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Sustainable Management In The Implementation Of Photovoltaic Solar Power Plants: Best Practices For Reducing Environmental Impacts

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Abstract:
Background*: The expansion of photovoltaic solar energy has become a relevant alternative within the context of the energy transition, while simultaneously raising challenges related to land use, environmental conservation, and responsible project management.*
Materials and Methods*: This study adopted a qualitative approach with exploratory and descriptive characteristics. The analyses were supported by technical data and consistent theoretical references. The research was developed through two complementary procedures, namely bibliographic and documentary research, which enabled the examination of regulations, studies, and academic publications related to the topic.*
Results*: The findings indicate that the adoption of sound environmental management practices contributes to the mitigation of adverse environmental impacts associated with the implementation of photovoltaic solar power plants. In addition, such practices support a more responsible development model for renewable energy projects and increase reliability and attractiveness for new investments in the solar sector.*
Conclusion: *Sustainable management in the implementation of photovoltaic solar power plants plays a strategic role in promoting balance between energy expansion and socio-environmental sustainability, reinforcing the importance of photovoltaic solar energy within the national energy and electricity matrix.*
Key Word: *photovoltaic solar energy; sustainable management; environmental impacts; renewable energy.*
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I. Introduction

The large-scale adoption of photovoltaic solar energy has increasingly consolidated itself as a fundamental component of strategies aimed at the energy transition. This shift is driven by the pressing need to diversify the current electricity matrix while simultaneously reducing greenhouse gas emissions derived from traditional energy sources that have historically been predominant. In this sense, solar energy not only presents itself as a viable alternative, but also as an essential solution to contemporary energy challenges.

The implementation of solar power plants, while offering a range of environmental benefits, nevertheless involves significant interventions in territorial space, as well as the use of natural resources and changes in the social and economic dynamics of the surrounding regions. This reality requires the development of detailed and careful planning to ensure that such transformations are managed in an effective and sustainable manner.

Within this context, sustainable management emerges as a fundamental guiding principle capable of reconciling clean energy generation with environmental preservation. It seeks to integrate, from the early stages of project development, technical, regulatory, social, and environmental criteria into enterprises of this nature. This approach implies that sustainable management goes beyond economic considerations, prioritizing environmental and social responsibility and ensuring the necessary balance between progress and ecological protection.

The adoption of good practices in the installation of photovoltaic solar power plants reduces negative impacts on soil, fauna, flora, and water resources, while also increasing social acceptance. Sustainable management extends beyond mere regulatory compliance and constitutes an essential guideline for strategic decision-making. Such decisions ensure adherence to legal requirements while strengthening environmental sustainability and the long-term viability of solar power plants. This approach is applied throughout the entire life cycle of the facilities, from conception to decommissioning, ensuring that operations consistently follow sustainable practices.

To carry out the present study, a qualitative research design with exploratory and descriptive characteristics was adopted, aiming to support, through data and theoretical frameworks, the hypotheses raised throughout the article. The research was structured based on two research procedures: bibliographic and documentary analysis.

The general objective of this research is to analyze sustainable management in the implementation of photovoltaic solar power plants, identifying practices and strategies capable of minimizing environmental impacts and promoting a balance between energy development and socio-environmental sustainability.

The specific objectives of this research are as follows: to examine the principles and instruments of sustainable management applicable to the implementation phase of photovoltaic solar power plants; to evaluate the challenges and opportunities associated with the adoption of sustainable management models in large-scale photovoltaic generation projects; and to identify and systematize good practices aimed at mitigating environmental impacts during the implementation and operation of solar power plants.

This article is structured into four sections in order to ensure analytical rigor and logical consistency in the organization of the content presented. The first section, Introduction, contextualizes the theme, defines the research problem, and presents the objectives of the study. The second section, Methodology, describes the procedures adopted for the development of the research, as well as the criteria used in the analysis. The third section, Theoretical Framework, brings together the main conceptual references and relevant studies that support the proposed discussion. Finally, the Conclusions synthesize the results obtained, highlight the contributions of the study, and present final reflections on the topic addressed.

II. Material And Methods

For the purposes of this study, a qualitative research design with exploratory and descriptive characteristics was adopted, aiming to substantiate, through data and theoretical frameworks, the hypotheses developed throughout the article.

