Application of the Delphi Method for the identification of relevant variables in the development of low-power photovoltaic solar projects in Colombia

Aplicación del método Delphi para la identificación de variables relevantes en el desarrollo de proyectos solares fotovoltaicos de baja potencia en Colombia

Aplicação do método Delphi para a identificação de variáveis relevantes no desenvolvimento de projetos solares fotovoltaicos de baixa potência na Colômbia

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Abstract

Introduction: This paper is the product of the investigation "Identification of relevant variables in the development of photovoltaic solar projects in Colombia" developed at the Universidad Distrital Francisco José de Caldas (UDFJC) between 2020 and 2021. Due to the increase in the number of photovoltaic energy projects in Colombia, it is necessary to quantify the level of relevance related with the factors involved in order to optimize the planning and execution processes.

Methods: In this research, the Delphi methodology is applied to evaluate a set of variables selected from literature, putting them to an evaluation by a group of experts with the purpose of quantifying the relationship, under a subjective judgment, between those variables and parameters immersed in low power photovoltaic solar projects in Colombia. Together with the Delphi method, the Torgerson Model was used to quantify what experts said, in order to determine which variables are the most relevant ones to the experts. Subsequently, the validation of these answers is carried out with the application of a second evaluative stage throughout the application of structured instruments.

Results: After obtaining the general consensus, the results are analyzed with the ideal of identifying the variables that obtained a higher level of relevance, in which six relevant variables were identified.

Conclusions: This paper shows how the results of research processes get the most relevant variables, being 6 variables in total, and their impact is analyzed.

Originality: Applying the Delphi method, it is possible to find the most relevant variables in the development of low power photovoltaic solar projects in Colombia, making this paper an important element in the advancement of renewable energies.

Limitation: A massive sample of results was not achieved due to the difficulty in contacting the appropriate professionals in the area analyzed.

Keywords: Electrical energy, Alternative energy sources, Photovoltaic solar energy, Delphi method, Torgerson model, non-interconnected zones.

Resumen

Introducción: Este artículo es el producto de la investigación "Identificación de variables relevantes en el desarrollo de proyectos solares fotovoltaicos en Colombia" desarrollado en la Universidad Distrital Francisco José de Caldas (UDFJC) entre los años 2020 y 2021. Debido al incremento en el número de proyectos de energía fotovoltaica en Colombia, es necesario cuantificar el nivel de relevancia de los factores involucrados para optimizar los procesos de planificación y ejecución.

Métodos: En esta investigación se aplica la metodología Delphi para evaluar un conjunto de variables seleccionadas de la literatura, sometiéndolas a la evaluación de un grupo de expertos con el objetivo de cuantificar la relación, bajo un criterio subjetivo, entre dichas variables y parámetros inmersos en proyectos solares fotovoltaicos de baja potencia en Colombia. En conjunto con el método Delphi, se utilizó el Modelo de Torgerson para cuantificar cada una de las respuestas con el fin de determinar qué variables son las más relevantes para los expertos. Posteriormente, la validación de estas respuestas se realiza con la aplicación de una segunda etapa de evaluación mediante la aplicación de instrumentos estructurados.

Resultados: Luego de obtener el consenso general, se realiza análisis de resultados, identificando las variables que obtuvieron un mayor nivel de relevancia, se identificaron seis variables relevantes.

Conclusiones: Este trabajo muestra cómo los resultados del proceso de investigación alcanzan seis variables, que son las más relevantes y se analiza su impacto.

Originalidad: Aplicando el método Delphi es posible encontrar las variables más relevantes en el desarrollo de proyectos solares fotovoltaicos de baja potencia en Colombia, haciendo de este trabajo un elemento importante en el crecimiento de las energías renovables.

Limitación: No se logró una muestra masiva de respuestas debido a la dificultad para contactar con los profesionales adecuados en el área analizada.

Palabras clave: Energía eléctrica, Fuentes alternativas de energía, Energía solar fotovoltaica, método Delphi, modelo Torgerson, zonas no interconectadas.

Resumo

Introdução: este artigo é produto da pesquisa "Identificação de variáveis relevantes no desenvolvimento de projetos solares fotovoltaicos na Colômbia" desenvolvida na Universidade Distrital Francisco José de Caldas (UDFJC) entre 2020 e 2021. Devido ao aumento do número de projetos de energia fotovoltaica na Colômbia, é necessário quantificar o nível de relevância dos fatores envolvidos para otimizar os processos de planejamento e execução.

Métodos: Nesta pesquisa, a metodologia Delphi é aplicada para avaliar um conjunto de variáveis selecionadas da literatura, submetendo-as à avaliação de um grupo de especialistas com o objetivo de quantificar a relação, sob um critério subjetivo, entre essas variáveis e parâmetros imerso em projetos solares fotovoltaicos de baixa potência na Colômbia. Em conjunto com o método Delphi, o Modelo de Torgerson foi utilizado para quantificar cada uma das respostas, a fim de determinar quais variáveis são mais relevantes para os especialistas. Posteriormente, procede-se à validação destas respostas com a aplicação de uma segunda fase de avaliação através da aplicação de instrumentos estruturados.

Resultados: Após a obtenção do consenso geral, é realizada uma análise dos resultados, identificando as variáveis que obtiveram maior nível de relevância, foram identificadas seis variáveis relevantes.

