SOCIOECONOMIC IMPACT ASSESSMENT AND EMPOWERMENT OF SOLAR PHOTOVOLTAIC PROJECTS FOR AUTONOMOUS HOMES IN COLOMBIA

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ABSTRACT

A statistical model has been developed using multivariate analysis techniques to evaluate the social and economic impacts of photovoltaic solar energy projects for autonomous rural housing in Colombia. All the general variables of each impact and the conditions specific to each project were analyzed, according to their location, size of the project, among others related to economic and social impacts to create an appropriate evaluation methodology; through a questionnaire, survey was able to measure the satisfaction of beneficiaries in a project developed by the IPSE (Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas). The social investment project was aimed at improving the quality of life of 100 families in the department of Casanare, Colombia. This research has a descriptive and applied field methodological approach, including visits to rural dwellings, application and analysis of instruments, photographic record, interview with experts and direct observation. For the validation of this research work, experts in the field of solar photovoltaic electrification were invited as potential users of the evaluation tool.

Keywords: statistical model, impact assessment, social impact, economic impact, solar photovoltaic, autonomous system.

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INTRODUCTION

The generation of electricity with solar energy using photovoltaic systems has always been directed to the rural sector, where the high costs of generation originated mainly in the price of fuels, and the costs of Operation and Maintenance in remote areas, make solar photovoltaic generation more economical and confined in the long term. In Colombia this progress also occurred, photovoltaic energy began with the arrival of telecommunications power plants in the 1980s; small photovoltaic generators of 60 WP (WP: watt peak) were installed to power systems located in the rural area. (Rodriguez Murcia 2008).

In Colombia, available sources of solar resource information indicate that the country has an average irradiation of 4.5 kWh/m^2/d (UPME, IDEAM, 2015), which exceeds the global average of 3.9 kWh/m^2/d, and is well above the average received in Germany (3.0 kWh/m^2/d) (ArticSun, SF) country that makes greater use of solar PV worldwide, with approx. 36 GW of installed capacity as of 2013 (REN21, 2014).

Electrification from photovoltaic solar systems is a solution for rural homes that are far from the electricity grid, however, all projects implemented through IPSE do not achieve economic impacts, expected, therefore, to create a model or tool that allows to predict these impacts, or to carry out an ex-post evaluation, is a great alternative and instrument of approval before the calls at the national level. As background to this project our work corresponds to Sota Sández (2013), who performed the: "Model for the Design and Evaluation of the Impact on Human Development in Renewable Energy and Energy Efficiency Projects". The methodology is based on a set of indicators, that contemplate all the potential impacts that Renewable Energy and Energy Efficiency projects can have on the living conditions of the communities where they are implemented. The indicators are grouped by criteria, and these, in turn, in four principles (or dimensions), which mark the objective and scope of the model: Economic, Social, and Empowerment.

The S & E methodology (Sustainability & Empowerment) is a flexible tool, based on a system of principles, criteria and indicators. Since there are tools designed to measure the contribution to development on a global scale, and taking into consideration previous studies that point to the need to include the development component from the design stage of the CDM in order to really generate sustainable development in the communities in which these projects are implemented (Boyd *et al.*, 2007; 2. Hobbs et al., 2008; Sirohi, 2007), This evaluation model presents the multivariate statistical analysis of the instrument entitled "intervention survey", which was applied to a total of 76 inhabitants in Hato Corozal (Casanare) and whose general objective was to collect useful information on the construction of a model that assesses the social and economic impact of solar photovoltaic projects for homes located in areas not interconnected to the grid, with the aim of contributing to optimal decision-making in the study context.

The analysis involves the implementation of quantitative and qualitative variables, which is divided into three parts: the first one being the descriptive analysis of the variables, the second refers to an explanation concerning the importance of community empowerment in the implementation of this type of energy and finally, the construction of each impact model using multivariate analysis techniques.

From the study "Technical, socioeconomic and environmental analysis of electrification with photovoltaic isolated solar energy for rural housing in Hato Corozal, Casanare, Colombia" The results of the surveys showed that the beneficiary population is 100% stratum 1, the use of housing is residential, the main activity is agriculture and livestock, the source of water for human consumption 93% get it from deep well with pump. Most houses have soil or cement floors, roofs of homes are zinc and other palm, 30% of homes have no toilet, the remaining have toilet with septic well, there is no sewer, 83% use candles and lanterns for lighting (Rua 2017).

There is currently no model or tool to evaluate the social, economic and empowerment impacts of these energy projects. As indicated by the IDB (2015), According to the Development Plan for Non-conventional Energy Sources in Colombia developed by CorpoEma (2010), among the main difficulties faced in the formulation of policies aimed at promoting the development of renewable energy in Colombia, there is the absence of an objective diagnosis regarding the availability and use of such sources at the national level, together with limitations evidenced in the existing information and knowledge on the subject. In line with this failure, between 2009 and 2010, UPME developed a system called SGIC-FNCE (Sistema de Gestión y Conocimiento en Fuentes no Convencionales de Energía) as a virtual platform with the participation and dialogue of those working in this field to gather information that would allow producing a real diagnosis of the FNCER in Colombia and at the same time facilitate efficient coordination between actors of various sectors for the development of projects and initiatives to take advantage of these sources (IDB, 2015).

For impact assessment, quantitative and qualitative methods are used, are not exclusive methods and are usually used in combination, depending on the characteristics of the program to be evaluated. The National Council for the Evaluation of Social Development Policy (CONEVAL) states that: The Logical Framework Matrix or Indicators Matrix is a planning tool that in summary, simple and harmonious form clearly establishes the objectives of a program, incorporates the indicators that measure these objectives and their expected results; identifies the means to obtain and verify the information of the indicators and includes the risks and contingencies that may affect the performance of the program (Coneval.org.mx., 2017).

