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Characterization of photovoltaic solar energy systems in a Colombian region

Caracterización de sistemas de energía solar fotovoltaica en una región colombiana

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Abstract

Objective: To establish a baseline about the solar photovoltaic energy systems installed in the department of Caldas, Colombia. **Methodology:** The solar photovoltaic installations were identified from secondary sources of information, followed by field visits to collect information on the characteristics of these systems. An evaluation instrument was designed consisting of 6 categories which was subsequently evaluated by expert peers. It was applied accompanied by interviews with owners of the identified systems. **Results:** 41 solar photovoltaic systems were identified and installed in 11 municipalities of Caldas. Data was collected from 28 installations with different characteristics. 50% of the solar photovoltaic systems are in the Central-South region of Caldas. 71% of the systems are mainly installed in the urban area; 64% correspond to small-scale isolated solar photovoltaic energy generation systems, with a maximum power of less than 600W. These installations have become a viable energy alternative for the region and are being used especially for lighting and the operation of household appliances in residences, hotels, restaurants, and educational institutions. **Conclusions:** Although regulations on solar energy installations had not been established, these systems have already been implemented in the department in a successful, but moderate, manner.

Keywords: Characterization, solar energy, photovoltaic solar systems, Caldas Department.

Resumen

Objetivo: Establecer una línea base acerca de los sistemas de energía solar fotovoltaica instalados en el departamento de Caldas, Colombia. **Metodología:** Las instalaciones de energía solar fotovoltaica fueron identificadas desde fuentes secundarias de información, seguidamente se realizaron visitas de campo para recopilar la información sobre las características de tales sistemas. Se diseñó un instrumento de evaluación que consta de 6 categorías que posteriormente fue evaluado por pares expertos. Se aplicó acompañado de entrevistas a dueños de los sistemas identificados. **Resultados:** Se identificaron 43 sistemas solares fotovoltaicos instalados en 11 municipios de Caldas. Se recopilaron datos de 28 instalaciones con diferentes características. El 50% de los sistemas solares fotovoltaicos se ubican en la región Centro-Sur de Caldas. Un 71% de los sistemas están principalmente instalados en el área urbana; un 64% corresponde a sistemas de generación de energía solar fotovoltaica aislada a pequeña escala, y tiene una potencia máxima inferior a 600W. Estas instalaciones se han convertido en una alternativa energética viable para la región y se están empleado especialmente para iluminación y funcionamiento de electrodomésticos en residencias, hoteles, restaurantes e instituciones educativas. **Conclusiones:** A pesar de que la reglamentación sobre las instalaciones de energía solar no se había establecido en el país, ya en el departamento de Caldas se habían venido implementando estos sistemas de una manera exitosa aunque moderada

Palabras clave: Caracterización, energía solar, sistemas solares fotovoltaicos, Departamento de Caldas.

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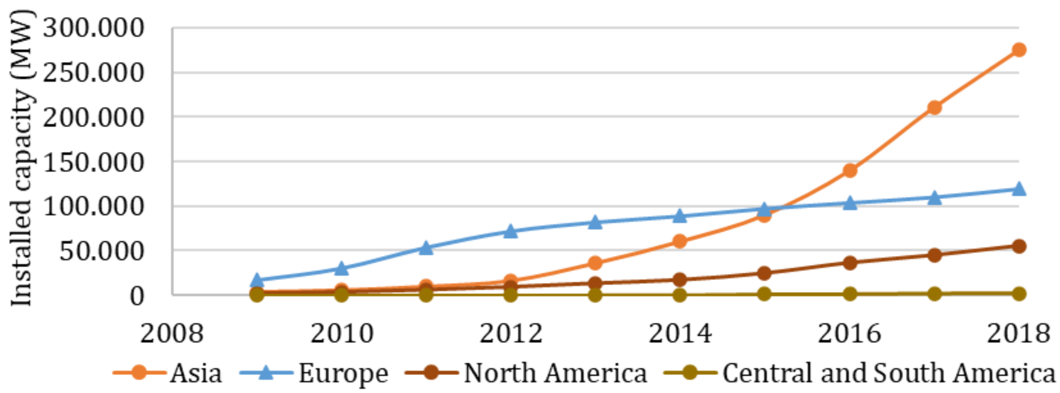
Introduction

Globally, renewable energies have registered exponential growth. The installed capacity change from 1.136.226 MW in 2009 to 2.350.755 MW in 2018 [1], this capacity is measured as the maximum net generating capacity of power plants and other installations that use renewable energy sources to produce electricity. On the other hand, solar energy has also registered an exponential growth trend but with a higher growth rate. Thus, in 2009, the capacity was 23.371 MW in comparison with 485.826 MW in 2018. In this sector, the capacity of photovoltaic solar energy globally increased from 22.606 MW in 2009 to 480.357 MW in 2018 [1]. Growth trends in the installed capacity of photovoltaic solar energy systems are shown in Figure 1.

Figure 1. Solar Photovoltaic Capacity



Source: Authors own creation based on [1]

Photovoltaic solar (PV) energy is a key source of renewable energy and its growth is notable in several markets on all continents, the International Energy Agency (IEA) expects that the share of global electricity from photovoltaic (PV) systems will reach 16% by 2050. In Asia, the countries with the highest installed capacity are China, Japan, and India. The significant increase in the Asian market was mainly due to China, at least 175.018 MW of solar energy were installed in 2018, the total capacity by roughly six times in comparison with 28.388 MW in 2014. The solar energy resource in China is substantially rich and stable, but also has notable spatial heterogeneity [2]. However, the highest growth was recorded in India, where installed capacity increased from 3.290 MW in 2014 to 26.869 MW in 2018. Japan doubled its capacity in this same period, 23.339 MW in 2014 to 55.500 MW in 2018 [1]. On the other hand, Europe installed 30.567 MW of new PV capacity between 2014 to 2018.

