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Efficiency and Sustainability in Solar Photovoltaic Systems: A Review of Key Factors and Innovative Technologies

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Abstract: PSS (Photovoltaic Solar Systems) are a key technology in energy transition, and their efficiency depends on multiple interrelated factors. This study uses a systematic review based on the PRISMA methodology to identify four main categories affecting performance: technological, environmental, design and installation, and operational factors. Notably, technological advances in materials such as perovskites and emerging technologies like tandem and bifacial cells significantly enhance conversion efficiency, fostering optimism in the field. Environmental factors, including solar radiation, temperature, and contaminants, also substantially impact system performance. Design and installation play a crucial role, particularly in panel orientation, solar tracking systems, and the optimization of electrical configurations. Maintenance, material degradation, and advanced monitoring systems are essential for sustaining efficiency over time. This study provides a comprehensive understanding of the field by reviewing 113 articles and analyzing three key areas—materials, application of sizing technologies, and optimization—from 2018 to 2025. The paper also explores emerging trends, such as the development of energy storage systems and the integration of smart grids, which hold promise for enhancing photovoltaic module (PM) performance. The findings highlight the importance of integrating technological innovation, design strategies, and effective operational management to maximize the potential of PM systems, providing a solid foundation for future research and applications across residential, industrial, and large-scale contexts.

Keywords: energy efficiency; system losses; solar photovoltaic systems; module technologies and materials; efficiency factors

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Academic Editor: Antonio Gil Bravo

Received: 30 January 2025
Revised: 3 March 2025
Accepted: 4 March 2025
Published: 6 March 2025

Citation: Iturralde Carrera, L.A.; Garcia-Barajas, M.G.; Constantino-Robles, C.D.; Álvarez-Alvarado, J.M.; Castillo-Alvarez, Y.; Rodríguez-Reséndiz, J. Efficiency and Sustainability in Solar Photovoltaic Systems: A Review of Key Factors and Innovative Technologies. *Eng* **2025**, *6*, 50. https://doi.org/10.3390/eng6030050

1. Introduction

Technological advances have led to the development of increasingly robust solar energy collection systems. Current challenges focus on improving the efficiency of these systems by employing techniques that maximize the use of solar resources while minimizing environmental impact. Research has also focused on the materials used in photovoltaic systems, as material selection significantly influences environmental sustainability [1]. According to [2], the type of material is critical because its level of degradation does not affect the environment. The study by [3] shows the need for durable materials that can adapt to long-term environmental changes to maintain optimal panel performance.

Regarding efficiency, research has primarily concentrated on controlling the maximum power point in photovoltaic systems. However, additional techniques such as those implemented in [4], involve using PVsyst software (version 8) to measure installation effectiveness by assessing system orientation, estimating CO_2 emissions, and achieving potential savings of up to 7.45 t/year per household.

Understanding efficiency losses under various conditions is fundamental to optimizing solar photovoltaic system performance across different applications. From a technological perspective, solar cell conversion efficiency varies depending on the materials used, such as monocrystalline silicon, polycrystalline silicon, and advanced technologies like perovskites and tandem cells, each with distinct thermal and optical loss rates. Regarding design and installation, parameters such as panel orientation, inclination, solar trackers, and electrical configurations influence energy capture and conversion, making assessing associated losses for optimization essential. Additionally, operational aspects, including material degradation, inadequate maintenance, and the absence of advanced monitoring systems, can result in cumulative losses that compromise long-term performance. Addressing these factors through optimization and innovative management strategies is crucial to maximizing overall PM system efficiency and ensuring their viability in residential, industrial, and large-scale applications [5–7].

Multiple variables must be considered for efficient installation, ranging from energy demand to roof conditions suitable for housing a photovoltaic system [8]. According to [9], installation location directly affects panel operating temperature, with ground installations experiencing losses of up to 27.95%. Given this context, various techniques influencing the efficient installation of photovoltaic systems have been explored in the literature. However, limited research explicitly analyzes the relationship between material selection and installation methodologies. This systematic review aims to investigate and assess the optimal conditions and material selection strategies documented in the literature to enhance photovoltaic system efficiency. Furthermore, this study seeks to address the following research questions:

- How do the most commonly used materials in photovoltaic cells influence energy conversion efficiency, and to what extent are they considered in PM system sizing?
- What are the key variables to consider in the sizing and operation of PSS, and how do they behave under boundary conditions for different site characteristics?
- How do emerging technologies, such as tandem and bifacial cells, impact the efficiency and viability of PM systems at various scales, and how does this impact differ based on local conditions?

The paper is structured as follows: Section 1 introduces the PRISMA methodology and discusses similar work in the field. It also presents the problem formulation, highlighting the need for a comprehensive understanding of factors affecting solar photovoltaic system efficiency and sustainability. This study aims to bridge existing research gaps by systematically reviewing and analyzing these factors. Additionally, the section outlines the contributions of this work. Section 2 describes the PRISMA methodology, detailing its application in engineering research, the steps followed, search and exclusion criteria, and the equations used to associate PSS efficiency with the research objectives. Section 3 presents the research process, results, and a comprehensive analysis of findings. Section 4 discusses research trends, proposes a methodology for PSS sizing, and compares this study with similar works in the field. Finally, Section 5 summarizes the main findings and conclusions drawn from the results.

2. Materials and Methods

A systematic review is a type of scientific research in which the unit of analysis consists of original primary studies on the same subject. In this case, the review focuses on the main factors affecting the efficiency of PSS, the variables of interest, and their percentage ranges under different conditions. The objective of the systematic review is to answer a formulated research question clearly and concretely. This approach provides a comprehensive and reliable perspective while minimizing potential research biases [10,11].

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology is a standardized set of guidelines designed to enhance the transparency and quality of systematic reviews and meta-analyses. It aims to help researchers conduct and report systematic reviews more clearly and comprehensively, particularly in healthcare. PRISMA consists of a 27-item checklist that authors should consider when writing their review, along with a flow diagram that illustrates information progression through the different stages of a systematic review. The application of PRISMA improves research quality, facilitates understanding, and promotes transparency in research processes [12,13].