Among the variables to be evaluated in the social, economic and empowerment impacts of solar photovoltaic systems projects for isolated homes in Colombia are education, health, gender equality, social security, housing, poverty, public order, among others; from the economic impact is found productivity, employment, investment, rate of return, etc. "The climate of Colombia is determined by environmental, geographical and atmospheric aspects such as precipitation, intensity, solar radiation, temperature, wind systems, latitude, altitude and atmospheric humidity" (Arango, 2008). Previous projects have shown that there is a welfare in relation to electricity. Anna Göras and Christoffer Mohajer state in their master thesis that "There is a strong positive association between energy consumption and human development. In Colombia, electricity coverage is 93 percent in urban areas and 55 percent in rural areas. About 2.3 million people still do not have access to electricity. Areas outside the interconnected system pose particularly difficult electrification conditions with installed capacity based almost exclusively on diesel, 80 percent of the capacity is in plants at the threshold below 100 kW." L. T. D., & Velandia, Y. A. U. (2018).

Models for Impact Assessment

Statistical models for impact assessment have been very useful since the middle of the last century in the design and evaluation of public and private policies aimed at promoting the economic and social development of the countries of the world, which after the Second World War were faced with the need to plan a comprehensive development process (either by historical backwardness or by reconstruction tasks). Statistical tools are so present in the analysis of economic policy impacts from data, that there is a whole set of methods focused on this type of analysis catalogued as econometric methods, (which go beyond time series analyses). Statistical methods are widely used in determining the target population. From the simple exploratory analysis tools used to characterize individuals, to sophisticated geo-statistical tools that allow locating territorially those individuals with certain types of characteristics, through clustering techniques and classification methods (Soto, 2010).

The International Principles of Social Impact Assessment define Social Impact Assessment (SIA) as "the processes of analysis, monitoring and management of the voluntary and involuntary social consequences of planned interventions (policies, programs, plans, projects) and any process of social change invoked by such interventions" Vanclay (2015). For decades, the predominant idea was to "evaluate is measure", giving weight only to quantitative dimensions and indicators. Currently, impact assessment is valued as a broad and global process, in which qualitative techniques are added to the quantitative approach (Abdala, 2004).

General Conceptual Framework of the Project Cycle of the National Planning Department (DNP)

From the Conceptual Support Manual General Methodology for the Formulation and Evaluation of Public Investment Projects, the Adjusted General Methodology (AMS) is analyzed as a computer tool that helps in a schematic and modular way the development of the processes of identification, preparation, evaluation and programming of the Investment Projects.

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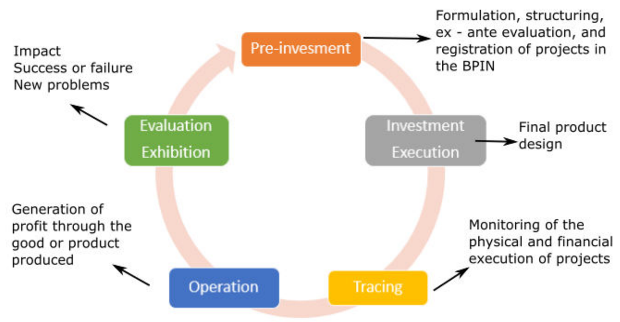

Figure-1. Cycle of public investment projects.
Source: (Directorate of Investment and Public Finance, 2013)

Impact Assessment with Quantitative Methods

The quantitative method seeks to verify the causal relationship between the action of formation and its impacts. To this end, it uses the information contained in the objectives of the program and, based on the information collected, establishes the degree to which the objectives were achieved, using an indicator.

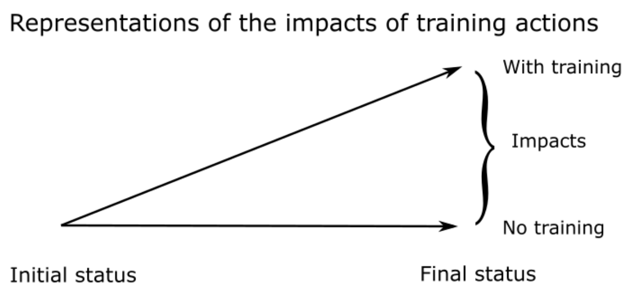

Figure-2. Representation of impacts in training actions.
Source: http://guia.oitcinterfor.org/como-evaluar/que-tipos-indicadores

Materials and Methods

A multivariate methodology is established. The sample had a total of eighty (80) families to which solar photovoltaic electrification systems were installed, whereby the use of the Stata Statistical package the analysis was built, which worked with 64 qualitative and quantitative dichotomous and polynomial variables that were included in the analysis. The procedure or method of multivariate analysis supported by correlation statisticians (SPEARMAN coefficient), for each of the three factors defined in the survey. The questions included in the survey were extracted from several international, national and institutional instruments, among which are the "Socioeconomic and environmental impact assessment of solar energy projects in rural areas of Kenya", among others.

Design of the research

Descriptive research, has a qualitative-quantitative approach where information is collected without manipulation, the design is observational according to purpose, it is prospective according to chronology, Descriptive and cross-sectional transactional type according to the number of measurements. To determine the variables a questionnaire - survey was designed, applied to a finite sample, personal type. The analysis of the surveys is done through statistical software. Based on these variables, the design of the mathematical model for the social and environmental impact assessment of solar photovoltaic systems projects for isolated homes in Colombia is carried out.

Population and Sample

The population in this research project refers to one hundred (100) houses benefiting from the IPSE for isolated photovoltaic solar electrification. For the determination of the sample size, simple random sampling characteristics were used for finite populations, as this type of sampling allows the number of surveys to be determined taking into account the following aspects:

- Sample size calculation using 95% confidence and 5% margin of error

- Proportional distribution, according to the premises under study, in order to have a sample with characteristics sufficiently representative for the study.