In the Member States of the European Union, growth was more modest, 32%, with 115,234 MW installed in 2018 compared to 87,233 MW installed in 2014. Germany, Italy, and Spain have more installed capacity in Europe. Germany is a leader with a total installed capacity of 45.930 MW in 2018, the growth was 21% compared to 2014. In Italy the growth of photovoltaic solar energy capacity was 8% while in Spain it was only 1% in 2018 compared to 2014. This data led James Watson, the Chief Executive Officer (CEO) of SolarPower Europe, to urge the European Union to take greater measures to support the expansion of the sector.

In Eurasia, Turkey is the leader with a total capacity of 5.063 MW in 2018, this country registered the highest growth because in 2014 the installed capacity was only 40 MW, according to official sources. In Central America and the Caribbean, the installed capacity of PV energy grew five times from 341 MW in 2014 to 1737 MW in 2018. Honduras has the highest installed capacity. Otherwise, in South America, the installed capacity of PV energy increased sharply from 469 MW installed in 2014 to 5469 MW in 2018. The countries with the highest capacity in PV energy are Brazil and Chile.

The Gulf Cooperation Council (GCC) nations have each set different strategic goals of producing certain share of their total energy from renewable sources, for example, the solar power is a preferred choice for its relatively advanced technology and seemingly limitless potential in the region. The daily average solar radiation typically exceeded 6kWh/m2 with 80-90% clear skies throughout the year [3].

With respect to Latin America, the diversification of energy resources is key for some countries that depend on hydroelectric energy. This fact makes them vulnerable to meteorological events for the changes in the hydrological regime especially for the Southern Oscillation associated with the phenomena of El Niño and La Niña [4]. Therefore, the region seeks mechanisms to diversify the energy matrix using renewable resources such as biomass, wind, and solar resources to complement its generation with hydroelectric power plants [5,6,7,8].

PV solar power plants represent financially competitive options in comparison with other technologies [9]. In this regard, Colombia faces challenges such as expanding coverage, improving the service quality and reliability, diversifying the energy matrix, and sustaining economic development, without an increase in CO_2 emissions [10,11].

Colombia is a privileged country in water resources and, consequently, the highest energy generation, 68.3%, is carried out in hydroelectric power plants. On the other hand, the country has coal and natural gas deposits and, accordingly, thermal generation has played an important role, with a 30.7% share in the energy matrix for 2019. Therefore, the penetration of renewable energy sources other than hydroelectric power has been minimal compared to other developing economies. Nevertheless, due to its geographical location, Colombia also has several energy resources that need to be further explored, such as solar energy, wind power, and mini-hydroelectric power plants, which constitute an important source of renewable energy.

Energetically, Colombia is divided into two types of zones: The Interconnected Zones (ZI) and the Non-Interconnected Zones (ZNI); the first are those that have access to the electric power service through the National Interconnected System (SIN) and the second are in geographical areas which are not electrically coupled to the SIN. According to the Colombian Superintendence of domiciliary public services, in 2018, the ZNI covers 51% of the national territory where 70 municipalities, and 218.401 users are located. According to the National Institute for planning and promotion of energy solutions for non-interconnected areas, IPSE, the ZNI has an operating capacity for electricity generation of 241 MW, of which only 3% corresponds to non-conventional renewable energy sources [12].

In 2017, net effective capacity of the National Interconnected System (SIN) reached 17.326 MW; the annual energy demand was 10.700 MW [13]. In 2018, the generation in the SIN was 82.16% in hydroelectric plants, 16% with thermal power plants and the remaining with non-conventional energy sources. In April 2019, the largest renewable energy plant in the country, with an installed capacity of 86.2 MW, was inaugurated in the municipality of El Paso, in the department of Cesar, which represents 80% of the installed capacity of solar energy in the national territory. This solar park has 250.000 panels located on about 210 hectares [14].

In 2019, the reliability charge auction was held to contract a Firm Energy Obligations, which is a product designed to ensure the reliability of long-term firm energy supply at efficient prices. The additional net effective capacity for the Colombian energy system in 2022-2023 will be 4.010 MW: 1.240 MW thermal, 1.372 MW hydraulic, 1.160 MW wind and 238 MW solar. As a result of the auctions, wind and solar energy will go from representing less than 1% of total net generation capacity to approximately 6% in 2022. The government's goal is to install to at least 1500 MW of non-conventional renewable energy [15]. This is a starting point to achieve what was predicted by the study of the Assistance Program for the Administration of the Energy Sector of the World Bank which establishes that enough exploitation of wind and solar energy could cover more than the country needs. renewable energy technology produces competitive electricity when compared to alternative fossil fuel-based technologies. Many publications exist where the cost of renewable power is computed and/or compared to alternative power technologies at a global scale. A recent study by the International Energy Agency (IEA) calculated the production costs for various power generation technologies based on cost data gathered from 190 power plants in 21 selected countries in Asia Pacific, Europe, North America, Brazil, China, Russia, and South Africa also estimates that investments in renewable energies should increase annually by 150% - about $US16 trillion cumulatively between 2015 and 2050 – to keep up with the Paris Agreement goals. However, investments in renewable energies in the power sector are not scaling up fast enough to reach this target [16].

The studies of the Energy Mining Planning Unit, UPME, and the Institute of Hydrology and Meteorology of Colombia, IDEAM, have defined great potential in the country for solar energy project due to its annual average radiation of 4.5 kWh/m2, which exceeds the world average value of 3.9 kWh/m2 [17]. This potential is also evident in the Caldas department which exhibits all thermal floors. These privileged characteristics of geographic location and solar radiation are significant when it comes to investing in photovoltaic systems and their use, so experts in the sector call for a better understanding of the projects in operation.

