BBR BRAZILIAN BUSINESS REVIEW

ARTICLE

Research and Development and Investments in Renewable Energy: A Study on Power Generation Companies

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ABSTRACT

Spending on Research and Development (R&D) stimulates technological innovation and is necessary to coordinate renewable energy consumption and the electric power industry's sustainable economic development. This paper analyzes whether R&D expenditures influence sustainable economic development through investments in renewable energy matrices in the electric power industry. The study was carried out with thirteen power generation companies from 2017 to 2020. The results reveal that R&D expenditures positively affect investments in renewable energy, endorsing the view that allocating resources for R&D is essential for innovation in the Brazilian electric power industry. As contributions, we highlight the importance of R&D expenditures and this area's ability to develop solutions and technologies to allow the industry's sustainable economic development.

KEYWORDS

Research and Development, Electric power industry, Investments, Renewable energy matrix

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Received: 06/28/2022.
Revised: 10/21/2022.
Accepted: 02/06/2023.
DOI: https://doi.org/10.15728/bbr.2022.1435.en

Pesquisa e Desenvolvimento e os Investimentos em Energia Renovável: Um Estudo nas Geradoras do Setor Elétrico

RESUMO

Os gastos em Pesquisa e Desenvolvimento (P&D) estimulam a inovação tecnológica e são necessários para coordenar o consumo de energia renovável e o desenvolvimento econômico sustentável do setor elétrico. O objetivo desta pesquisa é analisar se os gastos em P&D influenciam no desenvolvimento econômico sustentável por meio de investimentos em matrizes energéticas renováveis do setor elétrico. O estudo foi realizado em treze empresas geradoras de energia nos anos de 2017 a 2020. Os resultados revelam que os gastos em P&D produzem efeitos positivos nos investimentos em energia renovável, endossando a visão de que a destinação de recursos para P&D é essencial para o processo de inovação do setor elétrico brasileiro. Como contribuições, destaca-se o protagonismo que deve ser enfatizado nos gastos com P&D e sua capacidade em desenvolver soluções e tecnologias que tornem possível o desenvolvimento econômico sustentável do setor.

PALAVRAS-CHAVE

Pesquisa e desenvolvimento, Setor elétrico, Investimentos, Matriz energética renovável

1. INTRODUCTION

The finitude of natural resources puts concepts related to sustainability, environmental, and energy policies, and their connection with economic development, on the world's debate agenda (Lopes & Taques, 2016). Specifically regarding energy, incentives for efficiency and renewable sources are intrinsically related to sustainable economic development.

For organizations to keep up with energy consumption growth and survive in competitive markets, managing resources and making investments are crucial to adapting to changes and market demands. In the fight against climate change, especially due to carbon emissions, there has been a significant increase in renewable energy production in the last decade after significant investments from different countries in new energy sources (Abban & Hasan, 2021).

Spending on R&D has helped the electric power industry to cope with its challenges without compromising future needs. The Brazilian Ten Year Energy Expansion Plan 2032 (EPE, 2022) points out that, in 10 years, the installed electricity supply capacity based on wind and solar energy will grow by 170.5%, while that arising from hydroelectric power plants will grow by 0.09%.

Despite the growth in the participation of other renewable sources, the distribution of the Brazilian energy matrix continues to depend on water sources, centered on large hydroelectric power plants. This scenario is worrying due to water's climatic vulnerability regarding the levels needed to generate energy (Pereira & Silva Neto, 2020). Therefore, national power generation must improve in order to achieve sustainability, safety, and independence, and spending on R&D is crucial in this process.

According to Xie et al. (2020), spending on R&D stimulates technological innovation and is fundamental for coordinating renewable energy consumption and sustainable development. For the authors, renewable energy must be supported by technology, arguing that insufficient technological capacity leads to expensive and less efficient production.

Brazilian law 9.991 of 2000, amended by law 13.203 of 2015, goes in this direction. The law aims to promote innovative and original projects for the electric power industry by establishing the Research and Development Program of the Brazilian National Electric Energy Agency (ANEEL). According to the program, companies must invest a minimum percentage of their net operating income in projects to modernize the industry.