The research was structured around two methodological procedures, namely bibliographic and documentary research, with the objective of deepening the understanding of sustainable management applied to energy projects, particularly within the context of photovoltaic solar power plants (Gil, 2021; Rodrigues & Neubert, 2023). To this end, books, scientific articles, environmental legislation, and institutional reports were consulted, originating from recognized bodies and institutions, such as the National Environmental Council (CONAMA, 1997), the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), in its role as the federal authority responsible for enforcing CONAMA regulations, Law No. 6,938/1981, and the EPE Synthesis Report (2025).

The arguments developed in this study were based on a systematic bibliographic review, prioritizing sources with strong technical and scientific grounding, as well as up-to-date research aligned with the proposed theme. In addition, an analysis of Brazilian environmental legislation was conducted through the examination of technical documents addressing fundamental environmental management instruments, such as Environmental Licensing, Environmental Impact Assessment (EIA), and sustainable management applied to energy projects. This approach enabled an integrated understanding of theory, practice, and the legal regulatory framework (CONAMA, 1997).

To support the analyses presented, authors of recognized academic and technical relevance were selected, whose contributions directly engage with the scope of the study, notably Elkington (1997), Barbieri (2017), Dantas (2020), and Medeiros, Costa, and Carvalho (2025). Furthermore, recent official documents and institutionally recognized materials were employed, proving essential for the comparison between theoretical references, applied practice, and the current legal framework (Gil, 2021; Rodrigues & Neubert, 2023).

This methodological approach is consistent with the perspective articulated by Rattner (1979, p. 212), who argues that pure research consists of the pursuit of knowledge for its own sake, representing an investigative effort directed toward themes that have not yet been sufficiently explored, with the aim of explaining specific phenomena.

III. Theoretical Framework

The theoretical framework of this study aims to present and discuss, in a systematic manner, the main concepts, instruments, and approaches related to sustainable management applied to the implementation of photovoltaic solar power plants. To this end, theoretical references encompassing the fields of sustainability, environmental management, energy planning, and governance are examined, grounded in contributions from well-established authors and in legal provisions relevant to the Brazilian context.

Initially, the concept of sustainable management and its application within the photovoltaic solar energy sector are addressed, highlighting its principles, guidelines, and interfaces with sustainable development. Within this scope, the main environmental management instruments employed in the implementation of such projects are examined, with particular emphasis on environmental licensing and Environmental Impact Assessment (EIA),

which are considered essential mechanisms for the identification, prevention, mitigation, and compensation of socio-environmental impacts arising from energy generation activities.

Subsequently, the challenges and opportunities associated with the adoption of sustainable practices in photovoltaic projects are discussed, encompassing technical, economic, regulatory, and institutional aspects. This analysis underscores the need for integration between energy planning, public policies, and environmental governance, in order to ensure project feasibility and compatibility between the expansion of the energy matrix and environmental preservation.

Finally, good practices aimed at mitigating environmental impacts throughout the planning, implementation, and operation phases of photovoltaic solar power plants are presented. Emphasis is placed on the importance of professional training, appropriate waste management, recovery of degraded areas, and the strengthening of environmental governance mechanisms. Such practices are understood as fundamental elements for promoting efficient, responsible management aligned with sustainability principles.

Thus, the theoretical framework seeks to provide the necessary conceptual basis for understanding the role of sustainable management as a strategic element in the implementation of photovoltaic solar power plants, contributing to the consolidation of an energy development model that reconciles productive efficiency, socio-environmental responsibility, and long-term sustainability.

Sustainable Management and Its Instruments in the Implementation of Photovoltaic Solar Power Plants

Sustainable management in the implementation of photovoltaic solar power plants is essential for mitigating environmental impacts, optimizing energy efficiency, and ensuring long-term socioeconomic benefits. In this context, the proper management of projects from the initial phases, especially during the installation stage, as well as throughout their operation and at the end of their life cycle, becomes fundamental to ensuring a balance between energy development and environmental sustainability.

According to Elkington (1997), a sustainable society must use renewable resources within their regenerative capacity, while maintaining emissions and pollutants within the environment's assimilation limits. The author also introduces the concept of the *Triple Bottom Line*, in which sustainability is understood through the balance among economic, social, and environmental dimensions, ensuring that present actions do not compromise opportunities for future generations (Elkington, 2000). This approach is particularly relevant to the energy sector, which has historically exerted significant impacts on natural resources.

