Performance Evaluation of Photovoltaic Projects in Latin America

Cristian León-Ospina, Heyner Arias-Zarate, Cesar Hernandez
Universidad Distrital Francisco José de Caldas, Bogotá D.C, Colombia

***Abstract*—Photovoltaic solar energy has been booming worldwide due to the scarcity of non-renewable resources, from there arises the need to modernize and innovate in the methodologies for the use of energy resources as well as in the correct installation of this system at an urban or level rural. In recent decades in Latin America there have been presented advances in the implementation of photovoltaic projects, which is why this document aims to evaluate the feasibility of these at a technical and technological level, so that they are in accordance with the systems implemented in Asia, Europe, and North America. The analysis determined that the main factors affecting the feasibility of a photovoltaic execution project are economic and technological, in addition to the adverse impacts found on the ecosystem and the local population, but in general it was observed that they are weaknesses that can be corrected, since there are different countries that are working on establishing strategies to educate their community, so there is an improvement in the quality of life in sectors with high CO_2 pollution and lack of fossil fuels.**

Keywords*—*Evaluation; Latin America; photovoltaic; project

I. Introduction

At present, due to the inconveniences presented by the scarcity of non-renewable resources that are used for energy generation in the world, it is necessary to implement new methods that take advantage of natural resources, as is the case of photovoltaic systems. In this procedure, solar energy is harnessed by storing, regulating, and transforming it into electricity for use in residential and industrial electrical installations [1].

The definition of solar energy refers to the electromagnetic radiation emitted by the sun that can be harnessed using multiple technologies. Modeling and simulation of these types of systems have become a widespread practice in the academic and industrial world [2]. They are essential tools for the design and installation of a solar plant, and for the estimation of its productivity.

Photovoltaic systems are recognized as a group of components that make it possible to harness and use electromagnetic radiation emitted by the sun to produce electricity. These types of systems are identified according to the types that compose them and the materials or elements with which they are manufactured and put into operation.

This document details the analysis of the factors that make it possible for a photovoltaic project to be carried out satisfactorily in a sustainable, energetic, and economic way. This analysis aims to contemplate the feasibility of these projects and contribute to the strengthening of knowledge about photovoltaic energy and therefore motivate research and development of strategies that optimize it, to contribute to the improvement in the quality of life and in turn with the reduction of CO_2.

This was done through specific IEEE bibliographic sources that document the axis of analysis of this project; these documents were compared by analyzing the different implementation strategies of photovoltaic projects in specific Latin American countries, using graphs, figures, and descriptions of each. To contemplate the factors those were most relevant when materializing this type of project.

This document brings a unique added value as it offers innovation and solutions for energy problems that are difficult to address. This means that this document stands out from other documents because of the usefulness of its content. Photovoltaic technology is especially useful for companies and organizations that seek to optimize production and service processes for communities with difficulties in accessing electricity. This makes it possible to save time and money by providing information that facilitates decision-making on critical factors of the project and at the same time improves the efficiency of the photovoltaic generation process.

II. Related Works

In [3] performs a return analysis on the study of various photovoltaic systems, investigating three generations of photovoltaic technology taking into account efficiency, embodied energy and return on investment in energy to identify relevant elements that allow generating technological development. One of the main objectives is to find ways to reduce the financial costs of the production of photovoltaic systems. It is found that the first-generation wafer-based technology has a higher efficiency than the second-generation thin film, but at a higher cost per unit area and that for the third generation the technologies have not sufficiently emerged yet. But it is also highlighted that energy performance and environmental impacts or greenhouse gas emissions must be taken into account, which can be indicators of the benefits and costs, this was found that the thin film has the best advances in performance energetic and is currently working better [3].

In [4] described the impact assessment of net metering for Distributed Residential Photovoltaic Generation in Peru. The economic impact of what is known as net metering of the photovoltaic system interconnected to the grid is analyzed, where the user is able to deliver or receive energy from the grid depending on whether there is an energy surplus or not receive missing energy from the network to meet their needs through bidirectional meters, in addition, an analysis of the legal and regulatory mechanisms that define as such the economic conditions of energy exchange with the electrical distribution network in the city of Arequipa is carried out. This basically provokes a discussion in terms of the advantages and disadvantages that both distribution companies and end users present, since the payback time of applying this methodology is quite long and the effectiveness depends on the geographical area. Because if the location has a sufficient level of solar energy, it is more likely that the investment will be recovered a little faster. On the other hand, the distribution companies would see their business affected since it depends on the end user's consumption being higher and not lower due to the injection of energy that they would generate on the grid, for which the prices in the market would be affected [4].

In [5] presents an analysis of the different subsidies provided by the Mexican government to those who promote projects that implement renewable energy, more specifically photovoltaic energy, taking advantage of the great growth that this has had in recent years, measuring the economic feasibility of said generation projects. will have on the energy market in the country, sustaining that the use of this type of technology mitigates climate change, that this type of energy does not generate greenhouse gases and is booming, so Mexico is taking advantage of this opportunity to strengthen the agricultural sector, taking into account that Mexican investors carefully evaluate the risks of contributing their capital for this type of project. In order to see what factors must be taken into account, a study is also made of the dates of different regions of the country to see how much solar energy could be counted on to consider the energy potential, and what investment mechanisms can be used taking into account the affectation that this will have to implement in the agricultural sector due to the strong initial investment that must be made, so the incidence of subsidies on the viability of these projects will also be evaluated due to the analysis of the cost of the energy generated and the return time of the investment, but according to the analyzes carried out, everything points to the fact that without these subsidies, due to the high costs, this type of generation would not be profitable [5].

III. PHOTOVOLTAIC PROJECTS IN LATIN AMERICA

A. *Scientific Databases*

When delving into the research of photovoltaic projects in Latin America, it was use as query tools several databases among which IEEE Xplore and Scopus stand out. For this case IEEE publications that have been made on this topic in the last 20 years were used.

1) Documents per year: In this section we will recognize the evolution of research on issues related to photovoltaic systems in Latin America in the last 20 years according to the information provided by the databases. See Fig. 1.