The method used to prepare this article consisted of an in-depth review of the existing literature on the factors and variables that affect the efficiency of PSS, for which the PRISMA methodology was used as a reference. The steps followed were:

1. Define the objective:
   - Establish the purpose of the systematic review or meta-analysis.
2. Develop a protocol:
   - Design a protocol that includes the research questions, inclusion/exclusion criteria, and analysis methods.
3. Conduct a comprehensive search:
   - Search relevant databases to identify studies that meet the established criteria.
4. Select studies:
   - Apply the inclusion/exclusion criteria to the identified studies and select those included in the review.
5. Extract data:
   - Gather relevant information from the selected studies, such as participant characteristics and results.
6. Evaluate the quality of the studies:
   - Use appropriate tools to assess the risk of bias and the methodological quality of the included studies.
7. Analyze the data:
   - Perform a statistical analysis, if possible, and present the results.
8. Interpret the results:
   - Discuss the findings in the context of existing literature and consider the implications.

2.1. Information Search

For this search, the main keywords describing the behavior and efficiency of the PSS were selected. Scopus was chosen as the search engine due to its extensive database, which includes over 75 million scientific records, and its advanced search tools that enable filtering by various criteria. Additionally, Scopus provides impact metrics such as the h-index and CiteScore, which help assess the relevance of articles. It is continuously updated to incorporate the latest research across multiple disciplines. The following code was selected as keywords: TITLE-ABS-KEY (((“solar photovoltaic systems”) AND (“dust” OR "shadows" OR "materials" OR "photovoltaic arrays" OR "wiring" OR "types of modules" OR "climatic variables" OR "operating temperature" OR "orientation" OR "degradation" OR "installation")).

These keywords represent the main factors influencing the efficiency of PSS [5,14,15]:

1. Photovoltaic Panel Efficiency (η_{panel}), Equation (1):

$$\eta_{\text{panel}} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100 \quad (1)$$

   where:

   - P_{out}: Electrical power generated by the panel (W).
   - P_{in}: Solar power incident on the panel (W).

   Incident Solar Power, Equation (2):

$$P_{\text{in}} = G \cdot A \quad (2)$$

   where:

   - G: Solar irradiance (W/m^2).
   - A: Panel surface area (m^2).

2. Photovoltaic System Efficiency (η_{system}), which represents the efficiency with which the system converts incident solar energy into useful electricity measured at the inverter output, Equation (3):

$$\eta_{\text{system}} = \frac{E_{\text{AC}}}{G \cdot A \cdot t} \times 100 \quad (3)$$

   where:

   - E_{AC}: Electrical energy measured at the inverter output (kWh).
   - t: Solar exposure time (h).

3. Performance Ratio (PR), Equation (4):

$$PR = \frac{E_{\text{AC}}}{G \cdot A \cdot t} \quad (4)$$

4. Total System Efficiency (η_{total}), defined as the efficiency of the system considering the efficiency of the PM panel and the Performance Ratio (PR), Equation (5):

$$\eta_{\text{total}} = \eta_{\text{panel}} \cdot PR \quad (5)$$

2.2. Criteria for Selection and Exclusion of Research

A systematic review requires adherence to essential strategies and conditions to ensure accuracy and reliability. This type of study demands objectivity and rigor in both qualitative and quantitative approaches, as well as specific methodological tools that facilitate data integration while simultaneously assessing the quality of each study.

Although systematic reviews may appear straightforward, their growing popularity—especially among less experienced researchers—has led to variability in their quality. While these reviews have the potential to generate significant impact, they are not always conducted with the required level of rigor. Due to the absence of universally accepted guidelines for their implementation, some studies may lack the necessary reliability. Therefore, a well-defined protocol is essential to ensure the credibility of the review process.

For this research, the following exclusion criteria were applied:

1. Keyword Selection—The main keywords were identified based on a review of relevant articles, focusing on evaluating and formulating equations for calculating the efficiency and size of photovoltaic solar systems (PSS).
2. Timeframe Limitation—The search was restricted to articles published between 2018 and 2025.
3. Scope Restriction—Studies published in journals outside the research area were excluded, as they often emphasize certain factors while neglecting others.
4. Technical Exclusions—Articles focusing on algorithms, simulations, mathematics, artificial intelligence (AI), MATLAB, optimization, and software were excluded, as these may artificially model PSS efficiency rather than reflect real-world performance. However, such factors are considered in later stages of system improvement.
5. Economic and Financial Considerations—Studies focusing primarily on financial or economic aspects were excluded, as these often prioritize cost-effectiveness over system efficiency and quality.
6. Irrelevant Topics—Based on preliminary review rounds, additional exclusions were made. For instance, the term "energy" was excluded when related to wind power or fossil fuels, as these topics fall outside the scope of this study.
7. Search code final version: TITLE-ABS-KEY ((“solar photovoltaic systems”) AND (“dust” OR “shadows” OR “materials” OR “photovoltaic arrays” OR “wiring” OR “types of modules” OR “climatic variables” OR “operating temperature” OR “orientation” OR “degradation” OR “installation”)) AND PUBYEAR > 2018 AND (EXCLUDE (SUBJAREA, “revision”) OR EXCLUDE (SUBJAREA, “optimization”) OR EXCLUDE (SUBJAREA, “artificial intelligence”) OR EXCLUDE (SUBJAREA, “IA”) OR EXCLUDE (SUBJAREA, “AI”) OR EXCLUDE (SUBJAREA, “MPPT”) OR EXCLUDE (SUBJAREA, “Review”) OR EXCLUDE (SUBJAREA, “a Review”) OR EXCLUDE (SUBJAREA, “Math”) OR EXCLUDE (SUBJAREA, “economics”) OR EXCLUDE (SUBJAREA, “finance”) OR EXCLUDE (SUBJAREA, “software”) OR EXCLUDE (SUBJAREA, “methodology”) OR EXCLUDE (SUBJAREA, “maintenance”) OR EXCLUDE (SUBJAREA, “economic”) OR EXCLUDE (SUBJAREA, “art”) OR EXCLUDE (SUBJAREA, “simulation”) OR EXCLUDE (SUBJAREA, “COMP”) OR EXCLUDE (SUBJAREA, “MATH”) OR EXCLUDE (SUBJAREA, “PHYS”) OR EXCLUDE (SUBJAREA, “EART”) OR EXCLUDE (SUBJAREA, “BIOC”) OR EXCLUDE (SUBJAREA, “SOCI”)) AND (EXCLUDE (DOCTYPE, “re”) OR EXCLUDE (DOCTYPE, “cr”) OR EXCLUDE (DOCTYPE, “cp”) OR EXCLUDE (DOCTYPE, “ch”) OR EXCLUDE (DOCTYPE, “ed”) OR EXCLUDE (DOCTYPE, “bk”)) AND (EXCLUDE (EXACTKEYWORD, “Solar Concentrators”) OR EXCLUDE (EXACTKEYWORD, “Economic Analysis”) OR EXCLUDE (EXACTKEYWORD, “Investments”) OR EXCLUDE (EXACTKEYWORD, “Housing”) OR EXCLUDE (EXACTKEYWORD, “Costs”) OR EXCLUDE (EXACTKEYWORD,“MATLAB”) OR EXCLUDE (EXACTKEYWORD, “Fossil Fuels”) OR EXCLUDE (EXACTKEYWORD, “Cost Benefit Analysis”) OR EXCLUDE (EXACTKEYWORD, “Carbon”) OR EXCLUDE (EXACTKEYWORD, “Carbon Footprint”) OR EXCLUDE (EXACTKEYWORD, “Wind Turbines”) OR EXCLUDE (EXACTKEYWORD, “Wind Power”) OR EXCLUDE (EXACTKEYWORD, “Wind”) OR EXCLUDE (EXACTKEYWORD, “Simulation”) OR EXCLUDE (EXACTKEYWORD, “Diodes”) OR EXCLUDE (EXACTKEYWORD, “Algorithm”)).