On the basis of the above, approximate 79 rural dwellings were identified:

$$n = \frac{Z^2\ PQN}{e^2(N-1)+Z^2\ PQ} \qquad (1)$$

Where Z is the reliability margin (expressed in standard deviations), P is the probability of the event occurring (expressed in unit), Q is the probability that the event will not occur (1-P), e is the estimation error (maximum permissible error per unit), N is the population (universe to be investigated), and $N-1$ is the correction factor by finiteness.

$$\text{n} = \frac{(1.96)^2\ (0.5)(0.5)(100)}{(0.05)^2(100-1)+(1.96)^2(0.5)(0.5)} = 79.50$$

Variable

A. Social Impact (Dependent Variable): The social impact can be measured and evaluated in the different municipalities of the country from before and after the social investment project, (Photovoltaic Solar Electrification for off-grid housing) includes variables related to the characteristics of the dwellings and their environment. In total, a set of variables are taken into account:

- Housing, ceiling and floor materials

- Number of inhabitants in the house

- Electrical appliances in the home

- Type of lighting housing
- Availability of Basic Services
- Destination of the garbage
- Source of water supply

B. Use of Autonomous Photovoltaic Solar Systems (Dependent Variable): A photovoltaic system is a device that from solar radiation produces energy in conditions of being exploited by man. To ensure the proper use and maintenance of these systems the following recommendations should be followed:

- Know the capacity or electrical generation of the solar photovoltaic system
- Know the electrical consumption of household appliances
- Know how the isolated photovoltaic system works
- Know how the electrical system of the S.F.
- Know the function and use of all components of the S. F system.
- Know how to do maintenance (cleaning) of photovoltaic solar panels

C. Expectation of the Photovoltaic Solar System as an Electrical Solution (Independent Variable): One expectation is what is considered most likely to happen; in this project the expectation is that the social and environmental impact assessment model for solar photovoltaic systems projects for off-site housing grid in Colombia is a great functional tool and great application.

- Measuring social and environmental impacts
- Mathematical assessment supported by statistical models
- Impact assessment analysis
- Recommendations for further projects of the same type
- Internal and external feedback

Investigative Tools

Fieldwork includes visits to favored homes, photographic record, georeferencing with GPS equipment and the application of an instrument (questionnaire - survey) type Likert scaling. Validation of the questionnaire - survey will be done through pilot testing and validation by experts.

Analysis of the Data

To perform the analysis of data obtained in the surveys, it is compared which variables are related to each other from a correlation study. As indicated (Vinuesa, 2016) Correlation is essentially a standardized measure of association or linear covariation between two variables. This measure or correlation index r can vary between -1 and +1, both extremes indicating perfect, negative and positive correlations respectively. A value of r = 0 indicates that there is no linear relationship between the two variables. A positive correlation indicates that both variables vary in the same direction. A negative correlation means that both variables vary in opposite directions. The interesting thing about the correlation index is that r is itself a measure of the size of the effect, which is usually interpreted as follows:

Negligible correlation: $r < |0.1|$
Low correlation: $|0.1| < r <= |0.3|$
Median correlation: $|0.3| < r <= |0.5|$
Strong or high correlation: $r > |0.5|$

The correlation coefficient by Spearman hierarchies (Spearman's Rho) is a measure of linear association that uses the ranges, order numbers, of each group of subjects and compares those ranges. This coefficient is very useful when the number of pairs of subjects (n) to be associated is small (less than 30). Apart from allowing to know the degree of association between both variables, with Spearman's Rho it is possible to determine the dependence or independence of two random variables (Elorza, 1999). The Spearman correlation coefficient, also known as ordered ranges, is one of the most applied. Its usefulness stands out when the number of pairs of scores (n) to be associated is small (less than 30). If the number of such pairs is very large, a parametric model is used, since, by the central limit theorem, the condition of normality does not affect the results. This coefficient is a variety of the Pearson coefficient, so it is defined as follows:

$$rs = 1 - \frac{6T}{n(n^2-1)} \quad (2)$$

$$T = \sum_{t=1}^{n}[R(x_1) - R(y_1)]^2 \quad (3)$$

Where n is the sample size, $R(x_1)$ is the x hierarchical variables (ordenadas), and $R(y_1)$ is the y hierarchical variables (ordenadas). In addition to obtaining the degree of association between both variables with rs, it is possible to determine the dependence or independence of two random variables. For the independence test in which you use (rs) there are three things:

A. Two-Sided Test

H0: x_i and y_i These are mutually independent.
H1: a) When high values of x tend to be paired with high values of y. b) When low (or small) values of x tend to be paired with high (or large) values of y. If H_i is not rejected, both for a) and b), x and y are dependent.

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B. One-Sided Test, Positive Correlation

H0: x_i and y_i These are mutually independent.

H1: When high (or large) values, x and y tend to be paired at the same time. Then, x and y are dependent.

C. One-Sided Test, Negative Correlation

H0: x_i and y_i These are mutually independent.

H1: When small or low values of x tend to be paired with high or large values of y; the inverse case is also foreseen. X and y are considered dependent.

Although the null hypothesis of no correlation between x and y is more precise than the concept of independence between x and y mentioned above (and which implies existence) as indicated by the alternating hypotheses of correlation between x and y, in this text the concept of independence will be used because it is easier to interpret and has a wider use.

