International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 5, October 2022, pp. 4521~4528
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i5.pp4521-4528

Challenges and perspectives of the use of photovoltaic solar energy in Colombia

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Article Info

Article history:

Received Sep 22, 2021
Revised Feb 18, 2022
Accepted Mar 15, 2022

Keywords:

Environmental problem
Photovoltaic solar system
Renewable energy
Solar energy
Solar energy projects

ABSTRACT

This article quantifies the development of photovoltaic solar energy in Colombia and its current development prospects. The high demand for electricity in Colombia is increasing since there is a large population, industrial, and business increase, which brings a higher energy consumption and consequently economic, social, and environmental problems. Faced with this situation, a possible solution is proposed, using solar energy, to supply the increase in demand and mitigate the problems caused by current electricity generation because Colombia has high levels of solar radiation in almost the entire territory. The objective of this research is based on the analysis of the behavior of the projects on photovoltaic solar systems presented to the mining-energy planning unit (UPME) in the last 14 years until September 30, 2020, as well such as the study of the areas with the most effective implementation of this technology and their respective radiation indices. In addition, a synthesis is made of the regulations, laws, and tax incentives that exist for the implementation of this technology and the different stages of execution of the projects approved and in performance.

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1. INTRODUCTION

Colombia, a country located in South America, has an excellent geographical location for using, developing, and generalization technologies associated with renewable energies. For example, the high rate of solar radiation in many regions means that the country has great potential to use solar energy. However, the reality is quite different since it has a significant deficit in developing this sector [1]–[3]. There is no doubt that the private sector is one of the most interested in using and implementing technologies that use solar energy as a primary source, either with installing systems to generate electricity or with thermal systems to produce steam or heating liquids. In Colombia, this sector has been making significant efforts to develop projects involving photovoltaic systems or electricity generation through solar power plants. However, at present, the installed capacity is far from the development potential of the country [4], [5], so it is still far from the progress made by countries like Chile, Mexico, or Spain [6]–[9]. Let's compare Germany, one of the countries with the highest use of solar energy in the energy matrix, with Colombia, which receives 30% more solar radiation. We realize that there is still a long way to go to be close to the countries that best have managed the implementation of this technology [10]–[12].

According to studies carried out by the mining-energy planning unit (UPME for its abbreviation in Spanish), the energy potential of the department of La Guajira is so great that using 20% of its surface, 42,000 MW of electricity generation could be obtained using solar energy, achieving, in addition, to bring electricity to non-interconnected zones (ZNI for its abbreviation in Spanish) in the said department and other neighboring regions of the Caribbean region [13]. In correspondence with data from the Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Zones (IPPES-ZNI) in Colombia, 90 municipalities are in the ZNI, covering about 52% of the national territory. These municipalities include 32 departments, five departmental capitals, 39 municipal capitals, and 1,448 localities [13], [14].

Colombia has an annual average of solar radiation of the order of 4.5 kWh/m^2. These conditions propitiate the introduction of photovoltaic solar systems to supply electrical energy needs with the help of some type of subsidy from the national government [15], [16]. In 2005 there were approximately 145 photovoltaic systems, none of them presented to the Mining-Energy Planning Unit (UPME), whose installed capacity reached 208.06 kW; by 2014, it had increased to approximately 11.6 GW, and in 2015 it increased by 0.6 GW for a total of roughly 12 GW [17], [18]. These data show that the impact on the country's energy matrix of electricity generation from renewable sources was shallow [19]. This article analyzes the main aspects related to the introduction of photovoltaic solar technology in the last 14 years in Colombia. In addition, the potential of solar energy in the main cities of the country is studied to quantify the projects and investments that have been made until 2020, the development phases of the current projects, the statistics of the projects presented to the UPME, the review of tax incentives, as well as variations and updates of everything related to the laws and policies of the use of renewable energies.

