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Methodology for the photovoltaic solar energy projects evaluation

Metodología para la evaluación de proyectos de energía solar fotovoltaica

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Abstract

Scientific evidence points to the excessive use of fossil fuels as responsible for climate change. Within the world's high energy consumption, electricity has been the element with the fastest-growing demand in the last 25 years. The increase in renewable energy generation sources has transformed the global electricity supply, positioning electricity as a response to environmental challenges. Unfortunately, thousands of projects proposed and developed over time either have not met the expectations or have not been implemented. One of the most important reasons for these inconveniences is that these projects do not include a comprehensive feasibility analysis and evaluation methodology. The current proposals mainly consider a technical-financial evaluation and leave aside other essential evaluations such as social, environmental, legal, political, economic, and technological, which, when not evaluated, negatively impact the project. Consequently, it is proposed to innovate the development of a comprehensive evaluation methodology that includes the essential variables of the social, environmental, political, legal, technical, technological, financial, economic, and commercial dimensions that mitigate the frequent problems that occur in photovoltaic solar energy
Projects.

Photovoltaic solar energy, Methodology, Project evaluation, Sustainability

Resumen

La evidencia científica señala al excesivo uso de combustibles de origen fósil como responsables del cambio climático. Dentro del alto consumo energético mundial, la electricidad ha sido el elemento con más rápido crecimiento en la demanda en los últimos 25 años. El suministro eléctrico mundial ha sido transformado por el aumento en las fuentes de generación con energías renovables, colocando la electricidad como una respuesta hacia los desafíos ambientales. Desafortunadamente, miles de proyectos planteados y desarrollados a través del tiempo, o bien no han cumplido con las expectativas planteadas o no han llegado a implementarse. Una de las razones más importantes de estos inconvenientes es que estos proyectos no contemplan una metodología de análisis de viabilidad y evaluación de forma integral. Las propuestas actuales principalmente consideran una evaluación técnica–financiera y dejan de lado otras evaluaciones importantes como son las sociales, ambientales, legales, políticas, económicas y tecnológicas, que al no ser evaluadas presentan impactos negativos al proyecto. Derivado de lo expuesto anteriormente, se propone, innovar el desarrollo de una metodología de evaluación integral que contemple las variables indispensables de las dimensiones social, ambiental, político, legal, técnico, tecnológico, financiero, económico y comercial que mitigue los problemas frecuentes que se dan en los proyectos de energía solar fotovoltaica.

Energía solar fotovoltaica, Metodología, Evaluación de proyectos, Sustentabilidad

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Introduction

Energy is a major contributor to climate change, contributing 60% of greenhouse gas emissions, which is why governments around the world have committed to reducing these emissions in order to achieve the United Nations Sustainable Development Goal 7 2030: Affordable and Clean Energy (UN, 2015). As a result, thousands of projects have been implemented since the conference in Rio de Janeiro in 2012.

Unfortunately, most of the companies that carry out these projects with sustainable energy technologies do not consider a comprehensive assessment of the projects, so that during the implementation legal, social and environmental problems arise, among others, causing temporary or definitive suspension of work with considerable financial losses.

The current proposals mainly consider a technical-financial evaluation and leave aside other important evaluations such as social, environmental, legal, political, economic and technological ones, which, when not evaluated, have negative impacts on the project, according to Masera et al.

In an environmental impact assessment, the impacts produced by different alternatives of a project are evaluated in order to decide which of them, and with which requirements, will have the least negative effect on the environment. It is important to take into account the problems that can be encountered due to the lack of an environmental impact assessment, not only ecological damage, but also social and legal problems.

Ikejemba et al., (2017) also assert that, regardless of cultural differences, the reasons for failures in sustainable energy projects are due to factors such as project award processes, stakeholder cooperation, poor planning and implementation, and lack of public acceptance and inclusion.

Environmental problems have a difficult or impossible solution, such as in the case of extinction. This is why an environmental impact assessment is important to detect environmental problems that a given project may cause, before they occur, in order to avoid them.

Other environmental effects are on the type of land where the project will be built and, depending on the type of land on which it will be built - agricultural, livestock, forest - can minimise or maximise the repercussions on ecosystems and the impact on animal and wildlife life.

Several energy infrastructure projects have been suspended or at risk of being suspended due to social conflicts. The main reasons have been the lack of consultation with communities, ejidos or communal properties, lack of knowledge of the type of property regime, that for wind and photovoltaic energy projects, the forms of social property prevail, such as the ejido and agrarian communities; that with regard to land, it is resolved by the ejido or communal agrarian Assembly, in accordance with the provisions of the Agrarian Law (Chamber of Deputies, 2022).

