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SELECTION OF ENERGY PROJECTS: THE EFFECT OF DECISION MAKING ON THE RELATIONSHIP BETWEEN ENERGY SOURCE AND SALES PRICE

SELEÇÃO DE PROJETOS DE ENERGIA: O EFEITO DA TOMADA DE DECISÃO NA RELAÇÃO ENTRE FONTE DE ENERGIA E PREÇO DE VENDA

SELECCIÓN DE PROYECTOS DE ENERGÍA: EL EFECTO DE LA TOMA DE DECISIONES EN LA RELACIÓN ENTRE FUENTE DE ENERGÍA Y PRECIO DE VENTA

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Abstract

Objective of the study: This study aims to identify the effect of decision making on the relationship between the energy source and the establishment of the sales price in electricity auctions for the selection of auction projects.

Methodology / approach: Statistical tests were performed on an auction base that concentrates the majority of energy auctions held in the Brazilian market. The relationships between the establishment of the sales price and energy sources and the moderating effect of power, hours of operation, and period of use on this main relationship were evaluated.

Originality / Relevance: The formation of a portfolio of electric energy projects through the prior selection of energy auction projects, via a multi-criteria decision-making process, is a valid strategy for companies in the sector.

Main results: It was identified that there is awareness of the sales price based on the energy source and relevant criteria for decision making, such as capacity and implementation period.

Theoretical-methodological contributions: This study contributes to a process of analysis and preparation of the secondary database of electricity auctions made available by the Electric Energy Commercialization Chamber (CCEE). The theoretical contribution is made by enabling the use of multi-criteria processes for decision making.

Contributions to Society / management: Managers can use the methodology applied in this study to create a portfolio of projects with less risk for decision making.

Keywords: Decision making. Multi-criteria. Energy auctions. Project portfolio management.

Resumo

Objetivo do estudo: Este estudo objetiva identificar o efeito da tomada de decisão na relação entre a fonte energética e a formação do preço de venda em leilões de energia elétrica para a seleção projetos de leilão.

Metodologia / abordagem: Testes estatísticos foram realizados em uma base de leilões que concentra a maior parte de leilões de energia realizados no mercado brasileiro. Foram avaliadas as relações entre

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a formação do preço de venda e as fontes energéticas e o efeito moderador da potência, horas de operação e período de utilização sobre esta relação principal.
Originalidade / Relevância: A formação de um portfólio de projetos de energia elétrica através da seleção prévia de projetos de leilões de energia, via processo de tomada de decisão multicritérios, é uma estratégia válida para empresas do setor.
Principais resultados: Identificou-se que há a sensibilização do preço de venda a partir da fonte energética e por critérios relevantes para a tomada de decisão, como a capacidade e o período de implantação.
Contribuições teórico-metodológicas: Este estudo contribui com um processo de análise e preparação da base de dados secundária de leilões de energia elétrica disponibilizada pela Câmara de Comercialização de Energia Elétrica (CCEE). A contribuição teórica se dá pela viabilização de uso de processos de multicritérios para a tomada de decisão.
Contribuições sociais / de gestão: Gestores podem se basear na metodologia aplicada nesse estudo para a formação de portfólio de projetos com menor risco para a tomada de decisão.

Palavras-chave: Tomada de decisão. Multicritério. Leilões de energia. Gerenciamento de portfólio de projetos.

Resumen
Objetivo del estudio: Este estudio tiene como objetivo identificar el efecto de la toma de decisiones sobre la relación entre la fuente de energía y la formación del precio de venta en las subastas de electricidad para la selección de proyectos de subasta.
Metodología/enfoque: Se realizaron pruebas estadísticas sobre una base de subastas que concentra la mayoría de las subastas de energía realizadas en el mercado brasileño. Se evaluaron las relaciones entre la formación del precio de venta y las fuentes de energía y el efecto moderador de la potencia, las horas de operación y el período de uso sobre esta relación principal.
Originalidad / Relevancia: La conformación de una cartera de proyectos de energía eléctrica mediante la selección previa de proyectos de subasta de energía, mediante un proceso de toma de decisiones multicriterio, es una estrategia válida para las empresas del sector.
Principales resultados: Se identificó que existe conocimiento del precio de venta con base en la fuente de energía y criterios relevantes para la toma de decisiones, como la capacidad y el período de implementación.
Aportes teórico-metodológicos: Este estudio contribuye a un proceso de análisis y elaboración de la base de datos secundaria de subastas de energía eléctrica puesta a disposición por la Cámara de Comercialización de Energía Eléctrica (CCEE). La contribución teórica se realiza al posibilitar el uso de procesos multicriterio para la toma de decisiones.
Contribuciones sociales / gerenciales: Los gerentes pueden utilizar la metodología aplicada en este estudio para crear una cartera de proyectos con menor riesgo para la toma de decisiones.

Palabras clave: Toma de decisiones. Multicriterio. Subastas de energía. Gestión de cartera de proyectos.

1 Introduction

The growing search for additional energy sources (ES) to supply the increasing energy demand (Jayaraman et al., 2015) leads organizations trained in specialized technology to operate in this market. The most widely used ESs in the world largely focus on fossil energies such as oil and gas (Ferreira & Patah, 2017). As Brazil is favored by its wide hydrographic basin, contrary to the world trend, the main energy matrices are historically hydroelectric (Ferreira & Patah, 2017). In fact, the country boasts some of the largest hydroelectric plants in the world, supplying around 64% of all the energy generated (Ferreira & Patah, 2017).

Regarding the growing demand for energy, it is important to note that it is not on the same level as the supply curve, compelling actions by the Brazilian government to meet the latent need for energy (Ferreira & Patah, 2017). The demand for energy is apparent in several countries, such as Cyprus, Spain, Greece, Taiwan, and Turkey, and there are a number of scientific studies (Beccali et al., 1998; Gwo-Hshiung et al., 1992; San Cristóbal, 2011) proposing conceptual models for the solution of this demand, arising from decision-making processes based on multiple criteria. This implies that energy planning is complex and that technical, economic, environmental, and social aspects are considered in the decision making (Beccali et al., 1998; Hernández-Torres et al., 2015; Kaya & Kahraman, 2011).

Auctions for the sale of electricity are a mechanism used to meet this need, being focused on the exploration of renewable ESs (Ferreira & Patah, 2017). The use of auctions as a mechanism to meet demand is a prominent alternative in the sector (Azuela et al., 2014; del Río, 2017; Ferreira & Patah, 2017), however, while auctions are considered to be a useful alternative, offering a better remuneration mechanism (del Río, 2017; Hansen et al., 2020), there is the caveat that auctions do not always meet the expectations of their participants. Their applicability is justified in scenarios where sufficient proposals are expected so that gains arising from the competition can offset the implementation costs (Azuela et al., 2014) and improve the cost-benefit ratio (Hansen et al., 2020).

Thus, in order for such expectations to be met, it is necessary to consider good practices related to auction planning elements (del Río, 2017). The definition of criteria for the selection of projects in this area is not easy or trivial (del Río, 2017). Based on the aforementioned, for the current study, we aim to evaluate the relationship between ES and the multiple criteria for the selection of energy auction projects, which are power (POW), hours of operation (HO), and implementation period (IP), in the formation of the sales price (SP).