The tax benefits of Law 1715 of 2014 have generated an ideal environment for the development of PV energy projects [11,18]. Although hydroelectric generation has predominated in Caldas, there are some PV energy projects in different geographical areas that could reveal key strategic information [19,20]. Understand certain characteristics related to applications, installations and maintenance costs and the perception of user satisfaction are essentials to establish intervention strategies and actions for the promotion of nonconventional sources of renewable energy, and specifically, PV energy. In this sense, it is important to know the current state of the PV solar energy generation systems in order to have an overview and a baseline to determine the future impact of the policies which are beginning regulated in the country [18].

This article presents the research results carried out in the department of Caldas-Colombia to determine the status of PV solar systems in this region. First, it is showed the methodology followed to access the information, in which the evaluation instrument designed and used is included. Next, in the results section, a general description of the systems and the analysis through the criteria defined in the evaluation instrument are presented. Finally, the conclusions derived from this work are showed.

Methodology

These results were obtained in an exploratory research project whose objective is the diagnosis and perspectives of solar energy in Colombian departments. Initially, a technology surveillance analysis was carried out on the Scienti platform, and in national publications which included the Caldas department [21,22], to identify research groups and their publications on solar energy. The review of these publications and secondary information available in public reports and press articles allowed to identify the PV energy systems installed in the department of Caldas, in this case study.

An evaluation instrument was constructed with the experts' collaboration, to collect the data of the photovoltaic solar system (PVSS) installations. Six segmentation criteria for the data analysis were included. Next, field work was carried out to collect data from these systems; recognition visits and interviews were carried out for the application of the evaluation instrument to those responsible for the facilities. Finally, a descriptive and explanatory analysis of the data collected was performed. A description of the evaluation instrument and the population and the sample in which it was applied is presented below.

Data collection instrument

The instrument for collecting data consists of 36 questions arranged into six segmentation criteria as shown in Table 1. A pilot test was performed for instrument validation. The field visit and the recognition of the installation also allows verification of responses and ensure the data quality.

Table 1. Criteria and question of the instrument for collecting data

Segmentation Criteria	Questions
I General: This section aims to inquire about general knowledge in renewable energy	What do you know about renewable energy? How did you acquire such information? What type of renewable energy are you currently using?
II. Electricity supply information: This section aims to learn about the characteristics of the electricity supply through the SIN	What is the company that provides the electric power supply? What is the cost of kWh? How is your contract with this company? What is the power of the system? What is the system voltage level? What is your energy demand expressed in kWh per month? What are the operating hours of the electric power company?
III. Solar system information: Its purpose is to know the type of solar energy system and its characteristics	What type of solar system are you currently using? What is the type of photovoltaic solar generation currently available? If it is photovoltaic, what type of photovoltaic solar generation do you have installed? Is the system installed own or is it under concession or in bailment?
IV. Uses of PV energy: This section identifies the uses of the generated energy and expansions of the installed capacity	What are the uses of the PV energy? What are the applications of the PV energy? Have you made any extensions to the system related to number of panels or installed power? Has the energy consumption increased since the system implementation?
V. Operation and costs of the installed system: This section sought to know about the costs, operation and maintenance activities of the system	How long did the installation of the PV system take? What was the total cost of the PV installation? What was the return time of the investment? Do you have documented the investment project, its operation and costs? Did you have any subsidy or special financing system for the construction of the installed system? Do you perform maintenance on the installed system? What kind of maintenance do you perform? What is the system maintenance frequency? What is the cost of operation and maintenance? What do you consider the main failures and problems of the PV system? What personnel do you need to operate the system?. What is the level of staff training? What difficulties do you have in the system operation?
VI. Degree of Satisfaction: This section aims to know the degree of satisfaction and compliance with the expectations of the installed PV system.	Is the system working? What is your perception of renewable energy now that you use them? Were the expectations you had with the system installation fulfilled? What indicators do you handle? Would you expand the installed capacity of the current system? Would you complement the current system with other types of renewable energy? On a scale of 1 to 5, 5 being very satisfactory and 1 unsatisfactory, how is the degree of satisfaction with the installed system?

Source: Own elaboration

Unit of analysis for this study

The unit of analysis was the entire department of Caldas, which is divided into 6 subregions that are grouped in 27 municipalities as indicated in the right part of Figure 2. In each of the municipalities of Caldas, research was carried out through different channels such as "voice to voice" inquiries in the municipalities, secretaries of planning and infrastructure, offices of the Caldas Hydroelectric Power Plant [19] network operator, and the radio stations.

Figure 2. Regions of the Caldas Department population of this study Source: Caldas Governance

Source: Caldas Governance

A tour around these 27 municipalities led to the determination of the units of the population for the analysis, that is, a quota sampling. Data from all the identified places were included except for those with very similar conditions. A total of 28 surveys were applied in 11 municipalities of the department, as shown in Table 2.

Table 2. Description of the PVSS of the Caldas Department

Sub-region	Quantity	Municipality	Installation Site	Installed power -Generated (W)
South Central	14	Manizales	Bank of the Republic	14000
			Uribe station luminaire	120
			National University Campus La Nubia -Building	10000
			National University Campus La Nubia-Equipment loading	250
			Lighting for "Parque de la Mujer"	1200
			Transit Services Manizales	500
			SENA Regional Caldas	3000
			Housing Chipre neihborhood	380
			Center Concentrates	8640
			Vivienda San Peregrino	200
		Villamaría	Farm La Fonda	750
		Chinchiná	Las Pavas weather station	270
			La Pesebrera agricultural warehouse	3252
		Palestina	Confa-La Rochela	24375
North-West	5	Filadelfia	Finca San Fernando	600
			Rural Farm	560
		Riosucio	La Roca Restaurant	480
			Lighing Main Park	80
			Cultural school	280
South-West	2	Viterbo	Hotel El Samán	200
		Anserma	El Horro School	1500
North	2	Aguadas	Senior adult house	300
		Pácora	Houses	100
Magdalena Caldense	5	La Dorada	Housing Neighborhood La Alameda	350
			Neighborhood Pancoger	70
			Neighborhood Pancoger	70
			Neighborhood Pancoger	100
			Sena sectional La Dorada	690

Source: Own elaboration

Results and discussion

The PVSS found in the department of Caldas are presented. First, a general description of the installations is made, and then, the data obtained from the instrument application are analyzed for each of the established criteria.