2.3. Analysis Guide for Systemic Review

The following framework was used for the analysis: Multiple interrelated factors influence the efficiency and performance of photovoltaic solar systems (PSS). From a technological perspective, the materials used in solar cells, such as monocrystalline and polycrystalline silicon, as well as emerging materials like perovskites, have contributed to improvements in energy conversion efficiency. Additionally, advancements in bifacial and concentrated photovoltaic technologies have further enhanced performance. Design and installation also play a critical role. Factors such as panel orientation, tilt angle, the use of solar tracking systems, and component configuration (e.g., series or parallel connections and inverters) optimize performance. At the operational level, predictive and corrective maintenance, material degradation, and advanced monitoring systems are essential to ensuring long-term durability and efficiency. Finally, emerging technological trends focus on innovations such as energy storage solutions, integration with smart grids, advanced manufacturing and recycling methods, and next-generation monitoring equipment. These advancements collectively strengthen the role of PSS as a sustainable energy solution, see Figure 1.

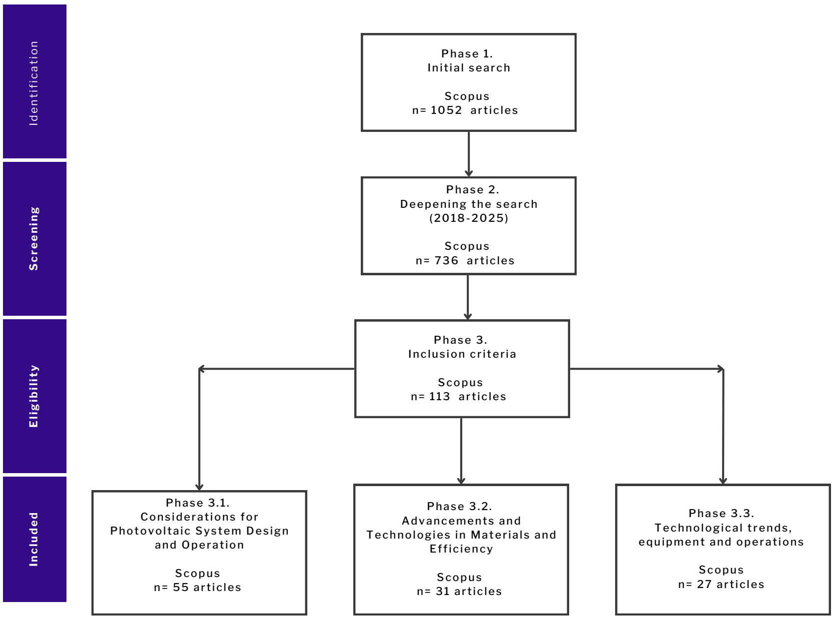
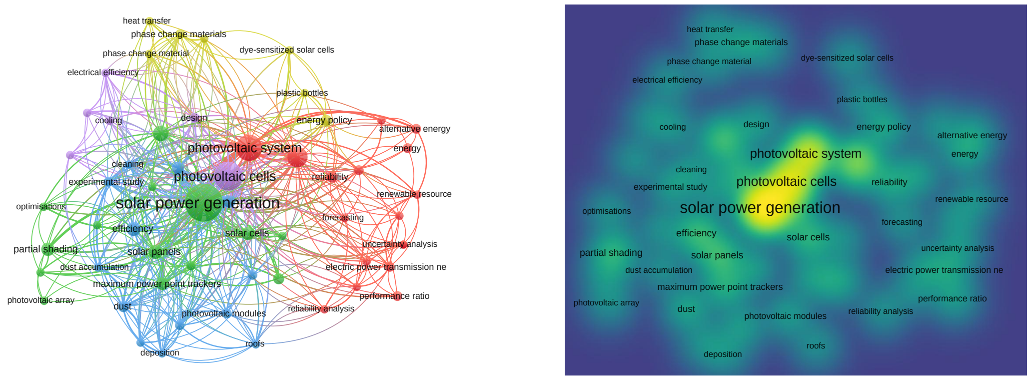


Figure 1. Flow chart of the selection process and exclusion of articles in the literature review.