2) Documents by region: The countries that have done the most research in the implementation of photovoltaic systems in this part of the continent are Brazil (87), Uruguay (61), Peru (38) and Ecuador (15).

3) Types of documents: It is highlighted that the documents issued by educational or academic institutions are conferences (228), scientific articles (123) and journals (3), generating a total of 354 documents.

4) Most frequent keywords: Based on the bibliometric analysis it was carried out using several tools such as VOS viewer, after was mapped for this case the keywords that are most used in the documents found the IEEE databases, thus recognizing which are the focuses of the research carried out in the area.

Fig. 2 shows the topics most frequently mentioned in the documents are solar energy, photovoltaic cells, photovoltaic systems, all implemented in Latin America.

B. *Projects with the Highest Energy Production in Latin America*

In this area of the continent the use of renewable energies is booming, in this case photovoltaic solar energy in recent years has excelled dramatically in several countries, some of the largest producers are: Brazil, Mexico, Chile and Argentina.

Fig. 1. Research trend in recent years.

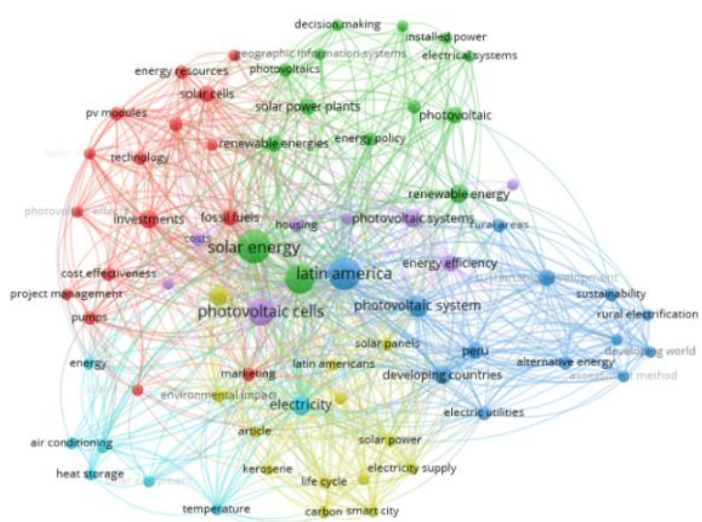

Fig. 2. Visualization of the network related to the keywords covered in the articles referring to photovoltaic systems.

Each of these nations was delved into to identify their most emblematic projects in this type of energy technologies, thus recognizing their technical specifications in order to demonstrate the current energy production and its contribution to the national interconnected system.

1) Brazil: It is the country with the largest population area in Latin America, because of this the increase in energy demand extends annually that is why they are implementing the use of new technologies for energy generation, among those are the photovoltaic systems who in recent years it has increased its power generation capacity exponentially as shows the Fig. 3.

Recognizing this renewable energy generation that the country has had, the attention will focus on the exploration of some of the largest solar farm projects that the country currently has, among which are:

a) Ituverava solar park: This solar park has been operating since 2017, being the largest plants in South America, has an approximate area of 600 hectares, houses around 850,000 solar panels, with a maximum production capacity of 550 GWh per year [7]. It is located in the state of Bahia in the municipality of Tabocas do Brejo Velho.

In the area where this solar park was built, the presence of a lot of biodiversity is evident, which is why mechanisms have been implemented to mitigate the environmental impact such as artificial nests for birds, recycling and water treatment systems and a mini solar farm. This is intended to supply a part of electricity to a neighboring community. On the other hand, the investment made by Enel for the construction and execution of this plant was around 4billion dollars, which is intended to supply the energy consumption of around 268,000 homes, thus preventing the emission of approximately 318,000 tons of CO2 [7].

b) Nova olinda solar park: It is currently one of the largest solar photovoltaic power generation parks in Latin America, its approximate installation area is 690 hectares, it has a total installed capacity of 292 MW, producing approximately a maximum capacity of 600 GWh [8]. It is located in the state of Piaui in the municipality of Ribeira do Piaui.

The company managing the service invested around 300 million dollars in the construction of nova Olinda, thus maximizing the energy coverage of around 300,000 homes, generating a reduction in greenhouse gas emissions of around 350,000 tons.

Both solar parks are managed by Enel, an Italian company that is one of the world's largest providers of renewable energy optimization for the purpose of cleanly electrifying the countries in which it operates.

2) Mexico: This Central American country has the second-best population in photovoltaic generation, due to the global energy crisis that has been presenting, Mexico has seen the need to implement new generation parks in order to meet the demand it currently has. The evolution it has had in the photovoltaic generation capacity in the last decade has grown exponentially, amplifying its generation in the last 5 years. Fig. 4 shows the trend of this energy production.

Next, some of the largest photovoltaic solar generation parks in the country will be observed.

a) Villanueva solar power plant: Since 2018 the Villanueva solar photovoltaic plant has been in operation with an installation area of approximately 2,400 hectares, thus projecting a production of 1700 GWh per year when it is fully operational. There are around 200 to 300 of solar panels [9], this plant is located in the state of Coahuila in the town of Viesca.

The investment for this plant was US$650 million, with a strong focus on environmental impact, waste management, CO2 emission reduction and economic growth for the communities living near the solar plant.

b) Magdalena II solar power plant: In 2019, the construction of this work was completed, housing an area of approximately 800 hectares, at maximum capacity it could generate 600 GWh per year. [10].

One of the technological advances that this plant has is that its photovoltaic modules are bifacial, in order to take advantage of the incidence of the sun on both sides of the solar panel [10], and these panels have a monitoring mechanism which is programmed to obtain the greatest use of solar radiation.