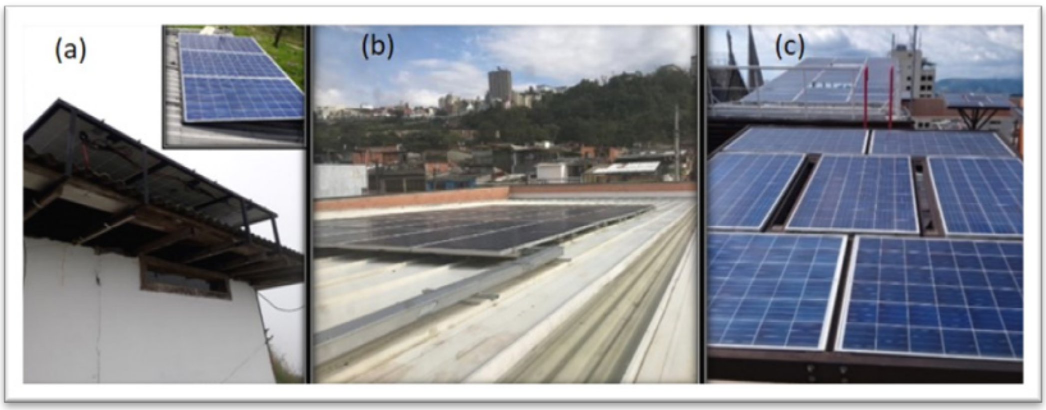
General description of the systems found

Table 2 shows the PVSS in Caldas found in the development this study. As it can be observed, PVSS were found in five of the six sub-regions of the department. In the Upper East part, there were no PVSS, and a high degree of lack of knowledge about this type of unconventional energy generation was observed.

A greater use of these systems is observed in the South-Central region, where the capital of the department is located. This means near 50% of the identified systems installations, are found here and followed by the regions Magdalena Caldense and Alto Occidente with 18%, each, and, finally, the regions under the West and North with 7% each. The following is a description of the photovoltaic solar energy generation systems of the different sub-regions of Caldas.

South-Central Sub-region: The solar power generation installations of the south-central region are mainly located in Manizales, the capital of the department. Some example are the following: the PVSS of the Banco de la República (Figure 3) with 14kW of installed power; the PVSS in Concentrados del Centro that came into operation in June 2018 which has 36 panels and an installed capacity of 9.7 kW; and PVSS in the Sena Regional Caldas.

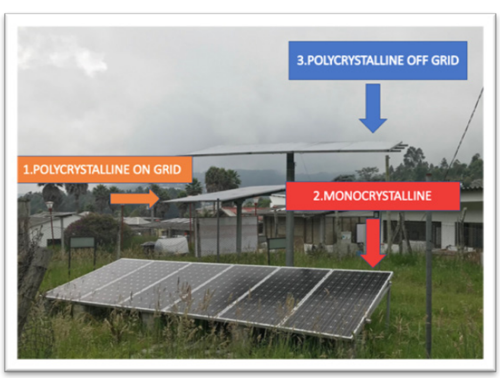
Figure 3. **Some PV systems installations in the municipality of Manizales a. Bank of the Republic. b. Concentrados del Centro. c. Vereda Playa Larga La Fonda farm.**



Source: Own elaboration

In the National Service of Learning SENA Regional Caldas, three small-scale PVSS were found. One of them is a system of 6 monocrystalline panels of 340Wp each for a total of 2040 W, which works with an ABB inverter which allows to have two PVSS at the entrance. The other system connected to this inverter has 9 polycrystalline panels of 235Wp each one for a total of 2115 W, and both systems have an on-Grid connection. On the other hand, they also have an off-Grid system of 1140 W, which can be seen in Figure 4.

Figure 4. Some PVSS in the SENA Regional Caldas. 1. Polycrystalline On Grid 2. Monocrystalline On Grid, 3. Polycrystalline Off Grid.



Source: Own elaboration

In the rural area of the municipality of Manizales, there was a system of solar power generation for a home that does not have access to the distribution of network operator and before the implementation of the system only had light by candles (Figure 3c). In the municipality of Chinchina, there were several photovoltaic solar power generation systems. One of them has a commercial use, and it is in a warehouse of agricultural tools. It has 20 m2 of solar panels, and it is connected to the network. Another PVSS is in a weather station whose operation is supported by solar energy, and there are also some traffic lights and cameras (Figure 5a and 5b).