The negative impacts within the project are very varied, ranging from problems of delays in its execution, fines and sanctions for not attending to and complying with administrative and legal requirements, to the partial or total suspension of the project due to the lack of an integral evaluation, causing considerable social, environmental, legal and financial problems.

The advantage for companies is that they have access to large tracts of land, but with the disadvantage of having to negotiate with agrarian communities of hundreds or even thousands of ejidatarios or communal farmers in heterogeneous assemblies. Impacts affect the degree of satisfaction or deprivation of some social right.

Another problem is the lack of knowledge of the regulations for conducting Social Impact Assessments (SIAs), which has slowed down several energy projects. Currently, as stated by Pastor et al. (2016), there are many areas for improvement in terms of project evaluation.

While we find previous methodological proposals, within them the various aspects that comprise the project are developed in isolation, but the cross-cutting aspects, which make up the project as an interrelated system, are not analysed in a comprehensive manner.

The aim of this article is to improve the probability of success in photovoltaic projects by carrying out a comprehensive assessment of the most important variables to be considered in a project, such as financial, technical, economic, technological, commercial, legal, environmental, social and political. The majority of projects carry out technical-financial evaluations, failing to evaluate the other variables described above, causing social, financial, legal and other problems that lead to unforeseen financial expenses and even the loss of the project.

Due to the fact that carrying out a methodology such as the one proposed in large-scale projects requires large monetary investments, the validation will be carried out through the opinion of energy experts from the companies selected by the researcher, analysing the data obtained to determine the variables used in the implementation.

Methodology

The research methodology applied was a field study, with a descriptive and transversal qualitative design; the methodology was the result of surveys and consensus work with companies focused on energy projects with inclusion and exclusion criteria, considering the study variables that have an impact on the development of this methodology.

Additionally, the study is complemented by the experience of experts who have previously developed projects of this nature, allowing the design of an innovative methodological process for the integral evaluation of energy projects that mitigates negative impacts. Three indicators will be used that energy experts will evaluate for each item proposed in the survey: clarity, coherence and relevance.

For the definition of variables dichotomous nominal scales will be used, the selection of these will demonstrate the influence of economic, financial, technical and technological, environmental, social, legal, political and commercial factors which in turn are the main areas included in successful outcomes of energy projects.

The outcome of the survey analysis ensured that it can subsequently contribute to the development of a methodology for effective and successful energy projects.

Ítem	1	2	3	4	5	6	7	8	9	10	Final average
Survey app 1											
Survey app 2											

Table 1 Survey evaluation

Results

Once the information from the surveys of the ten selected companies was collected, the information was used to determine the proposed methodology for the evaluation of photovoltaic projects. For the development of the solar photovoltaic project, the following stages must be considered:

Figure 1 Stages of a photovoltaic solar project

Before the idea becomes a project, its feasibility must be verified. In this preliminary study stage, the necessary investigations and reports must be carried out and generated to support the decision to start or cancel the project.

Feasibility refers to the possibilities of being able to carry out the project, including the technical, technological, financial, economic, social, environmental, commercial, legal, political, etc. points of view. If the project is feasible in all of the above points, then the project is viable.

The feasibility analysis and the areas it includes must go through several stages, according to the depth, quantity and quality of the information involved, commonly referred to as profile, pre-feasibility and feasibility.

Feasibility and feasibility should include the points referred to in Figure 2 below.

Figure 2 Areas to analyse in preliminary studies

The feasibility analysis should include points such as:

1. Elaboration of a thorough map of the site.
2. Evaluation of solar and environmental resources.
3. Shading study.
4. Preliminary sketch of suitable spaces for the system.
5. Analysis of technologies with the best cost-benefit of:
   a. Photovoltaic solar module
   b. DC/AC inverter
   c. Supporting structure
6. Engineering design of the system
7. Building permits
8. Grid interconnection
9. Estimated energy production
10. Financing scheme

Choice of installation site

The choice of the installation site for the solar photovoltaic system is an essential part of the project's viability. The aim is to maximise energy generation and reduce costs. The following constraints must be considered and evaluated:

Solar resource: Solar irradiance incident on the installation area and its relation to geographical and climatological parameters. Annual and inter-annual behaviour

Climatological: Clouds, extreme temperatures, snowfall, windstorms, floods, pollution.