The structure of this document is as follows: the opening section comprises this introduction; the second section brings the theoretical references; the third section deals with conceptual development, being that these last two sections are necessary for the substantiation of the article and to test the hypotheses; the fourth section, covers aspects of the methodology for the elaboration of this report; the fifth is the results section; the sixth, the discussion section, will present the results and contributions obtained; and the seventh section, is the conclusion.

2 Theoretical framework

2.1 Decision-making process

The theory of decision making (DT) has its bases in economics, considering the four precepts on which it is founded (Edwards, 1954). This theory is based on the resolution of individual choices, in the sense of explaining what leads a decision maker to decide on one possibility among two or more.

This "decision" is the basis of the analysis of studies conducted by economists since the 1870s and, later, by psychologists (Edwards, 1954). The precepts that underlie the theory of DT are the theory of risk-free choices and its application to welfare economics, the theory of risky choices, transitivity in DT, and the theory of games and statistical decision functions (Edwards, 1954).

DT has evolved with the emergence of DT analytical methods or processes. Nowadays we have the concepts of Multicriteria decision making (MCDM) or Multicriteria decision analysis (MCDA). The MCDM is advocated as an appropriate operational assessment and decision support approach, addressing complex problems with a high degree of uncertainty (Kaya & Kahraman, 2011). The methodologies that fit the MCDM concept provide a series of tools for solving complex problems and are widely applied in the energy planning area (Ioannou et al., 2017; Kaya & Kahraman, 2011).

For this study we found that various DT methods are used in the planning of renewable energy, electrical energy, energy resource allocation, constructing energy management, and project planning issues (Kaya & Kahraman, 2011). The most widely used methods are AHP, PROMETHEE, ELECTRE, and TOPSIS (Kaya & Kahraman, 2011).

The Analytical Hierarchical Process (AHP) method, created by Thomas L. Saaty, is a method based on the elaboration of a hierarchy structure used to work with complex decisions (Hernández-Torres et al., 2015; Streimikiene et al., 2012). The possibilities of choices or solutions for a given problem are classified according to different criteria and an evaluation system. During the construction of the process, weights are defined through a step of paired comparisons that aims to simplify the selection process. Problems are modeled as criteria hierarchies.

Each criterion can have several sub-criteria, providing a detailed analysis of the context. Paired comparisons establish a weight by importance that is fixed for each criterion (Hernández-Torres et al., 2015). AHP is characterized by its simplicity, but also by its robustness, in order to deal with the complexities of real problems (Meade & Presley, 2002). The modeling provides for unidirectional hierarchy for decision making. Its components are the general objective and decision criteria that can be broken down into levels (Meade & Presley, 2002).

The VIKOR method provides a multi-criteria classification index based on the particular measure of "closeness to the ideal solution". This method was developed to be an alternative to the ELECTRE method. It is based on an aggregator function that represents a measure of proximity to the ideal solution (San Cristóbal, 2011).

This method uses a form of function aggregation to classify different types of normalization in order to eliminate the criterion function units. Linear normalization is also used and the normalized values do not depend on the evaluation unit of a criterion (San Cristóbal, 2011). An aggregator function is introduced, that represents the distance from the ideal solution, considering the relative importance of all criteria, and a balance between total and individual satisfaction (San Cristóbal, 2011).

The MCDM or MCDA deal with DT using objective or conflicting criteria and provide better DT when using multiple criteria (Jayaraman et al., 2015). It should be noted that the methods are not totally free from human interaction for the selection of the best or most viable solution (Jayaraman et al., 2015).

The MCDA is characterized by a set of decision support methods widely used in the energy sector, considering political, economic, social, and technological criteria (Ioannou et al., 2017). These methods make use of relationships such as priority, outranking, and distance to evaluate energy alternatives and factors for DT (Ioannou et al., 2017). As part of the process, the selection of these criteria is one of the most critical steps (Tsoutsos et al., 2009), and several studies demonstrate and defend criteria for the selection of solutions for the energy sector (Beccali et al., 1998; del Río, 2017; Gwo-Hshiung et al., 1992; Hernández-Torres et al., 2015; Ioannou et al., 2017; Jayaraman et al., 2015; San Cristóbal, 2011; Theodorou et al., 2010).

The use of multi-criteria methods to support DT in the selection of technologies for the elaboration of a renewable energy distribution plan can be performed in stages and evaluation scenarios (Beccali et al., 1998). Stage S1 will define the actions that will be examined and that represent the technologies to be understood. S2 defines the evaluation criteria for the actions defined in S1, which will enable evaluation of the possible consequences due to each action. S3 assigns weights to all criteria according to the evaluation of three different scenarios, and finally, S4 aims to apply the evaluation algorithm with preferences indicated by the weights stipulated in the three evaluated scenarios.

In this process of stages, there is the stipulation of weights through scenarios. The scenarios were stipulated considering (1) actions that generated the lowest environmental impacts (C1, environment-oriented scenario), (2) actions that offer the best direct economic and social benefits (C2, 'economic profit' scenario), and (3) actions related to energy savings and rationalization of the global energy system (C3, energy savings and rationalization scenario) (Beccali et al., 1998). In addition to the proposed procedural structure, the authors propose a list of 12 criteria for the comparisons of actions (Beccali et al., 1998).

Previously, in the 1990s, a multi-criteria evaluation method was used to broadly evaluate alternatives for the development of new energy systems (Gwo-Hshiung et al., 1992). At the time, the authors pointed out that there were pressures related to environmental issues, energy technology, and environmental, social, and economic impacts. In this situation, there is a defense of a hierarchical structure, based on five principles that enabled the analysis of what would be the criteria for evaluating new energy systems (Gwo-Hshiung et al., 1992).

The goal programming model was defended using four criteria, which are related to social and economic issues (Jayaraman et al., 2015). The defended goals were related to sustainability in the economy (GDP), energy (electricity consumption), and the environment (greenhouse gas emissions)(Jayaraman et al., 2015). Likewise, in another study, technical, economic, environmental, and social criteria were used in the evaluation of energy alternatives (Kaya & Kahraman, 2011).

2.2 Energy

The world energy scenario has been gradually changing over the last 25 years. Throughout the 1990s, the world's energy structure was oriented towards fully centralized energy generation and aimed at large-scale energy supply plants (Walter, 2003), but this scenario changed with the various financial incentives of world governments for the creation of small generation centers, closer to consumers and large cities, making the operation and distribution of energy more attractive for everyone. From this moment, a new concept of decentralized energy supply also emerges, which provides better values for final consumers and more profitable proposals for energy supply companies (Walter, 2003).

Addressing this decentralized energy supply scenario, new opportunities arise for smaller power plants and the ES supplied (Tiepolo et al., 2012). Since the Kyoto protocol signed in 1997, the world has opened its eyes to the generation of gases in all segments of the world (Sauer et al., 2006). This directly impacts the energy sector, as, until then, much of the ES in the world had been generated through fossil fuels, producing a high volume of gases that directly affect the environment (Sauer et al., 2006).

The decentralized energy supply model enables small and medium-sized suppliers to enter the electricity auction market and compete on an equal footing with the competition (Azuela et al., 2014; Sauer et al., 2006). Basically, energy supply regulatory organizations launch the auction offer to purchase energy and whoever is able and has the ability to supply can participate and sell their energy generation. In addition to opening the market to other suppliers, energy auctions help in the energy renewal for the country, opening the doors to the supply of other types of energy, whether through renewable and clean or non-renewable energies (Azuela et al., 2014).