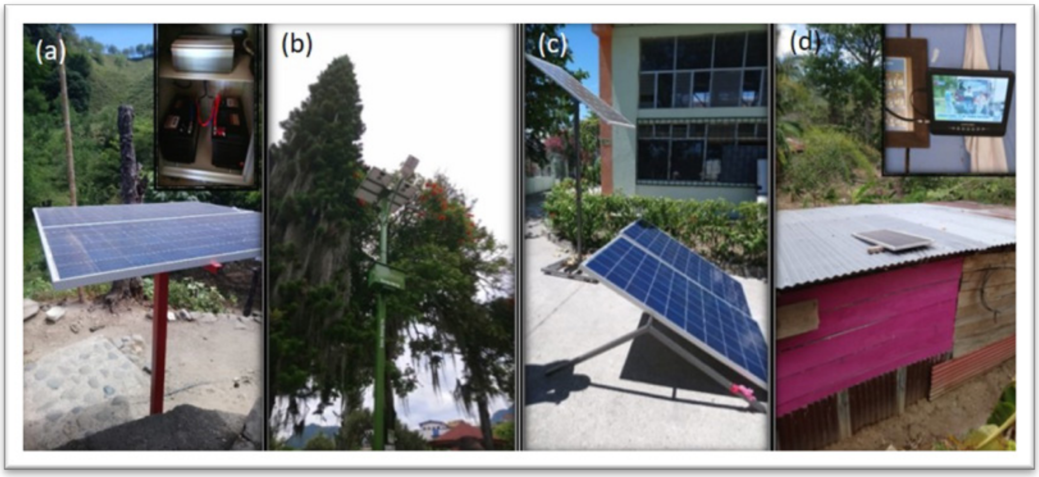
Figure 5. a. PVSS municipality of Chinchiná, La Pesebrera. b. PVSS camera and traffic light municipality of Chinchiná. C. PVSS charger of mobile equipment La Rochela.

Source: Own elaboration

The biggest system installed in the Department of Caldas is in the municipality of Palestina, which is in the south-central region with a capacity of installed solar power of 24.4 kW. This system is in the recreational center CONFA La Rochela, and it is connected to the network and supplies the demand of lighting and appliances. This recreational center also has a solar power generation system for charging mobile devices (Figure 5c).

High-West Subregion: There are two houses in the rural area of the municipality of Philadelphia with isolated PVSS (Figure 5a) (they have storage systems). They could not rely on an energy supply by a network operator. In the park of the municipality of Riosucio, a lantern operates exclusively with solar energy was installed. (Fig 6b). This luminaire was implemented to test this technology to the Major Office of the municipality, and, in the future, it could be implemented in a large-scale for public lighting. In this same municipality, lanterns were also found in La Roca restaurant. The system has 12 lamps to light the common areas and access to the restaurant. For the owners, it was a very good solution, and they plan to extend the system in their short-term plans due to money savings since its implementation. In Riosucio, companies are dedicated to the installation of PVSS, which allows the population to know about the topic. For that reason, it is one of the municipalities with the most PVSS to date.

Figure 6. a. PVSS in house in the municipality of Philadelphia. b. Solar energy lighting in Riosucio Park. c. PVSS in SENA La Dorada. d. Solar photovoltaic system in Pancoger house in La Dorada.



Source: Own elaboration

South-west Sub-region: In the South-west subregion of the Department of Caldas two PVSS were found. One of them was found in the municipality of Anserma in an educational institution called the Horro, located in a rural area. The solar energy installed and connected to the network has a capacity of 1500 Wp. It is mainly used to move the agricultural machinery of the school. In the municipality of Viterbo, there is a system in the Hotel El Saman. It has an installed capacity of 750 Wp, and it is used exclusively for water heaters in the rooms. It is remarkable that in Viterbo, they are building residential projects on the outskirts of the municipality, which will have small-scale PVSS for self-consumption.

Northern subregion: In the municipality of Aguadas, located in the northern region of the department, an isolated installation was found in a house owned by people with scarce economical resources. At times when the municipality runs out of energy, this is the only house that has energy because its operation in the evenings is powered by the energy stores from the solar energy batteries. Likewise, in the municipality of Pácora, the oldest solar energy installations in the Department of Caldas were found. They have approximately 5W luminaires with which the owner of the house lights the garden. These small luminaries were brought by the owner from the United States more than 10 years ago and are still in perfect condition and functioning.

Magdalena Caldense subregion: In the Magdalena Caldense region, two types of PVSS are installed at the residential level in Pancoger and La Alameda neigborhoods and at the institutional level at the SENA in La Dorada. The SENA in La Dorada has three solar panels installed. They are monitored constantly, and currently they are only used for research purposes. This means they are not connected to any load. The solar radiation data from the installed meteorological station conduct short-term projects to meet the needs of air conditioning because the biggest source of consumption is due to the climate characteristics of the municipality (Figure 6c).

In La Alameda and Pancoger neighborhoods of the municipality of La Dorada, 19 PVSS were found in houses owned by people with scarce economical resources. All these systems have similar characteristics related to power between 70 and 350 W, and they are used for lighting and the operation of TVs. Only 4 out of the 19 houses were surveyed due to access difficulties and the similarities of the systems. It is worth mentioning that these neighborhoods do not have power supplied by the network operator due to the lack of infrastructure for energy distribution of the networks of the interconnected system. The inhabitants of these houses chose this option after using small plants of diesel generation which had much higher costs, in addition to the auditory pollution generated by being inside each one of the houses (figure 6d).

