Analysis of environmental impacts in the construction of a photovoltaic plant at the Academic Unit of Cabo de Santo Agostinho, Brazil

Análise de impactos ambientais na obra de uma usina fotovoltaica na Unidade Acadêmica do Cabo de Santo Agostinho, Brasil

Análisis de impactos ambientales en la construcción de una planta fotovoltaica en la Unidad Académica del Cabo de Santo Agostinho, Brasil

Received: 03/04/2024 | Revised: 03/11/2024 | Accepted: 03/11/2024 | Published: 03/14/2024

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Abstract
The use of solar energy has been increasing its space in the energy matrix. Brazil has great potential for applications using photovoltaic energy. This potential is not fully explored. Due to this, this research aims to evaluate the environmental impacts caused by the production, implementation, operation and maintenance of a 1 MW photovoltaic plant implemented in the Academic Unit located in Cabo de Santo Agostinho, Pernambuco, Brasil, one of the branches of the of the Federal Rural University of Pernambuco. The Control List Method ("checklist") was used to identify and qualitatively evaluate the most relevant impacts. The environmental assessment of the plant identified that the biggest impact in the planning phase was the attraction of people, due to the publicity of the project. In the implementation phase, deforestation and soil movement stood out, while visual pollution and the increase in the supply of electricity were the main impacts in the operation phase.
Keywords: Solar energy; Viability; Sustainability.

Resumo
O uso da energia solar vem aumentando seu espaço na matriz energética. O Brasil possui grande potencial para aplicações com uso de energia fotovoltaica. Esse potencial não é totalmente explorado. Devido a isso, esta pesquisa tem como objetivo avaliar os impactos ambientais causados pela produção, implantação, operação e manutenção de uma usina fotovoltaica de 1 MW implantada na Unidade Acadêmica localizada no Cabo de Santo Agostinho, Pernambuco, Brasil, uma das vertentes da Universidade Federal Rural de Pernambuco. Foi utilizado o Método da Listagem de Controle ("checklist"), para identificar e avaliar qualitativamente os impactos mais relevantes. A avaliação ambiental da usina indentificou que o maior impacto na fase de planejamento foi a atração das pessoas, pelo fato da divulgação do empreendimento. Na fase de implantação destacaram-se o desmatamento e a movimentação do solo, enquanto que a poluição visual e o aumento na oferta de energia elétrica foram os principais impactos na fase de operação.
Palavras-chave: Energia solar; Viabilidade; Sustentabilidade.

Resumen
El uso de la energía solar ha ido incrementando su espacio en la matriz energética. Brasil tiene un gran potencial para aplicaciones que utilizan energía fotovoltaica. Este potencial no está completamente explorado. Debido a esto, esta investigación tiene como objetivo evaluar los impactos ambientales causados por la producción, implementación, operación y mantenimiento de una planta fotovoltaica de 1 MW implementada en la Unidad Académica ubicada en Cabo de Santo Agostinho, Pernambuco, Brasil, una de las sucursales de la Universidad Federal Rural de Pernambuco. Se utilizó el Método de Lista de Control ("checklist") para identificar y evaluar cualitativamente los impactos más relevantes. La evaluación ambiental de la planta identificó que el mayor impacto en la fase de planificación fue la atracción de personas, debido a la publicidad del proyecto. En la fase de implementación se destacaron la deforestación y el movimiento de suelos, mientras que en la fase de operación la contaminación visual y el aumento del suministro de energía eléctrica fueron los principales impactos.
Palabras clave: Energía solar; Viabilidad; Sostenibilidad.

1. Introduction

The area of clean energy generation is one of the aspects of sustainable construction, which challenge is to reduce the rates of global warming and gas emissions through fossil sources of energy production (Liao et al., 2014; Polman et al., 2016). The main representatives of clean energy are: hydroelectric energy, biomass, wind energy and solar energy (Melo, 2012).

The most used energy source in the production of electricity comes from fossil and non-renewable sources such as oil, coal and natural gas. The great dependence on non-renewable energy sources has led to the emission of toxic and polluting gases and particulate matter, in addition to the permanent concern with its depletion. Among the gases released into the atmosphere, the most worrisome from a global point of view are the greenhouse gases, especially carbon dioxide (Freitas & Dathein, 2013).