2.2.1 Types of energy

To better understand the electrical supply in the world, it is necessary to understand a little about the types of energy available and their main characteristics. In general, the main ESs can be classified as follows: hydroelectric, nuclear, thermoelectric, wind, photovoltaic (Tiepolo et al., 2012).

2.2.1.1 Wind

Wind energy is produced by taking advantage of the movements generated by the wind. (Sauer et al., 2006) and is considered a clean, renewable, and sustainable ES source (Evans et al., 2009). In some countries like Germany, Spain, United States, India, and Denmark, this ES is in strong expansion. Wind energy is generated through wind captured by turbines, known as wind turbines, which have a weathervane shape. After capturing the wind, basically, the kinetic energy is converted into mechanical or electrical energy (Terciote, 2002).

This process has the lowest emissions of greenhouse gases and water consumption, in addition to favorable social impacts compared to other technologies, such as the very low rates of fatalities per TWh installed (0.15%) (Kuleli Pak et al., 2017). However, wind energy requires the largest swaths of land and has high relative capital costs (Evans et al., 2009). For some authors, wind energy is the energy that has had the most significant results, because in terms of supply capacity and operating cost, it shows interesting numbers for companies and consumers (Hansen et al., 2020; Walter, 2003).

One of the biggest benefits to the use of wind energy is the non-emission of toxic gases into the atmosphere that other types of energy generate, in addition to the use of an abundant, infinite, and natural resource, wind. The emission of pollutants is minimal, having no effect on global climate change or acid rain (Sauer et al., 2006; Terciote, 2002). Some negative points can be observed in the use of this technology, such as the death of birds in the wind farms, the noise caused by the turbines, and the interference in telecommunications signals (Evans et al., 2009).

With the auction strategy, greater competition between wind energy suppliers has been made possible. More than 9,000 MW of wind farms were contracted until 2014 in the last four Brazilian auctions up to that time (Azuela et al., 2014). Additionally, there has been a drop in the prices of this type of energy due to the competitiveness of renewable energy auctions, which are being increasingly adopted worldwide (Azuela et al., 2014; Hansen et al., 2020). Global installation of wind and solar PV generating capacities increased from 148 GW in 2009 to 540 GW in 2018 (Hansen et al., 2020). In this way, the cost-effectiveness of this technology is increased (Hansen et al., 2020).

Brazil has great potential in the use of wind energy. In 2005, national consumption was 335.4 TWh and the use of wind energy could supply 81% of all demand (Sauer et al., 2006). In that year, the cost of wind energy in Brazil was US$ 1,100.00 per kW installed, while in Europe, it was around US$ 900.00 (Sauer et al., 2006). In 2021, 3 auctions were held, as shown in Table 1, for contracting renewable energy in Brazil. Investments in the order of R$7.1 billion were made, which corresponds to 55% in relation to the R$13 billion invested in the same year (CCEE, 2022). Of these, R$2.4 billion, or 34%, were earmarked for investment in wind energy. The result of the auctions shows that around 15.9 million MWh of this type of energy were contracted, at a price of R$152 per MWh (CCEE, 2022).

2.2.1.2 Photovoltaics

Solar electrical energy is obtained using photovoltaic cells, which convert solar radiation into electricity through semiconductor materials (Kemerich et al., 2016). When sunlight hits a photovoltaic cell, an electrical current is generated that is collected by wires connected to the cell, and transferred to the batteries that supply the energy; in this way the more photovoltaic cells are connected in series, the greater the production of electric energy (Kemerich et al., 2016). Like wind energy production, solar energy is also considered a clean and sustainable production method and is on the rise (Evans et al., 2009).

The report Renewables in Cities 2021 Global Status Report (Ren21-11, 2011) presents relevant data considering that 23.9 GW of cells and 20 GW of modules were produced in 2010. More recently, in the report Renewables global futures report: great debates towards 100% renewable energy (Ren21-17, 2017), it can be seen how this technology was underestimated, since in 2001 a total installed capacity of 100 GW was estimated by 2015, when in reality the actual capacity reached was 225 GW. In Brazil, in 2021, in the auctions held for this technology, 10.5 million MWh were contracted at an average price of R$144 per MWh. This represented R$1.5 billion reais (CCEE, 2022).

Regarding costs, like other sustainable energies, the production of solar electric energy has also benefited from the encouragement of governments in the production of clean energy. A study carried out in 2012 (Tiepolo et al., 2012) points out that between 2009 and 2011 the cost of installing solar energy using photovoltaic cells was reduced by 60%, reaching a cost of $100.00/MWh. In this sense, the report Renewables global futures report: great debates towards 100% renewable energy cites that costs are decreasing due to the evolution of photovoltaic module technology, implying a 58% drop in the costs of photovoltaic generators between 2010 and 2015 (Ren21-17, 2017).

2.2.1.3 Hydroelectric

The electrical energy from hydroelectric plants is generated through the force of the water. The generation of energy through hydroelectric plants is a complex process, however, in a general and simple way, the force of the water generates pressure that moves the hydraulic turbines, converting this hydraulic energy into electrical energy that is distributed in the transmission lines (Evans et al., 2009).

There are controversial points in the generation of energy through hydroelectric plants; the values for construction are very high and depend on large engineering projects for the creation of dams, and the plant can affect the local *habitat* of people and animals, in addition to local agricultural activities (Evans et al., 2009).

Although the technology used in hydroelectric plants is not new and has been mastered for many years, the cost is still not accessible to small and medium-sized electricity supply companies, considering the scenario of distributed electricity supply, hydroelectric plants have high operating and energy supply costs. The cost for the creation of a hydroelectric plant can be calculated by the supply capacity of each installed KW, reaching the order of US$ 1,100.00 per KW (Walter, 2003).

Despite the high cost of building hydroelectric plants, this technology is still considered attractive for the supply of energy to consumers. The cost of generating MWh in the hydroelectric plant is R$ 100.00, but by the time it reaches the final consumer, this cost per MWh has increased to R$ 300.00 (Tiepolo et al., 2012).

In this sense, there are initiatives to increase the participation of companies by reducing requirements. Regulatory improvements needed for a sustainable, safe, and organized opening are currently being evaluated (CCEE, 2021). Additionally, the strengthening of commercialization and careful attention to the legacy contracts of the distributors are cited as relevant (CCEE, 2021).

2.2.1.4 Thermoelectric and nuclear

Thermoelectric and nuclear plants basically use the burning of fossil or non-fossil fuel to generate electricity. The most common types of raw material are: petroleum derivatives, natural gas, mineral coal, fuel oil, wood, bagasse, and others. In the case of the nuclear power plant, radioactive material such as uranium is used (Tiepolo et al., 2012).

The operation of these plants essentially consists of a large boiler, which, through the fuel used, heats water and produces high pressure steam, moving the turbines and converting this mechanical force into electrical energy for the supply networks (Hammond, 2004).

The biggest problem in the use of thermoelectric and nuclear plants is the burning of fuels that generate toxic gases into the atmosphere, such as carbon dioxide. These gases cause several problems to the environment, for example, the greenhouse effect, pollution of rivers with waste, climate change, and acid rain, among other environmental impacts (Hammond, 2004).

One of the biggest attractions of this ES is the cost. The costs for the raw material are extremely varied, but compared to other types of energy they are still much lower, as it is possible to use the burning of waste that would otherwise have no use except for disposal. (Hammond, 2004).