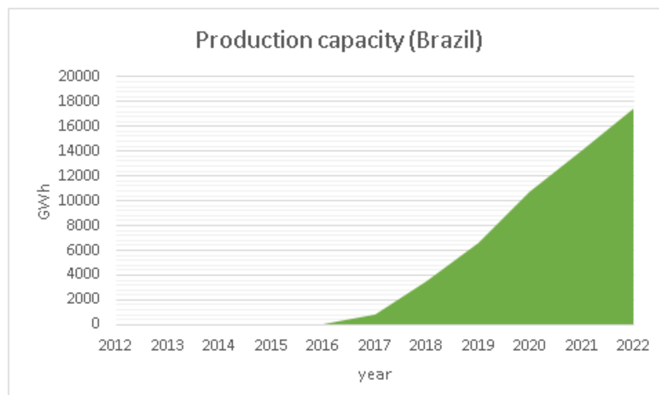

Fig. 3. Photovoltaic solar production capacity in Brazil [6].

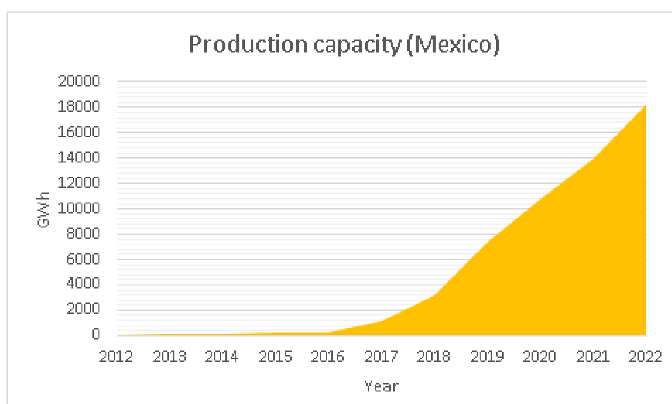

Fig. 4. Photovoltaic solar production capacity in Mexico [6].

This Park is located in the state of Tlaxcala and is intended to supply the consumption needs of approximately 456,000 Mexican households.

3) Chile: In this area of the continent there is the best solar radiation in the world, which is why the boom it has acquired in the last decade on the generation of photovoltaic solar energy has been wide.

It must recognize that lately the materials that are being used by the entities that execute this type of energy projects are of high efficiency, this in order to make the most of the energy resource. Fig. 5 shows the increase in the production capacity of gigawatt hours of photovoltaic solar energy.

Some of the projects that stand out most in the country are the following:

a) Domeyko solar plant: The construction of this project is in charge of Enel Power Chile, it has an approximate area of 700 hectares where approximately 473000 bifacial photovoltaic modules are installed [6], in order to generate greater use of the reception of solar radiation, It should be noted that in this area of the world is where there is greater energy efficiency regarding this type of energy. When the plant operates at its maximum capacity it can generate approximately 590 GWh per year. It is located in the region of Antofagasta.

The cost of this project was 164 million dollars, the execution of this was carried out during the pandemic therefore its workers complied with all safety protocols in order to guarantee their health and that of their community, this project aims to avoid the emission of CO2 of approximately 439000 tons annually [6].

b) Sol de lila photovoltaic park: This solar plant is located in the Atacama Desert, has an installation area of approximately 720 hectares, where approximately 408,000 bifacial photovoltaic modules are installed [12]. when the maximum operation is found, it is expected to generate approximately 500 GWh per year, thus benefiting the surrounding population of the Antofagasta region.

The greenhouse gases that can be mitigated when this solar park is in execution would be approximately 372000 tones. The execution of this work was carried out by more or less 500 workers in times of pandemic, each of them maintaining safety protocols.

4) Argentina: In this country, despite being in an area where there is a great solar radiation, it had not invested much money in energy innovation due to its political and economic problems.

Despite the situation, it can be seen that in the last decade it has begun to increase its photovoltaic solar energy production capacity gradually since 2017, thus recognizing its need to implement renewable energies in the national interconnected system. Fig. 6 will show the increase in energy production.

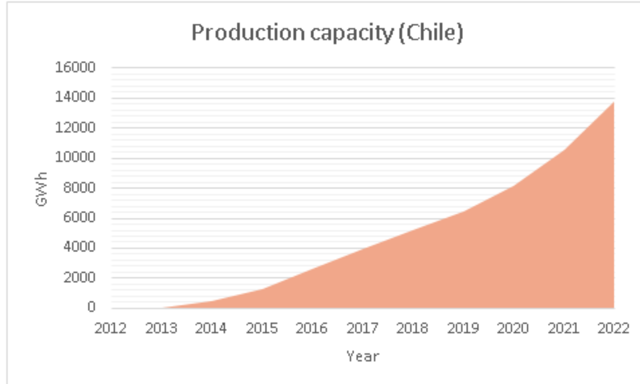

Fig. 5. Photovoltaic solar production capacity in Chile [11].

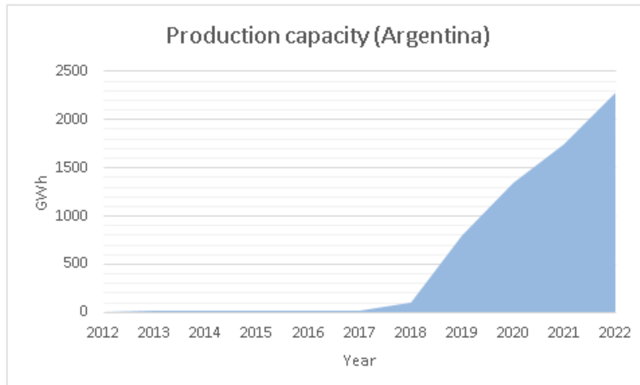

Fig. 6. Photovoltaic solar production capacity in Argentina [11].

The most relevant solar plants in the country are:

a) Cauchari solar plant: The energy company Jemse started up the largest solar energy plant in Argentina, located in the Puna region, with an area of approximately 800 hectares and an installation of 90,000 solar panels, producing 215 GWh annually at maximum capacity [13].

