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A Software Application to Support Decision-making in Small-scale Photovoltaic Projects

Paula Donaduzzi Rigo*, Carmen Brum Rosa, Graciele Rediske, Julio Cezar Mairesse Siluk, Leandro Michels

Federal University of Santa Maria, Santa Maria, Brazil. *E-mail: pauladonaduzzi@gmail.com

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ABSTRACT

Electricity generation through photovoltaic technology is the fastest growing in the world. Due to its linear power growth characteristic, small-scale generation on grid is common in several countries. In Brazil, in the context of this study, the small-scale solar PV exponentially grows since the implementation of the Distributed Generation market regulation in 2012. Several installer companies have emerged in the country and many residential, commercial and industrial investors are eager to invest in photovoltaic systems. As much as all installers offer the integration of a photovoltaic system, several peculiarities in service and quality are perceived by customers, which makes their decision difficult. So, the aim of this study is to present a software application to support decision-making in small-scale photovoltaic projects. The modelling and application are presented through a case study with an investor who needed to choose between four projects to invest. With the software application use, the investor can reflect on his preferences and changes in the project to improve his satisfaction. Besides, he can compare different projects budgeted by installers, helping in the decision-making process. In the case study, it was possible to see the difference between the four budgets and choose the one that best met the investor's expectations.

Keywords: Computational Tool, Distributed Generation, Small Scale Projects, Household Systems
JEL Classifications: Q, Q4, Q420, O

1. INTRODUCTION

The environmental concern associated to the world population's growth and greater dependence on electric energy makes countries to invest in renewable energy sources. Breyer et al. (2018) highlight that the world population will grow from 7.3 billion people to 9.7 billion from 2015 to 2050. The large-scale development of the global economy and industrial revolutions have harmed all environmental elements, both in terms of depletion of the natural resource potential of the planet and in various pollution. The intensification of global trends toward decarbonization leads to alteration in the energy sector (Petrenko, 2021). Therefore, it is known that worldwide, the supplied energy is a precondition for poverty mitigation and therefore the accomplishment of the sustainable improvement goals. The more is the consumption of energy, the more would be the emission of carbon dioxide resulting from the consumption of energy as the petroleum derivative (Oil and Gas) establishes very nearly 70% of energy utilization while the sustainable power source goes about as a negligible role (Sadekin et al., 2021).

This study is set in the Brazilian scenario. The Brazilian electrical matrix is one of the cleanest in the world. Hydroelectric plants represent a large part of Brazil's electricity generation matrix, about 65.2%, followed by fossil fuels, with 15.9% (EPE, 2021). However, the growth in demand requires new investments all year round, and photovoltaic energy becomes a good option in the country, keeping the matrix mostly renewable. The world scenario depends on fossil fuels (Juárez et al., 2014), extremely harmful. These systems result in serious environmental problems and harmful to humans, such as greenhouse gas emissions. As a result, incentives are being made for commercial and residential establishments to invest in the installation of renewable energy sources. Rosa et al. (2018) emphasize that innovations and new technologies are significant for using natural energy resources. About this, according to Breyer et al. (2018), solar and wind will be the primary electricity supply source in the 21st century, with 4.9% in 2015 to 87% in 2050.

Among the alternative renewable energy resources used in the global electrical matrix, solar energy is a clean energy source, freely available and abundant worldwide (Constantino et al., 2018; Doljak and Stanojević, 2017). Brazil is a privileged country geographically in terms of solar irradiation because it is close to the Equator line. It means that in winter, when the solar variation is lowest in the year, there are acceptable levels of irradiation (Silva et al., 2020; Pereira et al., 2017) (Ceolin et al., 2017). Doljak and Stanojević (2017) call attention to those photovoltaic systems for electrical energy production use direct and diffuse solar radiation. It is also the lowest cost energy generation option involved (Breyer et al., 2018).

In Brazil, small-scale photovoltaic solar systems have been standing out in residential and commercial use with the Distributed Generation (DG) modality. As an incentive for the DG development in the country, the National Electric Energy Agency (ANEEL) published Normative Resolution No. 482/2012, which deals with distributed micro and mini-generation, establishing that consumers can generate its electricity from renewable sources and supply the surplus to the distribution network. When the energy generated is higher than consumption, they created credits for use until 60 months (ANEEL, 2018). The generation plant with installed power up to 75 kW is called microgeneration. The generation plant with power above 75 kW and less than 5 MW is called mini generation. Between June 2017 and June 2020, the number of PV installers active in Brazil has increased from approximately 1,600 to 14,200 companies (Greener, 2021). The installers grew in all Brazil's regions, and some installers act in the same city, generating competition among them (Rigo et al., 2021). This competition between installers makes the investor have difficulty in the decision process on which to choose to make the investment.