This study follows the debates and recognizes the importance that expenditures on R&D have in diversifying energy matrices by increasing the participation of alternative sources, achieving sustainable development, and increasing efficiency. Therefore, it aims to analyze whether R&D expenditures made by Brazilian power generation companies influence sustainable economic development through investments in renewable energy matrices.

The dissemination of innovation leads to better market decisions, influencing the ability to assess companies' profitability and cash flow. Tortoli et al. (2020) suggest that investments in innovation increase companies' market value above the book value, directly impacting valuation and growth in the future. Spending on innovation can become a strategic mechanism for managers, as investors observe spending on R&D as an indicator of company appreciation.

The implications arising from the structural transformation in the electric power industry are paramount for both market and policymaker as they represent significant changes in market dynamics (Sendstad & Chronopoulos, 2020). In this environment, in the quest for diversification of energy matrices, the research offers complementary insights into how companies are preparing for market changes. These perceptions are particularly relevant for the electric power industry, considering doubts regarding incentives for promoting technological innovation.

This study contributes to obtaining insights into how investment policymakers design more efficient incentive mechanisms for investments in renewable energy technologies. Additionally, complementary information for the industry is crucial in order to support systems that facilitate the responses to incentives designed to promote technological innovations and investment opportunities (Sendstad & Chronopoulos, 2020).

The sample consists of 13 power generation companies observed from 2017 to 2020. Data was collected through the companies' sustainability and management reports, gathering information regarding expenditures on R&D and investment in renewable energy. The methodology adopted consisted of the ordinary least squares (OLS) regression model with robust standard errors estimated by the Stata16® software. The results reveal that spending on R&D positively affects investments in renewable energy, endorsing the view that allocating resources to R&D is essential for the process of innovation in the Brazilian electric power industry. The findings suggest that the industry joins efforts toward new sustainable technologies to cope with the technological transition process in order to supply the market while guided by the prospect of greater future demand, economic growth, and seeking sustainability.

2. THEORETICAL FRAMEWORK

2.1. Research and Development (R &D) in the Electric Power Industry

In Brazil, all energy generation, transmission, and distribution companies must invest in R&D, except those that generate energy exclusively from wind, solar, and biomass; the small hydroelectric power plants; and qualified cogeneration facilities. Law 9.991 of 2000, amended by law 13.203 of 2015, establishes the minimum percentage of 0.5% of net operating income (NOI) for investment in R&D.

The R&D program of the electric power industry is regulated, monitored, and implemented by ANEEL's Superintendence of R&D and Energy Efficiency (SPE), which is also responsible for the Energy Efficiency program (ANEEL, 2012). It is important to emphasize that R&D expenses promote renewable energy technologies, as they are related to clean energy supply. In addition, innovation plays a leading role in developing renewable energy (Garces & Daim, 2012; Wu et al., 2020).

Law 9.991 of 2000 establishes that the electric power industry must invest a minimum percentage of its NOI in R&D projects. The invested resources are distributed as follows: 40% (forty percent) for the National Scientific and Technological Development Fund (FNDCT), 40% (forty percent) for R&D projects, according to the regulation established by ANEEL, and 20% (twenty percent) for the Ministry of Mines and Energy, to fund studies and research for planning the expansion of the energy system.

According to ANEEL (2012), the R&D program aims to allocate financial and human resources to projects that promote innovation by creating new equipment and improving services. These projects are expected to contribute to the security of the electricity supply, keeping low tariffs, and reducing the sector's environmental impact, and the country's technological dependence.

For Soares et al. (2020), the country has to guarantee a long-term energy supply and spending on R&D goes in this direction by facilitating the expansion of power supply from other renewable sources, recognizing that such expansion is a considerable challenge.

2.2. Investments of the Electric Power Industry and an Overview of the Energy Matrices

The last two decades have witnessed a growing interest in integrating renewable energy matrices in the mix of power generation options, aiming to guarantee energy security within the scope of transition policies and in the face of climate change (Hache & Palle, 2019).

Investments in renewable energy technologies are considered risky since they are new and interact with economic, technological, and political uncertainties (Sendstad & Chronopoulos, 2020). Innovation deals with economic uncertainties, making it challenging to adopt an innovative technology that may threaten the companies' commitment to investment targets based on internal policies.