For results analysis the Spearman correlation coefficient is a particular case of the Pearson linear correlation coefficient; therefore, for practical purposes, rs can be interpreted as rxy, although if there were many draws in the ordered data rxy and rs will disagree. (Pérez-Tejada, 2008)

D. Specification of Discrete Choice Models (Logit and Probit)

Since the use of a distribution function ensures that the result of the estimation is bounded between 0 and 1, in principle the possible alternatives are several, the most common being the logistic distribution function, which has given rise to the Logit model, and the distribution function of the standardized normal, which has given rise to the Probit model. Both the Logit and Probit models therefore relate the endogenous variable Y_i to the explanatory variables X_{ki} through a distribution function. In the case of the Logit model, the function used is logistics, so the specification of this type of models is as follows:

$$Y_i = \frac{1}{1+e^{-\alpha-\beta_k X_{ki}}} + \varepsilon_i = \frac{e^{\alpha+\beta_k X_{ki}}}{1+e^{\alpha+\beta_k X_{ki}}} + \varepsilon_i \quad (4)$$

RESULTS

The population surveyed is located entirely in rural areas, for this analysis, a total of 76 respondents were specifically counted, most of whom have a level of education at least of baccalaureate with 68.5%. The population of respondents is divided by gender into 17.1% women and 82.9% men, as shown in Figure-3.

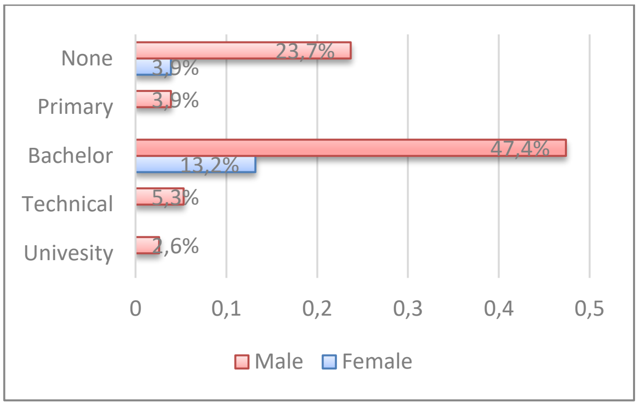

Figure-3. Distribution of the sample according to gender and level of schooling. Source: Authors

According to age, the sample is grouped by frequencies in seven classes, where a higher percentage of users of photovoltaic cells between 40 and 48 years of age predominates, with 39% of the population followed by 22% for adults between 48 and 56 years, as indicated in Table-1.

Table-1. Distribution of frequencies grouped by age.

Age range	Simple frequency	Percentage
[24 – 32)	3	4%
[32 – 40)	6	8%
[40 – 48)	30	39%
[48 – 56)	17	22%
[56 – 64)	12	16%
[64 – 72)	6	8%
[72 – 80)	2	3%
Total	76	

The distribution according to the marital status of the respondents is presented as follows (Figure-4), most of them are in a cohabiting state or are classified as a domestic couple, domestic pairing or free association, where such bonding and cohabitation between the members of de facto couples, which sometimes leads to economic dependence similar to that of a marriage, some legal systems have found it necessary to regulate them to avoid the abandonment of some members of the couple in certain situations such as death of the other, illness, etc.

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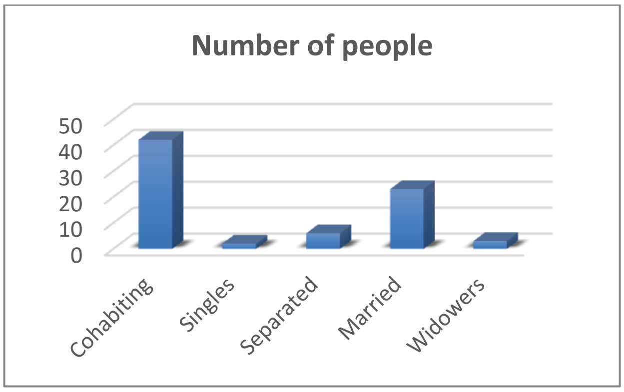

Figure-4. Distribution of the sample according to marital status. Source: Authors

Analysis of Empowerment Variables

The perception of the target population in terms of development in terms of empowerment is presented below. This project is synthesized in a strategy of sustainable community energy development, where training the population in the use and good management of solar panels, was contemplated through workshops, brochures or seminars, Illustration 15 shows the percentage of application of these strategies where the use of brochures stands out with 37.9%, this is an advertising strategy that aims to give information about a product in this case solar panels, because of this, it always pursues simplicity and exposing clear and succinct messages, This is according to the need of the community a very poor strategy to contribute in the empowerment of this type of energy without counting that the majority of the population only has a high school level, the strategy does not manifest a high effectiveness.

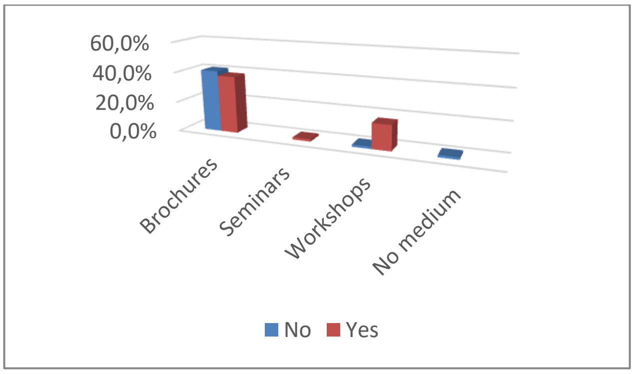

Figure-5. Distribution for the type of activities implemented to empower the implemented energy method (solar panels). Source: Authors

Figure-6, presents an effective strategy used for empowerment (workshops) since the use of leaflets reached a large population, but did not achieve the goal, the activity of how it is addressing the community must be addressed more effectively. The implementation of workshops, with 16.7% applicability, translates into the best strategy and should become a pioneering plan of empowerment with the community.