3. Results

The efficiency of photovoltaic systems is crucial in maximizing performance and ensuring their economic and environmental viability in large-scale applications. Several technological, ecological, design, installation, and operational factors directly influence the ability of these systems to convert solar radiation into usable energy. Additionally, emerging technology trends, including innovations in materials, energy storage, and intelligent systems, are redefining performance standards. This section examines the key elements affecting photovoltaic system efficiency, along with the latest trends and technological developments and equipment shaping the future of this field. A comprehensive literature analysis will assess relationships between keywords, trends in this research area, and the proportion of key variables influencing PSS efficiency. This will provide an updated perspective on the evolution of PSS performance over time.

To analyze the first 113 articles related to PSS efficiency, we used VOSviewer software (Version 1.6.20) to construct keyword-based bibliometric networks [16]. Figure 2a illustrates the resulting bibliometric network, highlighting key trends in the analyzed manuscripts. Notably, terms such as PSS, solar power generation, and solar cells emerge as the most relevant keywords, alongside related terms that directly impact PSS efficiency, including solar panels, dust accumulation, MPPT (Maximum Power Point Tracking), and electrical efficiency.



(**a**) (**b**)

Figure 2. Bibliometric analysis networks. (**a**) Bibliometric network for the analysis of articles on the efficiency of PSS. (**b**) Bibliometric network for the analysis of articles on the efficiency of PSS heat map.

Furthermore, Figure 2b presents a heat map of the same bibliometric network, where brighter areas indicate the relevance of these terms in the reviewed studies. The prominence of concepts such as solar panels, photovoltaic cells, MPPT, and dust suggests their significant role in discussions on PSS efficiency. Based on these initial findings, we structured the analysis into three major categories to enable a more precise and in-depth examination of the subject.

3.1. Considerations for Photovoltaic System Design and Operation

Exclusion methods were applied to refine the search for relevant articles on photovoltaic systems. Irrelevant topics such as artificial intelligence, economics, maintenance, and simulation were excluded. Additionally, document types including reviews, book chapters, and conference papers were filtered out using the DOCTYPE parameter. Studies containing undesired keywords such as "MATLAB", "Wind Power", and "Economic Analysis" were eliminated using EXACTKEYWORD. These filtering strategies ensured a focused selection of studies specifically related to the performance and operation of photovoltaic systems, minimizing irrelevant information.

Various environmental and design factors influence the performance and efficiency of photovoltaic systems. Optimizing system operation requires understanding how solar exposure, temperature fluctuations, and airborne pollutants impact energy production and system longevity. This section examines key environmental considerations, such as geographic variations in solar radiation, dust accumulation on panels, and the effects of extreme temperatures. Additionally, it explores critical design and installation aspects, including optimal panel orientation, the implementation of solar tracking systems, and appropriate electrical configurations. These factors provide a comprehensive perspective on the elements shaping photovoltaic system performance.

Figure 3 illustrates the evolution of the bibliometric network at three different levels. In Figure 3a, the relationship network highlights key concepts associated with the design and operation of photovoltaic systems, emphasizing terms such as electrical power, modules, components, and strategies to maximize efficiency, such as IA and MPPT techniques. External factors such as climatic conditions, cells, and material composition are also shown.

Figure 3b displays the overlapping of terms over time, grouping keywords by year to illustrate the thematic evolution of research. A growing trend is observed in applying optimization algorithms, advancements in cell material composition, and integrating renewable energy sources.

Finally, Figure 3c presents a density map, reinforcing the significance of these elements. Interestingly, module orientation, inclination, site geometry, and shading studies appear less frequently. This may be due to basic procedures, while the current focus is on optimization, indirectly incorporating these factors within more advanced models.

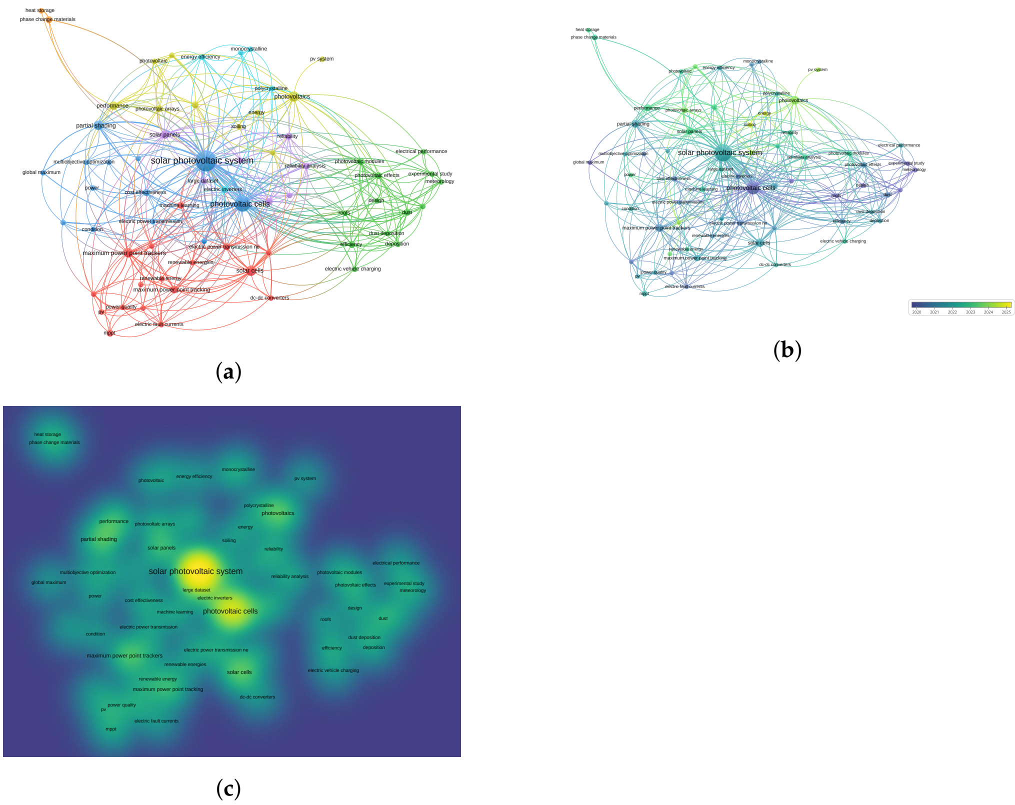


Figure 3. Bibliometric analysis networks: Considerations for photovoltaic system design and operation. (**a**) Relationship network. (**b**) Overlap network and years. (**c**) Density network.