2. SOLAR ENERGY IN COLOMBIA

Colombia has 550 automatic satellite stations and different points of measurement of atmospheric variables located throughout the country, of which 71 carry out direct measurements, 383 are dedicated to making routine measurements of the average solar hours, and 96 are dedicated to making relative humidity and temperature measurements. In the case of solar radiation at the country level, information is collected from all meteorological stations, and in the case of solar brightness, data is collected from 479 stations. The UPME has established monthly, and annual average radiation and irradiance levels since 1981; these values are expressed in kilowatt-hours per square meter (kWh/m^2) [20].

As already mentioned, the natural conditions in Colombia are favorable for the generation of electrical energy using photovoltaic solar systems since radiation levels throughout the year are considered very good. Most of the ZNIs in the country has an average solar irradiation resource of 194 W/m^2 and an average daily solar radiation of 4.5 kWh/m^2. These values exceed the global average of 3.9 kWh/m^2 per day [21]. Table 1 shows the data obtained and the characteristics of the geographical location of the meteorological stations installed in the country's main cities and the average solar hours in the year [22]. The high average hours of sunshine in Colombia are significant when investing in photovoltaic systems and taking advantage of them. There would be a heightened period of incidence (time) of solar radiation in the photovoltaic panels, consequently greater capacity generation of these. In addition, it should be noted that Colombia is within the equatorial zone, so in much of its territory, the seasonal phenomenon is not present, guaranteeing an average resource of good solar radiation throughout the year [23], [24].

Table 1. Potential for average global irradiance received on the surface in the main cities of the country [20]

Station	Municipality	Department	Latitude	Length	Elevation, MASL	Anual average, kWh/m^2 per day
Airport El Dorado	Bogotá	Cundinamarca	4.71	-74.15	2541	4.0377
Airport Olaya Herrera	Medellín	Antioquia	6.22	-75.58	1490	4.3351
Las Flores	Barranquilla	Atlántico	11.04	-74.82	2	5.9512
Airport Rafael Núñez	Cartagena	Bolívar	10.43	-75.5	2	5.5525
UPTC	Tunja	Boyacá	5.55	-73.35	2690	4.6574
Airport Olaya Herrera	Medellín	Antioquia	6.22	-75.58	1490	4.3351
E.M.A.S	Manizales	Caldas	5.09	-75.51	2207	3.7672
Univ. Tec. de Magdalena	Santa Marta	Magdalena	11.22	-74.19	7	5.4054
Airport Vanguardia	Villavicencio	Meta	4.15	-73.62	423	4.7507
Botana	Pasto	Nariño	1.16	-77.28	2820	3.7428
Armenia	Armenia	Quindío	4.53	-75.69	1458	3.9338
Airport Matecaña	Pereira	Risaralda	4.8	-75.73	1342	4.2109
Airport Gustavo Rojas	San Andrés	San Andrés	12.	-81.7	1	4.8183
Airport Perales	Ibagué	Tolima	4.42	-75.13	928	4.6632
UniValle	Cali	Valle del Cauca	3.38	-76.53	992	4.3326
Macagual - Florencia	Florencia	Caquetá	1.5	-75.66	257	3.6175
Airport Admiral Padilla	Riohacha	La Guajira	11.52	-72.92	4	5.6058

3. RESULT AND DISCUSSION

Colombia, although far from the countries that make the best use of solar energy, has made progress in terms of the implementation of renewable energy projects in the last ten years, especially about the service and use of solar energy, according to a study presented by UPME on September 30, 2020. Figure 1 shows the behavior of the renewable energy projects presented from 2007 to September 30, 2020. In 2014 the first solar energy project was presented, achieving a total of 883 to the reference date, being the year 2018 when more projects were executed with a total of 240. These advances are due, to a large extent, to the action of the private sector and the efforts made by the national government in the creation and modification of policies and laws that help stimulate the implementation of renewable energy projects [25]. Figure 1 shows the evolution in implementing and registering projects before the UPME, comparing the total enrollment of renewable energy projects versus the total of registered solar energy projects. It is evident that since 2016 there has been significant progress in the implementation and use of solar energy in the national territory, and in 2017 the highest percentage of participation in solar energy projects was achieved compared to the other sources of renewable energies with 78%.