2.3 Project Portfolio Management (PPM)

A set of projects, which are managed in a grouped way, with the aim of reducing uncertainties, prioritizing resources between projects, and that are executed under the management of an organization or sponsorship, is called a project portfolio (Müller et al., 2008) or wallet (Olsson, 2008). The portfolio concept was applied to projects, with the aim of implementing and achieving strategic plans for a given level of risk (Sanchez et al., 2008). In this way, PPM is composed of progressive tools to implement the strategy in organizations (Neverauskas & Čiutienė, 2011).

PPM has the role of recognizing, choosing, approving, and administering projects, programs, and other related activities, with the objective of achieving specific business strategies (Sanchez et al., 2008); that is, to enhance the financial value of the portfolio, link the portfolio to the organization's strategy, and balance the projects within the portfolio considering the company's capacity (Meskendahl, 2010). This can bring benefits to organizations through the collective and simultaneous effort between the various projects that share critical resources (Teller, 2013). Specifically, the central point of PPM is to align projects and programs with the organization's strategy in relation to risks and benefits (Teller & Kock, 2013).

The implementation of PPM allows organizations to form dynamic decision processes, through continuous evaluations of the lists of projects, that are frequently updated and revised (Padovani et al., 2010). The authors Cooper, Edgett and Kleinschmidt presented several methods for the use of PPM such as: financial methods, business strategy methods, bubble diagram, scoring models, and checklists (Padovani et al., 2010). However, many of these methods are not applied because they are different or complex, involving factors internal and external to the organization (Archer & Ghasemzadeh, 1999).

Thus, it is understood that PPM and how it is being applied in organizations has been evolving (Rabechini Jr. et al., 2005). It is also understood that the lack of PPM can cause problems such as: resource limitation even with many projects to develop, active projects that do not fit into the business strategy, bad projects that impair the progress of organizational processes, or weak decision making on projects (Augusto Cauchick Miguel, 2008). Thus, for multi-project environments, which work both top-down and bottom-up, the use of PPM methods is recommended (Rabechini Jr. et al., 2005).

There are techniques that can make an important contribution to the project portfolio selection process; the strategic consideration technique analyzes all internal and external information of an organization, such as financial, economic, medium/long-term results, among others (Archer & Ghasemzadeh, 1999); likewise, the technique of evaluating individual projects, which applies specific analysis criteria (Archer & Ghasemzadeh, 1999); finally, the portfolio selection technique, which analyzes the set of projects that are correlated with each other. (Rabechini Jr et al., 2005).

3 Conceptual development

3.1 Consolidation of the global electricity scenario

From the aspect of the relationship between costs and CO2 gas emissions, it appears that the hydroelectric plant has the best values, but the costs of implementing plants must be taken into account, as they are very high. Photovoltaics still has high costs due to the cost of manufacturing the plates (Evans et al., 2009). Overall, wind power has the lowest CO2 emission rate, with only around 25g/kWh CO2 and hydroelectric and photovoltaics also have low emissions, with average values reported of at least 100g/kWh CO2 (Evans et al., 2009). Emissions from fossil fuels have values considered high, reaching 1000 g/kWh of gas emission in the energy supply (Evans et al., 2009).

Thus, although it appears that the types of renewable and clean energy still have higher prices than energy that uses fossil fuels, clearly it is also possible to verify that the energy produced by fossil fuels generates many more pollutants to the environment. Likewise, by additionally analyzing the data from the auctions held in 2021, the average prices of the bids made for the ES, according to the A-3, A-

4, and A-5 auctions can be verified (CCEE, 2022). From this, it appears that the energies considered as the most renewable, clean, and sustainable, have the lowest average bid price (CCEE, 2021).

Therefore, all types of energy have characteristics and prices that differentiate them from each other, so the current study proposes the following hypothesis for testing:

- H1: ES is positively correlated with SP.

3.2 Decision making based on multiple criteria

The application of DT methods based on multi-criteria is also applied to the PPM discipline and is widely used in the process of selecting solutions for the energy sector. In this sense, some studies evaluated the main criteria used by Brazilian organizations for the selection of projects (Padovani et al., 2010; Resende Loureiro et al., 2018) or that link criteria to the organization's strategic orientation (Begičević et al., 2010). Other studies use multi-criteria DT methods for the selection and prioritization of energy projects (San Cristóbal, 2011).

The identification of the criteria most used by Brazilian companies, carried out by (Padovani et al., 2010), with 6 companies from different business areas, presents some important findings. The first finding is the identified criteria: complexity, risk, technical feasibility, project performance, and stakeholder satisfaction. The second finding is that these criteria are not fully adopted in the companies evaluated and, finally, that the only criterion adopted in full is the satisfaction of interested parties (Padovani et al., 2010). Through this study, it is clear that the identified criteria are not linked to the company's strategic issues.

The importance of PPM for the implementation of company strategies is noted (Begičević et al., 2010; Danila, 1989). Strategic priorities regarding the formation of project portfolios are increasingly highlighted (Begičević et al., 2010). Subsequently, two DT methods were used for the selection of renewable energy projects, for the Spanish decision making analysis matrix (San Cristóbal, 2011).

The methods used were AHP and VIKOR. AHP was used to assign the weights to each of the criteria used and VIKOR to establish the ranking of the best alternatives (San Cristóbal, 2011). The Compromise Ranking (VIKOR) method uses a multi-criteria ranking index based on a particular measure of "closeness to the ideal solution". This method, through an aggregator function, represents a measure of proximity to the ideal solution, by measuring the relative importance of the model's criteria, and the balance between total and individual satisfaction.

The applicability of this VIKOR x AHP model seems relevant in cases where projects have high complexity (San Cristóbal, 2011). Another application for the two methods together would be to eliminate the risk of stakeholder opinion bias in projects. Despite the use of the "weight" attributed from the evaluations used as input in the AHP and VIKOR, other technical characteristics are used for the selection of projects, which leads to the selection of projects with a more technical vision. Thus, it is possible to consider the application for this study (San Cristóbal, 2011).

Based on these precepts, the current study aims to understand whether there is a moderation in the relationship between the SP of energy in auctions in Brazil and the ES. Our expectation is that the application of a DT process based on multiple criteria will offer a tool for the selection of the best options for energy auction projects in the Brazilian market. The criteria that will be used to validate our hypothesis are POW, HO, and IP (San Cristóbal, 2011).