Factors Affecting the Efficiency of Photovoltaic Systems

Both environmental conditions and design considerations significantly influence the efficiency of photovoltaic systems. Understanding the interaction between these factors is essential for optimizing energy production and ensuring long-term system performance. Power generation can be enhanced by carefully selecting system configurations and installation parameters while maintaining operational stability. This section provides an overview of the key aspects affecting photovoltaic performance, emphasizing the importance of strategic planning in system design and implementation.

Table 1 presents an estimated range of losses associated with these factors.

Table 1. Factors affecting the efficiency of photovoltaic systems.

Works	Variables of Interest	Percentage/Range of Losses
[17–19]	Type of solar radiation	0–20%
[19–21]	Ambient temperature	5–25%
[22–24]	Operating temperature	3–20%
[25–27]	Dirt and soiling	2–30%
[19,20,28]	Weather	5–40%
[29–31]	Tilt angle	5–15%
[31–33]	Orientation	3–15%
[34–36]	Shading	5–25%
[37–39]	Photovoltaic array configuration	2–10%

It outlines the scales of losses currently observed in photovoltaic installations. It is important to note that this table only considers the parameters discussed in this chapter. The values were determined by reviewing articles available in Scopus.

To enhance advancements in photovoltaic materials and efficiency, the search parameters can be refined by focusing on specific factors, such as new material compositions, conversion efficiency, long-term stability, manufacturing techniques, and improvements in cells and modules. Additionally, considerations for anti-reflective and anti-soiling coatings and emerging technologies like perovskites should be included. To optimize the search and avoid irrelevant results, subjects such as economics, software, modeling, artificial intelligence, maintenance, social sciences, and business can be excluded. Document types like reviews, book chapters, and conference proceedings can also be filtered out using DOCTYPE.

Moreover, articles containing specific keywords that do not align with the research focus, such as "Cost Analysis", "Economic Viability", "Market Trends", "Financial Investments", "MPPT", "Wind Energy", "Hydrogen", "Battery Storage", "Simulation", and "Energy Policies", can be discarded using EXACTKEYWORD. This targeted approach allows for a concentrated search of recent studies to improve the materials and efficiency of photovoltaic systems while avoiding publications that do not meet the research objective.

3.2. Advancements and Technologies in Materials and Efficiency

The energy conversion efficiency of solar cells is closely linked to material properties, doping processes, and depletion region characteristics. Various materials have been utilized to achieve optimal efficiency. Among the most widely used is silicon, which exists in different forms. Monocrystalline silicon is known for its high efficiency and durability; its high production cost limits its use. Despite this, it remains the dominant material in the market. Amorphous silicon is inexpensive but less efficient than other variants. Polycrystalline silicon is more efficient than amorphous silicon. It is also more economical than monocrystalline silicon but with slightly lower efficiency. However, it has lost its previous economic advantage. Gallium arsenide exhibits excellent efficiency under low solar radiation but is costly. Cadmium telluride offers good efficiency at a lower cost but poses environmental concerns due to high toxicity. Table 2 shows different materials used in the manufacturing of photovoltaic solar cells [40,41].

Other trends used to improve ultra-violet (Uv) spectrum absorption are based on the combination of materials with different band gaps. These heterostructured materials help reduce recombination losses and extend the lifespan of charge carriers [42,43].

Table 2. Advantages and disadvantages of materials used for the production of photovoltaic cells.

Works	Material	Efficiency (%)	Advantage	Disadvantages
[41,44,45]	Silicon monocrystaline	20–26	Durability	High cost
[41,46,47]	Silicon policrystaline	15–20	Economical	Lower efficiency
[41,47,48]	Silicon amorphous	6–10	Flexible, lightweight	Lower efficiency
[41,49,50]	GaAs	>30	Excellent performance	High costs
[41,47,49]	CdTe	15–18	Economical	Toxicity
[41,47,49]	CIGS	>20	Flexible	Moderate costs
[47,51]	Peroskite	>25	Low cost	Toxicity
[51,52]	Organic materials	10–15	Flexible	Low efficiency
[42]	CdO/CdS/ZnO	—	Heterocyclic structure that allows high absorption of the UV spectrum	Toxicity
[51,53]	Quantum dots	7–10	Difficulties in manufacturing	High cost
[43]	β-Ga_2O_3/por GaAs/mono-GaAs	—	High stability and economic	High cost

3.2.1. Nanomaterials

Integrating nanomaterials in photovoltaic cells presents a significant opportunity to enhance energy conversion efficiency. Due to their unique optical, electronic, and mechanical properties at the nanometric scale, nanomaterials can overcome the limitations of conventional materials.

Various nanomaterial structures offer distinct advantages, opening new avenues for optimization in solar cell technology. Among the most notable are the following:

Nanotubes These one-dimensional materials, like carbon nanotubes, offer exceptional optical and electronic properties. They are used in silicon solar cells to form p-n or Schottky junctions, achieving remarkable efficiencies. They are also helpful in organic solar cells as charge carriers, improving efficiency and durability [54].

Nanowires: Nanowires, such as those made of silicon and metal oxides (e.g., ZnO), exhibit high charge transport capacity and outstanding optical properties. They are employed to reduce light reflectance in solar cells, thereby increasing absorption and device efficiency [54].

Surface Nano-texturing: Surface nano-texturing, as seen in "black silicon", significantly enhances light capture by minimizing reflection losses. This approach optimizes optical characteristics and increases efficiency compared to traditional microscale textures [54].

Table 3 lists works where different nanomaterials have been used to improve efficiency in solar cells.

Table 3. Efficiency results by material and method.