The power that handles this solar plant is 300 megawatts, the implementation cost was 390 million dollars, pretending to cover the energy need of approximately 160,000 homes, it is located at 4020 m above sea level.

b) Altiplano 200 photovoltaic solar park: This solar park is located in the town of Olacapato, has an installation area of approximately 350 hectares, locating there a total of 500550 solar panels, producing at maximum capacity a power of 200 MW [14]. The investment for this project was 313 million dollars, this project was created by merging the projects of Puna and Altiplano. The project is managed by Cammesa for a period of 20 years.

IV. Technical and Economic Feasibility of Photovoltaic Projects

A. Type of Environment or Geographic Area

The optimal environment to implement a photovoltaic system is one that allows the greatest solar radiation throughout the day, although this depends on some atmospheric phenomena that are listed in Table I.

TABLE I. ATMOSPHERIC PHENOMENA PRESENTED IN SOLAR RADIATION [25]

Phenomenon	Definition
Absorption	A large accumulation of solar radiation that is filtered by the gases present in the atmosphere thus preventing its transit to the surface of the earth.
Diffraction	It is a phenomenon that occurs when solar radiation transits through clouds, the incident ray when reaching these is fragmented in such a way that each of these has less energy.
Dispersion	For this case, the sun's rays are deflected by dust particles water molecules present, thus preventing their arrival on earth.
Reflection	This phenomenon has the characteristic that when it meets the particles that are suspended in the clouds, as well as the gases that it contains, they cause the sun's rays to be returned to space.

Complemented the above, it is necessary to emphasize that this energy resource has great variability also due to climatic factors such as the conditions that occur throughout the day, as well as the change at night and the time of year in which this system is used.

Photovoltaic installation depends on the place where it can be located, if they are generation parks at a macro level such as those managed by large energy companies in the world it is necessary that this is located in a desert or arid area allowing ease of construction and in turn the feasibility of the system mitigating its environmental impact, on the other hand if our photovoltaic installation is micro level this can be located anywhere in the world that is outdoors and can capture solar radiation.

Depending on the location it has at its latitude this will define an estimate for the angle of inclination that solar panels can possess if they are of fixed type. Fig. 7 shows a mapping of the areas where there is greater solar radiation in the world.

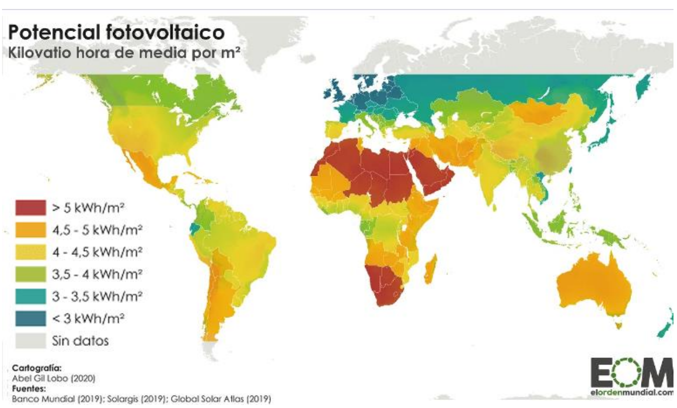

Fig. 7. World map of the areas with the greatest solar irradiation.

B. Space required for the Installation of these Systems

1) Solar parks: When large photovoltaic projects are executed, it is necessary that these are located in areas where the greatest irradiation in the country is present, such as deserts, among others, this type of spaces must have a level ground so that when installing the structure of the solar panels there are no variations in the This would affect the optimal reception of this energy resource.

2) Isolated photovoltaic systems: This type of installation is intended to locate the solar panels in a clear area either located on the ground or attached to the roof of the place where they are going to be implemented, this in order to avoid deviations or obstructions of the solar radiation that is directed to the panels. For the rest of the components such as the inverter, batteries, regulator and protection systems, it is required that these be located in a place that is not outdoors and in turn allows a high flow of air in order to reduce the temperature of these electronic devices.

3) Grid-connected PV systems: When they are installed at the residential level you can follow the parameters seen in the isolated systems, there are other cases that are being presented at an industrial and commercial level in the continent are the integration of solar modules on the facades and terraces of buildings and factories in order to take advantage of the great irradiation that It reaches this type of structures and likewise contrasting with the architecture of these so that they do not lose their attractiveness. Some grid operators are encouraging this type of microgrid and are regulating its correct installation to minimize dependence on other types of non-renewable energy sources [17].

Some countries such as Brazil are conducting multiple investigations that are allowing to evaluate the energy performance of this type of systems, which is why certain scenarios propose to use several types of inclinations of solar modules in order to recognize what is the optimal angle for the reception of solar radiation , P Grams such as PVsyst allow us to model some of these scenarios to have great certainty about the nominal power that can be obtained in a period of time, thus corroborating what is calculated in the theory.

C. Required Materials

In this section, attention is focused on the materials used for installation in a given site or area.

1) Panel brackets: The fastening systems aim to support the solar modules as well as to fix the inclination they must carry in order to receive as much of the energy resource or as possible. There are two types of supports which are fixed supports and variable supports. See Fig. 8.

2) Solar modules: This material is one of the most important for this type of energy generation systems, initially the panels were single-facial type thus allowing the reception of energy radiation only on one side, currently a new module has been implemented in the market that takes advantage of both sides called bifacial module as mentioned above allows the capture of solar radiation in the upper part and lower of it. In distributed generation it can be seen that there is a generation power limit of 5 MW as it happens in some Latin American countries, due to this restriction there has been the need to optimize energy capture in order to make the most of the implementation of these systems [18].

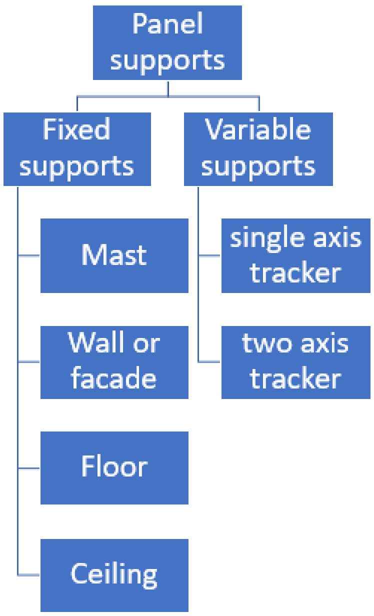

Fig. 8. Types of supports for solar panels [25].