Thus, this study proposes the following hypotheses:

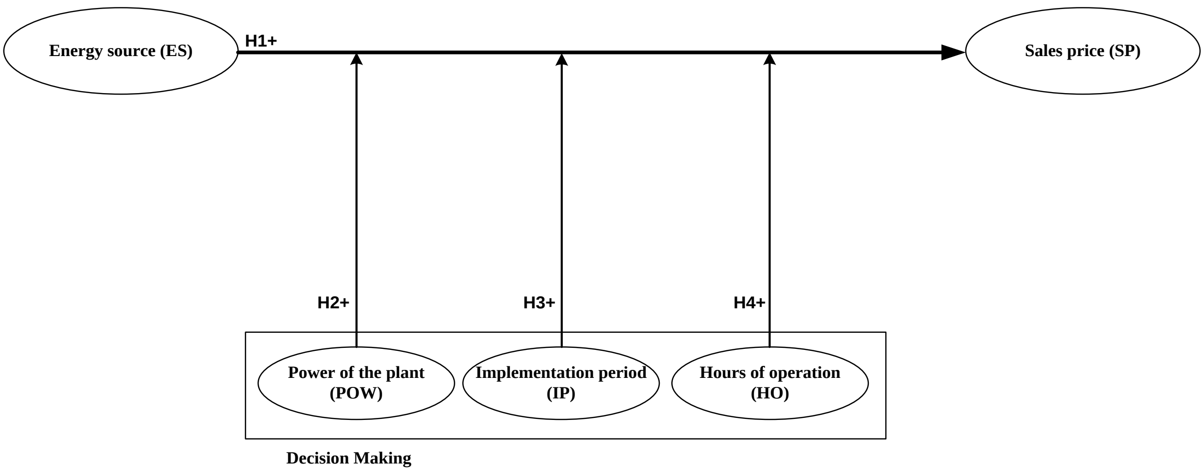
- H2: POW positively moderates the relationship between ES and SP.
- H3: IP positively moderates the relationship between ES and SP.
- H4: HO positively moderates the relationship between SE and SP.

3.3 Model of the hypotheses

Considering the hypotheses defended in this study, our model is represented by Figure 1.

Figure 1

Model of the hypotheses



Source: Prepared by the author.

4 Method

The present study adopted a quantitative approach. This method describes the application of quantification, which can be related to the collection of information and procedures, through statistical techniques from the simplest to the most complex (Dalfovo et al., 2008).

4.1 Data collection

The basis used for data collection is secondary. The data for the proposed research refer to electricity auctions in Brazil, extracted from the CCEE, which promotes the activities of buying and selling energy. The database is public and updated monthly by the CCEE. The base is rich in information, and has been accessed for several research studies, for example, the authors Ferreira & Patah, (2017) used this database in their article on renewable energy from biomass sources.

For our study, the base for the month of July 2018 was used. The data employed were the consolidated results of the Electric Energy Auctions by contract, which has 28,971 records. In this way, the first step, to work with the base, was to identify the variables necessary to arrive at the result. The variables deal with data that can be measured or explored through samples to understand the phenomenon studied (Creswell, 2010).

After defining the variables, some procedures were performed to select and delimit the sample, such as: (1) cut-off period, (2) removal of rows without data, and (3) exclusion of duplicate data. For the cut-off date, we delimited the study period from 2010 to 2018, which resulted in 20,782 records, a considerable volume for carrying out the statistical tests. With respect to the removal of rows without data, the deletions occurred for the columns of ES, POW, and SP, reducing the data to 17,222 records. Finally, the sellers that were duplicated in the base were removed, which resulted in 591 records at the end of the process. This total is an expressive number to answer the hypotheses, using the methods of correlation and multiple linear regression (MLR).

4.2 Data analysis

The results obtained through the statistical analysis were generated using the techniques of descriptive analysis, correlation, and MLR. The MLR was analyzed from 3 statistical models. Model 1 presents the result for the direct relationship between ES and SP. Model 2 demonstrates the results obtained for the direct relationship between SP, ES, POW, IP, and HO, without considering the effect of moderation. Finally, model 3 presents the results obtained for the direct relationship between SP, ES, POW, IP, and HO, considering the effect of moderating variables on the relationship between SP and ES.

4.3 Dependent variable

For this study, we only considered a single dependent variable, which is the SP, described as “final selling price” or “cost benefit ratio” (CBR) on the auction date (CCEE, 2021). This is the value, expressed in reais per Mega Watt-hour (R$/MWh), resulting from the auction and which was used to select the winners (CCEE, 2021).

4.4 Independent variable

Likewise, we considered the ES variable as an independent variable. This variable is composed of seven types of energy generation technology, which are (1) Biomass, (2) Coal, (3) Wind, (4) Natural Gas, (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric (UTE) (CCEE, 2021).

Renewable, clean, and economical ES are preferred over traditional (Kuleli Pak et al., 2017). However, the alternatives do not meet the demand alone. Therefore, the need to determine energy policy becomes a DT problem that considers multiple criteria (Kuleli Pak et al., 2017; Streimikiene et al., 2012). In this way, the selection of sustainable energy sources involves conflicting and complex criteria. Thus, future energy policy must be oriented towards sustainable energy technologies, such as hydroelectric, wind, and solar (Streimikiene et al., 2012).

4.5 Moderator variable

The variables POW, IP, and HO (San Cristóbal, 2011) were used as moderators in this study. The IP and HO variables were developed through the use of the “auction date”, “supply start date”, and “supply end date” fields that are available in the database (CCEE, 2021).

5 Results

Subsequently, the results of the descriptive analysis were evaluated. Table 1 presents information related to the sample (N=591) used in this study. The descriptive analysis of the model variables shows that the majority of the auctions carried out were for wind ES (3). The IP indicates that, on average, projects are built in 3 years, with a standard deviation of between 2 and 4.5 years. On the other hand, the HO shows that the operation takes place for between 135,000 and 240,000 hours, with an operating average of around 184,000 hours. After the delivery of the projects, the POW generated is, on average, around 50 MW during the period of operation. Finally, the SP analysis demonstrates that the price variability is between R$105 and R$215, with an average of R$161 when calculating the bids made in auctions which result in deals closed.

Table 1

Descriptive statistics for each model variable

	N	Minimum	Maximum	Mean	Standard Deviation
Energy source (ES)	591	1	6	3,623	1,501
Implementation period (IP)	591	0,003	5,036	3,290	1,289
Hours of operation (HO)	591	8736	262968	187301,848	52667,003
Power of the plant (POW)	591	1	1672,599	50,563	149,204
Sales price (SP)	591	67,600	305,510	161,323	55,547

Source: Data extracted from R.

Subsequently, the normality and multicollinearity of the variables were evaluated. The objective of this step was to ensure that the sample distribution follows a normal course (Hair et al., 2009). The result of the Shapiro-Wilk test presents a level of significance (*p-value* <0.000) for all variables, which indicates that there are no differences in relation to a normal distribution (Hair et al., 2009). Likewise, when evaluating the results of the VIF test, it is verified that the variables do not present a degree of multicollinearity greater than 5.00, indicating that they do not share a certain level of variance (Hair et al., 2009).

The model correlations were evaluated, as shown in Table 2. The results demonstrate significant associations between the variables. The correlations found in the statistical analysis indicate that SP is influenced by all other variables.

Table 2

Correlation matrix

Variables	1	2	3	4	5
1 - Sales Price (SP)	1.000				
2 - Energy Source (ES)	0.392***	1.000			
3 - Power (POW)	0.119**	-0.011	1.000		
4 - Implementation period (IP)	-0.186***	0.116**	-0.082.	1.000	
5 - Hours of operation (HO)	0.136***	0.386***	-0.142**	0.628***	1.000

Source: Data extracted from R.

It can be seen that the higher the SP, the higher the values of the variables POW and HO. On the other hand, for IP the trend is inverse and significant, indicating that the higher the SP, the lower the IP. Likewise, for ES, positive and significant trends are verified for IP and HO. In the case of the variable POW, there is an inverse and significant relationship with HO, indicating that the higher this variable is, the lower the HO. Finally, IP is positively related, in a significant way, with HO.

Subsequently, the results of the regression tests of the 3 proposed models were evaluated, according to Table 3.

