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Equity and Renewable Energy: An Analysis in Residential Users in the Department of Atlántico-Colombia

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ABSTRACT

Sustainable development has its complexity in seeking a balance between the three dimensions, renewable energies require an economic investment and are friendly to the environment; but due to socioeconomic differences, access and widespread use may be limited. Colombia has a subsidy mechanism according to socioeconomic strata, where the lower strata receive a reduction in the price of energy by a set amount of kWh, while the upper strata contribute a 20% of the final price. This research performs an economic evaluation due to the investment made in a photovoltaic system, considering socioeconomic factors; The results will make it possible to identify factors that affect equity and access to these technologies.

Keywords: Energy Policy, Barriers, Equity, Renewable Energy
JEL Classifications: K29, Q48

1. INTRODUCTION

Energy is an essential element for economic and human development (Embid and Martín, 2013; Salahuddin et al., 2018), ensuring that each place has this service is a priority for any nation that wishes to improve the well-being and progress of its population (Chen et al., 2019; Kaur and Luthra, 2018). For this, it is necessary to have a robust infrastructure that facilitates the integration of new technologies for the generation, transmission and distribution of electrical energy (Puentes, 2020). The electricity sector is integrating renewable energy sources through smart grids so that they can interact amicably with the traditional electricity system and achieve sustainable implementation (Babadi et al., 2018; Barrozo et al., 2020; Shahid, 2018).

This work requires government policies and the participation of the private sector (Hassan et al., 2018; Hvelplund and Djørup, 2017); The Colombian government began its route with Law 1715 (2017), which dictates the regulation for the promotion, integration, development and use of non-conventional renewable energies to the national energy system. Seeking to achieve participation in non-interconnected zones, reduction of greenhouse gas emissions, generate sustainable economic development and improve energy security (Núñez et al., 2020).

To achieve interaction, the Ministry of Mines and Energy (MME) issued resolution 40072 which established the mechanisms to implement the Advanced Measurement Infrastructure (AMI) in the public electric power service; committing to goals where it projects that by the year 2030, 95% of urban users and 50% of users of populated and rural centers should be included in the implementation of advanced measurement infrastructure (MME, 2018), and maintaining promoting efficient energy management, which includes both energy efficiency and demand response.

The environmental impacts linked to energy development generate environmental implications mainly associated with the generation of polluting emissions such as CO_2 (Belaïd and Zrelli, 2019), social such as social equity (Grover and Daniels, 2017; Milanés-Batista et al., 2020) and universal access to energy (Łapniewska, 2019), and economic services due to the purchasing power and business opportunity for private investors (Lekavičius et al., 2019). By integrating renewable energy technologies and energy efficiency, environmental impacts have a positive impact (Belaïd and Zrelli, 2019), but achieving economic viability and access to the network for less favored users is the greatest challenge for this transition (Grover and Daniels, 2017; Łapniewska, 2019). Developing business models that allow solving these gaps are key to sustainable development and the achievement of government objectives (França et al., 2017; Shomali and Pinkse, 2016).

The research will evaluate the economic capacity for the implementation of photovoltaic generation systems based on the socioeconomic conditions in the department of Atlántico, the results obtained will allow analyzing the social equity for the access of these technologies and will help to identify barriers that affect the government aims.

2. METHODOLOGY

This research presents the description of the Colombian legal and regulatory framework, a three-phase methodology was used, first a characterization of the socioeconomic conditions of the population of the Department of Atlántico is carried out, analyzing the variables of electricity consumption and economic income, A search is made of the services offered by companies for the acquisition and installation of photovoltaic equipment and thus secure market prices. In the second phase, an economic evaluation is carried out, the savings from the use of the generated energy are calculated and compared with the investment returns. Finally, the results obtained are analyzed and factors affecting equity and the electric power market are identified, which act as inhibitors for the massification of this generation technology.

3. RESULTS

Colombia has implemented a regulatory framework to encourage renewable energies, Law 1715 (2014) was the beginning to begin this energy transition, with tax and tariff exemptions being the benefits offered. Table 1 presents the Colombian regulatory framework in relation to non-conventional renewable energies.