Companies must make accurate investment decisions, while policymakers must consider how private companies respond to different uncertainties to stimulate such investments (Sendstad & Chronopoulos, 2020).

Investments in renewable energy technologies rely on these technologies' abilities to be cost-competitive compared to those based on fossil fuels (Egli, 2020). Globalization has facilitated access to technological advances to increase the use of renewable energy reducing the costs related to such projects (Koengkan et al., 2020).

The energy matrices correspond to the energy sources exploited to supply society's demand. While the Brazilian energy matrix is strongly based on renewable sources (84,8%), most countries still depend on non-renewable energy sources such as coal, oil, and natural gas (EPE, 2022).

In Brazil, hydroelectric power is the main energy source in the country. Although it is a renewable energy source, hydroelectric power depends on the weather and is highly vulnerable to climate change. The country's supply problems due to droughts have demonstrated the need to diversify the energy matrix to avoid shortages and build energy security (Silva et al., 2016). Faced with this reality, Bondarik et al. (2018) recall that the country has saught strategies to maintain its renewable matrix while meeting the demand for energy and carrying out consistent economic development, considering the environmental and social impacts. However, according to Mantovani et al. (2016), the country needs investments in technology to reduce costs related to the implementation and expansion of new matrices.

The distribution of the power sources in the Brazilian energy matrix shows the country's dependency on water sources and the centralization of generation in large hydroelectric plants (Pereira & Silva Neto, 2020). These characteristics lead to vulnerability when considering climate change.

Perceiving technological transformations and understanding their effects on organizations is essential for tracing new development routes and improvements. In the current economic reality, marked by competitiveness and demand for product quality, the success of organizations depends on the capacity for technological innovation to create value in the long-term market. Since the beginning of the century, R&D has demonstrated a leading role in the companies' technological innovation process (Andreassi & Sbragia, 2002).

Studies on renewable and less polluting energy sources point to possible solutions regarding efficiency in energy production with lower environmental impacts (Salgado Junior et al., 2017). In addition, analyses of the characteristics of R&D expenditures, especially in expanding energy matrices, are important to guide the planning of the electric power industry, ensuring its development and adaptation to market changes (Mantovani et al., 2016).

In environments of economic uncertainty, timely technology adoption makes it possible to meet the current demands for investments in the industry's modernization. However, one cannot fail to consider that investment in renewable energy technologies is risky due to scenarios of uncertainties that permeate economic, technological, and political aspects (Sendstad & Chronopoulos, 2020).

3. METHODOLOGY

The sample comprised all publicly traded companies that operated directly and indirectly in generating electricity listed on the Brazilian stock exchange B3 S/A (Brasil, Bolsa, Balcão) between 2017 and 2020. Thus, the companies were analyzed to verify the relationship between R&D expenses and sustainable development. It was not possible to apply a more extended temporal analysis due to the scarcity of information made available by companies in their sustainability and management reports before 2017.

The B3 S/A segment "electric utilities" represent the industry analyzed in this study and counts 61 companies operating in the generation, commercialization, transmission, and distribution. As the research sought to analyze power generation companies and the production based on renewable matrices, 30 companies that did not fit these criteria were disregarded. Also, 13 companies that did not have the necessary data were not considered.

The state-owned company Eletrobras was excluded from the sample because of the biases arising from its institutional nature, social function, and particular characteristics regarding size, R&D expenditures, and investments compared to other observations. The company has significant participation in the electric power industry, and because its relationship with the federal government gives it political advantages and the ability to take less risk than its competitors (Wu et al., 2020), the company's behavior alters the average among the observations collected.

Finally, four companies were excluded to avoid data duplication since they were subsidiaries of other firms and had their results consolidated in the parent companies' financial statements. Thus, the final sample comprised 13 companies analyzed for the period from 2017 to 2020. The share of these companies in the internal electricity supply was 73.0% in 2020 (MME, 2021).

Therefore, the final sample consists of publicly traded power generation companies listed in the electricity utilities segment of B3 S/A in 2022, characterized as non-probabilistic (Table 1).