Geographical: Daily rotation, translation, latitude and longitude.

Available area: Space required for solar PV modules, access roads, slope angle, shading between rows.

Land use type: Effects on land cost, impact of landowners surrounding the installation site, environmental susceptibility.

Topographic: slopes and orientation towards the solar resource that favours the project.

Geotechnical: Composition and properties of the area. Mitigation for natural hazards such as avalanches, mudflows, landslides, rock falls, sinkholes and volcanic eruptions.

Geopolitical: Avoid building near militarised regions.

Accessibility: proximity to existing roads, extension of new roads if needed.

Grid interconnection: availability, cost, capacity, proximity.

Soiling of the arrangement: Caused by climatic factors and animals.

Water supply: water supply for cleaning the modules needs to be ensured.

Financial stimulation: Stimuli and tariffs vary from nation to nation and territorial area to territorial area.

Energy productivity forecasting

The energy productivity forecast provides the basis for forecasting project earnings. The purpose is to anticipate the average energy generation per year over the lifetime of the solar PV system. To accurately forecast the energy generated, it is necessary to know the temperature data of the site, solar resource data, technical data of the equipment and the engineering design of the solar PV system. This forecast can be obtained through specialised systems available on the market. These systems model the performance of solar photovoltaic equipment using time steps with annual periods, and can guarantee reliable results that allow for decision making.

The development stage includes the preparation and submission of project authorisation and interconnection applications, design verifications and construction permits, type of construction contracting, type of financing, PV and inverter procurement documentation, supplier selection and contracting, construction tenders, project risk studies, social impact assessment, environmental impact assessment, project executive report, as well as project financial approval. On the other hand, the project design stage comprises various activities as shown in Figure 3.

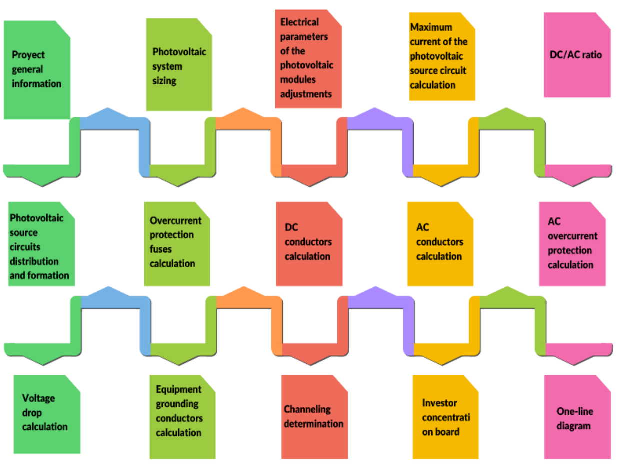

Figure 3 Activities in the design stage

Solar PV system design

Having the lowest levelised cost of energy implies having a detailed engineering design. The levelised cost of renewable energy systems is calculated by taking the cost of installation plus the cost of operation, divided by the expected lifetime energy production cost of the system. Correct technology selection is essential to optimise costs and operation of the system over its lifetime.

The most important devices are solar PV modules and inverters, which require a thorough technology assessment. Solar photovoltaic modules require a detailed technical evaluation that considers the type of technology, module power, technical parameters, inverter compatibility, technical certifications, quality, degradation gradient, cost, performance, degradation, warranties, among others.

Considerations when selecting an inverter include the type of technology, interoperability with the grid code, compatibility with grid interconnection regulations, technical parameters, compatibility with the solar PV module, inverter capacity, efficiency, power factor, quality, price, among others.

Important points in system design:

– Modules oriented to the solar path to receive the maximum annual average solar energy and produce the highest amount of electrical energy.
– Angle of inclination of the modules to receive the maximum annual average solar energy and produce the greatest amount of electrical energy, according to the geographical latitude of the installation site.
– Avoid or minimise shading of the modules by choosing suitable locations and calculating the spacing between rows.
– Optimal wiring distribution design to reduce electrical losses due to distance and reduce costs.
– Optimise the module installation space to obtain the highest solar energy capture, allowing sufficient space between rows for module maintenance.

The design of the electrical system is composed of two subsystems, Direct Current (DC) and Alternating Current (AC).

The DC electrical system consists of the following components: solar photovoltaic modules, DC/AC inverters, photovoltaic power cable, photovoltaic connectors, combiner boxes, disconnectors, countercurrent protection devices and electrical grounding system.

The AC electrical system consists of the following components: AC electrical cable, electrical control substation, transformers, electrical substation, electrical grounding system and countercurrent protection devices.