Material	Structure	Electrical Efficiency (%)	Works
Ag/TiO_2	Nanofluids	33.70	[55]
TiO_2/SiO_2	Nanofilms	21.10	[55]
AlGaAs/ GaAs	Nanowires	48.30	[55]
GaAs	Nanocomposite	33–36.10	[56]
ZnO	Nanostructure	0.36–6.75	[57]
Sc_2O_3–ZnO	Nanostructure	11.41	[58]
RuO_2–ZnO	Nanospheres	17.10	[59]
$SWNT/SiO_2$	Nanotubes	17	[60]

3.2.2. Phase Change Materials

The efficiency of photovoltaic modules is affected by the choice of solar cell material and thermal conditions (surface temperature). Module efficiency can decrease by 0.4–0.5% per degree Celsius temperature increase. Consequently, maintaining an optimal operating temperature is crucial for sustained performance. Phase Change Materials (PCM) are specialized coatings applied to photovoltaic modules to regulate temperature through their physicochemical properties.

Among the materials used are organic PCMs, which are chemically stable, have a latent heat of fusion between 170 and 260 kJ/kg, and are non-corrosive. Inorganic PCM possesses high thermal conductivity and is more cost-effective. However, they tend to subcool the surface. There are also eutectic mixtures, which are combinations of materials offering high thermal conductivity and greater thermal density, as shown in Table 4 [61].

Various materials have been evaluated to reduce the temperature of photovoltaic modules. The main objective is to demonstrate the viability of PCM as a sustainable solution to mitigate efficiency losses caused by temperature increases. Table 5 shows studies that tested different PCM to evaluate their effectiveness.

Table 4. PCM materials, properties, and applications.

Material	Type	Thermal Conductivity (W/mK)	Latent Heat (kJ/kg)	Applications
Paraffin	Organic	0.18–0.24	170–260	Cooling PM modules; non-corrosive and recyclable.
Salt hydrates ($CaCl_2 \times 6H_2O$)	Inorganic	1.08	High	PM systems with higher conductivity; lower cost.
Eutectic mixtures	Organic-Inorganic	>0.50	Variable	Greater thermal storage density and stability.

Table 5. Comparative study of the application of coating materials in photovoltaic systems.

Works	Material	Classification	Working Conditions	Ffficiency	Advantages	Disadvantages
[62]	Paraffin RT-42	Organic	Fusion: 38–43 °C; PCM thickness: 1–3 cm; tilt: 15–30°	14.4%	Non-corrosive, chemically stable, improves electrical efficiency by 14.4%	Low thermal conductivity (0.2 W/m·K), volumetric expansion of 12.5%
[63]	$Na_2SO_4 \times 10H_2O$	Inorganic	Fusion: 32 °C; radiation: 800 W/m²; tilt: 35°	3.05%	High thermal conductivity, reduces temperature by 37 °C;	Subcooling, degradation over prolonged cycles
[55]	$CaCl_2 \times 6H_2O$	Inorganic	Fusion: 29.9 °C	24.68%	High conductivity (1.08 W/m·K), cost-effective	Subcooling, damage to flexible containers
[55]	Coconut oil	Organic	Fusion: 22–24 °C	-	Non-toxic, recyclable	Low thermal capacity (103.25 kJ/kg)
[55]	Eutectic mixtures	Organic-Inorganic	Fusion: variable	-	High thermal density, better conductivity	Higher costs compared to pure inorganic materials

3.2.3. Future Technologies

Solar cell technology continues to evolve, enabling the efficient capture and conversion of solar energy. Large-scale solar panels are essential for harvesting incident sunlight, with the converted energy stored and utilized in various applications. However, challenges related to installation, maintenance, and space constraints, particularly in densely populated regions like Asian countries, necessitate the development of more advanced and efficient solar panel designs. Table 6 highlights key technologies being developed to overcome current challenges in photovoltaic system implementation [51].

Table 6. Analysis of emerging solar module technologies.

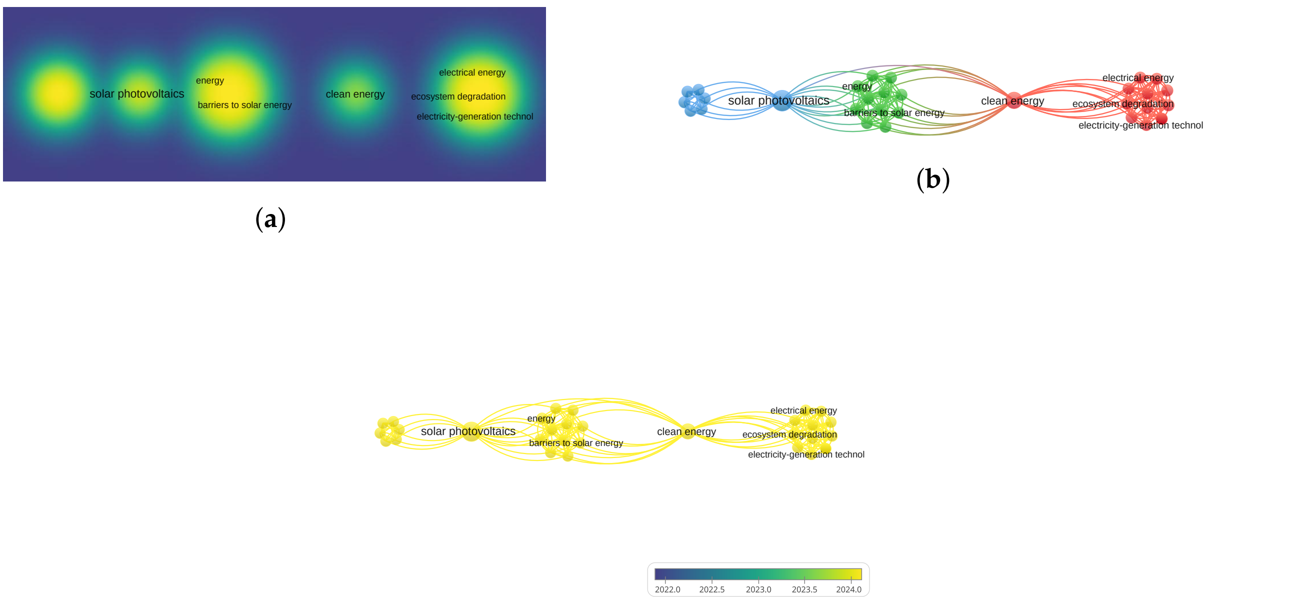
Technology	Description	Advantages	Applications
Bifacial solar cells (PERC)	Advanced technology generates electricity from both direct sunlight and reflected sunlight at the rear of the cell.	Higher efficiency due to capturing light from both the front and rear of the cell.	Utilized in areas with high light reflection, space optimization.
Floating PM technology	Installing solar cells on large bodies of water to prevent land wastage.	Solution for lack of terrestrial space: allows the use of water bodies for installation.	Installation of lakes, reservoirs, and other water bodies.
Integrated PM panels	Solar panels integrated into building architecture.	Reduces the size of solar installations, enhances aesthetics, and has a lower visual impact.	Residential, commercial, and public buildings.
Solar trees	Artificial trees that convert incident sunlight into electricity.	Electricity generation without occupying large areas of land, use of urban spaces.	Urban installations, parks, and public areas.
Agro-photovoltaic	Simultaneous use of agricultural land for crop cultivation and solar panel installation.	Maximizes available space; generates energy without compromising agricultural production.	Agricultural zones, rural development.