Table 1
Companies in the sample

	Companies	Services
1	AES Tietê Energia S.A.	G
2	Cemig Geração e Transmissão S.A.	G and T
3	Centrais Elétricas de Santa Catarina	G and D
4	CESP – Companhia Energética de São Paulo	G
5	Cia Estadual de Geração e Transmissão de Energia Elétrica-CEEE-GT	G and T
6	Companhia Paranaense de Energia S.A.	G, T, and D
7	CPFL Energia S.A.	G and D
8	EDP Energias Brasil S.A.	G, T, and D
9	Empresa Metropolitana de Águas e Energia S.A.	G
10	Enel Brasil S.A.	G, T, and D
11	Engie Brasil Energia S.A.	G
12	Neonergia S.A.	G, T, and D
13	Rio Paranapanema Energia S.A.	G

Source: Research data.
Note: Services are G – generation; T – transmission; D – Distribution

The year 2021 was not included in the sample since there was no standard regarding the date to release the firms' sustainability reports. The year 2022 was also not included because some companies had not published their reports at the time of data collection. Information regarding R&D and investments in assets buying and expansion was retrieved from sustainability and management reports released by the companies and published on the B3 S/A website.

The orientation of the companies' annual investments in assets buying and expansion was approached based on their management reports, observing the industry's perspective regarding the supply of innovations and renewable energy in the long term.

As for the control variables, data were obtained directly from the companies' annual financial reports, using their financial statements as a tool (complemented by explanatory notes). The variables used in the study are supported by the literature (Table 2).

Table 2
Research variables

Variable	Description	Operacionalization	References
Dependent variable			
RE	Disbursement to buy or expand assets related to renewable energy matrices	RE_{it}	(Wu et al., 2020; Yang et al., 2019)
Independent variables			
RandD	R&D expenditures		(Kose et al., 2020)
Asset	Total asset	$Total\ Asset_{it}$	(Wu et al., 2020; Yang et al., 2019)
Concentration	Proportion of shares held by the main shareholder		(Wu et al., 2020)
ROE	Proportion of net profit divided by the average balance of net equity	$ROE = \frac{NP}{\bar{x}NE}$	(Wu et al., 2020; Yang et al., 2019)
Growth	Growth rate of net operating income	$Growth_n = \frac{NOI_n}{NOI_{n-1}}$	(Wu et al., 2020)
Covid19	Dummy that takes the value 1 for the year influenced by the COVID-19 pandemic (2020)		(Amorim et al., 2022)
Sector	Dummy that takes the value 1 for companies that work 100% with power generation		(Yang et al., 2019)

Source: Elaborated by the authors

Investments in renewable energy represent the dependent variable (RE), measured by the net amount paid by the company for the purchase of fixed assets, intangible assets, and other long-term assets related to renewable energy matrices (He et al., 2019; Wu et al., 2020; Yang et al., 2019).

R&D expenditure represents the independent variable (RandD) carried out by the company and informed in the companies' sustainability reports. The demand originated from economic growth challenges in the electric power industry regarding technological solutions, which are unlikely to be achieved without coordinated R&D efforts (Amaral et al., 2017). Kose et al. (2020) show that research development positively impacts the growth of European Union countries, and Sim (2018) points out that investments in renewable energy positively influence the value of R&D expenditures.

A set of variables in this study controls the interference of other factors relevant to the companies. According to previous studies involving R&D and investments in renewable energy, all these variables can affect companies' investment decisions (Chen et al., 2018; Meuleman & Maeseneire, 2012; Wu et al., 2020; Colombo et al., 2013).

Equation 1 presents the econometric model:

$$RE_{it} = \alpha + \beta_1 RandD_{it} + \beta_2 Size_{it} + \beta_3 Concentration_{it} + \beta_4 ROE_{it} + \beta_5 Growth_{it} + \beta_6 Covid19_{it} + \beta_7 Sector_{it} + \beta_8 Year_{it} \varepsilon_i \quad (1)$$

The COVID-19 pandemic influenced the results for the year 2020, and uncertainties about the future affected corporate decisions, which means that, sometimes, investments were made through biased decisions (Amorim et al., 2022). Therefore, the scenario involving managers' expectations and how they influence investment decisions during this period were represented by the "Covid19" dummy, which takes the value 1 for 2020. This dummy variable is not intended to control the years in the statistical model but to assess the impact of the pandemic on investments.

