do que a tecnologia que está apenas na TRL 4, ou seja, validação em ambiente relevante de componentes ou arranjos experimentais, com configurações físicas finais. Capacidade de produzir protótipo do componente do produto.

=> TRL/MRL 6: A tecnologia constitui um protótipo totalmente funcional ou modelo representacional, sendo demonstrado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras).

=> TRL/MRL 7: O protótipo está demonstrado e validado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras).

=> TRL/MRL 8: A tecnologia foi testada e qualificada para ambiente real, estando pronta para ser implementada em um sistema ou tecnologia já existente.

=> TRL/MRL 9: A tecnologia está comprovada em ambiente operacional (fabricação competitiva no caso das principais tecnologias facilitadoras), uma vez que já foi testada, validada e comprovada em todas as condições, com seu uso em todo seu alcance e quantidade. Produção estabelecida.

Responda as questões 18, 19 e 20 com base no nível de TRL observando o planejamento, implementação e resultados do programa de inovação da sua organização.

Avaliação de Nível de Maturidade Tecnológica

Os Níveis de Prontidão de Tecnologia (TRLs) são um sistema de métrica/medição sistemático que apoia avaliações da maturidade de uma determinada tecnologia e a consistência da maturidade entre diferentes tipos de tecnologia.

A abordagem TRL foi usada intermitentemente no planejamento de tecnologia espacial da NASA por muitos anos e foi recentemente incorporado no Manual de Instruções da NASA (NMI 7100) e integrado ao planejamento integrado de tecnologia na NASA.

Níveis de Prontidão da Tecnologia
Autor: John C. Mankins, 1995, editado em 2004.
Escritório de Conceitos Avançados. Escritório de Acesso ao Espaço e Tecnologia da NASA.
Nota: Os conceitos utilizados nesta pesquisa (2ª Seção) são de Mankins (1995; 2004) adaptados por Gilmar dos Santos Marques. As questões foram elaboras pelo autor.

20. 18. Minha organização planeja a fase inicial da inovação no SEB (até a prova de conceito) com base em *

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- estudos analíticos e/ou laboratoriais que são necessários nesse nível para ver se uma tecnologia é viável e pronta para prosseguir para o processo de desenvolvimento. Nesse caso, muitas vezes, é construído um modelo de prova de conceito (TRL3).
- princípios básicos que foram definidos e em resultados com aplicações práticas que apontam para a confirmação da ideia inicial (TRL2).
- ideia da pesquisa que está sendo iniciada e esses primeiros indícios de viabilidade estão sendo traduzidos em pesquisa e desenvolvimento futuros (TRL1).
- reação, com ações não-estruturadas.
- a prática não ocorre em minha organização.

21. 19. Minha organização implementa a inovação no SEB e elabora protótipos (fase intermediária) com base em *

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- tecnologia com um protótipo totalmente funcional ou modelo representacional, sendo demonstrado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras) (TRL6).
- tecnologia que deve passar por testes mais rigorosos do que a tecnologia que está apenas na TRL 4, ou seja, validação em ambiente relevante de componentes ou arranjos experimentais, com configurações físicas finais. Capacidade de produzir protótipo do componente do produto (TRL5).
- colocar em prática a prova de conceito, que consiste em sua aplicação em ambiente similar ao real, podendo constituir testes em escala de laboratório (TRL4).
- reação, com ações não-estruturadas.
- a prática não ocorre em minha organização.

22. 20. Minha organização implementa a inovação no SEB atingindo em sua fase final (Mercado: escala final/completa) o estágio em que *

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- a tecnologia está comprovada em ambiente operacional (fabricação competitiva no caso das principais tecnologias facilitadoras), uma vez que já foi testada, validada e comprovada em todas as condições, com seu uso em todo seu alcance e quantidade. Produção estabelecida (TRL9).
- a tecnologia foi testada e qualificada para ambiente real, estando pronta para ser implementada em um sistema ou tecnologia já existente (TRL8).
- o protótipo está demonstrado e validado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras) (TRL7).
- a tecnologia constitui um protótipo totalmente funcional ou modelo representacional, sendo demonstrado em ambiente operacional (ambiente relevante no caso das principais tecnologias facilitadoras) (TRL6).
- a prática não ocorre em minha organização.

23. Espaço reservado para você fazer comentários sobre o PP&D e PEE do SEB.

24. Caso você queira receber o resultado desta pesquisa, fineza informar o seu e-mail, pois esta pesquisa cumpre a LGPD e não captura dados. Obrigado pela sua contribuição!