Conclusões: Este trabalho mostra como os resultados do processo de pesquisa atingem seis variáveis, que são as mais relevantes, e seu impacto é analisado.

Originalidade: Aplicando o método Delphi é possível encontrar as variáveis mais relevantes no desenvolvimento de projetos solares fotovoltaicos de baixa potência na Colômbia, tornando este trabalho um elemento importante no crescimento das energias renováveis.

Limitação: Não foi possível obter uma amostra massiva de respostas devido à dificuldade de contato com os profissionais adequados na área analisada.

Palavras-chave: Energia elétrica, Fontes alternativas de energia, Energia solar fotovoltaica, Método Delphi, Modelo de Torgerson, Zonas não interligadas.

1. Introduction

According to data from the UPME (Mining-Energy Planning Unit), in its monitoring reports related with energy demand in the national interconnected system during the last three years, Colombia has been a country with a stable electricity demand [1] [2]. The demand is accomodated mainly by hydroelectric power, which in 2018 represented 68.3% of the country's installed capacity. Due to the equatorial location of the country, this strong dependence on water resources can be problematic [3]; for example, the natural phenomenon El Niño generates a decrease in rainfall precisely where the most hydroelectric plants are located, and therefore a deficit in the level of the reservoirs, affecting the country's electricity production.

Situations like this require thermoelectric plants to start operations, which in the end is reflected in an increase in the cost of energy for the inhabitants, due to the fact that, compared with other sources of energy, fossil fuels present a clear disadvantage [5]. An efficient response to this kind of situation is the implementation of small photovoltaic systems at the residential level; for example, Bogotá has an average capacity of between 3.5 and 4.5 kWh per square meter as a result of incident solar radiation [6], which means that, at least at the residential level and according to the location and layout of the residence, the city could be sustained from this resource. The above, added to benefits such as the one covered by Resolution 030 of 2018, which establishes the limit of energy that autogenerators can inject into the network, promotes the implementation of photovoltaic systems, not only for environmental benefits but also economic [7].

The boom for the development of photovoltaic solar projects began in 2014, with the introduction of Law 1715, which established the policy guidelines for the promotion of investments with FNCER (Non-Conventional Sources of Renewable Energy) [8]. For the year 2017, 283 solar projects were waiting to receive the environmental benefit certification, granted by the competent environmental authority, in this case the ANLA (National Environmental Licensing Authority). These projects correspond to 86% of the applications corresponding to FNCER presented before the cut-off point for the year 2017 [9], making it clear that, at that time in Colombia, the non-conventional energy source with the greatest interest was solar as shown in Fig. 1.

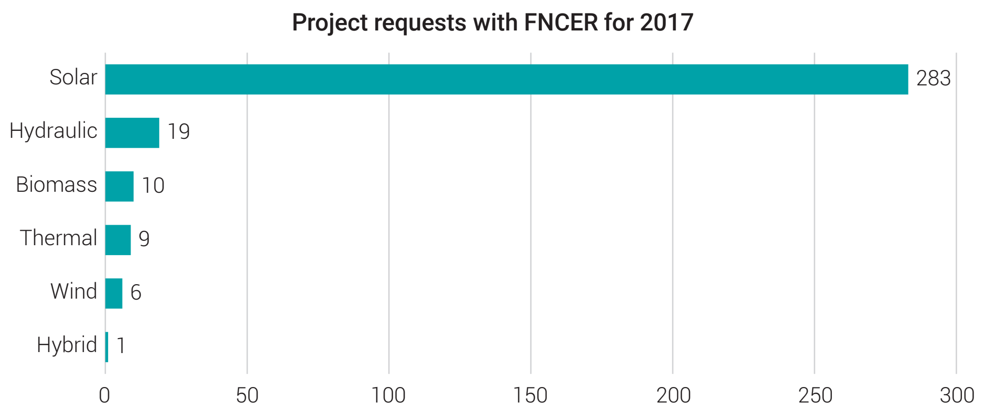

Fig. 1. Generation projects for 2017 [9].
Source: own work

As a result of the increase in the number of solar photovoltaic projects in the country, both public organizations and private companies require methodologies that increase the acceptability of projects by government entities. This requires that the most relevant factors in planning and execution of those projects are determined. For this, the investigation applied the Delphi methodology to determine and quantify the relationship between the variables and parameters involved in the development and presentation of low power projects at the national level.

For the development of this work, a panel of 10 experts participated, including academics, technicians and members of the public sector, all of them directly related to the use of photovoltaic solar energy both at the theoretical and practical level.

2. MATERIALS AND METHODS

2.1. Review of the literature for the definition of the variables

The evident growth of the energy sector, especially the residential sector, which for the first semester of 2012 presented a participation of 55%, with a total of 70.1 million kilowatt hours [kWh], that is much higher than the country's commercial and industrial consumption. As shown by Díaz Abella, Óscar Javier, in his thesis "Photovoltaic energy: a solution for the population of the municipality of Cumarimbo, lacking electricity service" [10]; The capacity to supply the population with electricity (installed capacity) does not grow as fast as its demand, which has caused a general increase in the cost-of-service provision. Therefore, it is necessary to consider alternative methods that fill the energy gap that occurs.

Thus, alternative energies seem to be the most viable and rapid response to solving the problem of the growing energy demand. However, the development of projects that take advantage of these resources generally require a high economic investment, depending of the power that required. In this way, variables, such as the profitability of the executed project and the cost at which the generated energy is traded, are of the utmost importance for investors who bet on the development of this type of project [10].

