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A Model for Measuring the Photovoltaic Project Performance in Energy Auctions

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ABSTRACT

Electricity trading occurs under different mechanisms in each country, with auctions being one of these mechanisms. Auctions are widely used to determine their remuneration in the scope of clean energy technologies, such as photovoltaics. Added to the auction process's bureaucracies and uncertainties, the competing photovoltaic project must keep its technical and economic performance maximized. Given this context, this study aimed to contribute to the competitiveness of photovoltaic plant projects in energy auctions through a performance diagnosis model to identify, measure, and analyze factors in the designing process. For this, a systematic literature review was performed to identify the factors that influence the implementation of a photovoltaic plant project; additionally, the fuzzy Delphi method was applied to examine the factors' importance. An analytic hierarchy process weighted the factors, and the key performance indicators were developed based on the literature and regulation of the electric energy sector. The model was applied in a centralized photovoltaic energy generation project, which presented a performance index of 41.91%, and the sensitivity analysis and prioritization matrix comprised the post-application study of the model. Our model can help planners improve the competitiveness of photovoltaic projects in auctions by observing underperforming indicators.

Keywords: Photovoltaic Project, Energy Auctions, Performance Index, Fuzzy Delphi, Analytic Hierarchy Process, Key Performance Indicators
JEL Classifications: Q, Q4, Q420, O

1. INTRODUCTION

Solar energy is an abundant and clean renewable source utilized for lighting, heating, and generating electricity (Chandrasekar and Senthilkumar, 2021). It is generated by photovoltaic (PV) technology and is an important system to transform non-renewable energy generation into clean energy generation worldwide (David et al., 2021; Rigo et al., 2019), and large-scale PV power generation has shown exponential growth in recent years around the world (IRENA 2021; Liang et al., 2021). Projections have shown that renewable energy sources will be responsible for two-thirds of the world's electricity by 2040, with solar PV and wind energy the leaders in this growth (IEA, 2019). Given this scenario, solar PV energy has been considered the most promising and technically viable large-scale renewable energy source for the sustainable development of world economies (Feng and Xu 2021; Rigo et al., 2022).

Electricity trading takes place under different mechanisms in each country, with auctions being one of these mechanisms. Auctions occur in several countries, such as Turkey, France, Portugal, Germany, Denmark, the United Kingdom, China, South Africa, and Brazil (Bento et al., 2020; Bichler et al., 2020; Kruger et al., 2021; Ozcan, 2021). Auctions are widely used to determine their remuneration in the scope of energies generated by renewable sources, such as PVs (Bichler et al., 2020). In new energy auctions, which refer to projects in the planning or construction phase, several projects compete, seeking to offer projects with a lower cost per unit of electricity generated (Matthäus, 2020). However, support auctions of renewable energy create uncertainties for designers during project development, affecting capital costs and financing elements, as bidders have no support guaranteed until they win a bid (Đukan and Kitzing, 2021).

Added to the uncertainties of the bureaucratic process inherent to an electricity auction, it must keep its technical and economic performance maximized for a PV project to succeed in the competition, although this technical and economic performance depends on several factors (Qi et al., 2021). For the PV project to be competitive in new energy auctions, the designers must verify a series of characteristics in the design phase before the auctions and installation of the PV plant. Thus, there is a need to contribute to the competitiveness of PV plants in energy auctions by identifying, measuring, and analyzing factors necessary for the development phase of a PV project in order for managers to identify the indicators requiring improvements in the planning process.

In this context, researchers have analyzed PV energy projects to support the decision, such as Rediske et al. (2019; 2020), who studied determining factors for deciding the location of large-scale PV plants by applying a model that combines multi-criteria decision-making (MCDM) and geographic information system in southern Brazil. Ratner and Nizhegorodtsev (2017) planned a model for analyzing large-scale renewable energy projects in Russia. Despite the growing research on the theme, only 30% of projects succeed in competing for government investment. Rigo et al. (2020) developed a model to assess the success of small-scale distributed PV power generation projects using MCDM and key performance indicators (KPI), while Gao et al. (2021) developed an MCDM framework for a large-scale rooftop PV project site selection based on intuitionist Fuzzy arrays. Sreenath et al. (2021) performed energy, exergetic, economic, environmental, energy-economic, exergoeconomic, and environmental analyses of a plant operating in Malaysia. Nonetheless, this study approach differs from previous research in developing models for measuring the PV power generation projects' performance in energy auctions mainly because it seeks to translate the project's performance into a single metric encompassing indicators, allowing a global assessment of the project and a detailed investigation of the indicators.

Hence, developing the model proposed in this study brings the following contributions: (i) speculating the factors and indicators for a self-assessment of the PV plant project's performance and its competitiveness in the energy commercialization; (ii) based on the standardized factors and indicators for self-assessment, the fuzzy delphi method (FDM), with consultation with experts, identifies critical factors; (iii) the factors weighting through the analytic hierarchy process (AHP) technique, ranking the factors, and also based on expert opinion; (iv) the possibility of reflection and learning by PV plant designers; (v) compare the performance of different projects when the manager needs to make decisions; (vi) the dependent variable concept (overall project performance index) that determines the explanatory relationships between overall performance and factors; and (vii) the modeling demonstration in a case study and the proposition of prioritizing actions to improve the project's performance level.