With the market focused on the solar source, many investors budget small-scale projects in installers companies. However, they have doubts about which project to choose, or which characteristics would best meet their expectations. Due to the rise of photovoltaic systems and the complexity of investors' choice, it is necessary a tool with the ability to support investors in decision making regarding the best project to be invested in small scale distributed generation. Structuring the decision-making process for a long-term investment with high invested capital reflects the various aspects that can generate uncertainty and cause failure by not meeting the investor's objectives. Thus, the article aims to present a software application to support decision-making in small-scale photovoltaic projects. The modelling and application are presented through a case study with an investor who needed to choose between four projects to invest.

2. SOLAR PHOTOVOLTAIC MARKET IN BRAZIL

Photovoltaic energy is the direct conversion of light into electricity, under the photoelectric effect (Peng and Lee, 2011). In this effect, the photons in sunlight are converted into electrical energy when they affect the photovoltaic cells. The electrons of the semiconductor materials that make up the system generate an electron flow, generating electricity (Husain et al., 2018). Therefore, the electricity produced by the system depends directly on the solar radiation on the panels.

Photovoltaic energy drives one of the fastest-growing industries around the world, and, to maintain this growth, it is essential to develop new materials, improve the design and seek new technologies to maintain the efficiency of the devices involved (Jäger-Waldau, 2006; Parida et al., 2011). With this, numerous research and developments of tools and solutions appear to assist companies in this segment. Also, renewable energies are vital for environmental issues and the best use of natural resources. Solar energy technologies have enormous potential to mitigate climate change by reducing energy-related emissions (Shahsavari and Akbari, 2018).

This subject becomes relevant for debates at events and seminars since estimates indicate that the Brazilian energy network will be changed. According to studies, in 2050, photovoltaic energy will have a 63% share of total world generation (Breyer et al., 2018). Businesses, consumers, and the government must be prepared for the changes that will occur gradually. Brazil is the largest country in South America, which has a large amount of energy from hydroelectric plants, but also a good structure for solar and wind energy (Breyer et al., 2018). The sun's rays incident on the Brazilian territory is of vertical incidence, providing high incidence rates of solar radiation throughout the country, which allows advantages for solar energy (dos Santos Carstens and da Cunha 2019; EPE, 2018). Jong et al. (2019) report that in the 2080s, superficial solar radiation is expected to increase in Brazil, with an increase of 3.6% in the Northeast region compared to 1970. The authors Santos Carstens and da Cunha (2019) highlight the ample existing silicon reserves in Brazil, which is an indispensable material for photovoltaic cells' production.

For more significant investments in photovoltaic solar energy, the government must present incentives and initiatives for this segment to achieve greater representation in the Brazilian electric matrix. By providing incentives to this energy source, the government will be contributing not only to the environment, but also in social and economic terms, creating opportunities for employment, income, and economic development (dos Santos Carstens and da Cunha 2019).

According to a survey conducted by ANEEL (2017), there will be in Brazil until 2024, a considerable increase in the number of consumers that will adopt microgeneration in the residential and commercial sectors. Greener's research and consulting company, specializing in the photovoltaic solar energy sector, declares that in 2020 the Brazilian DG market reached a turnover of R$ 7.0 billion reals (Greener, 2021). And, in August 2021 it was 6,905,265 kWp (ANEEL, 2021). Thus, countless companies are offering installations of the photovoltaic system with different proposals and negotiations. However, the final consumer must understand his priorities in carrying out this project and making decisions based on factual information.

3. METHOD

The model behind the application is based on multi-criteria decision support analysis and key performance indicators. In the first step, we carried out a systematic literature review published in Rigo et al. (2019), where we extract the factors that impact this sector, with the research in the Scopus, Web of Science, and Emerald databases. Therefore, we determine that investors should evaluate their projects concerning their objectives. The achievement of their objectives results in the project's success. These factors evaluating can point to improvements in the project or help the investor choose between projects. Based on these surveys, we organized the success factors for decision making in the photovoltaic sector, giving origin to a hierarchical structure.

The success factors are divided into six categories: Economic, market, social, technical, political and environmental. These categories have numerous ramifications, totaling 33 factors that, presented in Table 1. For this work, the project's success is the achievement of the investor's objectives about the factors mentioned. Each investor has a different opinion than what he considers important or not, so he weights the indicators. A case study is proposed to understand the features and contribution of the tool.