Although, at the beginning, it might seem that the investment required for this type of project is very high, related to the expected revenue, information says otherwise. The UPME records show, from a single project of photovoltaic solar energy registered in 2014, there were 254 projects registered by the beginning of 2020 [11]. This shows a strong interest of the economic sector in capital investment for the development of this type of project. Therefore, one of the most important economic limitations for the development of photovoltaic solar projects in the country is the cost of raw materials. The fluctuating value of the dollar (USD), which on average for 2014 was at an approximate value of 2,000 COP (Colombian Pesos) and for 2021 was around 3,702 COP, represents an approximate increase of 85.1%. This aspect may be one of the causes of the decrease in the investment of photovoltaic projects, since, taking into account the registration reports of generation projects delivered by the UPME, the development of photovoltaic solar projects was greater between the years 2016 to 2018 when the price of the dollar had a downward trend. This then decreased dramatically at the beginning of 2019, a time in which the price of the dollar began a progressive increase until March 2020, where it reached a maximum value of 4,153 COP [12].

In January 2020, according to the UPME electricity generation project registration report, the number of solar projects in force between phases 1, 2 and 3 was 368, equivalent to 68.9% of the total number of projects in force in the country; of these, 49.2% corresponded to projects of less than 1 MW [13]. By March of the same year, just 2 months later, the number of current solar projects in phases 1, 2 and 3 decreased to 341, which represented an average decrease of 7.3% [14]. On March 9th, 2020, the Ministry of Health announced the first person infected with COVID-19 in the city of Medellin, beginning the COVID-19 pandemic in Colombia, and bringing with it changes in political, economic, social, cultural and health aspects [15]. These changes triggered a series of important effects in the photovoltaic solar generation sector in the country. In October 2020, the number of current solar projects decreased to196, meaning a reduction of about 50% of the current solar projects registered in January of the same year [11], as shown in Fig. 2.

The Non-Interconnected Zones (ZNI) are the municipalities, districts, towns and villages, which due to their geographical characteristics and their distance from the National Interconnected System (SIN) do not have a conventional electricity service, so they require isolated generation solutions [16], either due to geographical or technical aspects or, as in many cases, due to high connection costs for the user. These zones represent one of the greatest points of interest for the development of small-scale photovoltaic projects; this, due to the fact that the ZNI are located in places of difficult approach, with little public infrastructure and with difficulties in accessing communication networks. Taking into account that these areas represent 53% of the national territory, less than 3% of the country's population is supplied with this type of energy [17] and, for 2019, it was estimated that 338,383 homes located in isolated areas or ZNI of the country, did not have an electricity service. This makes these places a clear business objective for the development of alternative energies, whose installation versatility allows them to respond efficiently as well quickly to the energy requirements of the area in question.

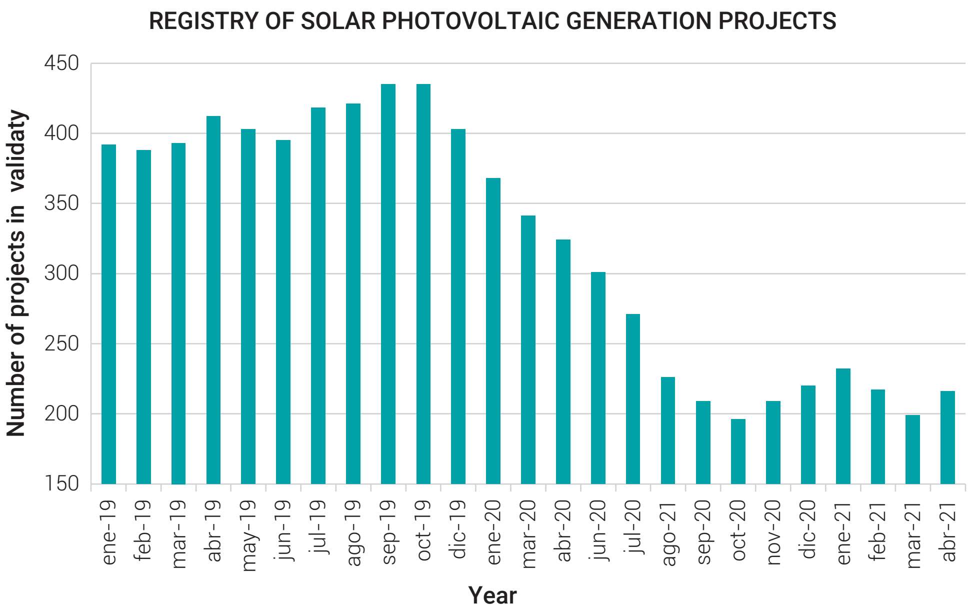

Fig. 2. Registration of current photovoltaic solar generation projects, based on the UPME generation project registration reports.
Source: own work.

In addition, the IPSE (Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Areas), has identified that the current model of expansion of the electricity sector presents difficulties in bringing an electricity service to the people living in rural areas, due to variables such as:

Difficult access areas, Low population density, Presence of ethnic communities, Environmental restrictions, Armed conflict, Low-income level of its inhabitants, Low economic development of its inhabitants, Inefficient operation and maintenance of power generation systems, Difficult access to training and education programs by the companies providing the service, Lack of integration with regional development programs, High costs of providing the service, Low or null profitability of the investments made, The dispersion of users that doesn't allow for the implementation of a centralized generation system.