This study is separated into five sections. Besides the introduction, the second section presents the methodology, modeling, and techniques involved, followed by the third section with the model application. The fourth section covers the post-application studies of the model and, lastly, the conclusions, final considerations, and future studies.

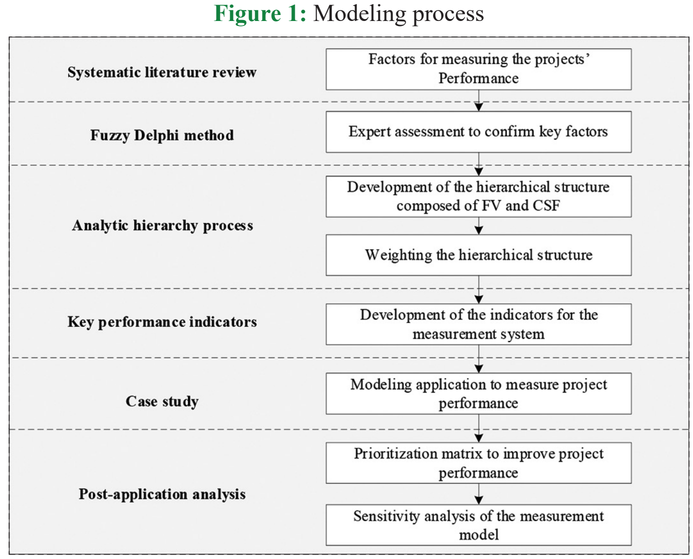
2. METHODOLOGY AND MODELING

The modeling process went through eight stages and involved different methodological techniques (Figure 1). First, a systematic literature review (SLR) was performed for the modeling by searching for the factors that influence the implementation of a PV plant project to compose the measurement system. Therefore, the FDM was employed to examine the importance of the factors identified through the SLR and determine the fundamental factors according to the reality of the energy sector. In this process, ten experts (decision-makers) in PV energy generation projects helped indicate the importance of the factors through the data collection instrument using FDM linguistic variables. Given the importance of the FDM, it was possible to validate the factors identified in the SLR.

A hierarchical structure was then composed of fundamental viewpoints (FV) and critical success factors (CSF) organized these factors. Given the hierarchical structure, weighing the factors was initiated using the AHP method. This process calculates the factor weight matrices, resulting in each factor's weight in the measurement structure. Next, the KPIs were developed based on the literature and regulations of the electricity sector for PV energy generation projects; KPIs are the metrics that enable data entry into modeling.

After defining the KPIs, it was necessary to develop a data collection instrument (Appendix A) to diagnose project performance and

Figure 1: Modeling process



aims at PV plant managers; the instrument serves to measure the KPIs associated with the CSFs. Sequentially, a case study applied the modeling with the data collected by applying the instrument with performance indicators. After the case study and based on the achievement of the indicators, a prioritization matrix was built to help improve the project. In addition, a sensitivity analysis was performed to verify the influence of the AHP weighting system on the project's final performance. The following subsections explain each step of the modeling in detail.

2.1. Factors from the SLR and Fuzzy Delphi Method

The SLR extracted the factors that make up the model from the scientific literature; we then applied the following string in the search: TITLE-ABS-KEY ("power plant" OR "solar farm") AND ("photovoltaic" OR "solar energy") AND ("factor" OR "criteria") AND ("project" OR "installation"). Next, we applied the search string to two scientific article indexers: Scopus and Web of Science. The search strategy was metadata (title, abstract, and keywords), without time restriction, journal venue, and in the English language. As a result, 79 articles were selected for full reading, and ten articles presented factors to evaluate the performance of projects; the nine factors extracted from the literature, references, and factors organized into three fundamental points are listed in Table 1.

Sequentially, the factors were assessed by ten experts in PV power plant projects, who act as project planning coordinators, PV project analysts, project engineers, energy research analysts, and civil engineers working in coordination and construction of solar parks of distributed and centralized generation. By using the FDM, it was possible to identify which factors must be included and excluded from the analysis according to the limit obtained from the linguistic scale with the importance level. Then, if $\tilde{a}_j \geq \tilde{a}$, then factor j is selected, and if $\tilde{a}_j < \tilde{a}$, then factor j is rejected (Dalkey and Helmer 1963). The defuzzification value ($\tilde{a}_j$) and the decision to exclude the factors are shown in Table 1. Given that the limit ($\tilde{a}$) is 0.6, two CSFs were rejected (proximity to roads and proximity to urban areas), resulting in a total of seven factors that remained in the measurement model. The $\tilde{a}$ limit is defined to select or reject the factors through the average of the minimum value of the "important" linguistic variable (0.5) and the maximum value of "indifferent" linguistic variable (0.7) (Singh and Sarkar 2020). The fuzzy triangular numbers used to evaluate the criterion and the geometric mean are: unimportant (0.1; 0.1; 0.3); little importance (0.1; 0.3; 0.5); indifferent (0.3; 0.5; 0.7); important (0.5; 0.7; 0.9); extremely important (0.7; 0.9; 0.9). The factors in Table 1 are called CSF in modeling and then encompassed by FV according to their synergy.