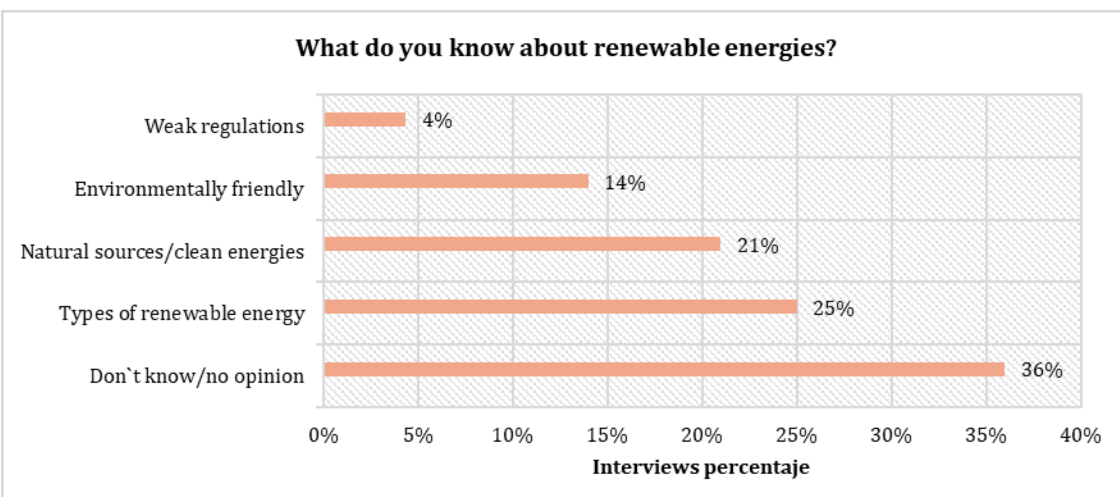
Criteria analysis of data gathered by the research instrument

The results obtained after the application of the instrument will be presented below. Considering the criteria of segmentation already mentioned in the methodology, the data are analyzed.

Segmentation criterion I. General questions

36% of the respondents answered that they did not know about PVSS as an alternative non-conventional energy generation, and 64% were aware of some of the topics related to photovoltaic solar energy. For example, regarding regulation, 4% of the respondents do not believe in the large-scale use of solar energy generation without having a clear path regarding the functioning and operation of solar photovoltaic systems. At this point, it is important to note that Law 1517 [18], which aims to develop and use non-conventional energy sources within the Colombian energy system, was enacted in May 2014 but only until February 3, 2018 was its regulation issued [23]. On the other hand, three main aspects are recognized: the benefit of being friendly whit the environment, the meaning of a renewable energy which they catalog as natural sources and clean energies, and some types of renewable energy generation such as the solar, wind, biomass, and water. Figure 7 shows the results of their knowledge of renewable energies.

Figure 7. Knowledge of non-conventional renewable energies



Source: Own elaboration

The knowledge about renewable energies was acquired mainly through supplier companies of these generation systems as well as voice to voice information transfer from people who already had some source of renewable energy production. For example, in La Dorada, Pancoger, and La Alameda neighborhoods, the solar photovoltaic energy is used at a residential level because it has been observed to function well in neighboring houses. Likewise, the information has also been acquired through internet searches, research, and training that have mainly been given for the capital city of the department.

Segmentation criterion II. Information of the company that supplies electric power

For the Department of Caldas, the network operator that supplies the electrical power is the CHEC - EPM group. The prices of electric energy vary from $233 and $462 per generated kWh. Like Pancoger and La Alameda neighborhoods in La Dorada, the houses surveyed in the municipality of Philadelphia were not connected to the national interconnected system, so they had no energy at any time of the day. However, the rest of the surveyed places had electrical power supply by the network operator CHEC 24 hours a day.

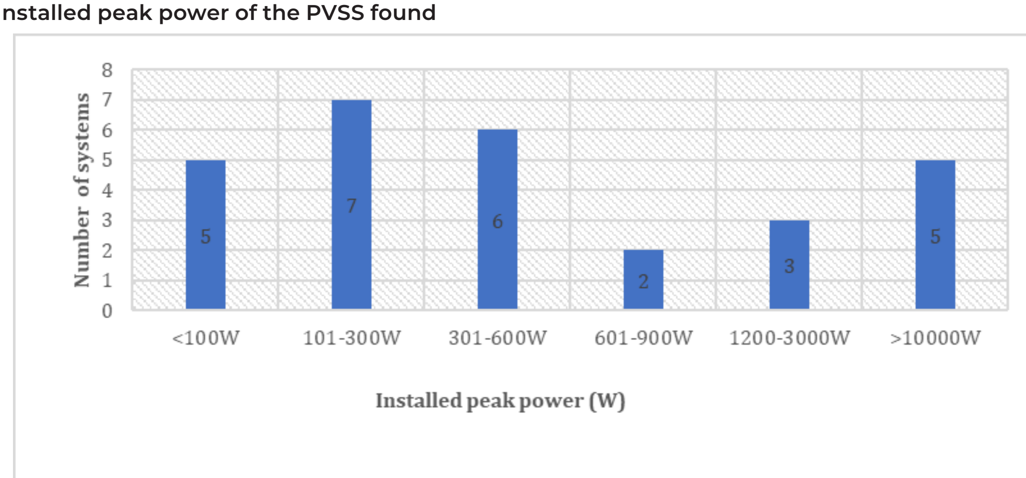
Segmentation criterion III. Information about the specific solar system and its characteristics.

From the surveys carried out in the Department of Caldas, it was determined that only photovoltaic solar power generation systems were used, no other solar thermal generation systems were found in use. However, there is a small thermal application in *Buencafé Liofilizado* that was not included in the study as the study was focused on photovoltaic solar systems.

It was found that 64% of the systems found were of isolated generation, and they were used for small applications, for example: lighting and some appliances functioning; 29% of the PVSS are connected to the network and installed in the Central South region, mainly in the capital of the department. Only 7% of the applications have hybrid generation, and these are very close to Manizales.

Figure 8 presents the distribution of installed potential peak in the evaluated PVSS in the Department of Caldas. All are in the small-scale category with a generation between 0 and 100 KW according to resolution CREG 030 of 2018 that began regulation on May 1st [23].