We built an indicator to measure each factor of the hierarchical structure, totaling 33 indicators that vary on a five-point evaluation scale. As an example, in indicator about factor "Conscious use of energy," the investor reflects on the culture of using electricity in his home or business, and their answer can vary from "Non-existent" culture, measuring 0% of the indicator to a "Very Advanced" culture measuring 100% of the indicator. Once the indicators were defined, it was necessary to determine each indicator's weight and the impact on the final result. Thus, the investor also evaluates the importance level of this indicator on a scale of 1 to 5. The six categories are pair-wise compared in a 9-point scale on Analytic Hierarchy Process (AHP) weight method (Saaty, 2012). Therefore, the modeling is adequate for the investor's objectives.

Table 1: Success factors

Category	Success factors
Economic	System Cost, Maintenance Cost, Electricity Bill, Payback Time, Residence/Company Appreciation
Environmental	Visual Impact in the Architecture, CO_2 Reduction, Conscious Use of Energy, Recycling of PV Modules, Animal Habitat
Market	Installer Company Location, Logistics, Advertising, Installer Company Reputation, After Sales, PV Systems in the Vicinity
Political	Financing Mechanism, Tax Exemption, Political Governance, Impact in Power Distribution Grid, Reliable Power Distribution Grid, Cooperation with other countries
Social	Participation in the Project Development, Acceptance Family/Management, Team Public Acceptance, PV System Knowledge, Reduction of Unemployment
Technical	System Efficiency, Possibility of System Expansion, Deadline for Installation, Installation Quality, System Durability, Maintenance Ease

If the investor does not consider relevant environmental factors, he will weigh these indicators with the smallest scale of importance, reducing their impact on evaluating the project's success. In the end, each project will result in a number that corresponds to the level of success achieved.

For judging the project based on this index, four judgments were made for the projects, in quartiles: extreme unsuccess, unsuccess, potential success and success. We degree the projects' judgment to facilitate investors' view of the system's reality and the potential for improvement with the project's adequacy. With the indicators and evaluation scales, it was possible to develop the application. The entire mathematical model proposed by the application was explained in Rigo et al. (2020), along with sensitivity and reliability analysis of the model. So, the model went through sensitivity and confidence tests to be implemented in this application.

To demonstrate the application, we carried out a case study. We accompany a small-scale residential investor to choose the project with a Brazilian installer. This investor has an average monthly consumption of 850 kW/h in three consumer units located in the city of Santa Maria, in Rio Grande do Sul, Brazil. He intends to acquire a photovoltaic system in the generation modality at the UC itself and send the remaining credits from his system to the other two consumer units under his name. This scenario is common for the Brazilian residential class, so this case study is representative for the reality of Brazil. He budgeted for a photovoltaic system with four installer companies located in the same city. The proposed application was used to assist in decision making.

4. RESULTS

In this section, we presented the application and the case study. The application tool uses the indicators developed according to the factors in Table 1. All of these inputs (indicators measurement) were added to the tool to generate quantifiable results for customers. So, they can reflect on the factors that involve the project's success, adapting it according to tool feedback on factors and indicators that can be improved. The application is based on Microsoft Office Excel® Software and registered in the National Institute of Industrial Property. The model in this system automates the measurement process. Society could have access to such a system, facilitating data entry, mathematical calculation, and visually presenting the projects' success results.

The tool was developed intuitively, communicating with the investor in micro and mini-generation distributed photovoltaic energy projects. The tool menu (Figure 1) addresses four options for the user: Answer the questionnaire, Dashboard with results, Details of Success Factors, and Development Team. The "Details of Success Factors" button takes the user to a tab that didactically explains all factors and indicators. The "Development Team" button takes the user to a tab that presents the research group, the materials, and the researchers involved.

The user interested in measuring his project's success starts the process by clicking on the "Answer the questionnaire" button. This button takes the user to the "Instructions" tab, which briefly explains the data collection instrument and indicates the "Next" button to start the data entry process.

The case study investor needs to meet its monthly demand of 850 kW/h. We accompanied him in contacting four installer companies to budget for the photovoltaic system. We'll call installers W to Z (Table 2). Note that the first two installers developed designs with more power than necessary. The best payback time is presented by installer W. The best guarantee conditions are presented by installer X. Only installers X and Z have a deadline for the installation of the system. The X installer's fastening frame has a 15-year warranty. Installer Y does not present the specification or guarantee of the fixing structure. Brazil tends to have many storms of up to 100 km/h and that is why the fixation structure is an investor's concern. The national average price per Wp for 8 kWp systems is R$ 4.38 (Greener, 2021). Installers W and Y are below average and installers X and Z are slightly above average.