3) Cables: For the correct installation of this type of systems it is necessary to implement electrical conductors that are dimensioned in such a way that they comply with the maximum admissible parameters according to the type d and installation and that in turn is governed by the rules or regulations that it administers in each country as appropriate. Some of the characteristics of these elements will be summarized below in Table II.

TABLE II. TECHNICAL CHARACTERISTICS OF DRIVERS

Feature	Details
Weather resistance	Maximum conductor temperature resistance to external temperatures, resistance to UV rays, etc.
Mechanical strength	Impact, abrasion and tear resistant
Mitigation environmental impact	Low emission of corrosive gases, no fire spreader, halogen-free, etc.
Life	Endure a minimum of 30 years.

4) Connectors: The main characteristic of this type of elements is that they allow the connection of electrical conductors without the need for a splice and in turn have resistance to weathering, thus facilitating the protection of the integrity of the people who transit through the area or manipulate these connections at times of the year when there is high humidity or weather conditions are not the most favorable for the photovoltaic system.

5) Electrical connection system: To generate the control and correct distribution of the photovoltaic system and also of its protection elements such as thermomagnetic switches, commissioning systems and the distribution of the branch circuits contemplated for residential or industrial use, it is necessary to do it in a connection box. Among its characteristics is that it must be covered and preferably not outdoors, this in order to prevent the risks of an electric shock when it occurs in a humid environment, the thermomagnetic switches or fuses that this connection box carries must comply with the electrical regulations of each country thus guaranteeing a maximum power support without risk to a short circuit or Overvoltage, CAD to element that is connected there must be labeled so that it can be clearly evidenced to which branch circuit it corresponds and the electrical conductors must comply with the color code presented by the local regulations.

D. Investment

Depending on the use that will be given to the photovoltaic installation, the influence of some evaluation criteria must be taken into account that allows the profitability of the projects to be recognized.

1) Evaluation criteria: Levelized cost of energy (LCOE): is a parameter that allows us to express the cost of a power generation system in a time interval. The variables that fall under this parameter are the net costs of the investment, the rate established for the discount and the total energy used. A project is viable if the LCOE has a lower value than the energy cost incurred in that investment. The expression defined for this case as shown in equation 1.

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}} \quad (1)$$

Internal rate of return (IRR): is a discount rate that generates a balance between expenses and income, thus causing the net present value to be zero. There is profitability in a project if the internal rate of return is greater than the profitability established for the investment, the expression is defined as shown in equation 2.

$$TIR = \sum_{T=0}^{n} \frac{Fn}{(1+i)^n} = 0 \quad (2)$$

Net present value (NPV or NPV): it is a parameter that makes the addition of cash flows in relation to the rate of capital cost, thus considers that a project has profitability at an economic level if the value obtained is greater equal to zero, the mathematical expression is shown in the equation 3.

$$VAN = \sum_{t=1}^{n} \frac{F_t}{(1+k)^t} - I_0 \quad (3)$$

2) Smaller-scale investments: Unfortunately investing in the implementation of this type of systems locally such as installing panels in a house can be relatively expensive, these values vary according to the place where the installation materials are purchased, the qualified, certified labor, regulation, and commissioning of the system. It foresees that this type of investment has a payback period of 5 to 15 years, although some countries are allowing that, if this type of systems are connected to the grid, they can then reduce the cost of the kWh that the network operator can charges thus reducing the recovery time.

3) Larger-scale investments: Large companies worldwide such as Enel Green Power, are pioneers in the implementation of this type of systems and in the last decade have generated a large investment in unexplored areas in some Latin American countries, on average investments per project are around 250 million dollars [19]. Based on the type of investment, the company agrees with local governments to manage this energy system for a minimum of 15 years, thus allowing control of it, gradually impacting the percentage of energy generation in each country and guaranteeing the recovery of its investment in a short time.

E. Incentives

1) Paid: For small solar farms, there are economic rewards for using clean technologies in their electrical installations, these are reflected in the reduction of the cost of kWh and in some cases in the financing of the installation of this type of systems [16].

Companies that manage the largest solar projects in the region receive incentives for mitigating environmental impacts in the area where the project is executed, as well as for the amount of energy they can supply during peak hours, where there is high energy demand.

2) Unpaid: Unpaid incentives are those that are presented as support for humanity, such as the brief mitigation of greenhouse gas emissions, reduction in the generation of hazardous substances to the environment and support for the vegetation of the areas where this type of energy systems is implemented.

F. Environmental Impacts

1) Soil: Despite considering this technology as clean, the environmental impact cannot be completely mitigated since in the case of an installation of a solar park an average of 2 hectares per megawatt installed is required, this over time generates an alteration in the soil thus impacting the habitat that is around this installation, It should be noted that this only applies in areas where there is high vegetation and fauna, therefore a solution mechanism is to execute this type of projects in desert areas.

2) Atmosphere: A considerable amount of the environmental impacts that occur when generating photovoltaic solar energy are the presence of aerosols in the atmosphere, these prevent the efficiency of solar radiation therefore it is integral to carry out studies that allow us to recognize this type of conjunctures and who that is can generate some type of solution in the short and medium term. [15].

3) Impact on local flora and fauna: Another type of environmental impacts that occur in this type of systems is when the flora and fauna of the area where it is going to be implemented is affected, as a result of this some projects have not been viable due to the damage they can generate to the population, in other places it has been possible to generate a common agreement between the population and the entrepreneurs with the in order to receive some series of incentives for allowing the construction of this type of works. [26].

V. Comparative Analysis of Projects

Recognizing the great importance that the implementation of large solar parks generates in a country, it is then possible to deepen this exploration in order to demonstrate what characteristics and parameters stand out between each of the projects, such as strengths, weaknesses, environmental impact, energy generated, investment costs and geographical location chosen for this document.