In the community, this condition generates situations such as: Incipient access to the public electricity service, restricted access to opportunities for education, health, productivity and information technologies, limited labor supply, poverty and inequality, increased cost of living, low use of infrastructure and public services [19]. This situation has led to proposed energy solutions through the use of FNCER, in order to guarantee the supply of high-quality electrical energy, in a continuous, safe and affordable way for the population, non-polluting towards the environment and taking advantage of the characteristic energy potentials of the regions where they are implemented.

Considering that, for electric generation projects with an installed capacity greater than 10 MW, the environmental license must be processed with the ANLA, as stipulated in Article 2.2.2.3.2.2 of Decree 1076 of 2015 [18]; It is necessary to consider the political will of the inhabitants and governors of the area, as well as their particular interests, because these will be the ones that ultimately give the go-ahead for the development of the project. Additionally, it is necessary to include the sustainability factors of the project's aspects such as: technical assistance to service providers, strengthening of administrative capacities, training of communities in energy and energy efficiency; one type of FNCER that complies with these requirements is photovoltaic energy [19].

The IPSE, together with the MinMinas (Ministry of Mines and Energy), managed the implementation of energy projects in the ZNI of the country. In 2019, they benefited 5,184 new users of the electricity service, in 14 departments and 20 municipalities, and also structured 26 energy projects, with an investment of $3,396 million pesos (COP), so that 8,117 homes have electricity service in these areas. By 2020, they benefited 7,877 new users with the electricity service, in 13 departments and 16 municipalities, in addition to structuring 4 projects that benefited 2,447 homes [20]. During the year 2020, an advance was presented in the structuring of 39 projects for 9,231 potential users, which could begin their development that year, demonstrating the great potential that photovoltaic projects have in the ZNI [21].

To address the topic of sustainability of the project, four different dimensions must be taken into account: economic, environmental, social, and technological. Starting with economic sustainability, it follows that the project is designed in such a way as to guarantee its financial and economic profitability, as well as persistent long-term income. Environmental sustainability seeks that projects are structured and designed in such a way that the impact on the environment is minimal, favoring the use of local sources, preferably renewable, that promote the reuse of waste and adequate mitigation measures, without negatively affecting the socioeconomic environment of the region, forcing the transfer of inhabitants or disturbing the quality of their environment [22].

Social sustainability seeks, through the implementation of the projects, the improvement of the economic and social conditions of the region, favoring the inclusion of the local population in the development and operation of the projects, guaranteeing the income that allows the users access to the energy service, implementing community schemes or local companies in which the territorial entities, and/or the residents, actively participate in the development of those projects. Finally, technological sustainability pursues the technologies compatible with the social and economic environment that are tested and efficient, and whose operation can be carried out with the adequate training of local human resources. If the mentioned conditions are achieved, the project can be adapted to the reality of its territorial entity, starting with the diagnostic analysis, which will help determine the conditions and requirements for the installation of individual photovoltaic solar systems in ZNI, according to the true needs of the context [22].

2.2. Delphi Method

Scientists have different methodologies and research techniques to build science and knowledge. The Delphi method is an expert method, based on the opinions of a group of people related to the topic to be analyzed [23]. The results obtained through this methodology allows for the quantitative comparison of the different opinions from the group of experts without these being influenced by the opinion of the other members belonging to the group. According to Vicens, this method could be defined as "a procedure for obtaining information from a group of experts in several stages, with three basic characteristics: anonymity, numerical response and feedback" [24].

Simultaneously, it is possible to define the Delphi method as a technique that consists of obtaining information by consulting experts in an area, in order to obtain the most reliable consensus of the consulted group. These experts are individually submitted to a series of in-depth questionnaires that are interspersed with feedback of what is expressed by the group. With this, starting from an open exploration, after successive answers, it produces an opinion that represents the group [25].

In any case, the purpose of applying this method lies in the possibility of evaluating different points of view regarding a specific topic and thereby achieving a consensus that compiles, in some way, the different opinions presented by an evaluating group. Thus, for this case study, the application of this methodology will lead to the selection of a set of characteristic variables for the development of low-power photovoltaic solar projects in Colombia.

2.3. METHODOLOGY

2.3.1. Application of the Delphi method

In this article, the application of the method was established in four fundamental stages, which are shown in Fig. 3.

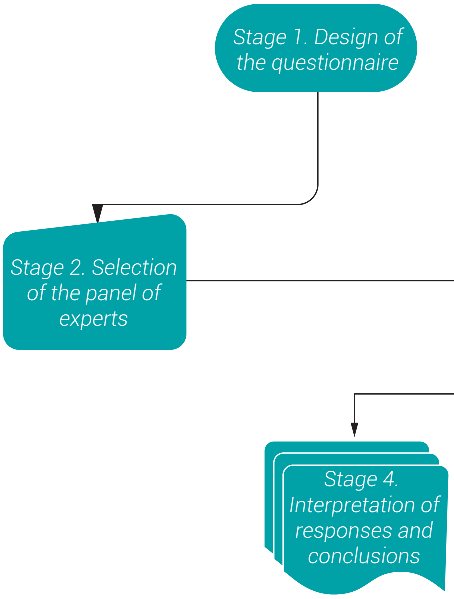

Fig. 3. Stages of the application of the Delphi method.
Source: own work.