Figure 2 presents the first indicator measurement question implemented in the tool. The user selects the button that represents his answer. The button automatically fills in the "Calculations" tab that contains the mathematical modeling with the scales for evaluating the indicators and the AHP weighting system. Using question 1, as an example of the economic factor, we observed that each question is subdivided into two sections. In the first section, we asked the investor about their satisfaction with the photovoltaic system's cost. In the second section, we asked the investor about the level of importance to the indicator, i.e., the system's cost importance for his success. According to the Likert Scale, he will answer this question from 1 to 5, with 1 not important and 5 very important. These questions about the level of importance are used to weight the indicators. Thus, the investor measures the success level of his project against his personal goals with that investment. In this case study, the investor responded to the weighting only once and responded to the measurement of projects 4 times, one measurement of success per project.

After completing all 33 questions about the nominees, the user needs to answer the paired analysis between the categories, referring to the AHP method. The investor evaluates the importance of the six categories (economic, environmental, market, political, social, and technical) in pairs, totaling 15 questions. These questions allow pointing out which category is most important for the investor, forming the "genetics" of the weighting system. The processing of the data inserted in the data collection instrument is modeled on a tab called "Calculations."

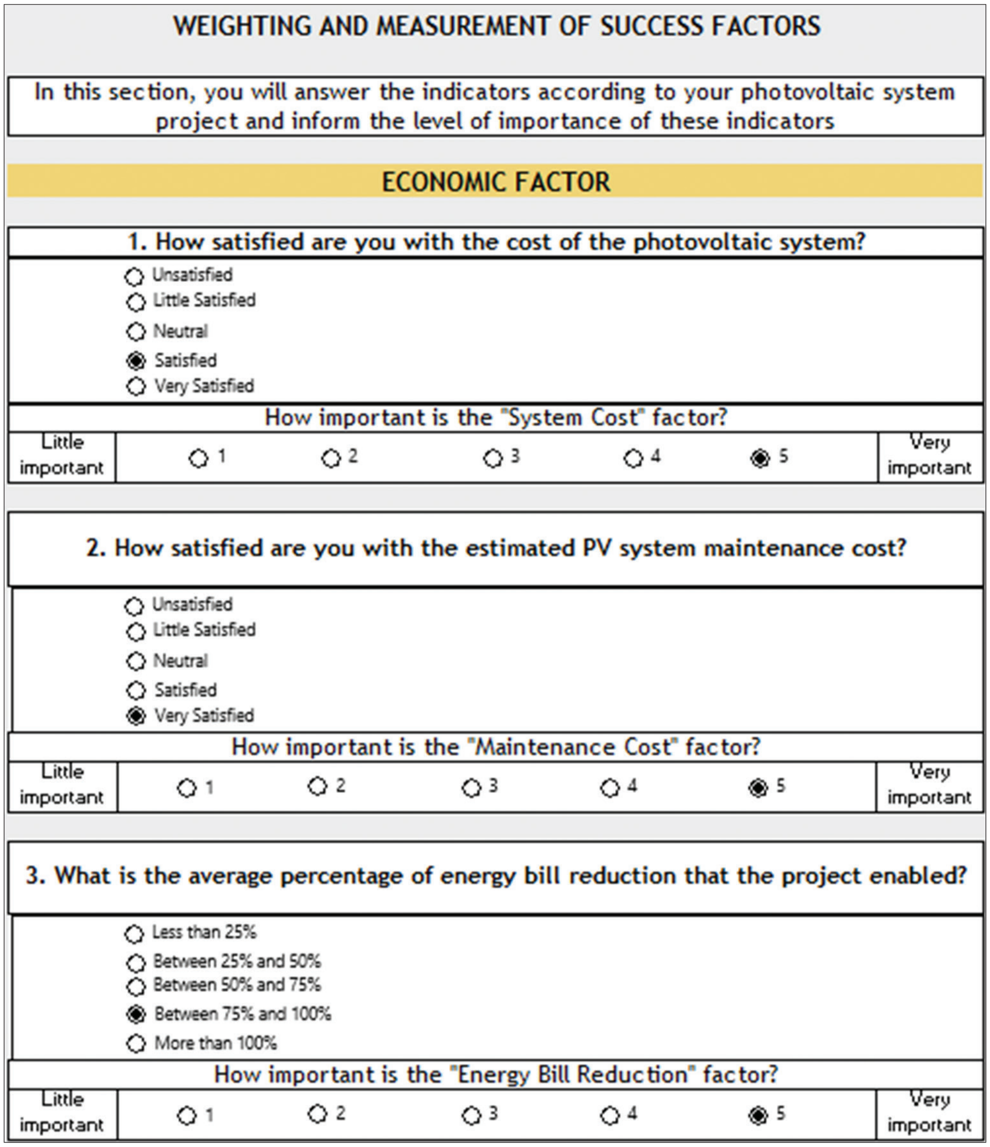
In the paired comparison between the categories, the investor states that economic and technical factors are much more important for his purposes than the others. Therefore, the global weights of factors in the economic and technical categories are greater than the others. For him, the environmental category is the least important, and the entire set of factors in this category accounts for only 3.21% of the project's final success. Table 3 presents the investor's weighting and the measurement of each indicator for each project. Some indicators do not vary from project to project as they are related to any project. For example the "Animal Habitat"