A. Comparison between Projects in the Same Country

1) Brazil: Between Ponta Pora and Fortaleza is the largest area that produces the largest amount of photovoltaic potential in the country, currently Brazil is one of the largest generators of electricity by photovoltaic solar parks. In 2021, it was consolidated among the ranking of the best country is worldwide occupying box 13 [20], with an installed capacity of approximately 14 GW that are currently in operation, in the map of photovoltaic power that Brazil has, it can see in which areas are more prone to the installation of solar parks to ensure that the reception of the resource is optimized.

Recognizing this energy impact that is presenting worldwide, it is necessary to delve into the main characteristics of the most representative solar parks of this country, this in order to have a base that allows us to recognize what parameters of owning a large-scale photovoltaic solar installation in this part of the continent.

As mentioned in Section II, the solar parks of Nova Olinda and Ituverava are those that present at the moment the greatest capacity of energy generation, therefore, each of its primary particularities is synthesized in Table III.

TABLE III. COMPARISON BETWEEN THE PROJECTS CHOSEN

Variables	Brazil		Mexico		Chile		Argentina	
	New Olinda	**Ituverava**	**Villanueva Solar Power Plant**	**Central solar Magdalena ll**	**Domeyko Solar Plant**	**Sol de Lila photovoltaic park**	**Cauchari Solar Park**	**Altiplano 200 Solar Park**
Strengths	They established a dialogue in common agreement with the surrounding indigenous communities and managed to generate an agreement in which they would provide work and educational training to a large part of the inhabitants of this area, this in order to generate social inclusion so that both parties are benefited from the execution of this project.	High reduction of carbon dioxide per year. Development of artificial nests to protect local fauna. Implementation of circular economy for the rational use of water.	Implementation of bifacial panels. CO2 reduction	Implementation of bifacial panels. CO2 reduction	Totake advantage of the energy resource since this plant was located in a desert. Use of bifacial panels.	Totake advantage of the energy resource since this plant was located in a desert. Use of bifacial panels.	State-of-the-art technology in solar panels and inverters.	Union of several distributed generation companies.
Weaknesses	Impact on the common evolution of the indigenous population the Quilombos.	Due to its location, it is predicted that in later years it will affect the soil and its rich production.	Effects on the local population in the cultivation of melon and grass.	Limitations in planting local growers	Limitation in its capacity.	Limitation in its capacity.	Effects on the local population.	Soil damage
Environmental impact	Medium-term damage to the soil in the area.	Effects on bamboo crops and endemic species.	EGO has implemented the sustainable construction site model in order to mitigate environmental impacts.	To mitigate the impact, water saving and waste recycling systems are implemented	Reduction of 439. 000 tons of CO2	Reduction of 365. 000 tons of CO2	Smog reduction annually	Limitation of CO2 emissions
Potential [MV]	292	254	754	220	204	161	215	200
Location	Piaui	Bay	Coahuila	Tlaxcala	Antofagasta	Atacama	Puna	Olacapato
Cost [USD]	$ 300.000.000	$ 400.000.000	$ 650.000.000	$ 165.000.000	$ 164.000.000	$ 135.000.000	$ 555.000.000	$ 313.000.000
System Losses [MW]	73	63.5	188.5	55	51	40.25	53.75	50

Based on this comparison, the magnitude of the investment in this energy technology is recognized, and how it can provide a better quality of life around 600,000 inhabitants of the surrounding areas, although it must be recognized if it generates certain environmental and social impacts that are not completely supplied, such as an affectation to the unique species of that region that despite the efforts to mitigate this impact will never be close to 0%, hence Ituverava presents a higher economic investment despite the fact that its generation potential is lower than that of nova Olinda. It should be noted that in most of its actions it is possible to recognize the great change that they are allowing the country to transcend at the technological and energy level in the medium term in order to mitigate the scarcity of non-renewable resources that is coming by leaps and bounds.

2) Mexico: This country has the characteristic of having a limitation in humidity and its vegetation is not very wide, which is why solar radiation is very large especially in the northern part of the country. Recognizing this favorability of the area and based on the limitations of fossil resources that this country can generate; it has been involved in the implementation of renewable energies in order to meet the energy demand [27]. Many of its technologies are similar to those it manages in the United States, all this based on a new law called the energy transition law that was published in 2015 which regulates the growth of clean energy in the national interconnected system.

Based on the above, entities such as Asolmex are at the forefront of irregularly enacting all projects related to solar energy, companies such as Enel have come to this part of the continent in order to generate investments that allow the execution of high-quality projects with a high capacity of energy generation [21], Next, the characteristics of some of them are shown in Table III.

Many of the characteristics of these large photovoltaic projects are recognized. This multinational has great campaigns to mitigate the environmental impact and in turn generates studies that have also allowed it to reduce the social impact with the surrounding communities implementing in these centers of academic and labor training, as well as the generations of direct jobs with the company for the short and medium term [22].

3) Chile: Currently in the country is inserted in the national interconnected system about 25% of energy from photovoltaic solar parks, entering around 6500 MW to the system. In the country Several companies that own solar power plants, some of the most prominent are the following:

- Enel: 18 solar power plants.
- Engie: 9 solar power plants
- Prime energy: 14 solar power plants
- Colbún: 6 solar power plants

Some of the regions with the highest solar radiation and that have the constructions of this type of plants are Antofagasta, Atacama and Metropolitan [23].

Some of the characteristics of this type of energy in the country is that the energy is cheaper can mitigate the environmental impact is available anywhere in the country, its maintenance is easy, and energy can be supplied in places where the power line does not reach. To further complement the importance of the implementation of these solar power plants will proceed to recognize some of the characteristics in Table III that handle the solar plants mentioned in Section II.