According to Table 1, the regulations for a residential home are established by Resolution 030 (2018); where it is established that the sum of the installed power of the generators that deliver to the network must be equal to or less than 15% of the nominal capacity of the circuit, transformer or substation where the connection point is requested; being a limitation the nominal capacity of the transformer for the residential sector, encouraging the installation of storage equipment or an off-grid configuration.

3.1. Users and Electricity Service

Colombia has a system of subsidies in the service of electricity, according to a socioeconomic stratification, this is a classification in strata of residential properties that should receive public services (DANE, 2020b). Table 2 shows the subsidy relationship according to socioeconomic stratum.

Table 1: Legal and regulatory frameworks related to NCRES in Colombia

Legal and regulatory frameworks	Commentaries
Decree 2492 (2014)	It defines provisions regarding the implementation of demand response mechanisms.
Decree 2469 (2014)	It establishes the energy policy guidelines regarding the delivery of surpluses from self-generation.
Resolution 038 (2014)	It regulates self-generation activity in non-interconnected areas and some provisions are issued on distributed generation in non-interconnected areas.
Resolution 0281 (2015)	It defines the maximum power limit for small-scale self-generation.
Resolution 024 (2015)	It regulates large-scale self-generation activity in the National Interconnected System.
Decree 1623 (2015)	It establishes modifications to the policy guidelines for expanding the coverage of the electric power service in the National Interconnected System and in the Non-Interconnected Zones.
Resolution 1312 (2016)	It establishes terms of reference for the preparation of the Environmental Impact Study required for the environmental license process.
Resolution 1283 (2016)	It establishes the procedure and requirements for the issuance of the certification of environmental benefit for new investments in projects of Non-Conventional Renewable Energy Sources and efficient energy management.
Decree 348 (2017)	It establishes additional guidelines for efficient energy management and surplus delivery from small-scale self-generation.
Resolution 167 (2017)	It defines the methodology to determine the firm energy of wind plants.
Resolution 201 (2017)	It modifies Resolution CREG 243 of 2016, which defines the methodology to determine the Energy for the Reliability Charge of photovoltaic solar plants.
Resolution 030 (2018)	It regulates small-scale self-generation and distributed generation activities in the National Interconnected System.

Through the Decree 4955 (2011) the payment of the solidarity contribution of the industrial sector with activities described in Resolution 00432 (2008) from activity 011 to 456 was exonerated. Colombia is a country that has thermal floors, through Resolution 355 (2004) the amount of subsidized energy per month was determined; for heights lower than 1,000 m above sea level they receive 173 kWh, and heights above 1,000 receive 130 kWh. The department of Atlántico is below 1,000 meters above sea level. Figure 1 shows the behavior of consumption according to the contribution and subsidies scheme during the period from January 2019 to May 2020, and Figure 2 shows the behavior of electricity consumption according to the socioeconomic stratum in the Department of Atlántico; the number of users is distributed

Table 2: Subsidy and contribution scheme of electricity price in Colombia

Strata	% Subsidy or contribution	Formula
Strata 1	Subsidy of 60%	*Ct ($/kWh) = CU ($/kWh) – Subsidy*
Strata 2	Subsidy of 50%	
Strata 3	Subsidy of 15%	
Strata 4	No subsidy, no contribution	*Ct ($/kWh) = CU ($/kWh)*
Strata 5	Pay a contribution of 20%	*Ct ($/kWh) = CU ($/kWh) - Contribution*
Strata 6	Pay a contribution of 20%	
Institutional	No subsidy, no contribution.	*Ct=CU ($/kWh)*
Commercial	Pay a contribution of 20%	*Ct ($/kWh) = CU ($/kWh) + Contribution*
Industry	Pay a contribution of 20%, with exceptions	*Ct ($/kWh) = CU ($/kWh) + Contribution*

Source: (CELSIA, 2020; ESSA, 2020)

according to their stratum as follows: 48%, 26%, 14%, 7%, 3% and 2% (SUI, 2020), stratum 1 and 2 are the 74% of the subscribers of electricity service.