Figure 2 shows the percentage of participation of solar energy in comparison with the renewable energy projects presented and registered with the UPME. When a single solar energy project was developed in 2014, the percentage of participation concerning the projects presented was 1.3%. In 2018, the most significant number of solar energy projects was registered with 240, equivalent to 66.7% of the total. However, in 201, projects related to solar energy reached the highest percentage of participation compared to other renewable energy sources, reaching a value of 78%.

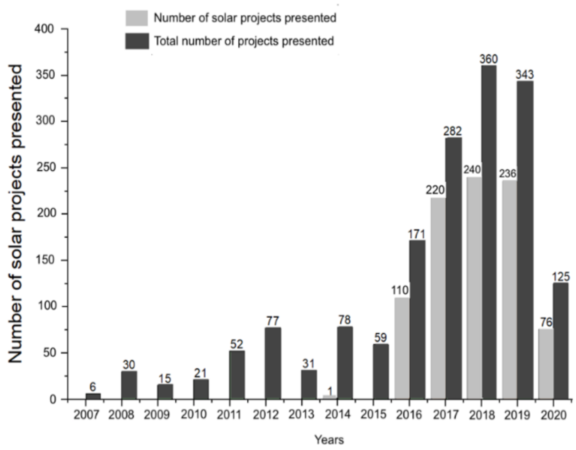

Figure 1. Total renewable energy and solar energy projects from 2007 to 2020

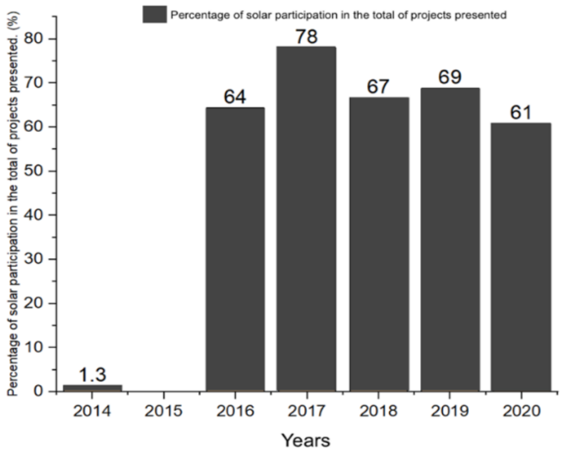

Figure 2. Percentage of participation in projects with solar energy since 2014

It should be noted that, in 2020 worldwide, due to the crisis generated by coronavirus disease (COVID-19), there is evidence of a decrease in the registration of renewable energy projects; however, in Colombia, the registration and development of renewable energy projects solar energy performed well, reaching 61% of the total projects presented. This demonstrates the commitment by the Colombian government and private companies to achieve an energy matrix where renewable energies have the highest percentage, thus achieving a less invasive energy generation system to the environment, where the use and penetration are encouraged, in the national network of unconventional energy sources with criteria of environmental, social, and economic sustainability. The objective is to ensure that by 2030 renewable energies are a matter of public utility, social interest, and national convenience due to the importance of using these unconventional sources to protect the environment and the efficient use of energy [26].

Renewable energy projects presented to the UPME must complete 3 phases, the first of which corresponds to the study and analysis of technical and financial viability where strategic markets are identified that offer attractive investment opportunities; The second stage corresponds to the technical design of the project to obtain the necessary permits, licenses, and authorizations to start the project. The last phase corresponds to the development, construction, assembly, and implementation of the system. Once these stages are completed, the necessary procedures must be carried out to certify the plant has been designed according to the project. In any irregularity, the corresponding modifications must be justified and documented. Until the end of September 2020 in Colombia, there were 146 solar energy projects in phase 1, 59 in phase 2, and 4 in phase 3. Figure 3 compares the solar energy projects that have been in development since 2018 and the total of projects that involve other renewable energy sources, concluding that there is a total of 668 current projects, of which 209 correspond to the use of solar energy, that is 31%.