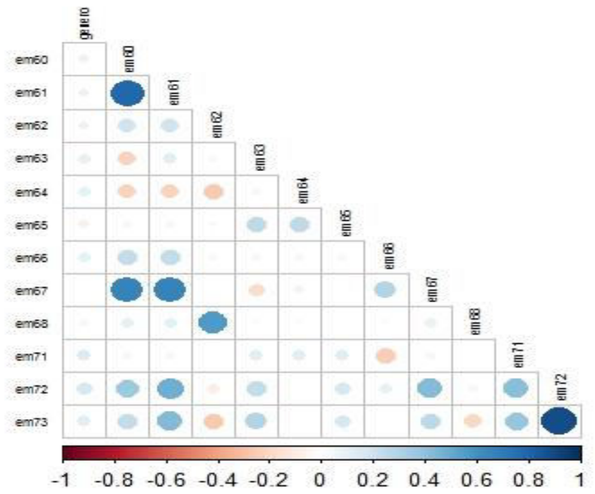

Figure-6. Spearman coefficient for empowerment variables Source: Authors

Questions number em60 shows a positive and strong correlation of approximately 90% with question em61, where there is an intimate relationship between the need to train people in solar panels and that this training must be carried out with regard to use and maintenance, the em60 question also shows a high correlation approximately 80% with the em67 question which contrasts in turn as a requirement the need to build a policy of care for the environment with the awareness of the population in the rational use of the renewable energy. These three questions become characteristics of empowerment. Question number em72 shows a positive and strong correlation, also 90% with question em73, which presents a substantial contribution to the community considering the increase of the female labor force and also positively improve the possibility of inclusion of disabled people in a labor force.

Factor 1 Analysis: Impact or Economic Dimension

Figure-7 presents an overall analysis of the correlation between 13 of the questions included for the economic impact factor. It is important to mention that the use of the Spearman coefficient applies mainly in samples that do not have a normal distribution, conditions identified in the survey carried out in this project.

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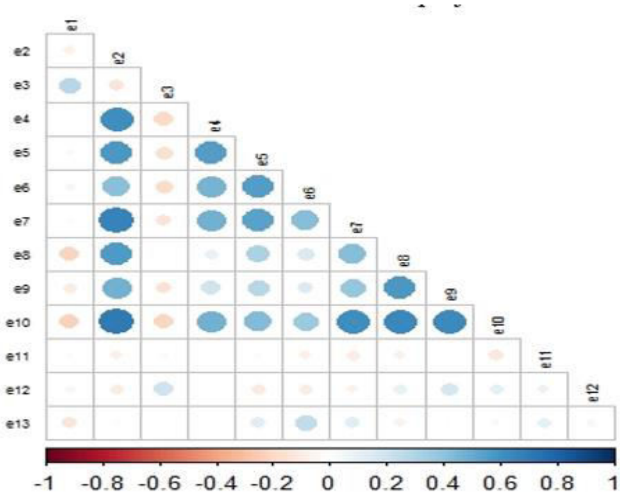

Figure-7. Spearman coefficient for variables, economic impact factor Source: Authors

Figure-7 shows the possible association between pairs of variables (questions), where it is established that the color red indicates a negative association, while the color blue refers to a positive association, Additionally, the higher the color intensity and the greater the area of the stronger circle is the association.

Question number e2, which refers to the creation of a project linking the use of energy through solar panels, has a positive relationship of almost 70% with variables such as e4, which speaks of a possible increase in infrastructure construction, which is closely related to the economic development of the region, with variables such as e5 and e6, which demonstrate satisfactory working conditions or which are intimately linked to an economic impact. In addition to showing a positive relationship with e8 of 60%, a variable that speaks of the satisfaction of users of solar panels in terms of meeting their needs.

Factor 2 Analysis: Impact or Social Dimension

Figure-8 presents an overall analysis of the correlation between 12 questions included for the social factor. It is important to mention that the use of the Spearman coefficient applies mainly in small samples that do not have a normal distribution, conditions identified in the survey carried out in this project.

Questions number 27 shows a positive and strong correlation of approximately 90% with question s26: s26 Do your children currently attend school? Can your children study longer at home since they got access to electricity from solar panels?

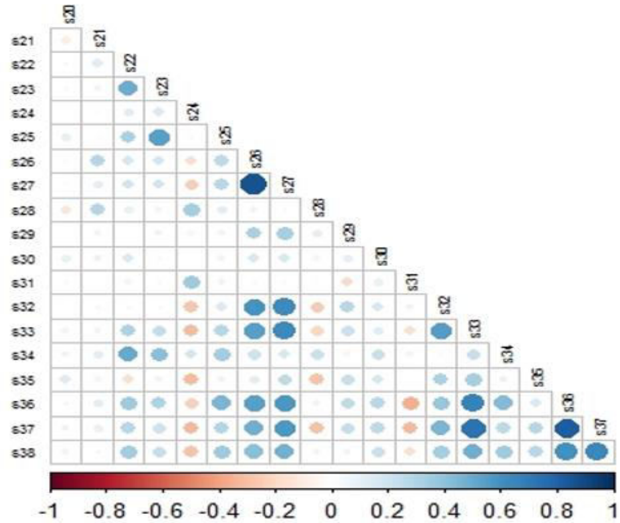

Figure-8. Spearman coefficient for variables, social impact factor Source: Authors

Multivariate Analysis of Economic and Social Impact

The second part of the analysis is called multivariate analysis and in it models are structured, using specialized software such as R-Study and Stata that allows evaluating the social and economic impacts of solar photovoltaic systems projects for homes located in areas not interconnected to the grid, in turn presenting the validation of each impact assessment model.

Thus, in this section, we will find two Logit models, associated with the variables returned economic impact factor, and social, for the project solar photovoltaic systems for isolated homes, in Hato-Corozal, Casanare municipality (Colombia).

The models were estimated with a confidence level of 80%, the previous effect that, for some variables, some respondents did not reply and there was a lack of this information, which reduced the information needed for higher confidence estimation.

The dependent variables for each of the models are defined and encoded as follows:

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Table-2. Independent variables by model.