The behavior of electricity consumption in Figure 1 shows an unbalanced behavior between the subsidized strata and the taxpayers, due to the exemption of the industrial sector by Decree 4955 (2011), few subscribers of strata 5 and 6 (5% of the residential) (SUI, 2020) and the incursion of self-generation projects in the industrial sector (SIEL, 2020); These conditions will generate a financial imbalance to sustain the subsidies and that will have implications such as the reduction and/or elimination of these.

The National Administrative Department of Statistics (DANE) carried out a study where the income of the population in deciles (DANE, 2020a), Figure 3 shows the behavior in Statutory Monthly Minimum Wage (SMMW).

Currently, the SMMW is at 232.96 USD (Market Representative Rate: 1 USD = 3768 COP), Figure 3 indicates that 20% of the Colombian population has income equal to or less than one (1) SMMW; 50% of the population has incomes greater than two (2) SMMW and only 5% has income from 12 to 114 SMMW. The behavior indicates a difficulty to access or respond to high-cost investments, 2 SMMW would be equivalent to 465.92 USD.

3.2. PV Generation in the Department of Atlántico

The Colombian market has allowed the development of companies specialized in products and services related to renewable energies and energy efficiency; massifying these services at an industrial, commercial and residential level, due to the benefits that are achieved by reducing the consumption of energy from the network, the tax benefits or the energy that is delivered to the network. The companies market PV generation kits of different requirements requested by the client. Figure 4 presents the irradiation profile for each of the months, the data between the years 2015 and 2019 were used (NASA, 2020); At 1:00 p.m. the highest irradiance value is presented, obtaining the highest value during the year in March. Table 3 shows an average cost ratio and the description provided by the companies.

Figure 1: Behavior of electricity consumption according to contribution scheme. Source: (SUI, 2020)

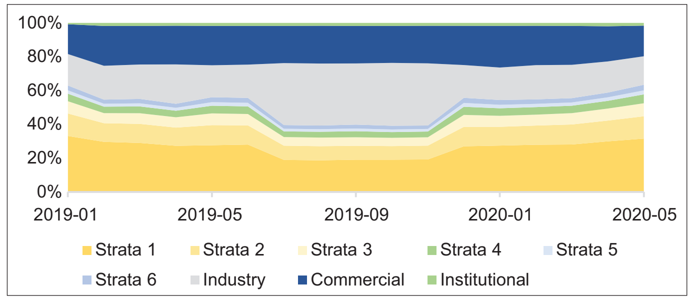


Figure 2: Electricity consumption according to socioeconomic stratum. Source: (SUI, 2020)

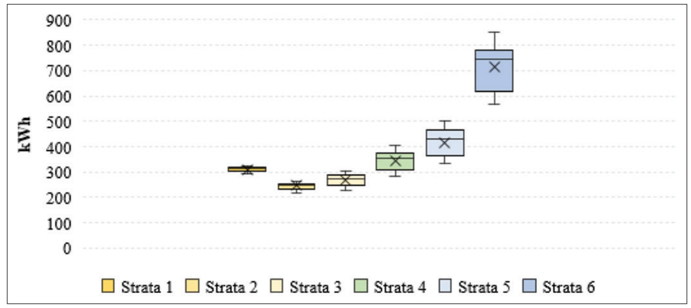
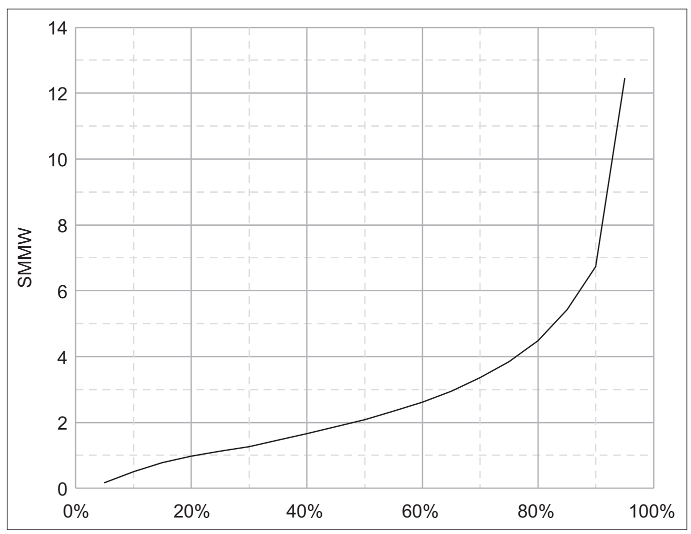