Permits

Approvals for solar PV infrastructure projects vary according to the geographical location of installation, but the essential approvals for any renewable energy project generally include:

Land purchase or lease agreement

Environmental impact assessment

Construction authorisation

Interconnection contract to the electricity grid
Energy consideration contract.

On the other hand, the consultation of authorities at all three levels of government and agencies concerned with the electricity sector, laws, regulations and standards that apply in each country such as energy regulatory commissions, energy control agencies, land use authorities, archaeological and historical authorities, environmental authorities, military and security authorities, wildlife authorities, aeronautical authorities, ejido communities, communal communities and urban planning delegations are essential to reduce the risk of delays, fines and cancellations of work; and increase the likelihood of successful project implementation.

Construction

The construction phase must be based on best practice management for the implementation of solar photovoltaic projects in the industry. The project must be constructed to meet quality, cost, and schedule objectives, and must comply with all applicable local, state, and federal health and safety, environmental impact, and local, state, and federal regulations.

Common details in the implementation of the project are:

- Foundations inappropriate to soil characteristics.
- Findings of hazardous or contaminated material
- Incorrect module inclination and orientation
- Improper torque on fasteners
- Improperly installed or damaged connectors and cables.
- Construction delays due to bad weather.
- Insufficient row spacing for vehicle passage.

Although some of these details may seem insignificant, they cause major problems with costly repairs.

It is important that staff or contractor supervision by a qualified and experienced engineer is carried out during construction to avoid such problems.

System start-up

System start-up must take into account that the power plant must be electrically and structurally safe during its lifetime and that the operation of the plant must be in accordance with the original engineering design.

Acceptance tests for system start-up can be seen in Figure 4.

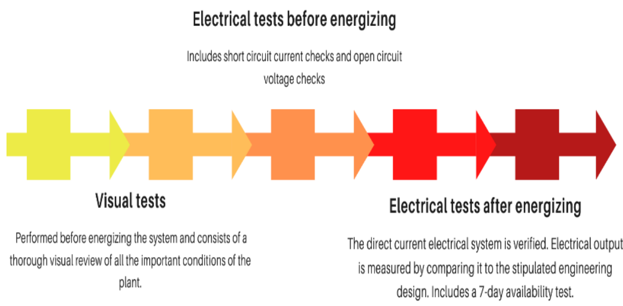

Figure 4 Acceptance tests for start-up

Maintenance to operation

Solar photovoltaic systems have minimal maintenance requirements, in contrast to many other energy production technologies. However, in order to improve the performance of the energy production and to maximise the lifetime of the plant, maintenance service is indispensable.

Maintenance service is divided into:

Preventive maintenance service.

This is scheduled maintenance with the purpose of preventing operational failures and maintaining the plant's functionality in optimal conditions.

This maintenance includes the cleaning of photovoltaic solar modules, verification of connectors and electrical wiring, verification of combiner boxes, thermographic revision of photovoltaic solar cells, inspection of the photovoltaic solar inverter, structural revision of the frame to hold the modules, surveillance and control of fauna and flora and general inspection of the plant.

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Corrective maintenance service

This is unscheduled maintenance with the purpose of repairing faults that occur during operation and includes: Adjustment of cable joints that have become misaligned, replacement of damaged fuses, repair of faults caused by electric shocks, repair of devices caused by animals or people, correction of errors in computerised systems, repair of the frame for holding modules and correction of errors in the solar tracking system.

Economics and finance

Growing solar photovoltaic projects bring a number of economic benefits at national, regional and local level. These include job creation, use of unproductive land, reduction of greenhouse gas emissions, increased energy security, reduced imports of energy products and increased tax revenues.

A comprehensive assessment of a solar photovoltaic project should contain a financial model that considers the financial benefits and obstacles for its development, which should include the points in figure 5 below.

Figure 5 Financial evaluation of the project

Environmental

The electricity generated, transported, distributed and consumed causes a certain degree of environmental impact. Gas emissions from the burning of fossil fuels, the silting of water in hydroelectric dams, combined cycle plants, coal, land clearing and earth movement in wind and solar photovoltaic systems, nuclear energy, all emit some type of pollution and waste into the environment.

As a result of the above, it is necessary to comply with certain standards and procedures to determine the impact on the environment caused by the installation of solar photovoltaic systems, which is why it is an essential requirement to submit an Environmental Impact Assessment (EIA) to the competent authorities.