Figure 1: Tool menu

Table 2: Projects proposed by each installer

Project characteristics	Installer W	Installer X	Installer Y	Installer Z
PV system power	8.80 kWp	7.40 kWp	7.12 kWp	7.92 kWp
Roof occupied area	43.4 m²	43 m²	35 m²	36 m²
Estimated monthly generation	962.49 kWh	912.00 kWh	842.53 kWh	861.00 kWh
Deadline	not informed	60 days	not informed	60 days
System Cost in Cash (R$)	34,900.00	33,327.10	29,359.30	35,318.46
Cost per Watt	R$ 3,96 per Wp	R$ 4,50 per Wp	R$ 4,12 per Wp	R$ 4,45 per Wp
Payback Time	3.17 years	3.92 years	4 years	4 years
PV module	DAH Half-Cell Monocrystalline 440 W Warranty: 12 years	Trina Solar Vertex monocrystalline PERC TSM-DE18M 495 W Warranty: 25 years	WEG 445 W Warranty: 10 years	DAH Half-Cell Monocrystalline 440 W Warranty: 10 years
Inverter	Solis 1P7K-5G 7kW Warranty: 10 years	Solis 1P7K-5G 7kW Warranty: 10 years	WEG 6kW Warranty: 7 years	Fronius 6 kW Warranty: 7 years
Structure	Zinc Warranty: 2 years	Aluminum Warranty: 15 years	not informed	Aluminum Warranty: not informed

Figure 2: Data collection instrument



WEIGHTING AND MEASUREMENT OF SUCCESS FACTORS

In this section, you will answer the indicators according to your photovoltaic system project and inform the level of importance of these indicators

ECONOMIC FACTOR

1. How satisfied are you with the cost of the photovoltaic system?

- ○ Unsatisfied
- ○ Little Satisfied
- ○ Neutral
- ◉ Satisfied
- ○ Very Satisfied

How important is the "System Cost" factor?

Little important	○ 1	○ 2	○ 3	○ 4	◉ 5	Very important

2. How satisfied are you with the estimated PV system maintenance cost?

- ○ Unsatisfied
- ○ Little Satisfied
- ○ Neutral
- ○ Satisfied
- ◉ Very Satisfied

How important is the "Maintenance Cost" factor?

Little important	○ 1	○ 2	○ 3	○ 4	◉ 5	Very important

3. What is the average percentage of energy bill reduction that the project enabled?

- ○ Less than 25%
- ○ Between 25% and 50%
- ○ Between 50% and 75%
- ◉ Between 75% and 100%
- ○ More than 100%

How important is the "Energy Bill Reduction" factor?

Little important	○ 1	○ 2	○ 3	○ 4	◉ 5	Very important

indicator, as all projects will be installed on the customer's roof, without the need to cut trees.