Figure 3: Economic incomes of the Colombian population. Source: (DANE, 2020a)



3.3. Economic Evaluation: Income from Generated Energy

Investing in a PV generation system will depend on the profit obtained from the energy left to consume; Figure 5 shows the behavior of the price of electricity, if this price exceeds the scarcity price, it will be billed with the scarcity price, acting as a limit to the increases (Ausubel and Cramton, 2010; Resolution CREG 156, 2016; XM, 2020b). For this case, the operator indicated a scarcity price value of 0.1468 USD/kWh.

The price of electricity has been increasing due to various factors such as the decrease in water contributions (XM, 2020a), delays in the entry of generation and transmission projects (UPME,

Figure 4: Average monthly irradiation of the Department of Atlántico

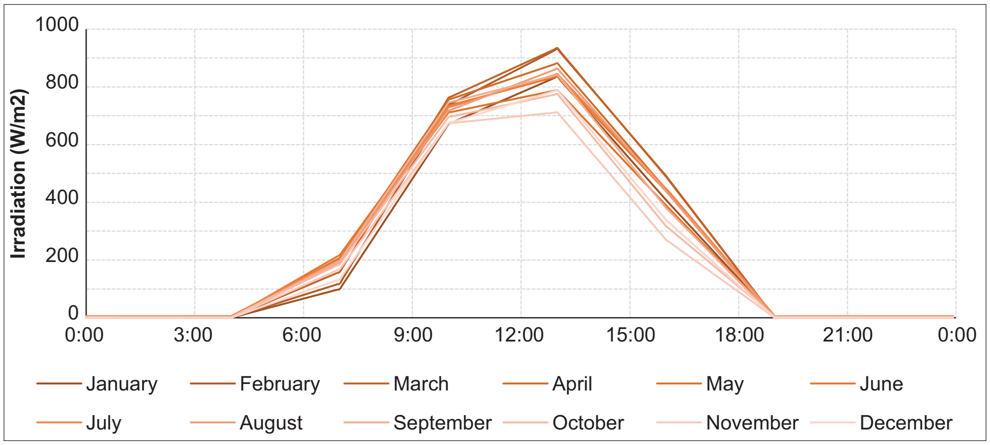
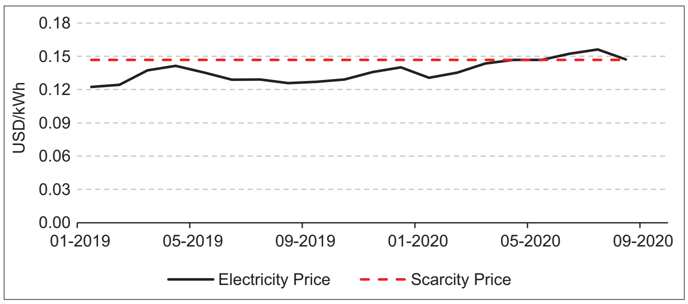


Figure 5: Behavior of the price of electricity



2020) and problems with contracts gas (PROMIGAS, 2020); in the last 3 months it has been invoiced with a scarcity price. The confidence interval for the price of electricity was determined, (0.1375±0.0094) USD/kWh, these values are lower than the established scarcity price; therefore, the evaluation is carried out with the worst-case scenario for the users, the scarcity price established at 0.1468 USD/kWh is used. Table 4 calculates the forecast of photovoltaic electric power production (Galindo, 2017) and the economic equivalence with the scarcity price.

A fixed fee is simulated according to the cost of each of the kits and the number of years to pay off the debt, using 25% as Annual Percentage Rate (APR); Table 5 shows the value of the fixed fee for the return on investment, it is carried out at a maximum of 12 years due to the change in efficiency set by the manufacturer.