Question	Variable	Name of the model question	Variable Type	Codification of the variables
Do you think that the use of solar panels has positively impacted your economy?	Economic impact	$e1$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Do you consider the use of solar panels to have a positive impact on your family's quality of life?	Social Impact	$s20$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$

Source: Authors

Economic Element

For the estimation of the changes of probability on the economic impact variable (e1), the following group of questions of the survey that will be the explanatory variables for this factor were selected, these variables are:

Table-3. Regressive variables, economic impact factor.

Question	Name of the model question	Variable Type	Codification of the variables
Since the implementation of solar panels, have you created or currently have a productive project that directly links this activity?	$e2$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Have you saved money since implementing the use of solar panels?	$e3$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
With the implementation of the solar panels project, do you consider that the number of infrastructures has increased as a result of the project, such as roads, bridges, community centers, schools, health centers, classrooms or Huts?	$e4$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Has your number of working hours decreased since the solar panel system was implemented?	$e6$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Did you receive training on new technologies, specifically on the advantages and disadvantages of using solar panels?	$e7$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Is the power supply sufficient to cover all your needs?	$e8$	Polynomial	$\begin{cases}\text{At odd} = 1\\ \text{Others} = 0\end{cases}$
What is your current occupation?	$e11$	Polynomial	$\begin{cases}\text{Livestock} = 1\\ \text{Others} = 0\end{cases}$
How much monthly money have you been able to save since the solar panel system was installed?	$e13$	Quantitative	The natural logarithm of this value shall be used for the model.
Can you say that the implementation of the solar panel system has prompted you to buy appliances or communication equipment for your home?	$s31$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
With the implementation of the energy system, do you think that employment options in the region have increased?	$s38$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Does it consider that there has been an improvement in yields or in the volume of crops after the use of solar panels?	$a48$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Age (From the person who answered the survey)	ed	Quantitative	

Source: Authors

For this first model, the information of 76 people of the 78 respondents was used, given that, in some variables chosen, there was missing information.

Table-4 shows the p-values of each of the variables selected as regressors, for the economic impact variable, and from them determine whether they are statistically significant or not.

Table-4. P-values regressive economic factor.

Dependent variable $e1$	**Coef.**	**Std. Err.**	z	$p > z$	**[80% Conf. Interval]**	
$e2$	-2.01	1.60	-1.26	0.21	-4.06	0.03
$e3$	4.04	1.76	2.30	0.02	1.79	6.29
$e4$	-0.35	1.54	-0.22	0.82	-2.32	1.63
$e6$	3.25	1.92	1.69	0.09	0.78	5.71
$e7$	2.25	1.66	1.36	0.18	0.13	4.38
$e8$	3.80	1.95	1.95	0.05	1.31	6.30
$e13$	-4.79	2.23	-2.15	0.03	-7.64	-1.94
$s31$	-0.55	1.47	-0.37	0.71	-2.44	1.34
$s38$	-0.15	1.16	-0.13	0.90	-1.64	1.34
$a48$	3.15	2.55	1.24	0.20	-0.11	6.42
ed	0.17	0.08	2.16	0.03	0.07	0.28
_cons	46.07	23.77	1.94	0.05	15.61	76.53

Source: Authors

Based on the fact that the level of significance for the present estimate of α=20%, it can be observed in Table-6 and in the third column of this, that the only variables that exert changes of probability on the economic impact variable are e3, e6, e7, e8, e13, e48 and ed. Since the p-values of these variables are less than or equal to 20%.

The variable e3 is positive and statistically significant, which implies that there is a strong relationship with the probability that a person who has saved money since the implementation of the photovoltaic system, considers that this system has positively impacted the economy of its environment. For the case of variable e6, its sign is positive and this is statistically significant, so a person who claims that by the effect of implementing solar panels could have decreased their working hours, increases the probability of this considering that in effects such energy system has positively impacted the economy.
For the case of variable e7, its sign is positive and this is statistically significant, so a person who claims that by having received training on new technologies specifically on the advantages and disadvantages of the use of solar panels, increases the probability of this considering that in effects said energy system has positively impacted its economy.

Variable e8 is another explanatory variable with a positive coefficient, so, although a person disagrees in stating that the energy supplies to today does not cover all its needs, increases the probability that it considers that in fact there has been a positive impact on the economy effect of solar panels, the reason is that in something has favored such implementation.

The variable e13, is the natural logarithm of the monthly money that people estimate has saved since the solar system was implemented, if that money only increases by $1 a month, the probability that people consider that there is indeed a positive impact of the solar panel system on the economy decreases as it does with the sign of the coefficient of the variable, this may be given because it is a very small increase over the monthly change.

In the case of variable a48, which is statistically significant and positive, if a person considers that the yield or volume of their crops has improved since the implementation of solar panels, the probability that this person considers that this energy system has positively impacted the economy, increases.

Finally, the variable ed, which corresponds to age, suggests that an additional year of age in people who accessed this photovoltaic energy system, will increase the probability that these people consider that this system has positively impacted the economy. It should be noted that all of the above interpretations were made on average. y ceteris paribus.

The following table shows the probability ratios (Odd Ratio) and the marginal effects (dy/dx), the economic impact factor.

Table-5. Odds ratio and marginal effects, explanatory variables.

Dependent variable $e1$	**Odds Ratio**	dy/dx
$e2^*$	0.134	-0.044
$e3^*$	56.651	0.427
$e4^*$	0.708	-0.008
$e6^*$	25.779	0.035
$e7^*$	9.508	0.058
$e8^*$	44.922	0.123
$e13$	0.008	-0.099
$s31^*$	0.578	-0.010
$s38^*$	0.858	-0.003
$a48^*$	23.396	0.024
ed	1.190	0.004
_cons	1.02E+20	
(*)dy/dx is for discrete change of dummy variable from 0 to 1		

Source: Authors

The probability that a person considers that there is a positive economic impact with the implementation of solar panels in Hato-Corozal, Casanare increases by about 42.7%, as long as this person could have saved money by implementing this energy system.