With the seven CSFs established by the FDM, the hierarchical structure of the measurement model was adjusted (Figure 2). The objective of the structure is to present the systemic and mathematical thinking of the measurement model. At the first level (left in Figure 2), the objective is to measure project performance. The second level is the FV, which unfolds the seven CSFs. The fourth and final level is the KPI, which was created to measure the reality of the CSF of each project (Appendix A).

2.2. Weighting the Hierarchical Structure

Once the ten experts judged the factors (k=10), the AHP weighting process began by constructing the judgment matrix (Saaty, 1989; Moreno Rocha et al., 2022). In this case, the matrix is of order $n = 7$ (i, j = {1, 2,…7}). Each weight matrix obtained according to the decision-maker is in Table 2. Each column results in the CSF weight, and each row represents the weighting according to the decision-maker ($w_{d1} \ldots w_{d10}$). Therefore, $\vec{W}_{d1}$ is the row vector obtained by applying the AHP method to expert 1, and so on. All decision-makers were consistent as they obtained a consistency ratio (CR) below 0.10. If the CR was <0.10, the decision-maker must be excluded for not showing consistency in their judgment (Saaty, 1989). The last line in Table 2 shows the arithmetic means of the weight matrices ($\bar{w}_{CSF_k}$); the process of measuring the performance of projects uses this weighting.

2.3. Measurement of KPIs and the Projects' Global Index

This process starts by quantitatively measuring the KPIs (Appendix A). For this, 10% indicates that the project does not meet the minimum requirements according to the regulationsand the literature. Furthermore, the 90% score indicates that the project meets all the requirements within the research scope, and it is up to the manager to evaluate the other aspects to reach 100% in its entirety; the five possible response levels and corresponding measurements are listed in Table 3.

In order to calculate the performance index (Id), it is necessary to multiply each CSF weight by the KPI measurement, being all m values resulting from this multiplication (Rigo et al., 2020), according to Equation 1.

Table 1: SLR and FDM results

FV		CSF		References	Fuzzy Delphi	
					ãj	Decision
1	Economic	1.1	Land cost	(Hafeznia et al., 2017; Wu et al., 2014; Mensour et al., 2019; Al Garni and Awasthi, 2017)	0.6	Selected
		1.2	Equipment cost	(Patel et al., 2019)	0.7	Selected
		1.3	Proximity to substations	(Mensour et al., 2019)	0.6	Selected
2	Location	2.1	Weather	(Daher et al., 2018; Yadav and Bajpai, 2018; Hafeznia et al., 2017; Al Garni and Awasthi, 2017; Doljak and Stanojević, 2017)	0.6	Selected
		2.2	Proximity to roads	(Hafeznia et al., 2017; Mensour et al., 2019)	0.5	Rejected
		2.3	Proximity to urban areas	(Hafeznia et al., 2017; Al Garni and Awasthi, 2017)	0.5	Rejected
3	Technologic	3.1	Inclination of panels	(Rachchh et al., 2016; Hafeznia et al., 2017; Yadav and Bajpai, 2018; Al Garni and Awasthi, 2017; Doljak and Stanojević, 2017)	0.7	Selected
		3.2	Solar irradiation	(Mensour et al., 2019; Al Garni and Awasthi, 2017)	0.8	Selected
		3.3	Module layout	(Awan et al., 2019; Hafeznia et al., 2017)	0.7	Selected