It could appreciate that both solar parks have similar characteristics since they are located in a desert, thus taking advantage of the incidence of the sun in this area limiting its environmental impact with the flower and fauna of this country. Among its policies for mitigating the environmental impact are the use of circular economy for the rational use of water, recycling solid waste and the limitation of generation of gases that affect the ozone layer, on the other hand, from the social field EGP has generated jobs for people in the area, this in order to take advantage of the national workforce and provide academic training that allows the population a better quality of life while the project is in execution [24]. Some of the features that stand out most is the implementation of bifacial panels, although taking into account the area in which it is installed, it is then limited to the generation capacity since for this area it is expected that energy can be generated 2 or 3 times more than what they currently produce.

4) Argentina: In the regions of Neuquén to Jujuy, there is the largest solar irradiation that Argentina has, which is why the importance of the implementation of this type of energy generation sources will yield a new horizon at the economic and energy level for the country. In recent years, the creation of photovoltaic plants throughout the country has been booming, which is why in the world ranking of energy generation it is ranked 42nd, largely supporting the national interconnected system with clean energies [14].

Some economic analysts indicate that the country would save around 300 million fuels if 1000 MW of renewable energy will be implemented, for this reason it is very important to recognize what characteristics one of the large solar parks that the country has can possess. Some of this information is provided below in Table III.

It can recognize then that this type of solar parks has required a large economic investment due to the environmental impacts they generate in the area, these impacts are of a social and ecological nature, therefore it was necessary that some generating companies will merge as is the case of altiplano 200 in order to maximize their profits by grouping each of the parks that had been created in the area [14]. There is an enormous energy potential of the country, but it is necessary that external agents invest this resource, countries such as China in the last decade have generated agreements and negotiations between energy peers of the country in order to establish some new solar plants that maximize the renewable energy generation of Argentina.

B. Comparison between Selected Projects

When entering each of the characteristics of the largest photovoltaic solar generation parks that Brazil, Mexico, Chile and Argentina have, it was able to show what strengths and weaknesses are presented in each of these projects, the ones that stand out below will be mentioned.

1) Strengths

- Implementation of state-of-the-art technology such as bifacial panels.
- Social inclusion policies that allow a good execution of these projects in the area.
- Capacity of generation to do with it is in the national energy system.
- Weaknesses.
- Effects on the flora and fauna of some areas.
- Excessive water consumption in the construction and execution of these projects.
- Damage to the ground in the medium and long term.

Although it is seen that large companies that develop this type of projects in Latin America, such as Enel, have multiple mechanisms to mitigate many of the weaknesses mentioned above, but unfortunately in some areas where ecology thrives, environmental problems are occurring whose consequences are irreversible. That is why a call is made for this type of policies to be more optimized so that the damage to the environment when these projects are developed and executed have been mitigated to the maximum and not only focus on the reduction of greenhouse gases since this is not the only environmental damage that can be generated.

Loss of energy in solar panels is usually due to two factors, which correspond to the temperature and dirt that are detrimental in photovoltaic installations; where between 15% and 25% of the energy generated can be lost by photovoltaic modules. When designing a photovoltaic installation, consumption must be taken into account and also estimate the number of panels to be installed for the energy demand, in order to correct possible increases or decreases in electrical energy. To mitigate the problems in terms of dirt that occurs in the panels due to climatic factors, a possible solution is to manually clean said modules for the conservation of the photovoltaic plant.

VI. Challenges at the Level of Research and Execution of Photovoltaic Projects in Latin America

The gap opens so that researchers and education centers related to renewable energy generation can inquire about the problems that currently afflict this type of energy systems such as:

- Improve the efficiency of solar panels.
- Regulate the stability of the system.
- Mitigate the impacts on generation due to pollution.
- Portable implementation of these systems at low cost.
- Use of solar cells in public and private means of transport.

Among other projects or mechanisms that optimize the use of these systems.

The technologies that implement photovoltaic systems are relatively recent date back about four decades, which is why there are multiple problems derived from this type of technology thus preventing the increase of its efficiency gradually, the reasons affect the science of these systems are shown in Table IV.

Taking into account the aforementioned affectations, it is necessary to investigate technologies or mechanisms ken to minimize this type of losses to the photovoltaic system that is why some of these are mentioned in order to provide approach tools for future research related to this topic.

TABLE IV. Effects on Solar Energy Systems

Problems	**Description**
Climate impacts	The parameters that affect are the temperature of the surface of the panel and its corresponding radiation, climatic factors, wind and humidity of the area
Environmental impacts	Dust pollution in solar panels, spaces where shadows can be generated, soil degradation, etc.
Characteristic features	Damage to the structure that holds the solar modules, failure of solar cells, elements tearing, etc.
System losses	Losses in conductors, inverters, material with which the cells are manufactured, environmental contamination and distortion of solar radiation. On average, losses are estimated at 25% of the estimated generation.

A. Optimization Mechanisms

1) Control of system stability failures: Based on the great boom in photovoltaic generation worldwide, it can appreciate some challenges or problems arising from this implementation such as voltage stability, power oscillations and frequency regulations. The energy oscillations of the system They are a situation that occurs mostly in areas where its energy flow is directly derived from photovoltaic systems, which is why for this work it is imperative to establish parameters to control the oscillations thus guaranteeing the reliability of the system. [22].

The proposed strategy to mitigate this impact is the implementation of a new control mode that applies to the inverter that is in the photovoltaic network and in the storage system at the moment where the energy oscillations that are parallel to the frequency variations and the state of the load of the storage cell are presented, thus imitating the maximum and minimum values of load and discharge [22]. The hysteresis control allows avoiding the frequent change of the working modes, on the other hand, initially the battery has the role of moderating the energy that comes from the outside, a reactive power controller is also attached to this system, and these mechanisms are used according to the energy level of the battery as shown in Fig. 9.

2) Model for detecting dust accumulation in solar cells: The generation of energy in a photovoltaic system depends directly on the efficiency of its modules or solar cells, this parameter changes according to external factors such as the dirt that can occur in these elements generally in arid areas, as part of the challenges faced by this type of technologies is the mitigation of this type of physical pollution. To detect such a change, it is necessary to make the relevant measurements to a new or recently implemented photovoltaic system [23].