The 209 current projects for the use of solar energy can be classified according to the design electrical powers, Figure 4, noting that 64 projects, corresponding to 30.62% of the total, have a nominal power between 0 to 1 MW. There are 62 projects, corresponding to 29.67% of the total, which have a power value between 2 MW and 10 MW. These data show that more than 50% of the total solar energy projects registered in Colombia correspond to projects with operating power between 0 MW and 10 MW. Only 17 projects, corresponding to 8.13%, have a greater than 100 MW design power.

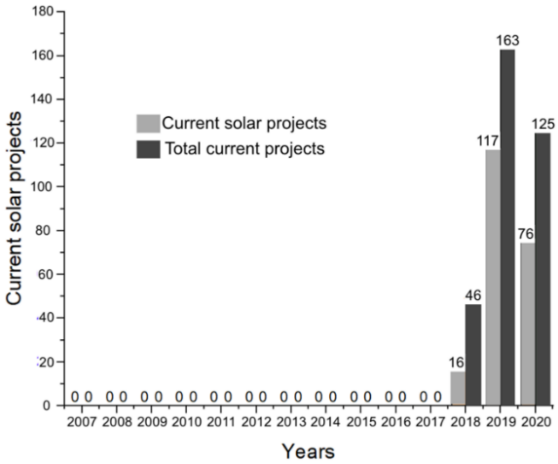

Figure 3. Current solar projects vs. total presented since 2018

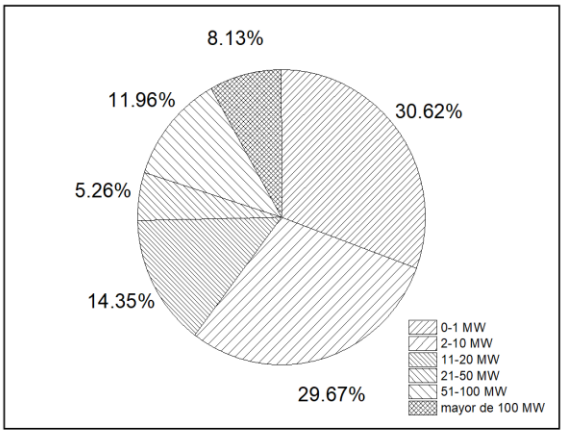

Figure 4. Classification by range of designing electrical powers in current solar projects

In 2018, there was an installed capacity of 2.4 MW from photovoltaic systems between the capital district and the 32 departments that make up the country. From the total value of installed power, there are 1.9 MW that are distributed in the departments of Cundinamarca, Atlántico, Valle del Cauca, Antioquia, and Norte de Santander [20]. However, at the end of 2020, the total power of the current solar energy projects amounted to 7,036 MW, of which 3,095 MW were in phase 1, 3,961 MW were in phase 2, and only 59 MW were in phase 3. The last value represents 48.34% of all renewable energy projects registered with the UPME. Figure 5 shows the solar energy projects in force in 24 of the 32 departments of the country, highlighting the departments of Valle, Atlántico, Boyacá, and Bolívar, with 73 projects that represent 35% of the total.