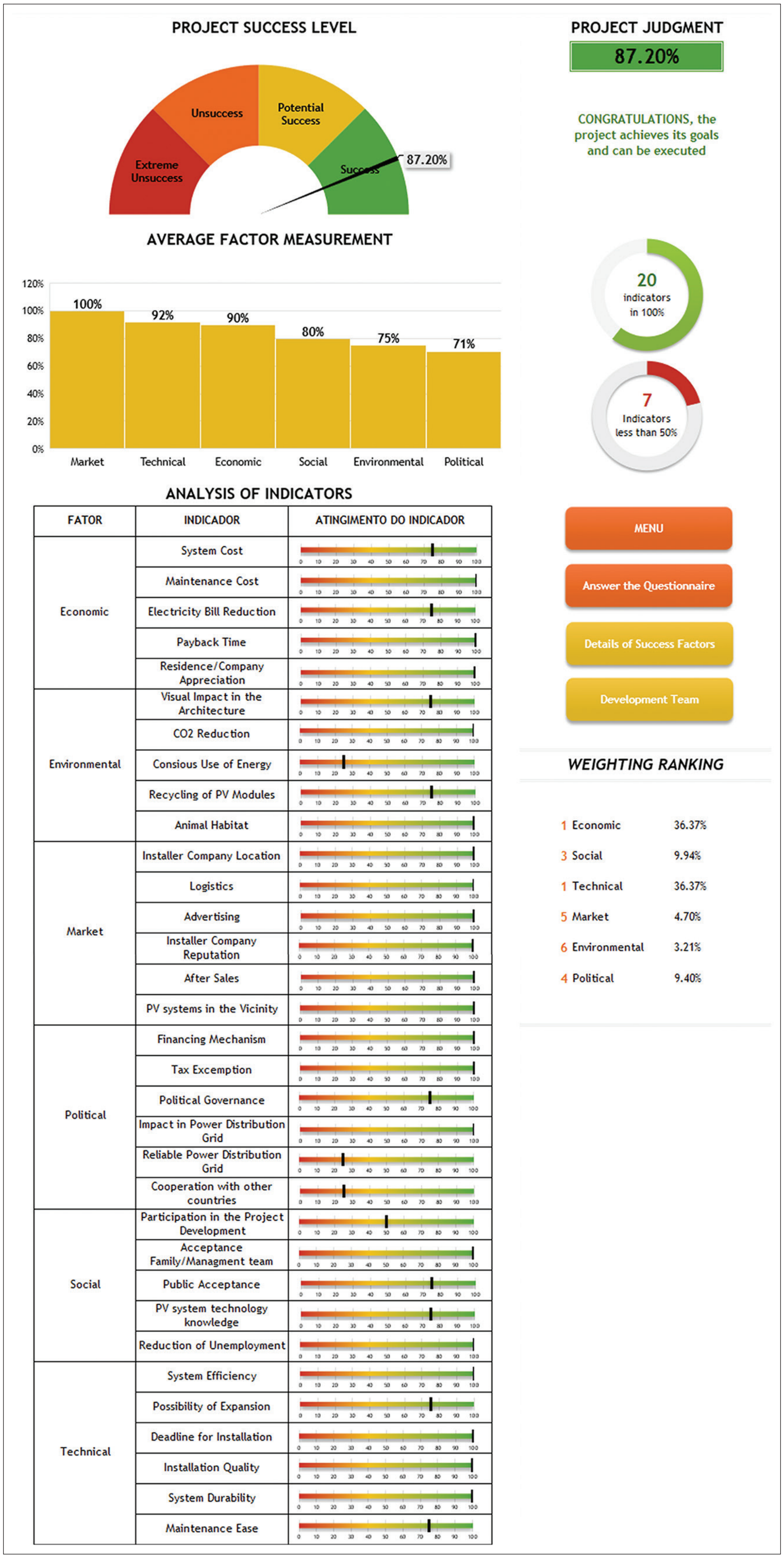
After completing the questionnaire, the user clicks to the "Results Panel" button that presents the project success index and its judgment. The measurement results of the four projects resulted in installer Y as potential success and installers W, X and Z as successful. But installer X had a high success index compared to the others. This result of installer X is due to the importance of technical aspects, as for the investor it presented good conditions in several indicators, such as: Deadlines, guarantees, fixation structure, monthly generation, in addition to the perceived quality of service and the company's reputation in the after sales.

In Figure 3, it is possible to observe four blocks of visual information for the investor about Installer X. The project's success level is presented using a "speedometer" type chart, in which the pointer shows the current value of the project's success, on a judgment scale. After presenting the current project level, it is necessary to explain which categories and indicators had the best or worst contribution to the judgment. With that, just below the speedometer is the bar graph that displays the category's level of achievement, automatically organized from the best to the worst performance. On the right side are two indicator count graphs. The first indicates the number of indicators that achieved 100%, and the second indicates the number of indicators that achieved 50% or less. Then, the objective of the next analyzes is to explain the achievement of each indicator.

The indicator analysis occurs using a "ruler" graph, in which the pointer varies within the scale of reaching the indicator, which is from 0% to 100%. In this way, the investor can quickly assess the indicators that he must improve to raise his project's level of success. As additional information, on the right side, below the navigation panel with the buttons to access the other functions, the ranking of the categories' weighting is displayed. This information helps the investor understand which categories have the greatest strength to raise or lower success.

With the tool, the investor can reflect on his preferences and changes in the project to improve his satisfaction. Besides, he can

Figure 3: Results dashboard



compare different projects budgeted by installers, helping in the decision-making process. In the case study, it was possible to see the difference between the four budgets and choose the one that best met the investor's expectations.