Brazil currently has hydroelectric plants as its main source of energy, currently comprising 1220 hydroelectric plants with a total installed capacity of 92,415 MW, corresponding to 61.34% of the brazilian electricity matrix (Agência Nacional de Energia Elétrica [ANEEL], 2016).

The photovoltaic effect is the generation of electric current or voltage through exposure to light of a semiconductor material, like silicon. Found abundantly in nature, silicon can reach high levels of purity and form crystals which do not have good electrical conductivity. But when combined with other chemical elements, such as phosphorus and boron, it becomes a semiconductor (Tolmasquin, 2003).

When it comes to solar energy implementation, Brazil is considered privileged, given the immense incidence of solar rays emitted in its territory and the abundance of quartz reserves for the production of silicon, used to manufacture solar cells (Aguilar et al., 2012).

Resolution N° 1, published in Brazil in 1986 by the National Council for the Environment (Conama), defines environmental impact as "any change in the physical, chemical and biological properties of the environment, caused by any form of matter or energy resulting from activities human resources", in addition to describing the criteria and guidelines for the analysis of environmental impacts (Resolução Conama nº 1, 1986).

Solar energy matrix has several benefits such as non-polluting gases in the atmosphere compared to other matrixes, minimal maintenance in its plants, its use in remote or difficult to access places, and a long useful life of its implanted systems (Aguilar, Oliveira, & Arcanjo, 2012). However, it still causes environmental impacts in production and shortcomings depending on weather.

The implementation of photovoltaic plants in academic units in Brazil has been the subject of recent studies. Silva et al. (2023) described the implementation of a photovoltaic plant at Christus Faculdade do Piauí, Brazil, sizing the system based on the survey of energy demand and implementation, operation and maintenance costs and financial return. The authors indicated the technical and financial viability of the project, with an acceptable financial return time.

Similarly, Silva et al. (2020) studied the economic viability of a photovoltaic plant on the Pombal Campus of the

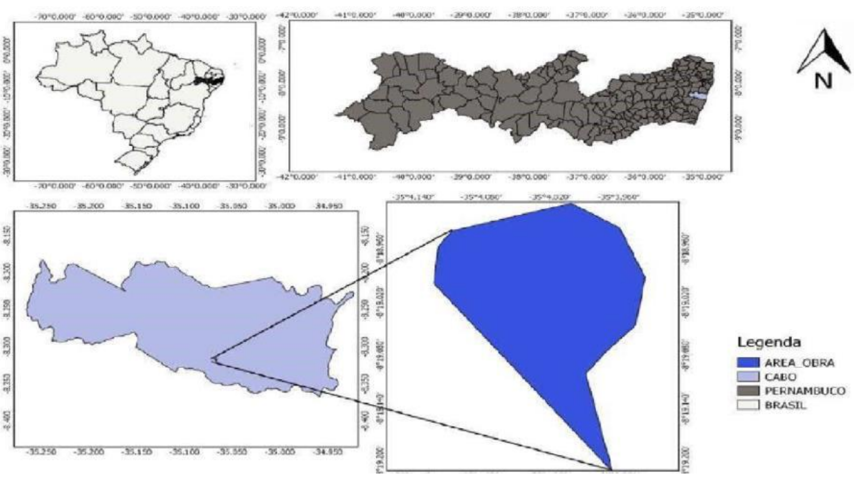
Federal University of Campina Grande, Paraíba, Brazil. Although the plant does not present satisfactory results in the economic aspect, due to the high initial investment value, the authors point out the initiative as a great socio-environmental advance.

Therefore, this research aims to evaluate the environmental impacts caused by the production, implementation, operation and maintenance of a 1 MW photovoltaic plant implemented in the academic unit of the Federal Rural University of Pernambuco, in Cabo de Santo Agostinho, Brazil.

2. Methodology

Built in the city of Cabo de Santo Agostinho, the campus is part of the Federal Rural University of Pernambuco, named as Academic Unit of Cabo de Santo Agostinho (UACSA). It locates 38.5 km from the state capital Recife (Figure 1) and will receive a 1.0 MW photovoltaic plant to supply its amenities.