Figure 2: Hierarchical structure

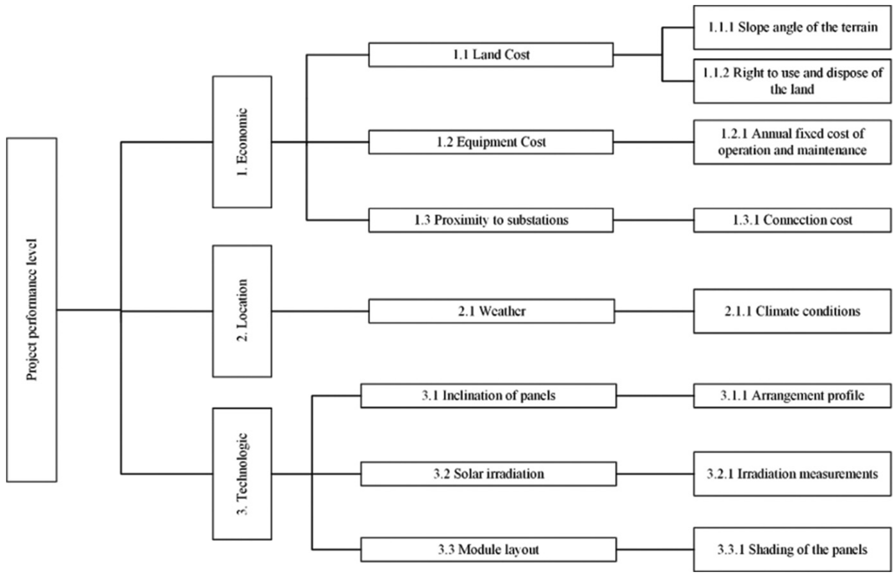


Table 2: AHP results

Expert	CSF 1.1	CSF 1.2	CSF 1.3	CSF 2.1	CSF 3.1	CSF 3.2	CSF 3.3	CR
$\vec{W}_{d1}$	5%	16%	16%	16%	16%	16%	16%	0%
$\vec{W}_{d2}$	34%	12%	12%	4%	12%	12%	12%	0%
$\vec{W}_{d3}$	7%	20%	20%	20%	20%	7%	7%	0%
$\vec{W}_{d4}$	10%	28%	3%	10%	10%	28%	10%	1%
$\vec{W}_{d5}$	18%	18%	18%	18%	6%	18%	6%	0%
$\vec{W}_{d6}$	3%	17%	3%	7%	16%	36%	16%	2%
$\vec{W}_{d7}$	2%	21%	8%	8%	21%	21%	21%	1%
$\vec{W}_{d8}$	6%	18%	6%	18%	18%	18%	18%	0%
$\vec{W}_{d9}$	20%	7%	20%	7%	20%	20%	7%	0%
$\vec{W}_{d10}$	14%	14%	14%	14%	14%	14%	14%	0%
$\bar{w}_{CSF_k}$	11.98%	17.00%	11.95%	12.13%	15.33%	18.94%	12.67%	

$$Id = \sum_{k=1}^{m} (\bar{w}_{CSF_k} \times KPI_k); (k = \{1, 2, \ldots 7\}) \quad (1)$$

The result of Equation 1 is the diagnosis goal. Each project will result in a percentage corresponding to the performance level obtained. This index classifies the project utilizing four different judgments (Table 4).

The presented limits were built based on the scale of values for KPI measurement. These limits will judge PV generation projects concerning performance to facilitate managers' interpretation of regulatory processes and potential improvements. After the mathematical formulation of the PV projects performance index, the model application and its result are presented in the following subsection.

3. MODEL APPLICATION AND DISCUSSION

A PV plant project to be installed in Brazil applied the measurement model. This section is divided into two parts, where the first presents the operation of energy trading in Brazil and the second presents and discusses the case study.

3.1. Energy Commercialization in the Case Study Scenario

In Brazil, electricity sale occurs in the free form or with prices and quantities defined by the government. In the National Interconnected System (SIN), the Electric Energy Trading Chamber (CCEE) operates these two forms of supply and use of energy according to the regulations established by the National Electric Energy Agency (ANEEL) (ANEEL, 2018). Thus, there are two negotiation environments: the Regulated Contracting Environment (RCE), with energy generation and distribution agents; and the Free Contracting Environment (FCE), with generators, distributors, traders, importers, and exporters, in addition to free and special consumers (CCEE, 2020). The main difference between them is that the first calls consumers "captive," as they purchase energy from the same company responsible for its distribution, while the second is the freedom to choose the electricity supplier (ABRACEEL, 2017).

Table 3: Value scale for measuring KPI

Managers' answer to the KPI	KPI measurement (KPI_k)
Completely unsatisfactory	10%
Unsatisfactory	30%
Regular	50%
Satisfactory	70%
Completely satisfactory	90%

Table 4: Project performance assessment scale

Performance index (I_d)	Project judgment
10% ------- 29.99%	Insufficient performance
30% ------- 49.99%	Low performance
50% ------- 69.99%	Regular performance
69% ------- 90%	Sufficient performance

Contracts between generators and distributors formalize the purchase and sale in the regulated environment. The contracts have regulations related to energy prices, contract registration submarket, and supply terms without bilateral agent changes. Nevertheless, in the free environment, the generators, importers, and special consumers can freely negotiate the volumes of purchase and sale of energy and their prices (CCEE 2016).

According to the Ministry of Mines and Energy (MME), in the regulated contracting environment, the last A4 energy auctions contracted 49 new solar projects, generating investments of US$ 1.49 billion by 2021 and guaranteeing an additional 1.8 gigawatt-peak (GWp) of power in Brazil. New solar plants were contracted in April 2018 with an investment of US$ 4.2 billion and should start operating by January 2022 (MME; ERC 2018). Auctions have two modes: existing energy and new energy. The first concerns the production of plants already in operation and delivers the contracted volumes in <1 year (A-1). The second are projects for the planning or construction phase, in which the delivery period is generally 3 or 5 years (A-3 and A-5). In addition, there are also adjustment and reserve auctions. In adjustment projects, distributors supplement the volume necessary to supply the market, and, in reserve, the object of contracting is the production of plants that will come into operation only in the event of a shortage of conventional plants (ANEEL, 2009).

The research scenario covers the Brazilian territory, as it contemplates determining factors in the elaboration phase of a PV plant project and centralized generation concerns projects contracted through energy auctions in the RCE; these auctions bring information to the general energy market based on their results. As for the planner, the factors serve as input for project planning, while from the entrepreneur's point of view, this demonstrates that the market is innovative and competitive, thereby requiring a constant development of projects with technical and financial excellence (Konzen et al., 2018).