Table 3: Measuring the success of installers' projects

Category	Category weight (%)	Indicator	Global weight (%)	Installer W (%)	Installer X (%)	Installer Y (%)	Installer Z (%)
Economic	36.37	System Cost	8.27	75	75	100	75
		Maintenance Cost	8.27	75	100	75	75
		Electricity Bill Reduction	8.27	100	75	75	75
		Payback Time	8.27	100	100	75	75
		Residence/Company Appreciation	3.31	100	100	100	100
Environmental	3.21	Visual Impact in the Architecture	0.19	75	75	100	100
		CO2 Reduction	0.95	100	100	100	100
		Conscious Use of Energy	0.95	25	25	25	25
		Recycling of PV Modules	0.19	75	75	75	75
		Animal Habitat	0.95	100	100	100	100
Market	4.70	Installer Company Location	0.78	100	100	100	100
		Logistics	0.78	25	100	25	100
		Advertising	0.98	100	100	100	100
		Installer Company Reputation	0.98	75	100	75	75
		After Sales	0.98	75	100	50	75
		PV systems in the Vicinity	0.20	100	100	100	100
Political	9.40	Financing Mechanism	1.57	100	100	100	100
		Tax Exception	1.57	100	100	100	100
		Political Governance	1.57	75	75	75	75
		Impact in Power Distribution Grid	1.57	100	100	100	100
		Reliable Power Distribution Grid	1.57	25	25	25	25
		Cooperation with other countries	1.57	25	25	25	25
Social	9.94	Participation in the Project Development	1.99	75	50	25	25
		Acceptance Family	1.99	100	100	100	100
		Public Acceptance	1.99	75	75	75	75
		PV system technology knowledge	1.99	75	75	75	75
		Reduction of Unemployment	1.99	100	100	100	100
Technical	36.37	System Efficiency	6.27	75	100	75	75
		Possibility of Expansion	6.27	50	75	25	25
		Deadline for Installation	5.02	25	100	25	100
		Installation Quality	6.27	75	100	75	75
		System Durability	6.27	100	100	100	100
		Maintenance Ease	6.27	75	75	75	75
Project success index				78.15	87.20	73.33	75.85

5. CONCLUSION

Considering the worldwide high potential for the installation of small-scale photovoltaic systems for electricity generation, studies must address issues related to the choice of the best project to be adopted, as well as a reflection on the project, for adjustments before execution, increasing the chances of success of the project. Photovoltaic energy is a renewable energy source with great possibilities for implementation in the coming years, serving as an alternative for the global electrical matrix due to the increased demand for electrical energy.

Based on the methodological procedure and the results presented in this article, we achieved the proposed objective since the application can measure the success of photovoltaic projects. As they are innovative projects with a high initial investment, they generate many uncertainties for investors. The application is available for use in Excel software, allowing the user, when implementing the project, to obtain a successful final result. In the case study, it was possible to see the difference between the four budgets and choose the one that best met the investor's expectations.

Developing a diagnostic model for micro and mini-generation distributed projects of photovoltaic energy contributes significantly to customers, installers, and the community itself. The computational tool speeds up the process of launching data and information and the necessary calculations to obtain the final result, which is the judgment of the projects. Having a project evaluation procedure can help warm up the region's market, generate income, and new jobs in the locality. Also, this is a tool with a visual interface, as it uses graphics with different colors to facilitate the understanding of the results. It also assists the user with didactic explanations of what each success factor represents.

We emphasize the need to conduct further studies involving photovoltaic and micro solar energy and distributed mini-generation and encourage disseminating knowledge so that the entire population is aware of the importance and benefits linked to this energy source. The installation of these systems is an essential option for the world electric matrix, which generates gains in the environmental, social, and economic sectors, reducing the world dependence on fossil fuels. It is suggested as future work the application of the tool with more investors so that the tool can be improved and update or insert new indicators of success over time or with new legislation in the energy sector that may occur.

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REFERENCES

Agência Nacional de Energia Elétrica. (2018), Revisão Das Regras Aplicáveis à Micro e Minigeração Distribuída-resolução Normativa nº482/2012. Available from: https://www.aneel.gov.br/documents/656877/18485189/6+Modelo+de+AIR+-+SRD+-+Gera%C3%A7%C3%A3o+Distribuida.pdf/769daa1c-51af-65e8-e4cf-24eba4f965c1

Agência Nacional de Energia Elétrica. (2021), Geração Distribuída. Available from: https://www.app.powerbi.com/viewr=yJrIjoiZjM4NjM0OWYtN2IwZS00Yj ViLTllMjItN2E5MzBkN2ZlMzVkIiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9

ANEEL, Agência Nacional de Energia Elétrica. (2017), Nota Técnica N° 0056/2017-SRD/ANEEL.

Breyer, C., Bogdanov, D., Aghahosseini, A., Gulagi, A., Child, M., Oyewo, A.S., Farfan, J., Sadovskaia, K., Vainikka, P. (2018), Solar photovoltaics demand for the global energy transition in the power sector. Progress in Photovoltaics: Research and Applications, 26(8), 505-523.

Ceolin, E.S., Rigo, P.D., Rosa, C.B., Rediske, G., Siluk, J.C.M. (2017), Microgeração e Minigeração Distribuída de Energia Solar: Cenário e Projeção Do Brasil. In 7th Congresso de Engenharia de Produção.