Figure 1 - Location map of the municipality of Cabo de Santo Agostinho.



Source: Authors (2024).

The academic unit has 56,000 m² and is intended to house several engineering and technology courses. The plant will have an area occupied by plates corresponding to 5883.15 m², consisting of 144 photovoltaic arrays, with an average production in the range of 2627.02 kW (Conselho Superior da Justiça do Trabalho, 2014). It is intended to supply part of the energy demand of UACSA, which has a maximum demand in the range of 6.0 MW. Therefore, the plant's production would correspond to 16% of the unit's maximum consumption, with 1.0 MW of installed power.

This research is a case study, aiming to identify and describe the socio-environmental impacts related to the installation and operation of a photovoltaic plant in an academic unit of a public university (Pereira, Shitsuka, Parreira and Shitsuka, 2018). For this, the qualitative-quantitative method is used, with field surveys carried out for on-site observation and analysis of the area where the project will be implemented and its surroundings, in order to collect data and photographic records.

To identify and map the processes, an operation flowchart was prepared, with information obtained from technical visits to the work. For this, the inputs and outputs of the process for the implementation and operation of the photovoltaic plant were observed.

It was possible to identify the environmental, social and economic impacts through the Control Listing Method ("checklist"), to identify the most relevant impacts. According to Bastos and Almeida (2002), it is one of the most used methods in the Environmental Impact Assessment, which is carried out in the identification and enumeration of impacts, which must be listed and organized into positive or negative, according to the type of anthropic modification, being introduced into the analyzed system.

As an advantage, this methodology facilitates the understanding of information and uses it immediately in the qualitative assessment of the most relevant impacts, showing good performance in relation to setting priorities and ordering information. I gathered the most likely impacts associated with a given project, facilitating their understanding for professionals from other areas (Stamm, 2003; Medeiros, 2010; Sanchez, 2013).

3. Results and Discussion

Land issues

As for the topographic conditions, the area must have a maximum slope of 10%, in addition to being far from high voltage transmission networks, of low agricultural fertility and not have housing in the surroundings, to avoid displacement of families or communities. The area defined for the installation of the photovoltaic plant has the potential to receive the project, respecting the ideal conditions for its installation (Figure 2).

Figure 2 - Installation location of the UACSA photovoltaic plant.

Source: Authors (2020).

The photovoltaic modules will be installed on the floor of the consumer unit. All photovoltaic modules used are identical, they have the same electrical, mechanical and dimensional characteristics. The photovoltaic modules will be installed on 4 plateaus of different levels and distributed in photovoltaic arrays.

Atmospheric emissions, noise and vibrations

There will be no toxic residues during the assembly of the photovoltaic plant. Materials containing asbestos will not be used on site for any purpose. This also includes the material of trims. Polychlorinated biphenyls (PCBs) must not be used on site. Gases composed of chlorine and any other gases with a known propensity to cause damage to the ozone layer through destructive catalytic reactions with ozone molecules will not be used. All persistent organic pollutants (POPs) are prohibited on site.

Industrial and sanitary liquid effluents generation

There will be no industrial effluents. Liquid or pasty products must be stored in places with secondary containment. During the construction phase there will be human activities, which will generate sanitary sewage, which will have physical-chemical-biological characteristics common to any sanitary sewage for an estimated 500 to 800 employees.

Considering that there is no technical feasibility for forwarding the sanitary sewage generated in the enterprise to a public sewage treatment network/station, due to the fact that there is none in the region, it was decided to implement a compact private sewage treatment plant.

Thus, for this location there is a need to implement a sanitary sewage treatment station, giving an adequate destination to these effluents. The alternative to be implemented in the enterprise will be the treatment and subsequent infiltration into the soil, through a septic tank and infiltration ditch. As this is a system for the construction site, it will be of a temporary nature.

Solid waste generation

The main residues (cardboard, wooden boards, polymer foams, lubricating oils, greases, solvents, paints, remains/cuts of cables and conductors, etc.) will be collected and stored in separate tanks or trays for each residue, in an area separated from the rest of the premises and protected against unauthorized access. This area must not have negative effects on soil and groundwater.