2.3.2. Stage 1. Design of the questionnaire

For the elaboration of the questionnaire, the first step consisted in the identification of the variables through the analysis of bibliographic material and review of the literature, from which it was possible to obtain a series of data which would later be compiled in different groups. The variables were divided into 2 groups and subdivided into 5 different categories, those groups were: endogenous (variables of the project development) and exogenous (variables that are related to the project externally, without being the cause of the same), taking into account that the information collected on the variables did not always relate them directly to the research topic, although they did have an effect on it.

Thus, once all the variables were separated into endogenous or exogenous, as shown in the table in Fig. 4, the next step was to subdivide them into 5 different categories, which are: Political, academic, social, economic and energetic. In this way it was possible to evaluate which variables were related to each other and also reduce the number. With this, it was possible to synthesize the information, which facilitated the design of a simple and concrete questionnaire, which provided the experts with a rapid but profound interpretation of each one of the questions.

EXOGENOUS		ENDOGENOUS	
1	Main economic activity of the population	1	Transportation of supplies
2	PIB of the region	2	Budget
3	public infrastructure	3	Financing
4	Marketing centers	4	Project profitability
5	Available capital of the population	5	Taxes
6	Tax system/policy	6	Support for similar projects
7	Type of services available in the area	7	local development plan
8	Productive capacity of the place	8	Distance between the point of development of the project and the population to which it is directed
9	Equipment and raw material costs.	9	Is it a ZNI or not?
10	dollar price	10	Layer
11	kWh cost	11	Is or was a conflict zone
12	Political will	12	Social integration
13	Economic incentives for the project (law 1715)	13	investment collection
14	Application for permits in projects	14	time of development
15	resource type	15	Environmental impact of the project.
16	type of weather	16	Ecosystem
17	Physiography (Relief)		
18	Literate population		
19	Level of study		
20	academic infrastructure		
21	access to technology		
22	Region research level		
23	Energy use (load projection)		
24	Predominant type of electricity generation in the area		
25	power quality		
26	Energy demand		
27	Municipal Performance Measurement		

Fig. 4. Endogenous and exogenous variables.
Source: self-made.

With the analysis of the different theoretical aspects (see Section 2.1 - Theoretical framework), the unique needs of each territorial entity are justified, and in this sense, project formulators must take these requirements into account in order to execute an in-depth diagnosis and identify the most suitable solution to deal with the problems and specific situation of each location. The solutions can be isolated mobile installations or installations interconnected to the electricity grid, solutions integrated into a microgrid or isolated solutions.

Based on this analysis, the following twenty-one (21) variables were selected, qualified and quantified, as to which were considered the most relevant of the initial group. These variables are the ones that were subsequently submitted to the panel of experts for validation through the method.

1. Private financing
2. Economic profitability of the project
3. Income from the investment
4. Public infrastructure in the area
5. Cost of equipment and raw materials
6. Dollar price
7. Cost per kWh
8. The area where the project is located (Is it a ZNI or not?)
9. Socio-economic stratum of the area
10. The area is or was a conflict zone
11. Social integration generated by the development of the project in the area
12. Environmental impact of the project
13. Level of appropriation of technologies by the community
14. Population density
15. Type of energy resources available in the area
16. Quality of energy in the area
17. Energy demand of the area
18. Political will
19. Application and processing of permits for the development of the project
20. Literacy level of the population
21. Level of access to technology of the population

2.3.3. Stage 2. Selection of the panel of experts

Although for the development of the study, the selection of the panel was shown as one of the most critical points, the related literature does not establish a consensus on regarding the minimum or maximum size of the panel; therefore, in order to generalize the results obtained through the development of the survey when applying the Delphi method, it is necessary to select a sufficiently large sample and, with this, carry out a significant statistical process. The sample size depends on the dynamics of the applied method and, in general, the literature recommends a panel of between 10 and 18 experts belonging to different fields involved in the study. Also, the respondents must remain anonymous without being related to each other [26].

In the process of selecting the experts for the panel, as a method to discern and evaluate the level of aptitude they have in relation to the subject, it is necessary to consider criteria such as the experience and knowledge they possess, related to the subject of interest. Similarly, it is necessary to consider aspects such as time availability, professional experience, commitment to the complete development of the survey, the number of scientific productions in which they have participated, the professional positions they have held and, in general, all levels of knowledge, either practical or academic, that is directly related to the topic to be developed [27].

For the development of this study, the panel of experts was segregated into two groups, depending on the area where they have a greater affinity; these areas are academic and technical [28]. With the selection of this group, it is guaranteed that the information is relevant and homogeneous, since different points of view are obtained from the multiple points of application related to the subject in question.

One of the procedures to evaluate the related competences of the experts is the use of the "coefficient of expert competence" or "coefficient K", used in recent years by various authors and which relates the self-assessment of the expert regarding his knowledge on the research topic with the sources that argue the established criteria.

The coefficient is obtained through the equation:

$$K = \frac{1}{2} * (Kc + Ka) \tag{1}$$

Where,

Kc is the "knowledge coefficient", which rates the knowledge that the expert has on the subject, through a self-assessment; on a scale of 0 to 1, 0 being no knowledge and 1 being extensive knowledge on the subject.