Nascimento (2017) stated that Brazil has a significant potential for generating electricity from solar energy due to the level of solar irradiation being higher than in countries where projects for energy use are widely disseminated, such as in Germany, France, and Spain. The CCEE (CCEE, 2019) reported that large-scale solar power plants in the national scenario grew 86.6% in the first half of 2019. Still, the installed power was 485 MW compared to the 260 MW by the SIN in 2018 (CCEE, 2019). According to ANEEL (ANEEL, 2021), 3914 PV plants are in operation, 33 projects are under construction, and 343 have yet to begin construction. The situation of photovoltaic generation projects and their respective states is illustrated in Figure 3.

The fact that PV projects are not present in the entire Brazilian territory may be related to the conditions of the electricity sector and characteristics of each region, including the position for capturing solar energy. The conditions in the electricity sector are complex and do not have simple solutions to most structural problems (CCEE, 2018). Therefore, the most competitive sources will have easy access and, consequently, projects approved for commercialization. In this context, the study scenario of this research focuses on the centralized generation present in Brazil.

3.2. Case Study

A centralized PV energy generation project with an installed capacity of 10 MW was applied to the model. This project was neither authorized nor contracted in the RCE. Regarding the situation of the project, construction has not begun. Since it has not been contracted or qualified yet, it allows the diagnosis of the project before starting the bidding process in the auction. The KPIs measuring result and performance index obtained are listed in Table 5.

According to the manager who answered the questionnaire, the land slope angle for constructing the PV plant project is between 4% and 7%. This situation represents 70%, corresponding to a satisfactory answer; an accepted economic land slope for constructing the solar power plant is 0-3% (Hafeznia et al., 2017). However, regarding the right to use and dispose of the land, the project does not have an environmental license and, therefore, is entirely unsatisfactory. The environmental license is mandatory to qualify the project in the energy auction and has been a recurring reason for not qualifying projects (Appendix B).

The choice and cost of equipment influence range from 40% to 60% in the values related to the fixed annual cost of operation and maintenance, and this is a regular return since the choice of equipment is necessary for project implementation and related directly to the costs and efficiency of the work, which consequently increase operating and maintenance costs. The connection cost, which in this case refers to the percentage of connection cost resulting from the distance from the plant installation site to the substation, is 20-40% and therefore satisfactory since the distance between the plant's location and the substation did not significantly impact the connection cost.

Regarding the analysis of the climatic conditions of the installation region, this KPI is unsatisfactory. The meteorological analysis of 12 consecutive months performed did not clarify whether the documentation and evaluation of the module's technology occurred according to the climate of the installation region. According to Manganiello et al. (2020), the PV module technology can be adapted to deal with the climate and environment of the installation, and it provides better energy production against seasonal variability.

From a technological perspective, the project presents a description of the arrangement profile, indicating the inclination of the modules and their separation, in addition to being unsatisfactory under regulations. Besides the description of the arrangement profile, the Energy Research Company (MME; ERC, 2018) reported that it is necessary to present the local latitude and project blueprint, especially the arrangement profile blueprint.

The enterprise has radiation concentration technology to analyze the radiation KPI measurements. Therefore, the project must present a history of at least 36 months of continuous irradiation measurements for the qualification process according to MME Ordinance No. 102/2016 (MME; ERC, 2018). Nonetheless, the project has a 10-month history of continuous irradiation measurements, which is a regular return as the project performs the measurements, although it is necessary to expand the measurement history to meet the qualification requirement. Finally, a simulation of the best layout of the modules is not performed, considering the shading conditions, which can reduce the module's efficiency even if the project presents techniques for identifying the possible barriers that shade the project region. Therefore, after the descriptive analysis, it is possible to observe that there are no completely satisfactory KPIs. The majority of the KPIs were unsatisfactory (3 KPIs), followed by 2 KPIs rated as fair, 2 KPIs rated as satisfactory, and 1 KPI rated as completely unsatisfactory. Hence, after performing the measurement, the performance index calculation was applied, where the project returned an I_d of 41.91%. This performance is considered low since the project presents both indicators that need improvements to meet the qualification requirements in energy auctions and some criteria according to the literature. In the next section, post-application analyses were developed.

Figure 3: Status of photovoltaic projects (Burin et al., 2020)