The results show that there is no viable scenario for the different residential users, because the value of the fixed fee is much higher than the value of the energy produced with the different kits; batteries increase the total value of the investment and it is preferable to invest in generation capacity and make the most of the available space, the best option being an on-grid system without storage. Despite using a scarcity price, the energy billed by the network operator is much cheaper and the increase (20%) in the final price for strata 5 and 6 does not reach the simulated fixed fees.

3.4. Equity and Sustainable Development

The results obtained show that the energy generated does not equal the simulated quotas, being a better option to acquire the energy from the network operator or implement lower-cost energy

Table 3: Economic proposals for PV generation systems

Kit	Investment (USD)	Description
1	3450	Six 340W solar panels One 3000W Hybrid inverter Materials and installation.
2	3980	Three 340W solar panels One 1500W Hybrid inverter Two 180Ah batteries Materials and installation.
3	4777	Six 340W solar panels One 3000W Hybrid inverter Two 250Ah batteries Materials and installation.
4	5308	Eight 345W solar panels One 2500W Hybrid inverter Four 205Ah batteries Materials and installation.

Table 4: Economic valuation of the PV generation

Kit	Case	PV Generation (kWh/day)	Valuation with 30 days of operation (USD)
1	Best	6.80	29,9
	Average	5.63	24,8
	Worst	4.67	20,6
2	Best	3.40	15,1
	Average	2.81	12,5
	Worst	2.33	10,4
3	Best	6.80	30,3
	Average	5.63	25,1
	Worst	4.67	20,9
4	Best	9.24	41,4
	Average	7.65	34,3
	Worst	6.34	28,5

efficiency strategies; Barriers are identified such as the high cost of photovoltaic generation equipment and that 50% of the population has incomes equal to or <2 SMMW, which makes it difficult to make investments such as those described in Table 3.

Problems such as the decrease in water inputs, delays in the entry of projects and a lack of gas for thermal generation ((PROMIGAS, 2020; UPME, 2020; XM, 2020a), increase the risk of loss of self-sufficiency and increase the price of the electric power, which in Colombia is limited by the scarcity price (Resolution CREG 156,

Table 5: Simulation of fixed fees (USD) for return on investment

Year	1	2	3	4	5	6	7	8	9	10	11	12
Kit 1	324	180	133	110	96	88	82	78	75	73	71	70
Kit 2	374	208	153	127	111	101	95	90	86	84	82	80
Kit 3	448	249	184	152	133	122	113	108	104	100	98	96
Kit 4	498	277	204	169	148	135	126	120	115	112	109	107

2016). Countries like Germany, the final price of electricity is 50% production cost and 50% taxes (Mendoza et al., 2020), causing a more attractive economic scenario and having as motivation the contribution to the environment.

According to income and energy consumption, the population with higher incomes and those residing in strata 5 and 6, could opt for these systems; due to the additional saving of 20% contribution (CELSIA, 2020; ESSA, 2020); part of the industrial sector was exonerated from contributing (Decree 4955, 2011) and there is a growing behavior of the price of electricity. These conditions generate inequity and energy poverty because the contributions for the subsidies will decrease and cause a fiscal deficit for the government, causing decisions such as the reduction or elimination of the subsidies of strata 1, 2 and 3, with low-income families being the most affected.

4. CONCLUSIONS

The research analyzed the legal and regulatory framework of renewable energies in Colombia, the methodology used considered the subsidy and contribution scheme for the electric power service. In addition, the electricity consumption behavior of the different sectors and specifically the residential sector was described, where the income profile of the Colombian population was identified, and the behavior of the price of electricity and solar irradiation was presented in the department Atlántico. Through an economic evaluation, the factors that affect equity and energy poverty were identified.

The results show that the stock price reached the scarcity price in the last 3 months, which generates an alarm for the national electricity system, and it is necessary to find solutions to control this eventuality. The investments made to acquire photovoltaic generation systems are not profitable compared to the savings for energy produced; and this decision will be taken in favor of increasing the reliability of the service.

The decrease in contributions is a factor that will open the inequality gap, due to the lack of income to pay for subsidies; This condition opens the opportunity to carry out research to inhibit this problem. Energy models are key to studying the impacts generated in the different agents involved, creating strategies to mitigate the problems identified, and increasing the accessibility of these technologies.

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