Table 3

Result of the linear regression

Model **Variables**	**1** ***B*** ***p-value***	**2** ***B*** ***p-value***	**3** ***B*** ***p-value***
Intercept	0.000 0.000***	0.000 0.000***	0.000 0.000***
Energy Source (ES)	0.392 0.000***	0.336 0.000***	0.790 0.000***
Power (POW)		0.129 0.000***	1.880 0.000***
Implementation Period (IP)		-0.380 0.000***	0.647 0.000***
Hours of operation (HO)		0.264 0.000***	-0.311 0.011*
Energy Source (ES) * Power (POW)			-0.004 0.000***
Energy Source (ES) * Implementation Period (IP)			-37.270 0.000***
Energy Source (ES) * Hours of Operation (HO)			0.000 0.000***
N	591	591	591
F	107.200	49.770	52.140
R2 %	0.154	0.254	0.385
R2 AJ. %	0.153	0.249	0.378
p-v (M)	0.000***	0.000***	0.000***

Note: p-value: 0 '***' 0.001 '**' 0.01 '*' 0.05 ',' 0.1 ' ' 1.
Source: Data extracted from R.

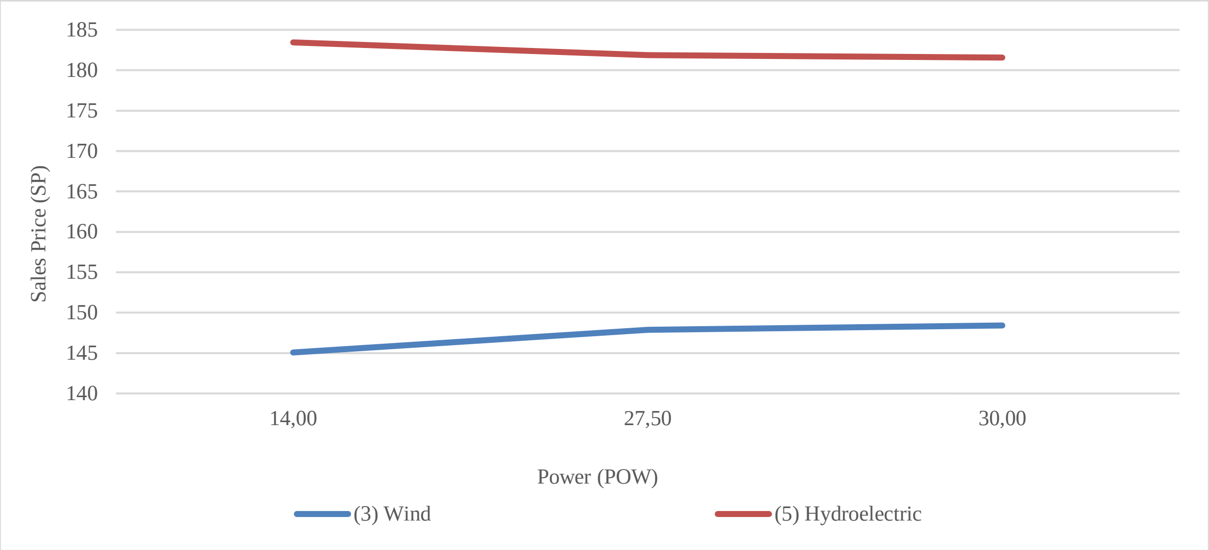
When evaluating the behavior of the relationship between ES and SP, considering the proposed models, it can be seen that the relationship remains positive and significant in models 1 (0.392/0.000***), 2 (0.336/0.000***), and 3 (0.790/0.000***). When analyzing the influence of POW, the consistency of positive and significant *beta* is verified in models 2 (0.129/0.000***) and 3 (1.880/0.000***). Thus, it is understood that the SP increases as the POW values increase, implying an increase in the SP. However, with the moderating effect, we found the *beta* inverted, becoming negative and significant (-0.004/0.000***).

In the same way, when evaluating the influence of IP, it appears that the beta is negative when evaluating model 2 (-0.380/0.000***) but becomes positive in model 3 (0.647/0.000***). In this sense, there is no clear trend of the influence of IP on the relationship between ES and SP. However, considering the effect of moderation, IP is potentiated in the negative sense, in a relevant and significant way (-37.270/0.000***). Finally, when evaluating the influence of HO, it appears that the *beta* is positive and significant when evaluating model 2 (0.264/0.000***) but becomes negative and significant in model 3 (-0.311/0.011*). When evaluating the effect of moderation for HO, the *beta* demonstrates a null effect (0.000/0.000***).

The effect of moderation was evaluated in depth based on Hayes' precepts and the use of the Process macro (Hayes et al., 2017). Initially, when evaluating the moderation caused by POW in the relationship between ES and SP, two ES were analyzed to understand the behavior of SP as a function of moderation, as shown in Figure 2.