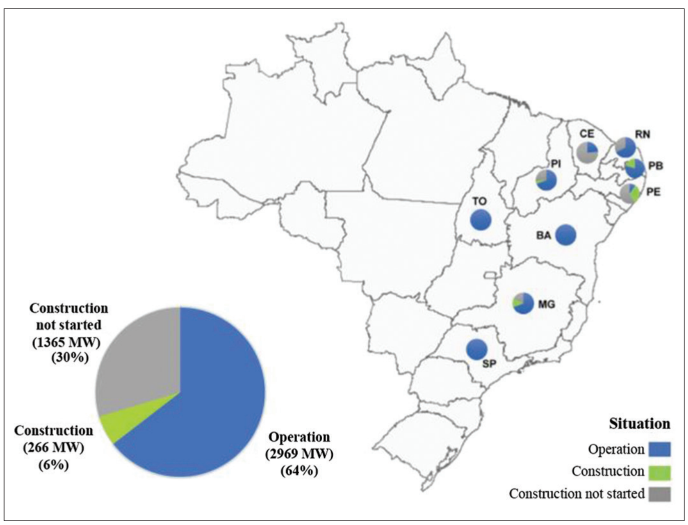


Table 5: Model application result

KPI	KPI measurement	
1.1.1 Land slope angle	Satisfactory	70%
1.1.2 Right to use and dispose of the land	Completely unsatisfactory	10%
1.2.1 Annual fixed cost of operation and maintenance	Regular	50%
1.3.1 Connection cost	Satisfactory	70%
2.1.1 Climate conditions	Unsatisfactory	30%
3.1.1 Arrangement profile	Unsatisfactory	30%
3.2.1 Irradiation measurements	Unsatisfactory	30%
3.3.1 Shading of the panels	Regular	50%
	Performance index (I_d)	41.91%

4. POST-APPLICATION ANALYSIS

The post-application analysis is divided into two subsections: the first subsection presents the prioritization matrix to help improve the modeled project, and the second one presents the sensitivity analysis of the model to identify the variation in the project performance index due to changes in the degree of importance of the analyzed factors.

4.1. Prioritization Matrix

This tool establishes the key factors prioritization, problems to be solved, and processes to be implemented in organizations. Tichauer (2016) reported that the best-known prioritization matrix is the GUT matrix, which establishes prioritization based on the gravity, urgency, and trend factors and consists of a score table, making it possible to visualize which items have higher priority than others.

The gravity aspect considers the intensity and depth of the damage that the problem can cost if not acted upon. The urgency factor considers the period in which it is necessary to avoid undesirable results, and the tendency aspect considers the proportion that the problem can assume in the future if no action is taken (Danini 2018; Queiroz et al., 2012). These aspects and each level with its respective score are summarized in Table 6.

The GUT matrix assigns values (weights) from 1 to 5 to the aspects, and the product of the values assigned to the aspects gives the result. Gravity (G) is according to a scale of values for measuring KPI (Table 3). Therefore, at the extremes, 10% corresponds to "extremely severe" and 90% to "without seriousness." Urgency (U) and tendency (T) are according to the regulatory requirements and characteristics found in the literature about photovoltaic projects, and immediate action is when the indicator is fundamental for the hiring and qualification process in auctions and verified the worsening of the situation to define the tendency. It is pivotal to emphasize that priorities can change according to the designer's experience and the need of the project in question. From the results obtained of each process, it is possible to organize them in descending order (Danini, 2018). The GUT matrix of the PV project is listed in Table 7.

Table 6: Prioritization aspects used in the GUT matrix

Score	G - Gravity	U - Urgency	T - Tendency
5	Extremely severe	Requires immediate action	If nothing is done, the situation will worsen immediately
4	Very severe	Urgent	It will get worse in the short term
3	Severe	As soon as possible	It will get worse in the medium term
2	Little severe	Not very urgent	It will get worse in the long term
1	No severity	It can wait	It will not get worse

Source: Adapted from Danini (2018)

Table 7: GUT matrix of the PV project

KPI	Gravity (G)	Urgency (U)	Tendency (T)	GxUxT	KPI action priority ranking
1.1.1 Land slope angle	1	1	1	1	8th
1.1.2 Right to use and dispose of the land	5	5	5	125	1st
1.2.1 Annual fixed cost of operation and maintenance	3	2	2	12	6th
1.3.1 Connection cost	2	1	1	2	7th
2.1.1 Climate conditions	4	4	4	64	3rd
3.1.1 Arrangement profile	4	5	5	100	2nd
3.2.1 Irradiation measurements	5	1	5	25	5th
3.3.1 Shading of the panels	4	3	4	48	4th

Through the GUT matrix, one can note the prioritization order. Starting with the KPI "right to use and dispose of land," because for qualification, it is necessary to have the environmental license and the environmental impact reports. Therefore, it is possible to perceive that this KPI is very serious and needs immediate action, as the tendency is for the situation of the enterprise to worsen and, consequently, its non-qualification. Next, the arrangement profile indicator shows that the panels' slope is severe and needs immediate action to enable the process.

After this prioritization, the KPI "climate conditions," including the analysis of the climatic conditions of the installation region, presents itself as very serious, urgent, and may worsen in the short term. The reason is that module's technology adapted to the climate of the installation region influences the energy production. Regarding the shading indicator of the panels, it is reported as very serious and requiring action as soon as possible, as the tendency is to worsen in the short term.

The irradiation measurement indicator is extremely severe because when the enterprise has radiation concentration technology, the qualification process requires a history of 36 months or more of measurements. Regarding urgency, it can wait until it reaches the necessary background; however, if there is no historical measurement data to date, the tendency is to deny the license.

Regarding the costs of equipment that influence the values of the fixed annual cost of operation and maintenance, the indicator deals with a stringent process, not very urgent, because at first the choice of equipment has already been made, however, the trend is that in the long term may increase the annual maintenance operation costs.