Figure 8. Installed peak power of the PVSS found



Source: Own elaboration

Most of the evaluated installed systems have a generation of less than 600 W (64%); they are small-scale applications mainly used at residential level and in housing without connection to the national interconnected system. The lower power systems (< 100 W) correspond to 18% of the analyzed PVSS, and the energy is used for lighting and for the loading of small devices such as cell phones and radios. On the other hand, systems with solar power generation capacities between 1,200 -3,000 W represent 11% while the largest represent 10,000 W 18%; all these systems are in the capital city of the department. Systems with a capacity of generation between 600 - 900 W were found in a rural area in the municipality of Philadelphia and in the installation of SENA in La Dorada.

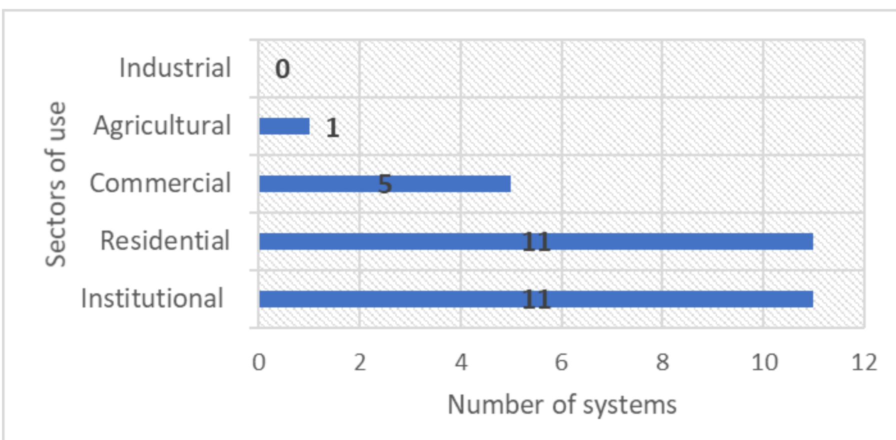
Criterion IV. Uses given to photovoltaic solar energy generated

It was found that 71% of the PVSS were in the urban areas of the municipalities while 29% were in rural areas and were mostly in houses that were not connected to the interconnected system and still had candlelight.

Figure 9 presents the distribution of PVSS according to the sectors of the economy. One of the sectors that aims more at the development of non-conventional sources of energy generation is the institutional sector, especially in education or government institutions, with 39%. The educational institutions that have installed systems are the National Learning Service SENA Regional Caldas in Manizales and in La Dorada, the National University of Colombia Sede in Manizales, Colegio el Horro in the municipality of Anserma, Colegio Cultural Riosucio, and government Institutions such as Transit Service Manizales.

The residential sector, like the institutional sector, also gets an important 39% in PVSS. The residential sector has small scale and low-cost applications such as lamps and LED TVs where few panels are required. Other uses are also found in traffic lights, charging of mobile equipment, radios, televisions, and appliances of lower consumption. It is noted that no PVSS were found to have been installed, and no-load increases had been made since its implementation.

Figure 9. Sectors in which PVSS is used

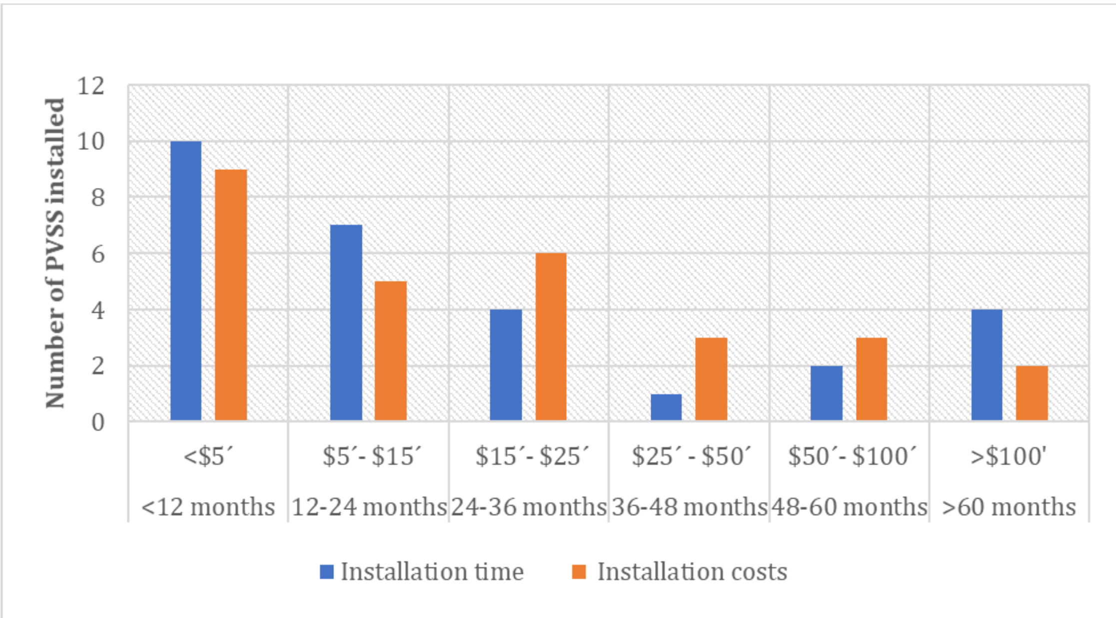


Source: Own elaboration

Criterion V. Time of uses, costs and maintenance of the installed system

In Figure 10, the usage period of installed PVSS is observed. The system with more than 12 months are distributed mainly in three regions of the department: South-Central, High-West, and Magdalena Caldense; while the systems that are installed between 12 and 24 months are found mainly in Riosucio correspond to the High-West Region. Systems between 2 and 5 years of use are mainly found in the South-Central region and Magdalena Caldense, and they represent 36%. The oldest facilities are in the northern region in the municipalities of Pacora and Aguadas with longer than 5 years of functioning, and they represent 7% of the total.