Ka is the "Coefficient of argumentation", which supports the criteria of the experts. This is obtained from the designation of points, according to the different sources that support the expert, which can be seen in Table 1, in which the different scores used to evaluate the experts who participated in the study are displayed [29].

Table 1. Assessment of the sources of argumentation.

Source of Argumentation	Description	Degree of influence of the sources		
		Low (L)	Medium (M)	High (H)
Work	Experience obtained in the labor sector of photovoltaic systems	0.16	0.28	0.4
Academic	Experience obtained in the academic sector of photovoltaic systems	0.16	0.28	0.4
Level of training	Level of academic training related to photovoltaic systems	0.04	0.07	0.1
Studies and publications	Studies and publications in the field of photovoltaic systems	0.04	0.07	0.1

Source: own work.

With the final value of the expert competence coefficient, they are classified into three groups:

- 0.8 < K < 1 => High influence in all sources
- 0.7 ≤ K ≤ 0.8 => Medium influence in all sources
- 0.5 ≤ K < 0.7 => Low influence in all sources

Table 2 calculates the argumentation coefficient Ka by evaluating the profile of each expert, based on the answers they gave to the questions posed in the questionnaire with respect to each of the sources of argumentation.

Table 2. Determination of the argumentation coefficient of the experts.

Results of the argumentation coefficient of the experts						
No.	Profile	Experience Work	Academic Experience	Training level	Studies and publications	Ka
1	Academic	H	H	H	M	0.97
2	Professional	H	H	H	H	1.0
3	Academic	H	H	M	H	0.97
4	Professional	H	H	H	H	1.0
5	Professional	H	L	M	L	0.67
6	Professional	H	L	M	L	0.67
7	Professional	L	H	M	L	0.67
8	Academic	L	H	H	L	0.7
9	Academic	L	H	H	L	0.7
10	Academic	H	H	H	H	1.0

Source: own work.

Finally, Table 3 determines the coefficient of expert competence Kc, which assigns the level of influence of each of the experts.

Table 3. Determination of the competence coefficient of the experts.

Results of the competence coefficient of the experts					
N°	**Profile**	**Kc**	**Ka**	**K**	**Influence**
1	Academic	0.9	0.97	0.94	High
2	Professional	1.0	1.0	1.0	High
3	Academic	1.0	0.97	0.95	High
4	Professional	0.9	1.0	0.95	High
5	Professional	1.0	0.67	0.84	High
6	Professional	0.8	0.67	0.74	Average
7	Professional	0.8	0.67	0.74	Average
8	Academic	0.8	0.7	0.75	Average
9	Academic	0.8	0.7	0.75	Average
10	Academic	0.9	1.0	0.95	High

Source: own work.

According to the methodological approach from the coefficient of expert competence, only experts who had obtained values greater than or equal to 0.7 in the coefficient of expert competence were selected, in other words, experts with medium or high influence, eliminating experts with low influence and finishing with the selection of the final panel of experts. In the case of this study, the panel is made up of 4 experts with medium influence and 6 experts with high influence.

2.3.4. Stage 3. Obtaining the answers from the panel of experts

With the analysis made in the design stage, the twenty-one (21) variables were submitted to the experts through a questionnaire divided into 2 stages, organized by the following structure:

In the first stage of the questionnaire, information was collected from the experts, such as: main occupation, academic background, experience, work and knowledge in low-power photovoltaic solar projects, as well as a personal rating regarding their level of knowledge on the subject, which helped quantify the importance of their responses compared to that of the other experts.

For the second stage of the questionnaire, the experts were asked to assess each of the twenty-one (21) variables, in order to establish the level of importance of each one. This was achieved by asking the question: "From your point of view, for the development of low-power photovoltaic projects in Colombia, how important are the following variables?", which led the experts to qualify the value of variables by selecting one of the following answers: Not at all important, Not very important, Important, Quite important, and Very important. In this way, the most relevant variables for each of the experts were identified.

After that, the quantification of the responses was carried out by assigning a value scale from 1 to 5 to each of the options, with 1 being the value assigned to the option with the lowest level of importance (Not at all important) and 5 being the value of the option with the highest level of importance (Very important), as shown in Table 4. Additionally, an optional open question was made in case the evaluator wanted to make any comments or observations of the survey carried out.

Table 4. Determination of the quantitative scale of the qualitative qualification.

Nominal	Ordinal Value
Very important	5
Quite important	4
Important	3
Little important	2
Not important	1

Source: own work.

3. RESULTS

3.1. First survey

The appropriate selection of a measurement method is a challenge for the Delphi method, since there are a wide variety of guidelines on the establishment of measurements through qualitative and quantitative paradigms. Quantitative analysis attempts to predict, while qualitative analysis seeks to delve into the responses and understand situations. However, quantitative analyses have generally been more accepted in the literature than qualitative ones [30]. For this particular case, the Torgerson model was specially used because, through a simple five-step methodology [31], it allows for the conversion of a qualitative evaluation to a quantitative one by the identification of the images in each one of the values of the relative frequency table accumulated by the inverse of the standard inverse normal curve. These values set the intervals in which the quantitative variables will be found (Not at all important/Much less important, Little importance/Less important, Important/Equally important, Quite important/ More important and Very important/Much more important) [32].