Waste management will include the purchase/lease of containers in accordance with local regulations and guidelines issued by the contracting party; acquisition of machines for separating wood and paper from PV module pallets in accordance with local regulations; removal and treatment in accordance with local regulations; and container, evacuation and treatment of metal/aluminum parts in accordance with local regulations.

Environmental impacts

The implantation of solar panels presents significant benefits for the supply of electric energy, coming from the sun, saving the environmental resources. However, it is important to observe some criteria during the planning and elaboration of the project and during the implantation and operation of the plant, in order to prevent the occurrence of potential negative environmental impacts (Dias, 1999), as well as the maximization of positive impacts.

For each of the phases of the activity, the project actions were identified. The implementation phase is where the greatest action of the projects takes place and, consequently, most of the environmental impacts.

With the actions characterized for each phase of the project, the impacts were identified in the planning, implementation and operation phases (Chart 1), reaching the total of 51 impacts.

Chart 1 - Project actions identified in the work.

Phases	Project actions	Environmental impacts
Planning	Disclosure of the enterprise	People attraction
	Preparation of basic and executive projects	-
	Budget for labor and materials	-
	Preparation of physical and financial schedule	-
Implantation	Hiring of labor	Development of local economy; Increase in job generation; Sanitary effluents generation
	Rental of machinery and equipment	Income generation
	Installation of construction sites	Visual intrusions
	Area signage	Accidents prevention
	Clearing terrain	Loss of native plant cover; Soil degradation; Fauna scaring away; Loss of fauna habitat; Increase of erosive processes; Landscape alteration
	Earthworks, excavation, embankments and earthmoving	Change in surface runoff; Change in air quality; Increase of erosive processes; Soil contamination; Visual intrusions; Decharacterization of the local landscape
	Civil works	Noise; Scaring away the fauna; Decharacterization of the local landscape; Accident risks; Solid waste generation; Increase in water demand
	Machine operation	Noise

	Installation of solar panels	Solid waste generation; Visual intrusions
	Connection of panels to control devices	-
	Connection of the power plant to power grid	-
	Testing and commissioning	-
	Demobilization of the work	-
Operation	Occupation of the area by photovoltaic panels	Decharacterization of the local landscape; Increase in the supply of electric energy; Visual intrusions
	Current voltage monitoring of the plant	-
	Maintenance inspection	-
	Cleanliness and conservation	Increase in water demand

Source: Authors (2024).

In the implementation phase, the main impacts were generated in the action of cleaning the area, with deforestation and in the earthworks with the movement of the soil (Figure 3).

Figure 3 - Photographic record of terrain changes.

Source: Authors (2020).

Oliveira (2000) reports that environmental problems appear as a sign that influences decision-making regarding the implementation of projects. According to the Brazilian Constitution, the environmental impact assessment is one of the most important instruments for the protection of environmental resources. The Art. 225, item IV, § 10 declares that one of the duties of the public power is to requirefor the installation of work or activity potentially causing significant degradation of the environment, a prior environmental impact study to be publicized (Constituição da República Federativa do Brasil, 1988).

According to Milaré (2000), in the Brazilian legal system, the environmental impact assessment is seen either as a planning and management instrument, or as a procedure associated with some form of decision-making process, such as environmental licensing. These two dimensions are, in fact, inseparable and, taken together, aim to analyze the environmental feasibility of a project, program or plan.

Environmental impacts can act, simultaneously or not, on biotic, abiotic and anthropic environments (Chart 2).

Chart 2 - Classification of the impacts by environment.

Environmental impacts	**Environment**		
	Abiotic	Biotic	Anthropic
People attraction			X
Development of local economy			X
Income generation			X
Loss of native plant cover		X	
Increase of erosive processes	X		
Soil degradation	X		
Loss of fauna habitat		X	
Fauna scaring away		X	
Landscape alteration	X	X	
Changes in surface runoff	X		
Change in air quality	X		
Soil contamination	X	X	X
Accident risks		X	X
Noise	X	X	X
Visual intrusions			X
Increase in water demand		X	X
Solid waste generation		X	
Sanitary effluents generation			X
Increase in job generation			X
Increase in the supply of electric energy			X

Source: Authors (2024).