Yang et al. (2019) point out that, like total assets, the size of the enterprise influences the number of investments made by companies due to the more intense internal cash flow. Thus, the "Sector" dummy was created to control the performance portfolio of the analyzed companies, taking the value 1 for companies fully focused on power generation. Such control is necessary because companies with more than one activity in the electric power industry (generation, transmission, or distribution) have more internal cash flow resources arising from a broader participation in the entire chain, which is a preponderant factor for decision-making on investments.

When estimating the regression, it was necessary to control the period. According to Hoffmann (2016), specific characteristics of each observation must be controlled, and as the electric power industry has a considerable scenario of change in the organizational environment, with growth in the number of companies listed on the stock exchange, mergers and acquisitions of large companies, in addition to political impacts (Bin et al., 2015; Loch et al., 2020), it was necessary to control the period using the "Year" variable.

The variables were winsorized at a significance level of 1% to avoid excluding another outlier. For the assumptions of the regression regarding normality, the Shapiro-Francia test was used, recommended for samples with more than 30 observations. The variance inflation factor (VIF) was adopted for multicollinearity. According to Montgomery et al. (2021), VIF is recommended when two or more variables are highly correlated, making it difficult to distinguish their influences separately in the regression model. The regression was considered acceptable when VIF for the estimators was less than 4 (Fávero et al., 2009).

The Breush-Pagan-Godfrey test rejected the null hypothesis that indicated the existence of heteroscedasticity for the models (p = 0.000). Thus, it is possible to say that, at a significance level of 1%, the model does not have the same variance in all observations. Therefore, it was decided to use estimation with robust standard errors to correct possible heteroscedasticity problems. Therefore, the ordinary least squares (OLS) regression model was used with robust standard errors, estimated by the Stata16® software, with investments in renewable sources as the dependent variable and R&D expenditures and control data as independent variables.

4. DESCRIPTION AND ANALYSIS OF RESULTS

4.1. Descriptive Statistics

Table 3 shows the descriptive statistics of the variables used in the research, observing the mean, standard deviation, median, minimum, and maximum values of the data about the power generation companies in the sample.

Table 3
Descriptive statistics of the variables

n=13					
Variables	**Mean**	**Standard deviation**	**Median**	**Minimum**	**Maximum**
RE	399,986,212	906,222,934	114,743,000	0	5,538,100,000
RandD	35,907,083	32,908,505	35,717,961	930,430	137,090,000
Asset	26,177,797,135	21,330,080,023	21,690,011,500	1,245,025,000	80,082,694,000
Concentration	0.667	0.217	0.625	0.277	0.993
ROE	0.169	0.103	0.154	-0.023	0.515
Growth	0.128	0.184	0.093	-0.476	0.667

Source: Research data (2022).
Note: RE – investments in renewable energy; RandD – annual expenses with R&D; Assets – total assets; Concentration – proportion of shares held by the main shareholder; ROE – proportion of net profit divided by the average balance of net equity; Growth – annual growth rate of net operating income.

The descriptive statistics of investments in renewable energy (RE) revealed that, on average, BRL 400 million were invested annually in purchases or expansion of assets related to renewable energy matrices. However, this value differed between companies, so while Engie invested BRL 5.5 billion in 2017, CEMIG did not invest in renewable energy in 2019.

Companies invested an average of BRL 35.9 million per year in R&D programs regulated by ANEEL, which were designed to bring innovation to the industry. The maximum amount invested was from Neoenergia, which disbursed BRL 137.1 million in 2020, while the lowest was EMAE, which applied BRL 930,000 in R&D in 2017.

Projects completed between 2017 and 2020 by the Research and Technological Development Program for the Electric Power Industry, regulated by ANEEL, received BRL 734.5 million from the companies analyzed. It should be noted that projects involving alternative energy sources corresponded to 33.8% of the resources employed.