3.3. Technology Trends, Equipment, and Operations

The review study focuses on solar photovoltaic system (PSS) operation, excluding research areas that do not align with its primary objective. The following topics were removed from consideration: Studies related to (AI, IA), optimization, literature review, maximum power point tracking (MPPT), mathematical methods, economics and finance, software and simulation, maintenance, social and business sciences, art, biosciences, geosciences, and agriculture and environment. Also, the following types of papers were avoided: Reviews (re), conference papers (cr, cp), book chapters (ch), editorials (ed), and full-length books (bk). Some excluded keywords include the following: Studies related to economic analysis, investments, costs, MATLAB, fossil fuels, and wind energy.

Although photovoltaic technology presents a promising solution to current energy challenges, its efficiency is significantly influenced by factors such as temperature, solar irradiance, and the angle of incidence of solar radiation. These variables directly impact the performance of PM systems. For instance, variations in solar height affect the amount of radiation received by the modules, while temperature fluctuations alter the electrical characteristics of semiconductor materials, leading to changes in efficiency. To optimize the design and operation of large-scale photovoltaic systems, these aspects must be carefully considered [64,65]. This section examines solar cell degradation, monitoring and management systems, and emerging technological and equipment trends aimed at improving solar energy conversion efficiency.

Figure 4 shows the behavior of the bibliometric network in three stages: (a) the heat map shows the main variables, such as electricity generation technology, ecosystem degradation, system losses, energy, and qualitative analysis in renewables. (b) The following network correlates with keywords such as clean energy, solar photovoltaic energy, and finally, (c) the network that groups them by years. Notably, advanced algorithms play a crucial role in enhancing efficiency and performance in photovoltaic systems. As a result, improving technology from manufacturing to installation remains a key priority in advancing solar energy solutions.



(**a**) (**b**) (**c**)

Figure 4. Bibliometric analysis networks: Technology trends, equipment and operations. (**a**) Density network. (**b**) Density network. (**c**) Overlap network and years.

3.3.1. Material Degradation

Solar photovoltaic systems gradually deteriorate over time, resulting in decreased energy efficiency. This phenomenon, known as degradation, has particular characteristics depending on the type of material used and the environmental and climatic conditions to which they are exposed [20]. Previous research has explored the electrical characteristics and degradation processes of photovoltaic modules, considering various aging factors. Adiyabat et al. [66] analyzed the behavior of monocrystalline (m-Si) and polycrystalline (p-Si) modules over six years in the extreme climatic conditions of the Gobi desert, determining an annual degradation rate of 1.5% using I-V (Intensity-Voltage) characterization techniques [20].

3.3.2. Monitoring and Management Systems

Corrosion and fragile connections are the primary causes of thermal failures in photovoltaic systems, accounting for nearly 90% of the reported incidents. One significant issue is shunt diode corrosion, often linked to junction box damage, which leads to reduced performance, arcing risks, and accelerated degradation [20,67]. Table 7 compiles research on failure detection methods and materials used in solar cell manufacturing, emphasizing that efficiency losses persist regardless of material type.

Table 7. Thermal fault detection methods and the type of material for each solar cell.

Panel Type	Detection Method	Dominant Climate	Loss of Performance Ratio	Works
c-Si and p-Si	Visual inspection, I-V curves	Dry and composite	1.5%	[66]
p-Si, m-Si, and a-Si	Visual inspection, I-V curves, IR imaging	Tropical and warm semiarid	Tropical: 1.15% and 0.99%	[68]
m-Si	Visual inspection, I-V curves	Humid and warm	30 W: 64.83% 40 W: 75.90%	[69]
p-Si	Simulation work on PSS	Simulation work on PSS	2.7%	[70]
a-Si, p-Si and m-Si	SMA inverter captured the data and extracted by sunn explorer software	Mountain temperature	±0.9% ± 0.75%	[71]
p-Al, m-Al-BSF, m, p-PERC, m-Si, p-Si	Isc to Voc, Voc to Isc, Flash test	-	±4% ± 0.58%	[72]
c-Si	QE, TIR, XRD and SEM	Hot and humid	Power loss up to 40%	[73]
p-Si	Cracks and Micro SEM Cracks	Moist and hot	Power loss: 0.9 to 42.8%	[74]

p- = poly; m- = mono; a- = amorphous; SEM = scanning electron spectroscopy.

3.3.3. Innovations in Energy Storage Systems

Optimizing photovoltaic energy production largely depends on energy storage efficiency. Lithium-ion batteries remain the industry standard; however, emerging technologies like flow batteries and hydrogen storage promise to enhance capacity and durability. Table 8 presents the most promising technological advancements in storage systems aimed at improving solar panel efficiency.

With the increasing demand for renewable energy, photovoltaic technology has evolved significantly. Selecting the optimal solar PV system requires evaluating panel typologies, configurations, associated equipment, and costs. Table 8 presents a comparison to assess the performance of various technologies and configurations of PM systems, along with some necessary equipment. This systematic evaluation aims to support the exploration of emerging technologies in solar photovoltaic energy.

Table 8. Solar panel technology trends.