In all phases of the project, 22 impacts were identified, 4 are positive and 18 are negative. According to Silva (1999) and Fernandes (1997), the environmental impact causes changes that need to be quantified, as they present relative variations, which can be positive or negative, large or small.

Benefits of a solar plant at UACSA

Besides the economic aspect of this power plant, as stated by Nascimento et al. (2022), it could be used to benefit small communities by supplying part of the generated energy to community projects, like Sabiá Community, founded more than 100 years ago, which locates close to UACSA and could use part of this energy to feed a kindergarten that operates in the residents' association.

Another important issue is the amount of carbon dioxide (CO_2) that will no longer be emitted into the atmosphere (Table 1), the amount of trees that would no longer be cut down and the amount of coal that would no longer be consumed.

Table 1 - CO_2 Emissions Factors x Annual kWh Consumption for the year 2017.

Monthly average factor (tCO_2/MWh)	Jan	0,0566
	Feb	0,0536
	Mar	0,0696
	Apr	0,0815
	May	0,0847
	Jun	0,0676
	Jul	0,0965
	Aug	0,1312
	Sep	0,1264
	Oct	0,1366
	Nov	0,1193
	Dec	0,0892
Annual average factor (tCO_2/MWh)		0,0927

Source: Authors (2024).

In Brazil, this factor is calculated by the ONS and MCTIC – Ministry of Science, Technology, Innovation and Communications. To estimate the CO_2 emission due to the use of electricity, the following equation can be used:

Amount of CO_2 = (Annual Average CO_2 Emissions Factor) x (Annual kWh Consumption)

Then:

Annual Electricity Production = 2,017.08 MW

Annual Average Factor = 0.0927 t/MWh

Total kg of CO_2 emitted = 2,017.08 MW x 0.0927 t/MWh = 186.98 tons of CO_2

Therefore, this photovoltaic plant prevents 186.98 tons of CO_2 from being emitted into the atmosphere, thus collaborating to reduce the greenhouse effect.

The coal used in thermoelectric plants has a low calorific value, less than 4000 kcal. To determine how much coal would be needed to produce the same amount of energy produced by the UACSA photovoltaic plant, the example of the Candiota thermoelectric plant was used. This plant uses sub-bituminous coal, with a calorific value ranging from 3200 to 2600 kcal/kg, ash from 52.2 to 59.0% and humidity up to 17% (Eletrobras, 2020).

It would take 169.09 tons of this coal to produce what the UACSA photovoltaic plant produces in a month, that is, 169.09 MWh. Not to mention the amount of ash produced after burning the coal, which would amount to 84.55 tons.

According to a study carried out by the Totum Institute and the Luiz de Queiroz Higher School of Agriculture (ESALQ), of the University of São Paulo in partnership with the Fundação SOS Mata Atlântica, it was estimated that each Atlantic Forest tree absorbs 163.14 kg of carbon dioxide equivalent over its first 20 years. Thus, for an amount of 186.98 tons of CO_2, which would be emitted in the generation of 169.09 KWh per month in a thermoelectric plant, 275,307 trees would be needed to absorb this CO_2.

4. Conclusion

The main environmental and social impacts of the installation of the photovoltaic plant were loss of native vegetation and loss of natural habitat for the fauna and the social impacts were the increase in employment;

In the planning phase, only one impact was identified regarding the attraction of people, due to the fact that the enterprise was publicized. In the implementation phase, the main impacts were generated in the action of cleaning the area, with deforestation and in the earthworks with the movement of the soil. In the operational phase, the impacts were visual pollution and an increase in the supply of electric energy. About 84.4% of the impacts identified are related to the implementation phase of the enterprise, followed by operations, with 12.5%, and planning, 3.1%.

For future research, it is suggested to evaluate the technical, economic, social and environmental viability of alternative energy matrices on other campuses of the Federal Rural University of Pernambuco.

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(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v13i3.45288

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