This movement for more resources applied to alternative and renewable energy sources was advocated by Amaral et al. (2017) when pointing out that organizations change to deal with the technological transition and join efforts in R&D to respond to the pressures imposed by society for sustainable technologies. If the companies do not take advantage of the potential of R&D investments to promote economic growth and productivity, they will face the consequences of being unprepared to meet market demands (Del Bo, 2016).

Therefore, in addition to the protagonism involving projects aimed at alternative energy sources, environmental awareness was also present in the choice of R&D projects, assuming the position of the second largest allocation of resources (11.1%). Figure 1 shows the distribution by the theme of expenditures made on R&D programs completed between 2017 and 2020.

Among the lowest allocations of resources, there was the project to generate energy from fossil fuel, such as thermoelectric generation, which in the analysis period received 0.3% of resources compared to all other projects. It is also observed that 10.4% of the projects were focused on supervision, control, and protection, and 9.2% on electrical system planning. In addition to the environmental aspects and the diversification of energy matrices, the R&D projects aimed to guarantee greater control, safety, and planning in the electrical system processes.

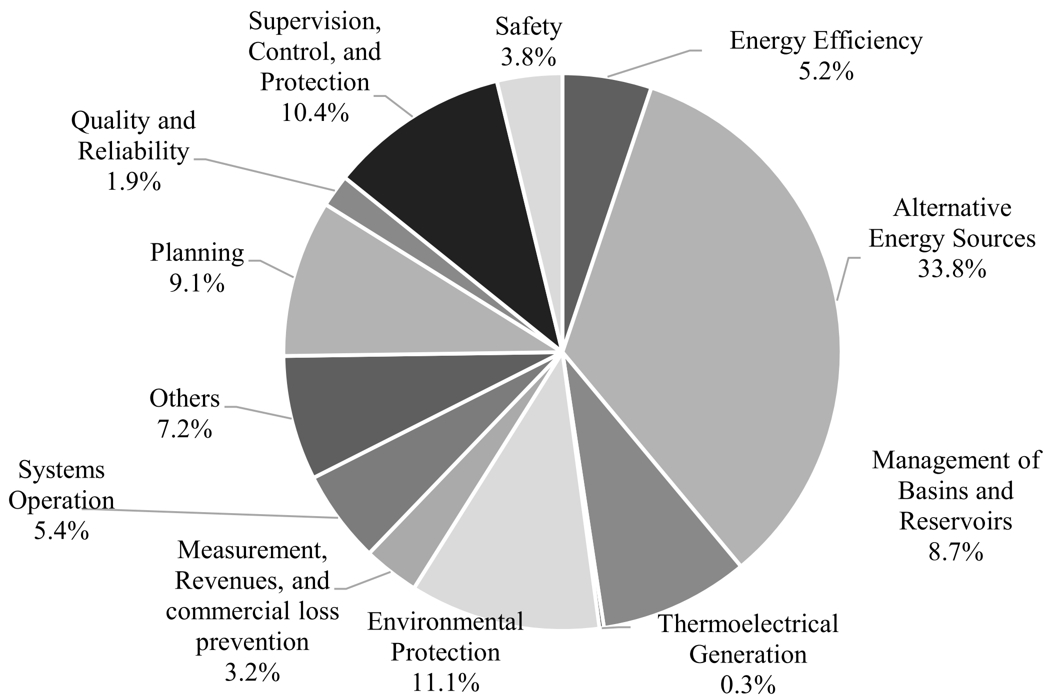

Figure 1. Research and development projects completed between 2017 and 2020.
Source: Research data.

4.2. Discussion of Results

The Stata16® software revealed the regression results, including tests to validate the models used. Regarding data normality, the Shapiro-Francia test was applied to test the residuals' normality. After testing, the null hypothesis of a normal distribution was rejected at a significance level of 5% (p-value = 0.00001). However, following the central limit theorem and the fact that the sample contains 52 observations, the assumption of normality of residuals was relaxed (Greene, 2003).

For the heteroscedasticity test, the Breusch-Pagan test was performed. The results rejected the null hypothesis that indicated the residuals' heteroscedasticity (p-value = 0.0000). Therefore, White's robust correction was used to adjust the standard errors since the null hypothesis of the White test indicating homoscedasticity was not rejected (p-value = 0.3121).