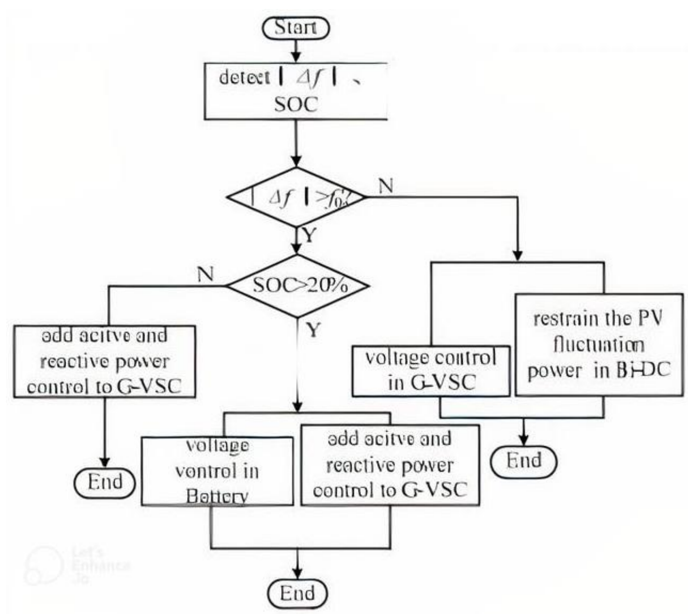

Fig. 9. Gram flow of the control coordination strategy [22].

As an object of this detection model, corresponding measurements of radiance, accumulated power, and temperature in a time interval in a desert of Saudi Arabia are implemented to establish the prediction model. The results of this analysis were that during a year in the months where more sandstorms occurred that is about half of the year, a loss of up to 20% of energy reception was created, thus recognizing the importance of implementing some technological mechanism that limits dust pollution in those months of the year where more losses are generated.

3) Hybrid systems: Starting from the premise that photovoltaic systems can only generate energy during the day, it is necessary to find a mechanism that allows generating energy at night. As a result of this problem, the connection of a wind system that allows generating energy at night has already been implemented so that it can be used 24 hours a day in energy generation [23].

Some of the limitations of the implementation of this type of system are that they can only be developed in isolated areas where power lines are limited. It should also be taken into account that to store this energy derived from a wind turbine, the transformation from AC to DC must be generated in order to regulate the load in order to adjust it to an energy that can receive the storage batteries, which are also implemented by photovoltaic systems.

B. New Technologies on the Continent

1) Two-sided solar panels: Currently some of the new technologies that are being implemented are the use of bifacial panels which allow the use of the entire area of the solar cells in order to increase the percentage of energy reception.

This type of panels has been used by corporations that implement large solar parks in countries such as Brazil, Chile, Mexico, among others. Itis expected that in about 10 years all single-facial solar panels that are used in solar power plants will be updated in order to optimize the performance of this type of generation.

2) Photovoltaic inverters: Another of the advances that are being implemented is the use of photovoltaic inverters that control the stability of the system, this in order not to introduce harmonics in the laying by the electricity network in order to avoid losses due to this type of distortions. The strategy is to control the injection of active and reactive power into the system to improve the efficiency of generation and distribution of photovoltaic solar energy.

3) Implementation in transport: They are currently conducting studies and have some prototypes of vehicles that have solar panels on their roof that are used to generate electricity in the device. At the moment there are only vehicles with very small panels which means that the energy received is not enough to guarantee the autonomy of mobility in a journey of more than 50 km in hours where the traffic is strenuous. In some countries in Europe, North America and Asia, are very common and the use of solar panels in your transport systems such as buses, electric vehicles, trains or ships thus allowing the non-dependence on fossil fuels and more now that due to the situation between Russia and Ukraine, the flow of oil and gas to the entire European continent has been limited.

VII. Conclusions

One of the main challenges in the study of the factors that affect the viability of photovoltaic projects is the lack of information on the different parameters such as geographic location, orientation of the installation, the amount of available sunlight, the level of solar irradiation and the level of energy captured. These limitations are important when evaluating the performance of a photovoltaic project.

In the future, photovoltaic projects are expected to be further developed in Central and South America feeding the electrical grid with clean and renewable energy. Additionally, projects can provide local employment and support economic development. These photovoltaic projects are gaining ground and are becoming a priority. This is due to the growing concern about climate change, as well as the intention to reduce imports of fossil fuels. Therefore, when analyzing the data, an overview of the situation in each country is given. Among the most important factors to consider were: the initial capital required, the installation costs, the geographical location and the cost recovery time, for which it is necessary to generate new knowledge and technologies that carry both the collection efficiency energy, either by improving the composition of the materials of each solar panel, adopting more intelligent economic and regulatory strategies, and becoming aware of the limitations that each country presents.

This article offers an overview of the main aspects that should be considered when evaluating a solar project. It can become a reference for students and professionals in the electricity sector, as it offers a concise and complete overview of the main factors to take into account when evaluating the feasibility of a photovoltaic project. This has led to a greater understanding and use of resources, as well as greater efficiency in the decision-making process.

It is recommended that for future work a study be taken into account that considers the effects that weather conditions and materials may have on the efficiency of the panels, since this can significantly affect performance. Therefore, for a complete evaluation of the viability of photovoltaic projects, this impact must be considered, analyzing how the components interact with each of the climatic conditions, emphasizing considering the resources that represent the best cost-benefit ratio and that can better benefit Latin American countries.

Taking steps to reduce the costs of photovoltaics is essential to ensure that the use of renewable energy is as economical as possible. A clear solution to reduce the costs of electricity is the improvement of solar panels, attacking this lack in energy capture by favoring the reduction of the costs of photovoltaic energy. Measures such as increasing research on solar panels, reducing production costs, and improving design must be taken to optimize performance and lifetime. Research and development in solar panels must be a priority to reduce production costs. This must include the development of new technologies and materials to optimize efficiency. Given that this type of energy once put into operation is a solution in terms of greenhouse gas emissions. Since they do not produce them and also provides a great tool for governments to meet their sustainable energy objectives.

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