On the other hand, the average of the cut-off points assigns the limit value N, which is used for the calculation of the number belonging to each of the variables. At the same time this makes it possible to place them at certain intervals; in this case, the N value was 1.54. With the answers provided by the experts, the absolute frequency of each answer is calculated, which corresponds to the twenty-one (21) variables used in the development of the questionnaire. Afterwards, the relative frequency of each response is calculated, dividing the absolute frequency value by the number of responses provided by the experts. Then, with the relative frequency, the accumulated relative frequency is determined.

After obtaining the value of accumulated relative frequency of each of the responses, it approximates to the closest value of the inverse standard normal curve. This calculation was made using a computational tool [28], giving an approximation of the accumulated relative frequency to the inverse standard function and the calculation of its image by the normal curve, considering that for values of accumulated relative frequency equal to 1 and 0, the inverse standard value corresponds to 3.5 and -3.5 respectively.

The results of this calculation are shown in Table 5. After the calculations, an average is made per column of the calculated values in order to estimate the cut-off point of each ordinal value, which are presented in Table 4, and, in the same way, calculate the limit value N. The value of N-P corresponds to the difference between the limit value and the average value of each question, determining the level of belonging.

Table 5. Identification of the images by the inverse standard normal curve, cut-off points of the ordinal scale and limit value.

Question	5	4	3	2	1	Average	NP
P1	-0.52	0.00	1.28	3.50	3.50	1.55	-0.02
P2	0.52	1.28	3.50	3.50	3.50	2.46	-0.92
P3	0	1.28	3.5	3.5	3.5	2.356	-0.82
P4	-0.25	0	1.28	3.5	3.5	1.606	-0.07
P5	-0.84	0.25	1.28	3.5	3.5	1.538	0
P6	0	0.25	0.84	3.5	3.5	1.618	-0.08
P7	-0.52	1.28	1.28	3.5	3.5	1.808	-0.27
P8	0.25	1.28	3.5	3.5	3.5	2.406	-0.87
P9	-0.84	-0.84	-0.25	1.28	3.5	0.57	0.97

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Question	5	4	3	2	1	Average	NP
P10	-0.52	0	0.52	1.28	3.5	0.956	0.58
P11	0	0.84	3.5	3.5	3.5	2.268	-0.73
P12	0	0.52	0.84	3.5	3.5	1.672	-0.14
P13	0.25	0.84	3.5	3.5	3.5	2.318	-0.78
P14	-0.84	-0.52	0	3.5	3.5	1.128	0.41
P15	0.25	0.25	1.28	1.28	3.5	1.312	0.22
P16	0	0.25	0.52	1.28	3.5	1.11	0.43
P17	0.52	0.52	0.84	1.28	3.5	1.332	0.2
P18	0	0.25	0.84	3.5	3.5	1.618	-0.08
P19	-0.52	0.25	1.28	1.28	3.5	1.158	0.38
P20	-3.5	-0.84	0	1.28	3.5	0.088	1.45
P21	-3.5	0	3.5	3.5	3.5	1.4	0.14
cut-off point	-0.48	0.34	1.56	2.76	3.5	1.54	

Source: own work.

Table 6 shows the range value of each of the cut-off points, as well as its assignment to each of the possible answers in this section of the questionnaire.

Table 6. Determination of definitive ranges and cut-off points.

Cut Point	Category
< -0.48	Very important
-0.48 < x < 0.34	Considerably important
0.34 < x < 1.56	Important
1.56 < x < 2.76	Less important
2.76 < x < 3.50	Nothing important

Source: own work.

Once the results of the N-P of each one of the questions have been compared with the cut-off points and the ranges shown in Table 6, it is possible to exactly determine the belonging of each one of the answers, and in this way assign the accurate qualitative value regarding to the answers provided by each expert in each one of the questions as shown in Table 7.

Table 7. Importance of the variables.

Question	NP	Category
P1	-0.02	Considerably important
P2	-0.92	Very important
P3	-0.82	Very important
P4	-0.07	Considerably important
P5	0	Considerably important
P6	-0.08	Considerably important
P7	-0.27	Considerably important
P8	-0.87	Very important
P9	0.97	Important
P10	0.58	Important
P11	-0.73	Very important
P12	-0.14	Considerably important
P13	-0.78	Very important
P14	0.41	Important
P15	0.22	Considerably important
P16	0.43	Important
P17	0.2	Considerably important
P18	-0.08	Considerably important
P19	0.38	Important
P20	1.45	Important
P21	0.137	Considerably important

Source: own work.

After analyzing the distribution of each question respecting the assigned nominal rating value, a favorable response was identified from the panel of experts for each of the variables presented, showing that, of the twenty-one (21) variables presented, 5 of them are considered “Very important” (23.81%), 10 are considered “Quite important” (47.62%), 6 are considered “Important” (28, 57%) and in none of the cases was a variable identified as “Not very important” or “Not at all important”.

The five variables that the experts considered most important in this first survey are:

1. Economic profitability of the project
2. Investment collection
3. The project location zone is or is not a ZNI
4. Social integration generated by the development of the project in the area
5. Level of appropriation of technologies by the community

3.2. Ratification of responses

To establish the consensus of the answers provided by the experts, a second questionnaire divided into 2 stages was carried out, in which the experts were asked to compare the variables, in respect to the others.