Figure 10. Time of use and investment of PVSS



Source: Own elaboration

As figure 10 shows, 36% of the installed PVSS have costs lower than 5 million, which is consistent with the analysis presented above due to their given use in the residential setting and with small-scale generations. Systems with global values between 5 and 25 million (39%) are a little more elaborated, and in some cases, they have energy storage elements which makes the overall cost greater than that in battery-free systems. Finally, PVSS with global values above 50 million (21 %) were those with an installed power greater than 10 kW. These systems were found in the south-central region of the department mainly in the institutional and commercial sectors. Most of the systems were installed with the user's own resources, just three systems had some source of funding.

The estimated time for the recovery of the investment of different installed PVSS in the department of Caldas vary between 4 and 7 years. This time corresponds to increasingly low investment returns compared to those previously presented, because the overall weighted average of the installation cost for photovoltaic solar power at utility scale fell from USD 4394/kW in 2010 to USD 1388/kW in 2017 [1].

68% of the users of generation systems do not perform any maintenance to the system. In some cases, they argued that it was not necessary since the panels, when installed with some degree of inclination, allow the rainwater to remove any dirt on them. However, 32% do maintenance to clean their systems which allow the solar panel to operate as efficiently as possible.

Regarding the costs of corrective, preventive maintenance, cost of operation, and cost of replacement, no answers were obtained since, as mentioned before, in most systems no maintenance is carried out or the same beneficiaries of the system clean them. The main failures reported in PVSS were related to the losses due to dust particles on the surface of the panel, and in the south-central region, it was mainly related to the ash from volcanic activity.

Segmentation criterion VI. Degree of Satisfaction

It was found that almost all PVSS are still in operation, and only 4%, corresponding to a public lighting that had been installed as a pilot test, were not active. Similarly, when users of the systems were asked about meeting the expectations about the implementation of solar energy, the response was generally positive. Only the users who no longer had the system in operation claimed to be dissatisfied. The results for the assessment of the degree of satisfaction of people who use solar power generation systems on a scale of 1 to 5 with 5 being very satisfactory and 1 being unsatisfactory are as follows: 93% of users answered with high satisfaction degree. The 7% with low degree of satisfaction was attributed to the costs in the installation of the system.

Discussion

The outlook for continuing the installation of PVSS in the Department of Caldas and the country is encouraging since the Ministry of Environment and Sustainable Development issued Resolution 1303 of July 13, 2018 that amended Resolution 1283 of 2016. This Resolution established the procedure and requirements for issuing the certification of environmental benefit for new investments in projects of FNCER and GEE, necessary to obtain the tax benefits included in Law 1715 of 2014.

Based on the knowledge of the success cases identified in this research, the population's perception of renewable energies, and the policy guidelines, it can be said that the prospects for the installation of the FNCER in the department are encouraging. The applications with the generation of photovoltaic solar energy on a small scale were the ones that predominated in the tours through the municipalities of the Department of Caldas. These applications have been successful and have met and exceeded the expectations that were held prior to installation.

During the investigation and the search for PVSS throughout the Department of Caldas, it was found through voice-to-voice search, that the population is open to listen and learn more about the issue of energy generation through non-sources conventional. The community find it very new to take advantage of an inexhaustible natural resource that is counted on day to day: the sun.

Renewable energies, such as photovoltaic solar energy, are an alternative and an opportunity to bring clean energy to these ZNI and improve the quality of life of the inhabitants, as happened in the Pancoger and Alameda neighborhoods in the municipality of La Dorada. These systems are an energy generation alternative that helps minimize the impact of carbon dioxide emissions on the environment and generates an energy alternative for both the ZNI and the SIN. All this agrees whit the benefits that can be derived from developing RE technology that have been classified into three categories: energy, economy and environment [16].

Photovoltaic solar energy is providing access to energy for many inhabitants. However, this technology, which is already being applied in some of these isolated areas and is being successfully applied in the communities, has a major drawback: the high cost of the initial investment. According to a new report by GTM Research, the overall weighted average cost of installing utility-scale solar PV has declined from $4,394/kW in 2010 to $1,388/kW in 2017. In addition, prices for solar energy installations are projected to continue to fall by up to 27% by 2022 [1].

Conclusions

The results obtained led to the conclusion that more than 40 installed PVSS are functioning in the Department of Caldas in 11 municipalities especially in the south-central region’s urban sector. The majority are isolated systems and small-scale; this means that they generate less than 600 W and have not exceeded 15 million pesos in installation. Their uses are mainly institutional and residential, and they have the majority have been in operation for less than two years. 19 isolated systems with powers peak between 70 W and 350 W were found in the municipality of La Dorada for houses that do not have access to the networks of distribution of the CHEC. The use of these facilities especially for ZNI, and a good community perception in the department of Caldas about this kind of power generation systems, was evident [23, 24, 25].

In addition to the return on investment time projected for the different PVSS installed in the Department of Caldas, it ranges between 4 and 7 years. These return-on-investment times are getting shorter, as the overall weighted average installation cost for PV solar on a utility scale has been and will continue to be declining.

After using some of the sources of solar energy throughout the department, users concluded that they are a very good alternative of energy production that is becoming economically more viable and accessible to different social strata. Furthermore, it is a very innovative solution, especially for isolated places that are not in the SIN for being a type of modular and very versatile, adaptable to different situations. The respondents expressed that this type of technology will only able to be implemented if the Government and the academy propose dissemination plans and clear strategies for its implementation.

The methodology used allowed us to identify not only the systems installed in the department of Caldas, their characteristics, uses, generation capacity, but also the users' perception of this energy source. It was also possible to compare the systems in terms of their generation capacity, sector in which they are used, costs, and time of use, which is not compiled in this way in the sources of information consulted. This work stablishes a base line to compare in a near future the incidence of regulation of 1715 Law.

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