In light of the growing expansion of energy projects in Brazil, especially those based on renewable sources, intelligent management combined with public and governmental incentives becomes necessary to ensure that photovoltaic projects contribute to the diversification of the national electricity matrix while simultaneously reducing environmental impacts at all stages of the process. In this regard, environmental management instruments play a central role, notably environmental licensing, Environmental Impact Assessment (EIA), waste management, and the monitoring of sustainability indicators (Silva, 2020).

As highlighted by Silva (2020), environmental impact control instruments play an essential role in structuring contemporary environmental management, as they guide the planning, execution, and monitoring of activities that may cause pollution. With respect to photovoltaic solar power plants, these instruments are not limited to mere legal compliance, but rather function as tools that organize the decision-making process, enabling greater predictability regarding environmental impacts and stronger coherence between economic objectives and socio-environmental commitments. This underscores the importance of aligning regulatory instruments with management practices already adopted by project developers during the design phase (Gomes et al., 2025).

Environmental licensing constitutes one of the main instruments of the National Environmental Policy, established by Law No. 6,938/1981, and is mandatory for projects with effective potential to cause pollution. This process is structured into three stages: the Preliminary License (LP), which approves the location and conceptual design of the project; the Installation License (LI), which authorizes the commencement of construction; and the Operation License (LO), which permits operation after compliance with established conditions. According to Milaré (2013), environmental licensing represents the materialization of the preventive role of the State, ensuring that economic development occurs in a manner compatible with environmental protection.

In addition to environmental licensing, Environmental Impact Assessment (EIA) constitutes a fundamental instrument for the sustainable management of photovoltaic solar power plants, as it allows the identification, prediction, and evaluation of environmental impacts associated with such projects, supporting the definition of mitigation measures and monitoring programs. The integrated use of these instruments contributes to more informed decision-making and to the strengthening of environmental governance (Leal, 2022).

With regard to innovation in environmental management, Leal (2022) emphasizes the use of digital technologies as essential tools for the effective administration of environmental services and for monitoring adaptation actions related to climate change, which are increasingly necessary. In the context of photovoltaic solar energy, these tools hold significant potential for enhancing environmental control and oversight of projects. This is crucial to ensure that environmental data are recorded, monitored, and disclosed in a clear and transparent

manner, thereby ensuring compliance with current environmental regulations. Through the implementation of such technological innovations, cohesively integrated into sustainable management, it is possible to significantly increase the capacity to monitor environmental impacts. Moreover, this process generates actions that are fully aligned with the norms and institutions relevant to the environmental issues under consideration. Therefore, the integration of technology and sustainability is fundamental to ensuring a more responsible and environmentally conscious future.

In this context, Barbieri (2017) emphasizes that environmental management can be understood through three dimensions: the thematic dimension, related to actions aimed at solving environmental problems; the social dimension, which concerns the benefits generated for society; and the institutional dimension, which involves the agencies responsible for implementing environmental management. These dimensions reinforce the importance of a systemic and integrated approach in the implementation of photovoltaic solar power plants, aligning energy planning, socio-environmental responsibility, and public policies (Brazil, 1981).

Challenges and Opportunities in the Adoption of Sustainable Management in Photovoltaic Projects

The accelerated growth of new energy projects in Brazil, particularly photovoltaic solar power plants, has highlighted both challenges and opportunities for the adoption of sustainable management practices. According to data from the Energy Research Company (EPE, 2025), electricity generation from solar sources reached 70.7 TWh, representing a significant increase compared to previous years, along with a substantial expansion of installed capacity. These figures demonstrate the growing relevance of the photovoltaic sector in the country, in line with sectoral analyses presented by Ottonelli et al. (2021), who emphasize the gradual consolidation of this source within the national electricity system.

Despite this promising scenario, the implementation of sustainable practices faces several obstacles. Among the main challenges are the high initial costs associated with large-scale projects, such as centralized solar power plants, which may directly affect the return on investment period and, in some cases, compromise the economic feasibility of the enterprise. In addition, the requirement to conduct detailed environmental studies, although essential for project sustainability, may lead to increased timelines and costs, as also observed by Ottonelli et al. (2021) in their analysis of recent developments in the Brazilian photovoltaic sector.