A person who had reduced their working hours per day as an effect of the implementation of the photovoltaic energy system has about 26 more options on average and ceteris paribus, to consider that such solar panels have positively impacted the economy, to a person who could not reduce his working hours by acquiring such an energy system.

The probability that a person considers that if there has been a positive impact of the energy system on the economic factor, increases by about 3.5%, when this person disagrees with regard, that the supply of energy is sufficient to cover their needs in Hato-Corozal, Casanare, the above may be subject to that although all the needs are met, some needs of the home and work have been supported by the measurement of said energy system.

The probability that people claim that the implementation of photovoltaic energy has positively impacted the economy decreases by about 9.9% if the monthly money saved by a person from Hato-Corozal using solar panels, does not have a differentiating effect between one month and the other.

A person from Hato-Corozal, who claims that with the implementation of the photovoltaic system has given a better yield in their crops has at least 23 more options to consider that this energy system has positively impacted the economy, in front of a person who observes some change in their crops since the solar panels are being used, this took into account the variable a48 *.

Finally, the probability that the photovoltaic system is considered to have positively impacted the economy increases by about 0.4%, by one year older than the person using the system.

Therefore, the model estimated for the economic impact is thus defined:

Social Factor

From the representative sample of 80 households in Hato-Corozal, Casanare, for the estimation of the environmental factor model, only 73 people were employed, as there was missing information in some variables selected for the social impact variable (s44), so the information of 7 people was deleted. For the estimation of the social impact variable, the following explanatory variables were selected from the survey applied to families.

$$\widehat{(e1)} = 4.04\ e3 + 3.25\ e6 + 2.25\ e7 + 3.80\ e8 - 4.79\ e13 + 3.15\ a48 + 0.17\ ed \quad (5)$$

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Table-6. Regressive variables social impact factor.

Question	Name of the model question	Variable Type	Codification of the variables
Have you noticed an improvement in the water quality they use at home, after the implementation of solar panels?	$s23$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Can your children study longer at home since they gained access to electricity through solar panels?	$s27$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Do you think that the implementation of solar panels has helped to improve the educational service?	$s33$	Polynomial	$\begin{cases}\text{Agreed} = 1\\ \text{others} = 0\end{cases}$
Do you think that the implementation of this project through solar panels has generated loss of traditions in the community?	$s35$	Polynomial	$\begin{cases}\text{At odd} = 1\\ \text{Others} = 0\end{cases}$
Does it consider that there has been an increase in measures to facilitate women's employment since the introduction of solar panels?	$s37$	Polynomial	$\begin{cases}\text{At odd} = 1\\ \text{Others} = 0\end{cases}$
You would qualify that today access to water service has improved, taking into account the implementation of solar panels	$s25$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Do you think that the use of solar panels has positively impacted your economy?	$e1$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Has your number of working hours decreased since the solar panel system was implemented?	$e6$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Is the power supply sufficient to cover all your needs?	$e8$	Politómica	$\begin{cases}\text{At odd} = 1\\ \text{Others} = 0\end{cases}$
Does it consider that the use of solar panels has had a positive impact on the environment in its region?	$a44$	Dichotomic	$\begin{cases}\text{Yes} = 1\\ \text{No} = 0\end{cases}$
Age	ed	Quantitative	

Source: Authors

From Table-6, the estimation of the model whose independent variable is the social impact (s20) was made, so in the following table, p-values indicating which of the independent variables are significant with respect to the selected significance level which is α=20%.

Table-7. P-values regressive social factor.

Dependent variable $s20$	Coef.	Std. Err.	z	$p > z$	[80% Conf. Interval]	
$s23$	-5.397	2.420	-2.230	0.026	-8.498	-2.296
$s27$	-2.390	1.327	-1.800	0.072	-4.091	-0.689
$s33$	-0.243	1.035	-0.240	0.814	-1.570	1.083
$s35$	-3.967	1.773	-2.240	0.025	-6.239	-1.695
$s37$	1.916	1.180	1.620	0.104	0.405	3.428
$s25$	-0.442	1.439	-0.310	0.759	-2.285	1.402
$e1$	2.703	1.249	2.160	0.030	1.102	4.303
$e6$	2.687	1.454	1.850	0.065	0.824	4.550
$e8$	-0.883	0.982	-0.900	0.368	-2.142	0.375
ed	0.068	0.046	1.480	0.139	0.009	0.126
$a44$	-3.493	1.862	-1.880	0.061	-5.879	-1.107
_cons	3.165	3.276	0.970	0.334	-1.033	7.363

Source: Authors

Table-7 shows that the statistically significant variables for the estimation of the social factor are: s23, s27, s35, s37, e1, e6, ed, and a44. Since all p-values of each of these variables are lower at the significance level of 20%. The variable s23, is a negative and statistically significant variable for this sample, so if a person considers that since the implementation of solar panels if he has noticed an improvement in water quality, the probability that this person claims that the implementation of this energy system has improved their quality of life, decreases. This response is subjective, depending on what it means to them, improvement in the quality of life.

The variable s27 is negative and statistically significant. Therefore, the probability that a person considers that the implementation of solar panels has positively impacted the quality of life of his family decreases, if this person considers that since they use solar panels in their home, their children can study longer. This is related to the lack of schools and teaching centers in these distant sidewalks, lack of transportation and frequent damage to unpaved roads.

The probability that a person considers that the implementation of solar panels has positively impacted the quality of life of his family, decreases, if the person disagrees in considering that this energy system has generated lost traditions in the community, the above effect that s35 is negative and statistically significant.

The variable s37 is significant and positive, so it has a strong relationship with the probability that a person affirms that the implementation of solar panels positively impacts their quality of life, if this person disagrees in considering that since he began to use this type of energy in his home have increased actions to facilitate the employment of women.