Figure 2

Effect of POW moderation on the relationship between ES and SP

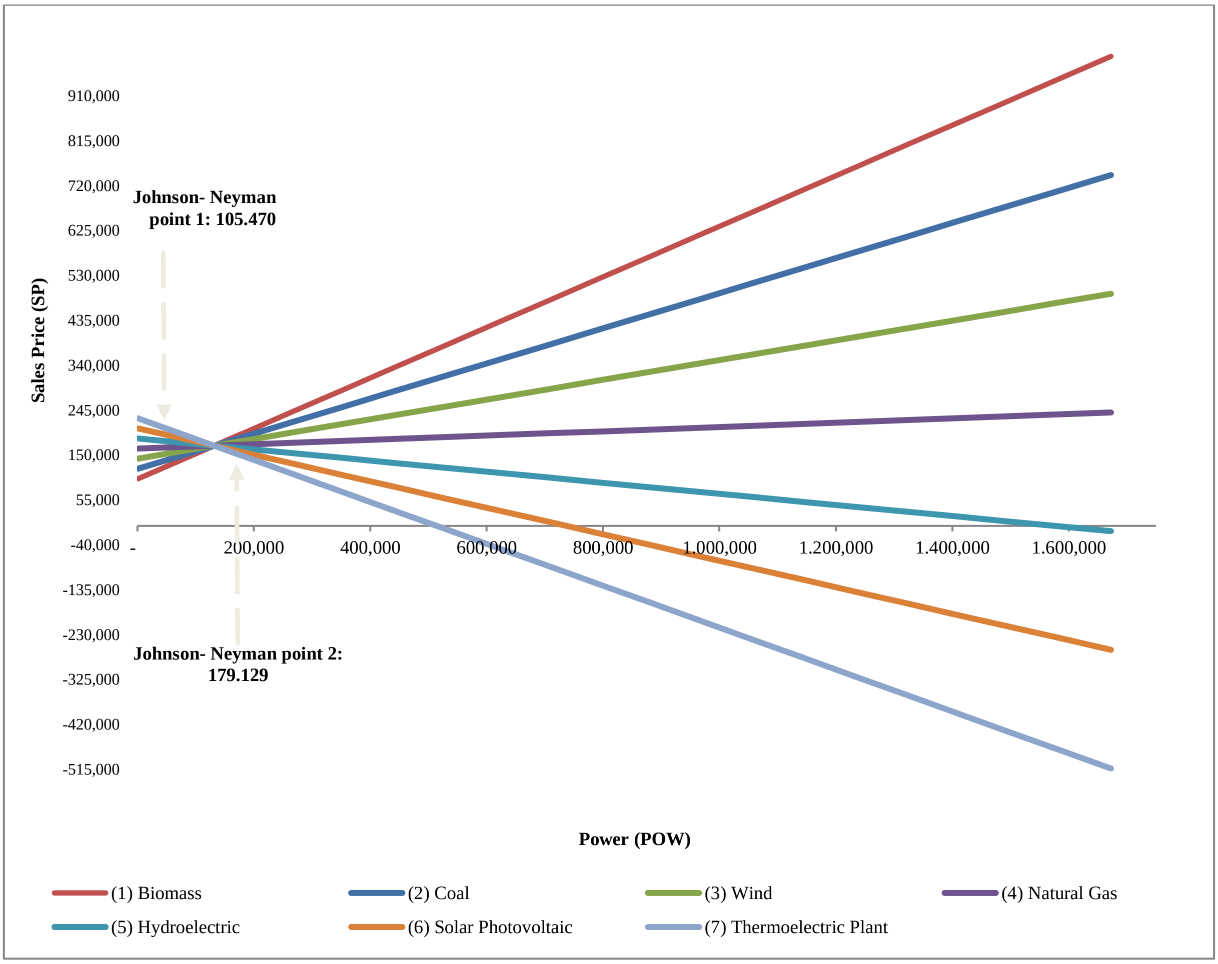


Source: Data extracted from R.

A different behavior of moderation was noticed for each ES. For (3) Wind, the SP ratio increases, while for (5) Hydroelectric, the SP decreases as the POW increases. Therefore, it is important to understand how the other ESs behave as the POW increases. At another time, the behavior of the SP was evaluated using the Johnson-Neyman concept. Two points of limits of occurrence of moderation were identified for each curve (Hayes et al., 2017), according to Figure 3.

Figure 3

Moments of the effect of POW moderation on the relationship between ES and SP



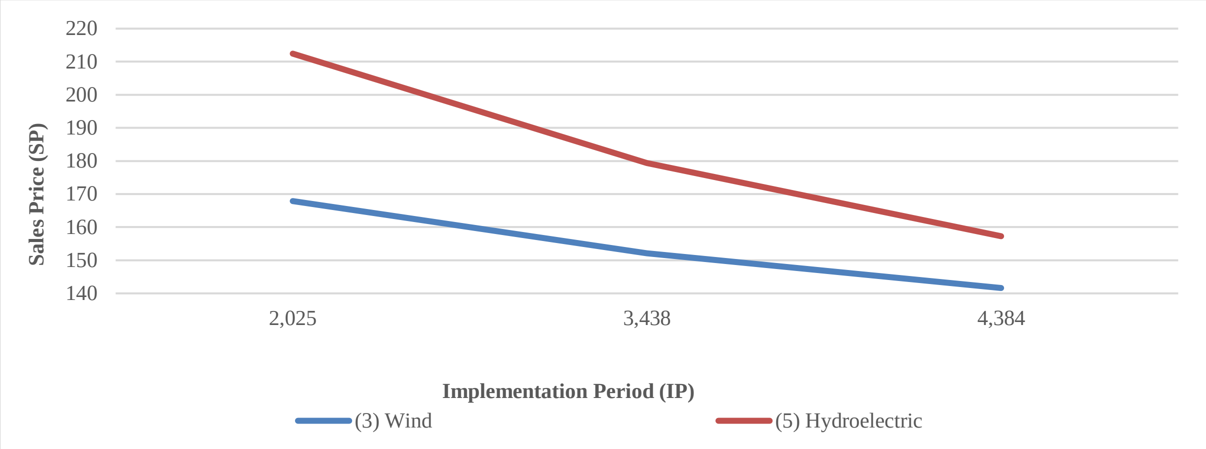
Source: Data extracted from R.

There are two distinct moments of the effect of moderation on the relationship between ES and SP. The first occurs when the POW is below the limit of 105,470 MW, which influences the increase in SP for ESs: (1) Biomass, (2) Coal, (3) Wind, and (4) Natural Gas. However, for the other ESs: (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric, the SP is strongly influenced downwards. The second occurs when the POW is above the limit of 179.129 MW, which maintains the high influence of SP for ESs: (1) Biomass, (2) Coal, (3) Wind, and (4) Natural Gas. Likewise, the ES: (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric Power Plant, remain with a strong downward trend in SP as the POW increases.

Subsequently, the analysis of the moderation caused by IP in the relationship between ES and SP was performed. Initially, two energy sources were studied to understand the behavior of SP as a function of this moderation, as shown in Figure 4.

Figure 4

Effect of the moderation of IP on the relationship between ES and SP

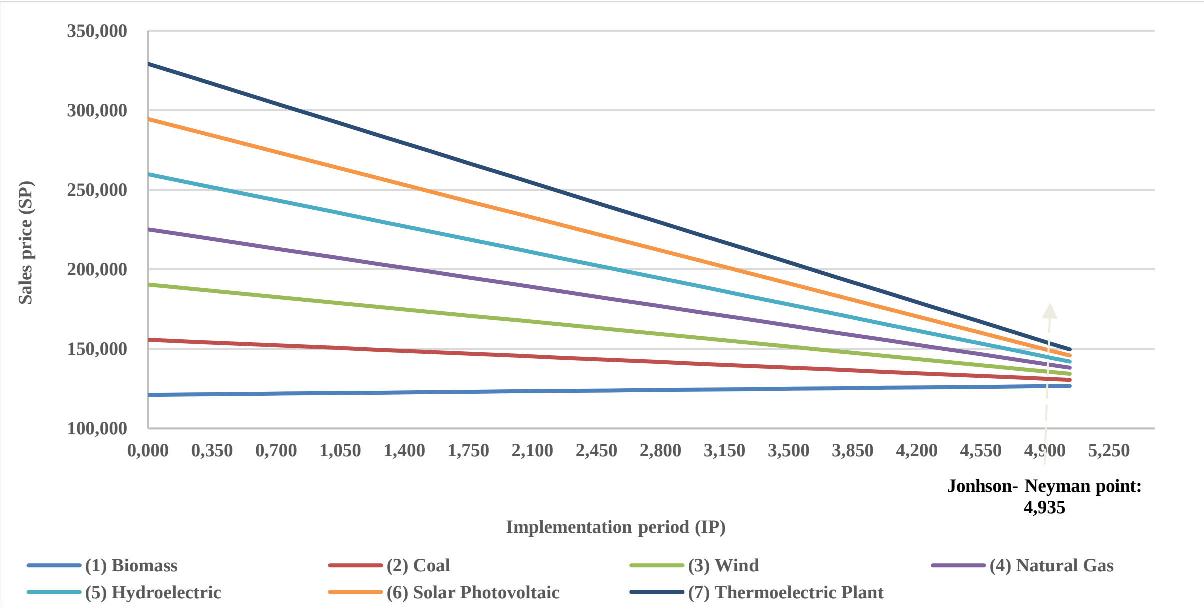


Source: Data extracted from R.

A drop in SP for both ESs can be seen with the IP moderator effect. This may mean that this moderation has an inverse effect on the relationship between SP and ES. For better understanding, the other ESs were evaluated with the support of the Johnson-Neyman technique, in order to understand the moment when moderation is significant, as shown in Figure 5.

Figure 5

Moment of the effect of IP moderation on the relationship between ES and SP



Source: Data extracted from R.