At a technological level, the indicator referring to the percentage of connection cost resulting from the distance from the plant's installation site to the substation indicates that it is not very serious and can wait for future actions since the trend is not to worsen since there were no significant costs involved due to the distance between the installation site and the substation. Furthermore, from an economic point of view, the indicator representing the inclination angle of the land for the construction of the PV plant project is not severe, as the inclination angle is close to what is considered economically viable. Therefore, no immediate action is required and does not worsen. Therefore, after analyzing the GUT matrix, it is up to the manager to assess the consistency of the priorities assigned according to the resources available for the enterprise.

Table 8: Sensitivity analysis

CSF	CSF weight	KPI measurement	
1.1 Land cost	14.29%	Satisfactory	70%
		Completely unsatisfactory	10%
1.2 Equipment cost	14.29%	Regular	50%
1.3 Proximity to substations	14.29%	Satisfactory	70%
2.1 Climate	14.29%	Unsatisfactory	30%
3.1 Panel inclination	14.29%	Unsatisfactory	30%
3.2 Solar irradiation	14.29%	Unsatisfactory	30%
3.3 Arrangement of modules	14.29%	Regular	50%
Total	100%	Performance index (I_d)	42.86%

4.2. Sensitivity Analysis

xThe sensitivity analysis discussed herein aimed to verify the variation in the performance index of projects due to changes in the degree of importance of the factors analyzed. From the classical referential perspective, the sensitivity analysis emerged from realizing the importance of obtaining simulations of the model's effect, considering variations in its input elements (Silva and Ghisi, 2013). Thus, this analysis is a systematic investigation of the response of a simulation concerning the extreme values of the observed quantitative parameters or based on the drastic changes in the qualitative parameters (Kleijnen, 1997).

Therefore, we decided to change the value of the quantitative parameters obtained for the critical success factors in the hierarchical process analysis. Given each factor's importance within the scope of qualifying projects in auctions, the ERC can consider these factors of equal importance for the procedures that exist in the sector. That being said, the factor weighting values obtained in Table 2 were changed to equal importance, and the simulation is in Table 8.

It is possible to observe that the I_d presented a difference of 0.95% in measuring the performance level carried out from the result of the application with the specialists in the area (I_d = 41.91%). Hence, it appears that the model is not very sensitive and, although it shows variation in project performance, it does not change its judgment, requiring improvement for a possible qualification as it has low performance even when changing the values of the CSF weight matrix for equal importance. In addition, evaluating the degree of data dispersion by sampling the standard deviation of the application result with specialists in the area presents a value of 3%. The greater the standard deviation, the greater the dispersion of the data (Martins, 2013). Hence, it appears that the value is close to zero even if the experts have not evaluated the factors with equal importance as simulated, and the data do not present large dispersions, approaching homogeneity.

5. CONCLUSIONS

Research on photovoltaic solar power generation projects does not present a source that establishes the fundamental factors and performance of the projects in any scenario. In this sense, the significant contribution of this study is to expand the literature by building a model to measure the level of performance of PV plant projects for energy trading. Given the definition of fundamental factors in implementing PV energy generation projects, based on literature and experts in the electricity sector, a performance measurement system based on indicators was used by grouping into critical success factors and fundamental points of view.

The fuzzy Delphi and analytic hierarchy process methods revealed the importance of the fundamental factors. Nonetheless, in order to diagnose the status of PV energy generation projects to participate in energy auctions, a performance level index was determined. When applying this performance index to a centralized PV power generation project, we found a low performance, needing improvement in all aspects. Once the performance level measurement model was applied, we conducted the post-application analysis through the prioritization matrix and sensitivity analysis, which suggested prioritizing the performance indicators. Then, we verified that the model was not very sensitive even with the variation of the critical success factor weight values to equal importance, as this did not change the judgment of the project.

The model developed herein for measuring the performance level of PV power generation projects is relevant for project managers as it was built based on experts working in the project area, and thus the factors are grounded on the sector's reality. Nevertheless, the model's highlight is the actions that can be taken after its application to increase the participation of PV projects in the electrical matrix and contribute to low carbon savings with cleaner energy generation.

For future research, applying the study to other renewable sources to identify the project performance of each energy-generating source is highly recommended. In addition to analyzing projects still in the implementation process, we propose analyzing the approved projects to investigate the impacts of the study after its approval and installation. Additionally, we emphasize that the study can be applied in another country to assess the weighting of factors based on the sector's reality.

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APPENDIX

Appendix A: KPI measurement questionnaire

Questionnaire for measuring the performance indicators of a photovoltaic project

To implement projects, it is necessary to observe the project aspects and geographic contexts to maximize energy production. This questionnaire seeks to assist managers in identifying and measuring the performance requirements for enabling a photovoltaic project.

Email address

Enterprise name

What is the installed capacity of the project?

What is your role in the project?

Has the project been enabled in the regulated contracting environment (RCE)?

- Yes
- No

Was the project contracted in the RCE?

- Yes
- No

What situation is the project in?