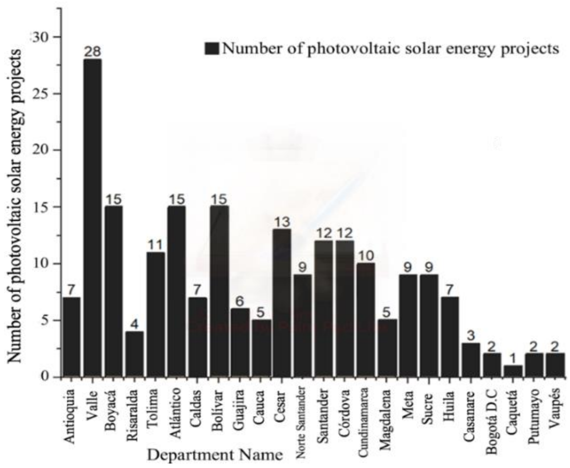

Figure 5. Current solar energy projects by department

The analysis also considers the total installed capacity in solar energy projects executed in each of the departments of the Colombian geography. Figure 6 shows that the sum of the installed electrical power in Santander, La Guajira, Cesar, and Atlántico is 4,157 MW. More than 50% of the total installed capacity in all the projects that are currently running in the country. The departments of Risaralda, Cauca, Bogotá D.C, and Putumayo, with a value of 6.2 MW, are the ones that have a lower design electrical power value in the solar energy projects that are executed in their territories.

It is also possible to include qualities such as the integrity of the information handled that depends on the design objective; mobility as the agent's ability to move in the environment and move through a network of processing nodes to perform specific tasks [27], [28]. Another quality is intelligence, which allows the agent to analyze and order knowledge about the environment and use it appropriately. It can self-reconfigure itself to adapt to its environment [29], [30]. Despite all these qualities, and due to the level of complexity existing in the architecture and process of the steelworks, a single agent does not provide an answer to the problem addressed, so it is decided to analyze the communities of agents.

It is interesting to note that the department of Valle has 28 registered projects, equivalent to 2.48% of the total installed capacity nationwide, while the department of Santander with 12 projects has a value of 20.4%. The department of La Guajira, located in the Colombian Caribbean region, which has good energy potential and an excellent solar radiation index, has only six solar energy projects, but equivalent to 15.71% of the total, that is, approximately 1,113 MW. Figure 7 shows the percentage behavior of the installed electrical capacity in each department, highlighting the Atlantic with 15 projects in execution and installed power of 611.7 MW, corresponding to 8.63% of the total installed capacity in the country.