There is a distinct moment in the effect of IP moderation on the relationship between ES and SP. The moderating effect occurs when the IP is below the threshold of 4.935 years, which influences the SP downwards for the ESs.: (2) Coal and (3) Wind, (4) Natural Gas, (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric. However, the ES for (1) Biomass is differently influenced by the moderating effect, according to the aforementioned limit, as there is a slight increase in the price as the IP increases.

6 Discussion

Based on the results, we initially verified the high correlation between the variables. In this sense, it appears that the correlation of the SP (del Río, 2017) with ES, POW, and HO, indicates that the higher the SP, the higher the POW and HO values, according to each SP level stipulated by the ES. On the other hand, the relationship between SP and IP indicates the inverse of the other relationships. This means that the higher the SP, the lower the IP, and vice versa. These correlations are free from the effects of moderation, which indicates that it would be natural for *stakeholders* to select projects based on the lower SP, when the POW and HO are higher.

However, for IP, the option would be to have longer deadlines to obtain greater competitiveness in the SP in each auction. We understand that this is a contribution of the current study, as it makes clear the natural behavior of the selection of electric energy projects when evaluating the relationship between ES and SP, considering, additionally, POW, IP, and HO.

When evaluating the regression results, for validation of H1, it can be seen that a positive and significant beta was demonstrated in the 3 evaluated models, thus confirming H1. In this way it is possible to confirm that the SP is influenced by the ES (Jayaraman et al., 2015). The statistical tests and the theoretical study in this research provide evidence that the types of energy are relevant factors to be used in the selection of electric energy auction projects for the composition of a portfolio (San Cristóbal, 2011).

Additionally, with the regression tests, it is understood that the relationship between ES and SP is positively and significantly influenced when moderated by the POW, becoming a relevant criterion for the selection of projects (San Cristóbal, 2011). Thus, the higher the POW, the lower the SP according to the ES. However, when analyzing moderation in a deeper way, it is noticed that the behavior is not the same according to the ES. For (1) Biomass, (2) Coal, (3) Wind, and (4) Natural Gas, the SP tends to rise as the POW increases. In this sense, it is understood that the implementation costs to generate higher POW directly influence the selection of energy projects for these ES (Azuela et al., 2014; Hansen et al., 2020).

However, for (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric, the SP was strongly influenced downwards. From the aspect of investment in infrastructure, it is clear that the structure for these technologies could be one of the factors that influence the relationship with the SP, as they serve to provide large volumes of POW (Hansen et al., 2020). Thus, it is understood that H2 was partially confirmed, since the positive influence, considering the drop in SP, occurs only for the ESs (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric.

When evaluating the relationship between ES and SP, it is noticed that it is significantly influenced when moderated by IP (San Cristóbal, 2011). In this sense, the higher the IP, the lower the SP according to the ES. However, when evaluating the moderating effect, it is noticed that the behavior, in the same way, is different for each ES. For (2) Coal, (3) Wind, (4) Natural Gas, (5) Hydroelectric, (6) Solar Photovoltaic, and (7) Thermoelectric, the SP is influenced downwards. However, the SP of ES (1) Biomass is influenced differently as there is a slight increase in SP as the IP increases.

Thus, it is understood that H3 was confirmed, as the SP is influenced downwards according to the moderating effect of the IP (San Cristóbal, 2011) for practically all ES, with the exception of (1) Biomass (Ferreira & Patah, 2017). In this way, deeper understanding is needed to better comprehend the factors that influence the SP relationship for this specific ES. The final hypothesis, H4, according to the analysis of the results, was not confirmed. It is understood that the ES to SP ratio is not influenced when moderated by HO (San Cristóbal, 2011).

Conclusively, based on the results, it appears that the variables POW and IP are predictive for SP. In this way, it is possible to confirm that the use of these in a multi-criteria model (San Cristóbal, 2011), in a decision-making process for the selection of the best projects, would be relevant for the composition of a portfolio of electric energy projects (San Cristóbal, 2011).

7 Conclusion

This study aimed to evaluate the relationships between the energy source (Evans et al., 2009; Ferreira & Patah, 2017), auction project selection criteria (Hernández-Torres et al., 2015; San Cristóbal, 2011) and the establishment of SP in electricity auctions in the Brazilian market (CCEE, 2022). Through a quantitative study, statistical tests were performed to understand these relationships.

The growing demand for electricity has led to the search for new mechanisms to encourage energy production in various areas, whether public or private (Jayaraman et al., 2015). One of the great incentives in the market are the governments that seek social well-being as their primary function (Azuela et al., 2014; Tiepolo et al., 2012; Walter, 2003). The need for electric energy enables companies with domains in specific technologies to position themselves in this sector as potential suppliers of electric energy.

There is a worldwide trend to decrease or replace energy production from fossil energy sources such as oil and gas (Ferreira & Patah, 2017; Ren21-17, 2017). In Brazil, due to its large hydrographic basin, the energy matrix traditionally focuses on hydroelectric plants. Despite the growing supply of energy, it appears that the energy demand is not met on the same curve as supply growth, resulting in lags in supply (Ferreira & Patah, 2017; San Cristóbal, 2011).

Through mechanisms such as auctions, governments around the world have sought to meet this growing demand (San Cristóbal, 2011). The incentive currently focuses on renewable energy sources, due to the finite resources that subsidize the current energy supply. These complexities imply several possibilities for decisions that may pose a risk to governments and companies operating in the sector. The multi-criteria decision-making process is a way to select the best electrical energy options (San Cristóbal, 2011). Based on MCDM or MCDA models (Ioannou et al., 2017; Kaya & Kahraman, 2011), such as AHP or ANP, companies can compose structured analyzes to understand the criteria and risks that may impact the selection of electric energy projects. These models are also applicable to the selection of electricity auction projects, according to a study proposed by San Cristóbal, (2011).

In the current study, which considers the CCEE auction base, we considered the relationships between ES, SP, and the moderating effect of decision-making criteria such as POW, HO, and IP on the primary relationship, to understand whether significance occurs in the establishment of the SP. This relationship aims to demonstrate that, through the selection of appropriate criteria and a decision-making process, private companies operating in the sector can select beneficial auction options in a more assertive way.

As the main results, we demonstrate that the relationship between SP and ES exists, implying that the ES perspective should be taken into account when selecting an electric energy project. In this way, the main result is in the identification of the significance of the POW and IP criteria for the selection of energy auction projects, highlighting the choice of ES for analysis together with these criteria. This relationship demonstrates that a structured and architected decision-making process using multiple criteria is relevant.

The limiting factors of this study were the small number of studies carried out in Brazil regarding the auction mechanism. Targeted and specific studies, such as the study of Ferreira & Patah (2017) which focused on ES (1) Biomass, aid understanding of important concepts, such as the preponderant formation of the Brazilian energy matrix, however, there are still too few for deeper analysis. Due to these limiting factors, we understand that there is a field of study for the electric sector in Brazil, regarding understanding of the best techniques for decision making for the selection of energy projects, or even for the selection of solutions and technologies to meet the latent supply of electrical energy.

Authors' contributions

Contribution	Sposito, L.	Serra, F.R.
Contextualization	X	X
Methodology	X	------
Software	X	------
Validation	X	------
Formal analysis	X	------
Investigation	X	------
Resources	X	------
Data curation	X	------
Original	------	X
Revision and editing	------	X
Viewing	X	------
Supervision	X	------
Project management	X	------
Obtaining funding	------	------

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