Another relevant challenge concerns regulatory and institutional aspects. The lack of national standardization in environmental licensing processes, combined with differing requirements imposed by state and federal environmental agencies, may result in legal uncertainty, difficulties in the evaluation of environmental studies, and delays in license issuance. These factors increase the complexity of the business environment and demand greater technical capacity and strategic planning from project developers, particularly in regions where institutional structures remain limited, as noted by Dantas (2020).

This situation indicates that the intensity of these challenges varies according to geographic location, reflecting realities that may differ significantly among regions. Dantas (2020), in an in-depth analysis of photovoltaic solar energy generation in Brazil's Semi-Arid region, emphasizes that factors such as limitations in local infrastructure, difficulties faced by developers in accessing credit, and regional asymmetries affecting the implementation of public policies can significantly influence the pace and progress of projects in this sector. These elements further underscore the importance of implementing sustainable management strategies that are tailored and sensitive to the specific characteristics of each territory. Such strategies must be capable of promoting effective articulation among energy planning, aimed at optimizing the use of energy resources; regional development, which seeks balanced and harmonious local growth; and socioeconomic inclusion, ensuring that different segments of society benefit from the opportunities generated. The integration of these dimensions is therefore fundamental to building a more sustainable and equitable future.

Nevertheless, the adoption of sustainable management also offers significant opportunities. These include gains in operational efficiency, reductions in environmental and legal risks, strengthening of corporate reputation, and greater social acceptance of projects. Initiatives that incorporate sustainable practices tend to achieve higher legitimacy among local communities and regulatory authorities, an aspect also emphasized by Ottonelli et al. (2021) in their discussion of the relationship between governance, corporate performance, and social acceptance in the photovoltaic sector.

Another noteworthy opportunity lies in the diversification of business models and new forms of integrating solar energy into the market. According to Ottonelli et al. (2021), diversified contracting arrangements, the participation of free consumers, and the growing role of private agents are making the sector more dynamic and attractive. In this context, sustainable management functions as a facilitator of decision-making processes by reducing uncertainties, improving planning, and promoting alignment between economic objectives and socio-environmental responsibilities.

Additionally, the expansion of the Free Energy Market within the Free Contracting Environment (ACL) represents a strategic opportunity for the photovoltaic sector, as it broadens consumer choice and stimulates investments in renewable sources. This environment favors more innovative and competitive business models,

contributing to the advancement of the energy transition in Brazil and to the consolidation of a cleaner and more diversified electricity matrix, in accordance with Dantas's (2020) analysis of the reorganization of the Brazilian electricity sector.

Best Practices for Reducing Environmental Impacts in Photovoltaic Solar Power Plants

Based on the discussions presented, it can be observed that the adoption of good environmental practices and appropriate waste management, combined with well-structured pre-project studies aligned with current legislation, enables the implementation of photovoltaic solar power plants in an environmentally responsible and financially viable manner. Proper planning, grounded in instruments such as Environmental Impact Assessment (EIA), contributes to the early identification of potential environmental impacts and to the definition of effective mitigation measures, in line with the paradigms of environmental sustainability applied to photovoltaic generation analyzed by Cardoso (2024).

Strict compliance with the requirements established within the environmental licensing process, through the Preliminary, Installation, and Operation Licenses, ensures that all stages of the project are carried out in accordance with environmental legislation, promoting sustainable management and reducing environmental and legal risks. Adequate preliminary studies are essential for site selection, as they allow for the assessment of impacts such as vegetation suppression, soil disturbance, and interference with local fauna and flora, aspects frequently addressed in recent literature on sustainability in photovoltaic projects, as discussed by Cardoso (2024).

During the installation phase of solar power plants, particularly with regard to the assembly of photovoltaic modules, the importance of proper management of generated waste is emphasized. Materials such as solar cables, rails, bolts, connectors, and other inputs must be correctly stored and, whenever possible, reused in future projects, thereby reducing waste and preventing improper disposal. These practices contribute to material recycling, pollution reduction, and the strengthening of an organizational culture oriented toward sustainability, in dialogue with the operational impacts identified by Medeiros, Costa, and Carvalho (2025).