Constantino, G., Freitas, M., Fidelis, N., Pereira, M.G. (2018), Adoption of photovoltaic systems along a sure path: A life-cycle assessment (LCA) study applied to the analysis of GHG emission impacts. Energies, 11(10), en11102806.

Doljak, D., Stanojevićm, G. (2017), Evaluation of natural conditions for site selection of ground-mounted photovoltaic power plants in Serbia. Energy, 127, 291-300.

dos Santos Carstens, D.D., da Cunha, S.K. (2019), Challenges and opportunities for the growth of solar photovoltaic energy in Brazil. Energy Policy, 125, 396-404.

Empresa de Pesquisa Energética. (2021), Relatório Síntese: Balanço Energético Nacional. Empresa de Pesquisa Energética. Available from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-601/topico-588/Relatório Síntese BEN 2021-ab 2020_v2.pdf

EPE, Empresa de Pesquisa Energética. (2018), Plano Nacional de Energia 2050. Empresa de Pesquisa Energética.

Greener. (2021), Estudo Estratégico Geração Distribuída 1º Semestre de 2021. Available from: https://www.greener.com.br/estudo/estudo-estrategico-mercado-fotovoltaico-de-geracao-distribuida-1-semestre-de-2021

Husain, A.A.F., Hasan, W.Z.W., Shafie, S., Hamidon, M.N., Pandey, S.S. (2018), A review of transparent solar photovoltaic technologies. Renewable and Sustainable Energy Reviews, 94, 779-791.

Jäger-Waldau, A. (2006), European photovoltaics in world wide comparison. Journal of Non-Crystalline Solids, 352(9-20), 1922-1927.

Jong, P., Barreto, T.B., Tanajura, C.A.S., Kouloukoui, D., Oliveira-Esquerre, K.P., Kiperstok, A., Torres, E.A. (2019), Estimating the impact of climate change on wind and solar energy in Brazil using a South American Regional Climate Model. Renewable Energy, 141, 390-401.

Juárez, A.A., Araújo, A.M., Rohatgi, J.S., de Oliveira Filho, O.D.Q. (2014), Development of the wind power in Brazil: Political, social and technical issues. Renewable and Sustainable Energy Reviews, 39, 828-834.

Parida, B., Iniyan, S., Goic, R. (2011), A review of solar photovoltaic technologies. Renewable and Sustainable Energy Reviews, 15(3), 1625-1636.

Peng, K.Q., Lee, S.T. (2011), Silicon nanowires for photovoltaic solar energy conversion. Advanced Materials, 23(2), 198-215.

Pereira, E.B., Martins, F.R., Gonçalves, A.R., Costa, R.S., Rutter, R., Abreu, S.L., Tiepoldo, G.M., Pereira, S.V., de Souza, J.G. (2017), Atlas Brasileiro de Energia Solar. 2nd ed. São José dos Campos: INPE.

Petrenko, L.D. (2021), Green trend in global energy development: Tendencies and opportunities. International Journal of Energy Economics and Policy, 11(5), 1-7.

Rigo, P.D, Siluk, J.C.M., Lacerda, D.P., Rosa, C.B., Rediske, G. (2019), Is the success of small-scale photovoltaic solar energy generation achievable in Brazil? Journal of Cleaner Production, 2019, 118243.

Rigo, P.D., Siluk, J.C.M., Lacerda, D.P., Rediske, G., Rosa, C.B. (2020), A model for measuring the success of distributed small-scale photovoltaic systems projects. Solar Energy, 205, 241-253.

Rigo, P.D., Siluk, J.C.M., Lacerda, D.P., Spellmeier, J.P. (2021), Competitive business model of photovoltaic solar energy installers in Brazil. Renewable Energy, 181, 39-50.

Rosa, C.B., Rediske, G., Rigo, P.D., Siluk, J.C.M., Michels, L. (2018), Ferramenta Computacional Para Mensuração Da Competitividade Na Geração De Energia Fotovoltaica. Gramado: 7th Congresso Brasileiro de Energia Solar.

Saaty, T.L. (2012), Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. 3rd ed. Pittsburgh, PA: RWS Publications.

Sadekin, N., Alam, M., Moudud-Ul-Huq, S., Hassan, M.G., Islam, T. (2021), Do energy consumption and environmental degradation (CO_2 emissions) matter for economic growth? Fresh evidence from a developing economy. International Journal of Energy Economics and Policy, 11(5), 289-297.

Shahsavari, A., Akbari, M. (2018), Potential of solar energy in developing countries for reducing energy-related emissions. Renewable and Sustainable Energy Reviews, 90, 275-291.

Silva, H., Uturbey, W., Lopes, B.M. (2020), Market diffusion of household PV systems: Insights using the bass model and solar water heaters market data. Energy for Sustainable Development, 55, 210-220.