Regarding the multicollinearity test, the VIF statistic was used. For Montgomery et al. (2021), multicollinearity occurs when two or more variables are correlated, making it difficult to distinguish their influences separately in the regression model. For the regression to be acceptable, we adopted a VIF of less than 4 for the estimators (Fávero et al., 2009).

Table 4 presents the VIF values demonstrating the absence of multicollinearity problems since all model constructs were less than 4.

Table 4
Variance inflation factor (VIF)

Variable	VIF	1/VIF
RandD	3.08	0.33
Asset	3.82	0.26
Concentration	1.75	0.57
ROE	1.44	0.69
Growth	1.19	0.84
Covid19	2.24	0.45
Sector	2.23	0.45
Year		
2018	1.57	0.64
2019	1.75	0.57
VIF (average)	**2.12**	

Source: elaborated by the authors.

Based on the assumptions above, we tested how investments in renewable energy behave concerning R&D expenditures. Table 5 presents the results evidenced by White's robust regression analysis.

Table 5
Influence of R&D expenditures on renewable energy

RE	Coefficients	Robust Standard Error	t-value	P>|t|	95% Confidence interval	
RandD	1.00E+01	4.57E+00	2.190	0.034**	7.85E-01	1.92E+01
Asset	-8.38E-03	7.23E-03	-1.160	0.253	-2.30E-02	6.20E-03
Concentration	7.04E+08	5.18E+08	1.360	0.182	-3.42E+08	1.75E+09
ROE	5.17E+09	2.39E+09	2.160	0.036**	3.45E+08	9.90E+08
Growth	-1.82E+08	5.63E+08	-0.320	0.748	-1.32E+09	9.55E+08
Covid19	-1.14E+09	6.59E+08	-1.730	0.091*	-2.47E+09	1.89E+08
Sector	-6.11E+08	3.62E+08	-1.690	0.099*	-1.34E+09	1.19E+08
Year						
2018	-2.29E+08	4.18E+08	-0.550	0.587	-1.07E+09	6.16E+08
2019	-8.28E+08	5.12E+08	-1.620	0.113	-1.86E+09	2.05E+08
2020	0	(omitted)				
Constant	3.22E+08	3.21E+08	-1.000	0.322	-9.70E+08	3.26E+08
R-Squared	0.377					
Root MSE	7.90E+08					

Source: research data.
Note: * p<0.10; **p<0.05; ***p<0.01. RE – investments in renewable energy; RandD – annual expenses with R&D; Assets – total assets; Concentration – proportion of shares held by the main shareholder; ROE – proportion of net profit divided by the average balance of net equity; Growth – annual growth rate of net operating income; Covid19 – Dummy that takes the value 1 for the year 2020; Sector – Dummy that takes the value 1 for companies that work 100% with power generation.

The coefficient of determination (R^2) demonstrates how much the dependent variable was explained within the model. According to Cohen (1988), values above 13% are considered medium, and values above 26% are high. In the model, investments in renewable energy were explained in 37.7% by the interest and control variables, representing high explanatory power.

The result shows a positive effect between investments in renewable energy and R&D expenditures (β = 1.E+01; p-value = 0.034); consequently, H1 was not rejected. Regarding the economic effect, for every BRL 1.00 invested in R&D, investments in renewable energy tend to increase by BRL 10.00. This finding suggests that R&D expenditures are important for innovation and the creation of new perspectives in power generation through diversified and renewed energy matrices. This result corroborates previous studies that indicate the potential of R&D to effectively promote investments in renewable energy (Wu et al., 2020; Zhang et al., 2016).

This finding corroborates Garces and Daim (2012), who show that investment in renewable and innovative technology positively affects long-term economic growth. Wu et al. (2020) also pointed out that government subsidies for R&D promote investments in renewable energy, which is essential for innovation in the sector.