- In operation
- Under construction
- Construction has not yet started

Economic point of view

1.1.1 What is the land angle slope for constructing the photovoltaic plant project?

a) 0-3%
b) 4-7%
c) 8-12%
d) 13-16%
e) 17% or more

1.1.2 For the right to use and dispose of the land, regarding the issuance of the environmental license documentation for the installation area, which option best describes the situation of your project

a) It does not have an environmental license.
b) It presents the environmental license issued for the exclusive purpose of participating in electricity generation auctions.
c) The environmental license attests to environmental viability.
d) The environmental license attests to the environmental feasibility and approves the location and design of the project.
e) The project has an environmental license according to the regulations and environmental impact reports.

1.2.1 How much did the choice and cost of equipment influence the values related to the fixed annual cost of operation and maintenance?

a) 0-20%
b) 20-40%
c) 40-60%
d) 60-80%
e) 80-100%

1.3.1 What is the percentage of connection cost resulting from the distance from the plant's installation site to the substation?

a) 0-20%
b) 20-40%
c) 40-60%
d) 60-80%
e) 80-100%

Local point of view

2.1.1 Regarding the analysis of the climatic conditions of the installation region

a) A simple meteorological analysis was performed.
b) A meteorological analysis was performed for 12 consecutive months.
c) A meteorological analysis was performed for 24 consecutive months.
d) The analysis of climatic conditions was carried out and added to the descriptive memorial.
e) The analysis of climatic conditions was documented, and the module technology was adapted according to the climate of the installation region.

(Contd...)

Appendix A: ***(Continued)***

Technological point of view

3.1.1 The arrangement profile indicating the panels' inclination includes

a) A simple description of the panels' inclination.
b) The description of the arrangement profile indicating the modules' inclination and the separation between them.
c) The simulation describes the arrangement profile indicating the modules' inclination and the separation between them.
d) The Simulation describes the arrangement profile indicating the modules' inclination and the separation between them and the local latitude in degrees.
e) The simulation describes the arrangement profile indicating the modules' inclination and the separation between them and the local latitude in degrees and added to the descriptive memorandum with the project drawings, the drawing of the arrangement profile.

3.2.1 How was the study on panels' shading executed and presented?

a) A simple list of possible screens that shade the project region.
b) A technique for identifying possible screens that shade the project region.
c) A technique for identifying possible screens that shade the project region and filling out the descriptive memorial with the information.
d) A technique for identifying possible screens that shade the project region and simulating the best modules' arrangement considering the shading conditions.
e) All previous steps were carried out and added to the descriptive memorial.

Does the enterprise have radiation concentration technology?

a) Yes
b) No

3.3.1 For continuous radiation measurements at the project site

a) The project does not have a history of continuous irradiation measurements.
b) The project features a 6-month history of continuous irradiation measurements.
c) The project features a 10-month history of continuous irradiation measurements.
d) The project features a 12-month or more history of continuous irradiation measurements.
e) The project has a history of 36-months or more of continuous irradiation measurements.

Do you want to comment on the implementation of photovoltaic projects and the qualification process?

Do you have any suggestions or criticisms regarding this study?

Appendix B: Reasons for photovoltaic projects not qualifying in auctions

Auctions	Reasons for not qualifying	Detailing
A-4/2017	ANEEL project/registration	Incompatibility of enterprise data with ANEEL registration Lack of ANEEL registration
	Connection to SIN	Lack of flow margin for the chosen connection point
	Environment	Absence of environmental license Incompatibility of enterprise data with those of the environmental license
	Physical guarantee and energy production	Inconsistencies between the information presented that hinder the proper calculation of energy production and physical guarantee of the project
	Right to use or dispose of the land	Failure to prove the right to use or dispose of the area intended for project implementation
A-4/2018	ANEEL project/registration	Incompatibility of enterprise data with ANEEL registration Lack of ANEEL registration
	Connection to SIN	Lack of flow margin No proof of technical feasibility of connection
	Environment	Absence of environmental license Incompatibility of enterprise data with environmental license data
	Physical guarantee and energy production	Inconsistencies between the information presented that hinder the proper calculation of energy production and physical guarantee of the project
	Right to use or dispose of the land	Failure to prove the right to use or dispose of the area intended for project implementation
A-4/2019	ANEEL project/registration	Problems in the project or incompatibility with the ANEEL registry
	Connection to SIN	Lack of flow margin No proof of technical feasibility of connection
	Environment	Absence of environmental license Inconsistencies in the license presented
	Physical guarantee and energy production	Inconsistencies between the information presented that hinder the proper calculation of energy production and physical guarantee of the project
	Right to use or dispose of the land	Failure to prove the right to use or dispose of the area intended for project implementation
A-6/2019	Project	Project problems (interference, fuel proof, and others)
	Connection to SIN	No proof of technical feasibility of connection
	Environment	Absence of environmental license Inconsistencies between the project and the license presented
	Physical guarantee and energy production	Inconsistencies between the information presented that prevent the calculation of the project's physical guarantee
	Right to use or dispose of the land	Failure to prove the right to use or dispose of the area intended for project implementation

Source: (EPE 2017; 2018; 2019a; 2019b)