The variable e1 is positive and statistically significant, so that a person who considers its economy is seen to be positively impacted since the implementation of solar panels, so the probability that this person considers that such an energy system has positively impacted their quality of life increases.

Variable e6 is positive and statistically significant, so if a person considers that their working hours have decreased since the implementation of solar panels, then the probability that this person considers that such an energy system has positively impacted their quality of life increases.

The positive sign and significance of ed, which corresponds to age, suggests that one year older in a person accessing the photovoltaic system, will increase the likelihood that such a person believes that this system has positively impacted their quality of life.

Finally, if a person considers that the photovoltaic energy system has positively impacted the environment, the probability that this person claims that this system has also positively impacted their quality of life decreases, which is the result of the coefficient sign of variable a44. Even if they manage to receive electricity, they still do not have access to media, internet, telephony, they need to supply more basic needs to improve their quality of life. Based on the above, the following table presents the odds' ratio (probability ratios) and the marginal effects (dy/dx), for all the statistically explanatory variables of s20 (social impact). In Table-8, for example, the probability that a person considers that the photovoltaic energy system has positively impacted their quality of life decreases by at least 87.39%, if this person has noticed that water quality has improved since the implementation of the system.

Table-8. Odds ratio and marginal effects, explanatory variables.

Dependent variable $s20$	Odds Ratio	dy/dx
$s23^*$	0.0045	-0.8739
$s27^*$	0.0917	-0.1675
$s33^*$	0.7840	-0.0195
$s35^*$	0.0189	-0.2524
$s37^*$	6.7955	0.1338
$s25^*$	0.6430	-0.0379
$e1^*$	14.9219	0.4223
$e6^*$	14.6910	0.1206
$e8^*$	0.4133	-0.0697
ed	1.0699	0.0051
$a44^*$	0.0304	-0.1327
_cons	23.6872	
(*) dy/dx is for discrete change of dummy variable from 0 to 1		

Source: Authors

A person who considers that, since the implementation of solar panels, their children can study longer, has about 9 fewer options to affirm that this energy system has positively impacted their quality of life, in front of a person who claims otherwise.

If a person disagrees in considering that the PV project has generated loss of traditions in the community, then the probability that this person claims that said energy system has positively impacted their quality of life decreases by about 25%.

If a person using solar panels in Hato-Corozal considers that this system has positively impacted their economy and has contributed to reducing their number of working hours, then the probability that this person considers such panels impacts their quality of life, increase by at least 42 % and 12 % respectively.

An additional year of age, will cause the probability that a person from Hato-Corozal who uses the solar panel system considers these to positively affect their quality of life, increase by at least 0.05%.

Therefore, the estimated model for social impact is defined as follows:

$$\widehat{(s20)}=-5.397\ s23-32.390\ s27-.967\ s35+1.916\ s37+2.703\ e1+2.687e6+0.068\ ed-3.493\ a44 \quad (6)$$

It is important to note that the two models had a good goodness of fit, so, according to the Test, the percentage of prediction on the total data of each of the models was: 89.19% (economic impact model), and 83.82% (social impact model)

5. CONCLUSIONS

The model applied in this study is probabilistic for the variables that are mostly quantitative. Linear regression models contribute to the analysis of a dependent variable, measured on a scale of interval (quantitative) according to explanatory variables measured also on the same scale. With this project, it is possible to apply a regression model that allows us to study nominal or ordinal variables as a function of quantitative variables, and also to consider qualitative variables. Through these three equations are obtained that relate the most significant variables in each economic and social factor, thus contributing to decision-making, for the implementation of ex ante and ex post energy projects in Colombia, Purposes addressed by the IPSE (Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas)

The model shows positive and negative probabilities, with these results you must then look for strategies or improvement plans to obtain an increasingly large positive coefficient and try to reduce the negative coefficient. In some cases, unexpected negative values or coefficients can be obtained when evaluating the impacts of each factor, this is because some questions are not very clear, contain words that may be subjective or are technical and unknown words.

Community empowerment in terms of the use and good management of a resource such as solar panels does not have much impact, the alternatives presented by the project leaders are not the most effective should be implemented a better method to reach the communicated with more effective communication.

The implementation of programs that contribute to the improvement of the living conditions of the population is undoubtedly fundamental and should become the cornerstone of any municipal or departmental public policy, but not only its implementation; the construction of methods that allow to estimate the impact of this is necessary it contributes to establish improvement measure and to avoid economic losses.

The survey is conducted to evaluate the economic and social impacts of solar photovoltaic electrification projects in Colombia. With the support of IPSE, the variables of each impact (economic, social and empowerment) its indicators and questions are determined. Through this, a mathematical and statistical model is elaborated that allows predetermining the impacts (prior to the realization of the project) taking into account quantitative and qualitative variables with different degrees of relevance. The mathematical and statistical model is performed in the Stata software.

The intention of the design of surveys is generated from the need to mediate the relationships between variables, in this case data that respond to areas that involve the impact of social and economic plans. To consolidate the design objectives of these, it is recommended to avoid the application of a sampling for convenience and to resort to an alternative that allows guaranteeing the reliability in the consolidation of the analysis of the same and to contribute in the part of the descriptive development and inferential. The design of the instrument is only the means of collecting information, this leads to require that the process of interviewing be as rigorous as possible. Complying with previously established sample size limits is necessary; this allows improving the reliability of the results.

Since the implementation of solar panels it is clear that it has evidenced an increase in the improvement of the social conditions of the municipality, this in reason of the fact that each family nucleus considers that it has evidenced a saving in money in its home, as well as an increase or yield in crops; in addition to the installation of this type of energy fully reaches to cover all your needs. The majority of the surveyed population belongs to the male gender, and the majority of them are heads of household, the implementation of this project is presented as a possibility of labor improvement for the female gender. The age of the beneficiaries should be included in the statistical mathematical model because it can generate some effect. The model obtained gives a high goodness fit.

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