According to Medeiros, Costa, and Carvalho (2025), from a socio-environmental perspective, the implementation of good environmental practices in photovoltaic solar power plants has a direct impact on the relationship between projects and neighboring communities. The authors note that appropriate waste management, local impact monitoring, and clear and transparent communication help mitigate socio-environmental conflicts and improve the territorial integration of projects, fostering a more harmonious coexistence between energy generation and social dynamics.

In addition, many companies in the sector have incorporated Environmental, Social, and Governance (ESG) principles, adopting actions such as the recovery of degraded areas and the reforestation of areas affected by projects. These initiatives contribute to environmental restoration and expand the socio-environmental benefits generated by projects, strengthening organizational commitment to sustainable development, in line with the environmental sustainability guidelines discussed by Cardoso (2024).

With regard to the social dimension of sustainability, Medeiros, Costa, and Carvalho (2025) emphasize the importance of implementing actions that not only reduce negative impacts but also promote the active participation of local communities. According to the authors, such actions are essential for maximizing the benefits provided by photovoltaic energy projects. By analyzing income generation for local populations, territorial organization, and societal perceptions of projects, the urgency of integrating environmental and social initiatives into plant planning becomes evident. This integration is crucial to enhancing the quality of outcomes during both the implementation and operational phases of solar power plants, ensuring that projects not only meet energy demands but also generate combined socio-economic and environmental benefits.

Finally, the importance of continuous professional training for those involved in photovoltaic projects is highlighted, through technical courses and training programs aimed at improving operational safety and fostering a deeper understanding of the benefits of sustainable management. Dialogue with local communities also proves fundamental, as it allows for an understanding of their perceptions, the presentation of project benefits such as job creation and energy supply, and the promotion of socially oriented sustainable management. As noted by Barbieri (2017), the integration of environmental, social, and institutional dimensions is essential for consolidating effective environmental governance and for the sustainable advancement of the renewable energy sector in Brazil.

IV. Conclusion

This study sought to demonstrate the importance of using environmental management tools that can and should be implemented in photovoltaic solar power plant projects, as, when aligned with the parameters of Brazilian federal and state environmental legislation, they contribute significantly to the minimization of environmental impacts, particularly during the installation and commissioning stages. With the advancement of investments in renewable energy sources, especially solar energy, recent years have seen a substantial increase in centralized power plants across several regions of the country, with particular emphasis on the Northeast. Based

on the analysis of theoretical references, institutional documents, and environmental legislation, it was found that the adoption of appropriate environmental management instruments is essential to ensure the technical, economic, and socio-environmental feasibility of these projects.

It is of paramount importance to emphasize that corporate environmental management, especially among companies seeking to adopt practices aligned with the ESG methodology, requires compliance with legal requirements imposed by different regulatory bodies, through adherence to norms, laws, statutes, and instruments such as environmental licensing and Environmental Impact Assessment (EIA). These tools support proper project orientation and more informed decision-making, contributing to the mitigation of environmental impacts, the reduction of legal and operational risks, and the strengthening of environmental governance. As a result, companies that adopt such practices tend to stand out positively within the sector, strengthening their institutional image and demonstrating a commitment to the sustainable management of natural resources.

Sustainable resource management in the implementation of photovoltaic solar power plants constitutes a topic of high relevance, particularly in light of the need to assess corporate compliance with operational processes and with current legal requirements.

In this context, the adoption of appropriate environmental management practices directly contributes to the mitigation of environmental impacts and to the promotion of more sustainable development of renewable energy projects, ensuring greater security and attractiveness for new investments in the solar sector, which plays a strategic role in the national energy and electricity matrix.

Additionally, the expansion of the Free Energy Market within the Free Contracting Environment (ACL) emerges as a relevant factor in stimulating investments in renewable sources, by fostering competitiveness and encouraging Brazilian companies to adopt efficient waste management and more rigorous environmental control, thereby minimizing potential environmental impacts and promoting harmonization between economic efficiency, environmental responsibility, and social inclusion.

Finally, it is recommended that future research further deepen the empirical analysis of the socio-environmental impacts of photovoltaic solar power plants in different regions of the country, as well as investigate the application of new technologies and environmental governance models in the energy sector. Such studies may contribute to the improvement of public policies and management practices, strengthening the role of photovoltaic solar energy as a driver of sustainable development in Brazil.

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