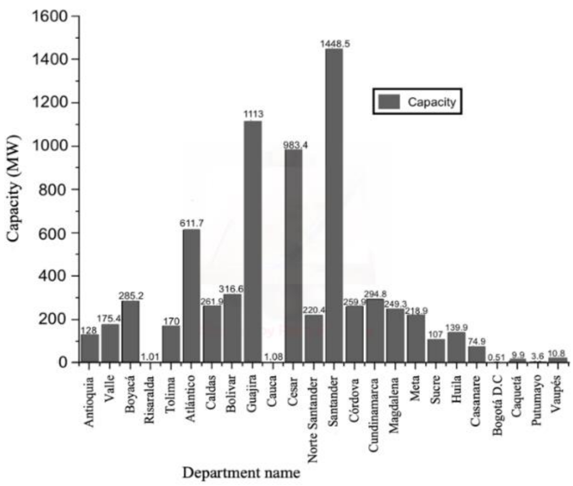

Figure 6. Electric power capacity installed in each department

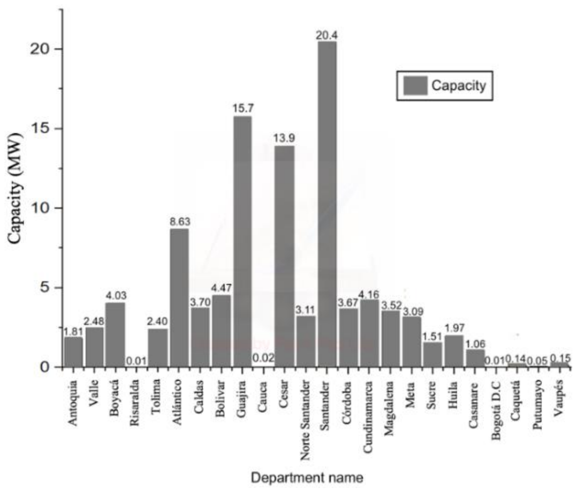

Figure 7. Percentage of installed capacity in each department

3.1. Regulatory framework and policies

At the global level, each country's policies and regulatory frameworks have been modified to facilitate and accelerate the introduction of renewable energy sources (RES). Colombia has not been immune to these changes, so it is intended to carry out a holistic review of the regulatory framework, analyzing the barriers and opportunities for improvements for the development of the RES. In Colombia, according to the UPME, the energy demand is increasing. Therefore, the environmental problems caused by electricity generation from fossil fuels and the depletion of natural resources are growing. This is one of the compelling reasons for the country to bet on the generalization and use of the RES through a regulatory framework and the creation of state entities responsible for controlling and managing them. Table 2 shows the main resolutions and laws of the Colombian regulatory framework that govern the policy for developing RES. Energy and Gas Regulation Commission

The regulatory framework has allowed the development and growth of renewable energies, taking as a starting point Colombia's participation in the Kyoto Protocol on climate change in 1997, Law 629 of 2000 that promotes the rational and efficient use of energy (REUE) and Decree 3683 of 2003. In addition, to promote the implementation of unconventional energies in the country, Law 1665 of 2013 was created. Finally, Law 1715 of 2014 was established to regulate the integration of renewable energies in the National

Energy System (NES), especially in non-interconnected areas (ZNI), create incentives for projects of this type, for example, exemption from value-added tax (VAT) and reduction of the payment of income tax.

Table 2. Colombian regulatory framework [23]

Colombian regulatory framework according to the Energy and Gas Regulation Commission (CREG for its abbreviation in Spanish)		
Organization	Resolution CREG 097/2008	– Regulation of distribution activity.
	Resolution CREG 179/2014 Resolution CREG 095/2015	– Regulated discount rate for the regulation of distribution activity.
	Resolution CREG 030-038/2018	– Whereby small-scale self-generation and distributed generation activities are regulated in the National Interconnected System.
	Law 1715/2014 and Decree 2649/2014	– The integration of non-conventional renewable energies into the Colombian system.
	Resolution CREG 011/2015 and 063/2010	– Demand response programs.
	Resolution CREG 197/2014, 180/2014, 119/2007	– By which special conditions are established to provide electric power service in areas of difficult access.
	Resolution CREG 037/2018	– Regulates the commercialization activity.
	Resolution CREG 038/2014	– Code of measurements and intelligent meters
	Resolution CREG 019/2019	– By which CREG Resolution 108 of 1997 is added about users' rights Small Scale Auto generators.

4. CONCLUSION

This research has made it possible to identify the current situation in Colombia regarding the use of renewable energy sources by analyzing the evolution that the use of solar energy has had during the last 14 years. On the other hand, it is possible to identify the percentage of participation of the leading departments in the current projects, observing the active participation of the departments located in the north of the national territory, including La Guajira, Atlántico, Cesar, and Santander stand out. In addition, these same departments have the highest installed electrical capacity with a value of 4,157 MW, more than 50% of the total registered in all current projects. The energy matrix that characterizes Colombia depends mainly on the behavior of the rains to achieve adequate water levels in the different reservoirs. The phenomena known as El Niño or La Niña alter the level of rainfall and therefore affect the generation of electricity in the other hydroelectric plants that the country has, therefore, on many occasions, it is necessary that the power plants that they were back-up in an emergency or abnormal situation and that they work with fossil fuels. Faced with these scenarios, the introduction, development, and implementation of renewable energy sources are beneficial. It should be noted that the electricity system has been evolving favorably in recent years, mainly due to the adequate willingness of private companies and the Colombian government to promote RES, for example, the implementation of Law 1715 of 2014 seeks to diversify the electricity matrix aiming at the inclusion of renewable sources through tax incentives for those who develop self-generation projects and sales of surpluses.

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