To do this, in the first stage of the second questionnaire, the experts were asked to once again evaluate the level of importance of each variable, but in this case, these variables were separated into 5 categories according to their area of influence, these being the academic, political, energy, economic and social areas. In this way, it was possible to evaluate the level of importance of each variable regarding the others of the same category. This was achieved by asking the question "From your point of view, for the development of low-power photovoltaic solar projects in Colombia, how important is the variable shown in the statement compared to the variables listed?" This led the experts to qualify the value of the variables by selecting one of the following responses: Much more important, More important, Just as important, Less important, Much less important. After that, the quantification of the answers was carried out by assigning a value scale from 1 to 5 to each of the options; 1 being the value assigned to the option with the lowest level of importance (Much less important) and 5 to the value of the option with the highest level of importance (Much more important), as seen in Table 8, identifying which of the variables of each group was the one with a higher level of relevance according to the experts' answers.

Finally, the experts were asked to categorize which of the five categories (academic, political, energy, economic and social) was the most important compared to the others when developing a low-power photovoltaic solar project in the country. This was achieved by asking the question "From your point of view, for the development of projects related with low power solar photovoltaics in Colombia, how important is the category shown in the statement compared to the categories listed?" with the same qualification and quantification of the previous stage, which is represented in Table 8.

The Torgerson model was used again to quantitatively evaluate the responses, which are shown in Table 8.

Table 8. Determination of the quantitative scale from the qualitative qualification.

Nominal value	Ordinal Value
Much more important	5
More important	4
Equally important	3
Less important	2
Much less important	1

Source: own work.

4. DISCUSSION

After analyzing the distribution of each question with respect to the assigned nominal rating value, it was identified that, in the category of economic variables, it is recognized that the "economic profitability of the project" and the "investment collection" are always equal to or more important than any other variable of the same category, which agrees with the previous answers because these variables were two of the five most important. Additionally, it is observed that, on this occasion, for the experts, the "price of the dollar" acquires a level of importance equal to that of the two prior variables.

In the category of social variables, it is analyzed that " the location of the project is a ZNI ", "Social integration generated by the development of the project in the area" and "level of appropriation of technologies by the community are the same" are more important than any of the other variables in the same category, which is consistent with previous responses where these variables were three of the five most important. Additionally, it is established that the most important variable of the three is the "social integration generated by the development of the project in the area", followed in importance by "the location of the project is a ZNI" and finishing with "level of appropriation of technologies by of the community"; the last two obtained the same level of importance.

It is also important to highlight the stage of comparison between categories, where it is established that the most important categories are economic and social, which agrees with the answers obtained in the first questionnaire, since it was in these categories where the most important variables were located. The least important categories are political and academic, which is consistent with the previous answers because none of the variables of those categories were part of the variables valued as “most important”; so it is considered that, at general levels, these categories are less important.

On the other hand, the Delphi method is a flexible tool that quickly evaluates different opinions that are difficult to quantify precisely or where the existing information cannot be analyzed directly. It involves the judgments of different qualified experts in different fields of knowledge in which they have their own perspectives on a specific topic that are also difficult to assess with statistical methods. Through the use of several rounds, the most reliable consensus of the evaluating group is achieved that covers the different individual judgments [33]. Obtaining results using this methodology allows for the quantitative comparison of the different individual opinions coming from the group of experts without these being influenced by the opinion of the others; its precision depends on the number of rounds that are carried out, the anonymity of the answers and the feedback of the questionnaires. This provides greater confidence that the method is reliable in correctly determining the set of characteristic variables that are the target of the study.

Finally, under consensus, the variables that the experts consider most important are:

1. Economic profitability of the project
2. Investment collection
3. Dollar price
4. Social integration generated by the development of the project in the area
5. The project location zone is or is not a ZNI
6. Level of appropriation of technologies by the community

5. CONCLUSIONS

The Delphi method was applied to determine the most relevant variables in the development of low-power photovoltaic solar projects, with a panel made up of 10 experts. This process allowed us to conclude that the most relevant variables are, economic profitability of the project, investment collection, dollar price, the area where the project is located is or is not a ZNI, social integration generated by the development of the project in the area, and level of appropriation of technologies by the community.

In the economic category, the most important variables are the economic profitability of the project and the collection of the investment. This behavior is consistent with the fact that many of the electricity generation projects are photovoltaic solar projects; by 2018, 97% of the projects of less than 1 MW, connected to the Colombian local distribution system, were solar [34]. Additionally, the use of autonomous photovoltaic solar systems is characteristic within the country, being used in rural electrification, agriculture, livestock, deforestation, military applications or energization of communications, signaling and control of equipment that are far from the network [35]. Huge parts of these are low-power private projects, with the purpose of benefitting the private capital of companies, organizations or individuals.

Once the responses of the panel of experts were analyzed, it was observed that, initially, the economic variable related to the price of the dollar was not highlighted as one of the most important, but after completing the second questionnaire, this variable acquired a higher level of equal importance correlated to the variables highlighted as "Very important" in this same category. This shows, in some way, that the fluctuation in the cost of foreign currency is one of the variables to consider when planning or implementing the development of photovoltaic solar projects in Colombia.

In 2020, the current projects between phases 1, 2 and 3 began to suffer a significant decrease, concluding in October of that year, with a reduction of registered projects of approximately 50% compared to January of the same year, demonstrating that there are various factors that drastically affect these projects; therefore, economic variables are not the only variables to consider. As shown by the results of the surveys, the social variables have an equal level of importance and within these, the three most relevant are: the area where the project is or is not a ZNI, social integration that generates the development of the project in the area and level of appropriation of technologies by the community.

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