A positive effect between return on equity (ROE) and investments in renewable energy (β = 5.17E+09; p-value = 0.036) was identified, which indicates that companies with better returns on the total capital invested by shareholders are encouraged to make investments. This result does not corroborate the studies by Yang et al. (2019) and Wu et al. (2020), who found that the effects of expected returns on renewable energy investments were insignificant. Also, according to the authors, although the profitability of Chinese companies is strong, a substantial amount of resources are used to meet production and operation requirements, which limits the expected gains. However, Koengkan et al. (2020) point out that economic growth positively affects investments in installed renewable energy capacity.

COVID-19's impact shows a negative relationship between the pandemic and renewable investments made by companies (β = -1.14E+09; p-value = 0.091). This finding suggests that the effects of the pandemic on the economic conjecture caused apprehension in companies, so large investments were made cautiously. However, this result does not corroborate Amorim et al. (2022), whose results indicated that decisions to initiate new projects had overconfidence biases during the pandemic, mainly due to the bold behavior of administrators to reverse economic impacts arising from the pandemic. On the other hand, Hud and Hussinger (2015) state that the uncertainties caused in periods of crisis make companies more cautious with investment decisions.

The negative effect was also identified in companies focused on power generation, who do not have transmission and distribution activities in their portfolio (β = -6.11E+08; p = 0.099). This finding suggests that companies operating more than one portfolio (generation, transmission, or distribution) have a greater capacity to invest in renewable energy. This result corroborates Yang et al. (2019) since, according to the authors, the larger the enterprise and portfolio of activity, the greater the internal cash flow for investments in profitable projects, and consequently, investments in renewable energy increase.

The role of R&D in the electric power industry is evident, so companies are looking for an organizational structure to deal with the challenges and increase the efficiency of their R&D programs and, as a consequence, the development of new technologies that favor the transition toward sustainability (Amaral et al., 2017).

Abban and Hasan (2021) found that developed countries do not consider renewable energy as an alternative method for producing electricity but as an essential method in terms of environmental protection. They are committed to investments in renewable energy and, therefore, show a tendency for greater expenditures on R&D projects and investments in the search for greater sustainability in energy generation.

5. FINAL CONSIDERATIONS

This study showed that R&D expenditures are essential for innovation and prospects for renewable energy generation, and 33.8% of such expenditures have been directed to alternative energy sources. As advocated by Amaral et al. (2017), companies' movements around generating renewable energy results from a joint R&D effort to cope with technological transition and to respond to market pressures pushing to renewable matrices and environmental issues.

The statistical data suggests that the promotion of investments in renewable energy is positively related to spending on R&D, corroborating similar studies. This finding shows the fundamental role of R&D expenditures in developing renewable and innovative technologies, essential for the innovation process in the electric power industry and long-term sustainable economic growth (Garces & Daim, 2012; Wu et al., 2020).

Additionally, the study points out that issues involving R&D and the environmental impacts of power generation are increasingly relevant, so social and market pressures on designing production chains through renewable energy occur more frequently. Therefore, spending on R&D toward innovation represents the companies' strategy to meet this supply chain demand and the continuity of related programs. In this sense, the resources invested in R&D are crucial because they facilitate the industry's adaptation to possible changes in the scenario and help involved parties in decision-making processes.

This study offers other perceptions regarding how companies in the electric power industry have been behaving in the face of uncertainties regarding incentives in the promotion of technological innovation and the search for diversification of energy matrices (Sendstad & Chronopoulos, 2020). The findings reveal the relevance of R&D expenditures as a leading investment to develop and implement solutions and technologies to increase the exploitation of renewable energy matrices and to guide policies for sustainable economic development and economic growth.

The main limitation of this study is the decision to focus on power generation companies, which does not allow generalizing the results to the entire industry but opens the possibility of future research exploring other types of organizations. This study focused on power generation and investments to access or expand the generation of renewable energy, understanding that transmission and distribution assets are not directly linked to the industry's process of structural transformation toward sustainable economic development and diversification of renewable energy matrices (Sarkodie et al., 2020; Sendstad & Chronopoulos, 2020; Souza, 2020).

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AUTHOR'S CONTRIBUTION

FS was responsible for the conceptualization, data collection, methodology, and formal analysis. DS was the research advisor, contributing to the review, writing, conceptualization, and formal analysis.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest in the publication of this article.