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It must be carried out through the identification, prediction and interpretation of possibilities to prevent and remedy them, as this assessment can be approved, amended or declined by the corresponding authority.

The basic activities for its elaboration are:

General project data, project description, identification of environmental problems and description of the environmental system, identification, description and evaluation of environmental impacts, measures to prevent and mitigate environmental impacts, environmental forecasts and evaluation of alternatives, identification of technical elements and methodological instruments that support the information.

Each of these activities can be broken down into other complementary elements.

Social

Solar PV infrastructure has a major impact on the local and regional economy and job creation.

In remote rural areas without access to the grid, solar PV is a competitive option that drives the development of these areas. Access to energy supports the development of agricultural and livestock businesses and internet access for students. Electricity is an indispensable element for poverty alleviation and education, having a direct implication on people's lives. In addition, the low cost of electricity production from solar photovoltaic systems can reach more households and foster business growth in both prosperous and developing nations.

In addition, PV projects generate jobs in both the construction and operation stages.

Social Impact Assessment

The Social Impact Assessment (SIA) is the document that includes the identification of the people and communities located in the area of influence of the project, in this case for the energy sector, as well as the characterisation, identification, assessment and prediction of the consequences that the project may have on the population and the corresponding mitigation measures and social management plans.

It is necessary to establish a methodology and research techniques to study the area of the installation of the solar photovoltaic system and to understand the cultural and social form of the population.

The basic factors covered by this methodology are:

1. General project data
2. Project description
3. Social impact assessment
4. Social management plan
5. Administrative steps related to the project

Each of these factors has several overlapping considerations, e.g. the environmental impact assessment includes:

a) Current diagnosis: communities and villages
b) Identification of key areas: downtown square, church, municipal delegation, ejido delegation, communal delegation, health centre, municipal cemetery, banks, sports centre, shops, industries,
c) Identification of stakeholders: Municipal, ejido and communal authorities, parish priest, civil organisations, leaders, among others. Classification by influence.
d) Determine the areas of influence: Direct and indirect. Direct territorial and demographic influences.
e) Establishment of the relationship with the community.
f) Tour of the area to understand the community.
g) Group meetings to review information and doubts.
h) Social impacts
i) Identification of impacts
j) Impact assessment
k) Mitigation measures

Policy

It is important to analyse both the general political conditions and the energy policy of the country in which the solar PV project is to be developed. This includes checking that the energy law and complementary laws for solar PV projects allow and regulate private investments in this sector.

With this perspective, the risk of a current and future political situation that may modify the conditions under which a business has been established and may change the investment prospects must be established and measured.

There are factors that can complicate investment, such as increasing economic nationalism, unstable politics, contractual obligations not respected and even risks external to the authority, such as revolutions, terrorism, coups, etc., or risks of political processes such as changes in trade, foreign investments, changes in the labour regime, in technology, in subsidies, among others.

Energy policies

Energy policy is implemented through laws, energy efficiency standards, investment incentives, tax incentives, and compliance with medium and long-term energy and environmental plans.

Energy policy should consider:

- Energy policy statement concerning energy planning, distribution, transmission, generation and consumption.
- Jurisprudence on energy commercialisation
- Energy use jurisprudence
- Level of openness to foreign investment
- Energy tax policy
- Level of energy security

Energy policies

They are essential to motivate the decision to invest in solar photovoltaic systems, including mechanisms and instruments that support financing, mitigate the risk of investment in the project, and give credibility and confidence to the investor. These include those to expand power generation capacity, provide regulation, incentivise return on investment through price premiums, incentivise return on investment, public tenders for specific supply or capacity quotas, tax credits, tax benefits, capital subsidies, consumer subsidies or rebates, financing, fossil fuel tax, clean energy certificate trading policies, or policies that prioritise the dispatch of renewables.

Public policy instruments

Public policies promote renewable energy investments through a variety of instruments. These can be market-based or regulatory, including the following:

- Financial and fiscal
- Direct public investment
- Feed-in tariff
- Feed-in tariff
- Power purchase and sale auctions
- Tax benefits
- Subsidies
- Loans and funds
- Guarantees
- Carbon taxes

Conclusions

Despite significant efforts to systematise the establishment of large-scale PV projects, there is no comprehensive methodology to ensure the successful implementation of such a project. This paper proposes a methodology 'based on the recommendation of ten companies and several of their experts at national and international level. Following this methodology improves the chances of a successful implementation with fewer setbacks in any region of the world, thus promoting sustainability in all its dimensions, social, economic, technological and environmental.

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