Technological Trends in PM	Manufacturer Comparison	Complementary Equipment	Efficiencies	Works
Perovskite solar cells	Efficiency, durability, cost, and optimum operating temperature	Analyze its impact on panel efficiency, cost, and lifespan	Scale device 26% combined 36%	[75]
Tandem solar cells	Compare power output, amount of space required, and aesthetics	Inverters: Compare efficiency, MPPT, communication options, and warranty	35%	[38]
Bifacial solar panels	Compare power output, amount of space required, and aesthetics	Inverters: Compare efficiency, MPPT, communication options, and warranty	18–24%	[76]
Solar trackerss	Compare the duration of the warranty and the coverages offered	Power optimizers: Evaluates the ability to maximize the power output of each panel individually	One axle 15–25% and two axles 30–45%	[77]
Energy storage: lithium batteries and hydrogen production	Research the track record, product quality, and customer service of different manufacturers	Compares storage capacity, charging and discharging efficiency, lifetime, and cost per kWh	Lithium batteries 85–95% and hydrogen option 25–45%	[78]
Artificial intelligence and the Internet of things (IoT)	Compare power output, amount of space required, and aesthetics	Monitors and controllers: Analyzes ease of use, monitoring functions, and remote control options	15–45%	[79]
Flexible and transparent solar panels	Compare the duration of the warranty and the coverages offered	Power optimizers: Evaluate your ability to maximize the power output of each panel individually	7–15%	[26]

3.3.4. Integration of Photovoltaic Systems with Smart Grids

Integrating photovoltaic systems into smart grids offers significant economic and environmental benefits. It enables efficient energy management, resource optimization, and operating cost reduction. Additionally, this integration facilitates renewable energy incorporation into the energy matrix, supporting the decarbonization of the electricity sector. Neural network optimization plays a crucial role in enhancing smart grid efficiency. By modifying parameters such as weights, biases, and learning rates and using gradient descent optimization, neural networks improve model accuracy by systematically reducing the loss function, thus contributing to higher solar panel efficiency [27].

3.3.5. New Panel Manufacturing and Recycling Techniques

Recent studies have shown that by integrating multiple-generation technologies, hybrid energy systems meet energy demands in isolated areas and minimize the environmental impact throughout their life cycle. The proliferation of these energy solutions has demonstrated the economic and technical feasibility of renewable energy production in various contexts, and the need to minimize the environmental impact associated with the production and final disposal of solar panels has motivated the exploration of new alternatives. The emergence of perovskite solar cells and developing efficient recycling processes are promising answers to these challenges, offering a path towards more sustainable solar energy production [80].

Manufacturing Techniques

1. Nano-engineered Composites [81]: Integration of nanomaterials to enhance mechanical and electrical properties.
2. 3D Printing of Panels [82]: Additive manufacturing for customized and efficient panel production.

3. Vacuum Infusion Molding [83]: A low-waste technique for fabricating high-strength composite panels.
4. Hybrid Material Panels [84]: Combining polymers, ceramics, and metals to achieve multifunctionality.
5. Low-temperature Sintering [85]: Reducing energy consumption while maintaining material integrity.

Recycling Techniques

1. Chemical Depolymerization [86]: Breaking down composite materials into reusable monomers.
2. Electrochemical Recycling [87]: Using electrochemical processes to separate valuable materials.
3. Mechanical Shredding and Reformation [88]: Grinding panels into smaller particles for reuse in manufacturing.
4. Thermal Pyrolysis [89]: High-temperature decomposition to recover useful components.
5. Bio-based Decomposition [90]: Employing microorganisms to break down biodegradable panel materials.

3.3.6. Advanced Equipment and Sensors for Efficiency Monitoring

The implementation of advanced sensors and monitoring systems has revolutionized solar installations. Devices like smart inverters, power optimizers, and irradiation sensors enable energy conversion, panel performance optimization, and efficient energy production. For example, lightning protection systems (LPS) are essential in photovoltaic installations to safeguard structural integrity and human safety from direct lightning strikes. Given the large exposed surface area of solar panels, the risk of being struck by lightning is considerable. An external LPS, equipped with air-termination devices and grounded down conductors, intercepts the lightning current, minimizing the damage caused by overvoltages and overcurrents. However, this protection is limited to the area covered by the system, leaving the surrounding areas exposed [91].

In industrial and scientific systems, efficiency monitoring is based on advanced sensors that collect real-time data to optimize performance [92–94]. Some key applications include:

- Energy consumption monitoring (current, voltage, and temperature sensors).
- Optimization of industrial processes (pressure, flow, and vibration sensors).
- Predictive maintenance (trend analysis to prevent failures).

The use of tools such as IoT (Internet of Things), AI, and Big Data enables the interpretation of this data and improves operational efficiency.

4. Discussion

This section interprets the findings of the study, analyzing their relevance across different contexts, including residential and industrial applications. It also examines the limitations of existing studies, identifying potential biases or knowledge gaps in the current literature. Furthermore, it explores the practical implications of the results and outlines future research directions that could enhance the understanding and application of the analyzed factors in diverse settings.

4.1. New Perspectives on Solar Efficiency

The pursuit of clean, sustainable, and renewable energy has accelerated in recent years, aligning with the objectives of Agenda 2030, specifically Goal 7, which aims to reduce energy poverty by promoting the adoption of eco-friendly and renewable energy sources. PM energy has become a leading technology in solar energy harvesting, contributing significantly to the global energy transition. Advances in materials science, module design, and operational strategies have been essential in enhancing the efficiency of PM systems. Researchers are investigating innovative materials and modules that provide higher energy conversion rates. As the demand for more efficient solar solutions rises, scientific interest in developing new strategies continues to grow, as reflected by the increasing number of studies in this field [95]. Innovations in solar energy are crucial for enhancing its accessibility and affordability, which supports the sustainability objectives of Agenda 2030. By tackling challenges such as efficiency losses, environmental impacts, and the integration of solar energy into existing energy grids, ongoing research is influencing the future of solar technology and laying the groundwork for next-generation photovoltaic systems. The findings presented in this work highlight a significant increase in research related to photovoltaic systems, showing that the number of articles on the topic has tripled since 2019, with only 10 articles published in that year compared to 31 articles published in 2024 (Figure 5).

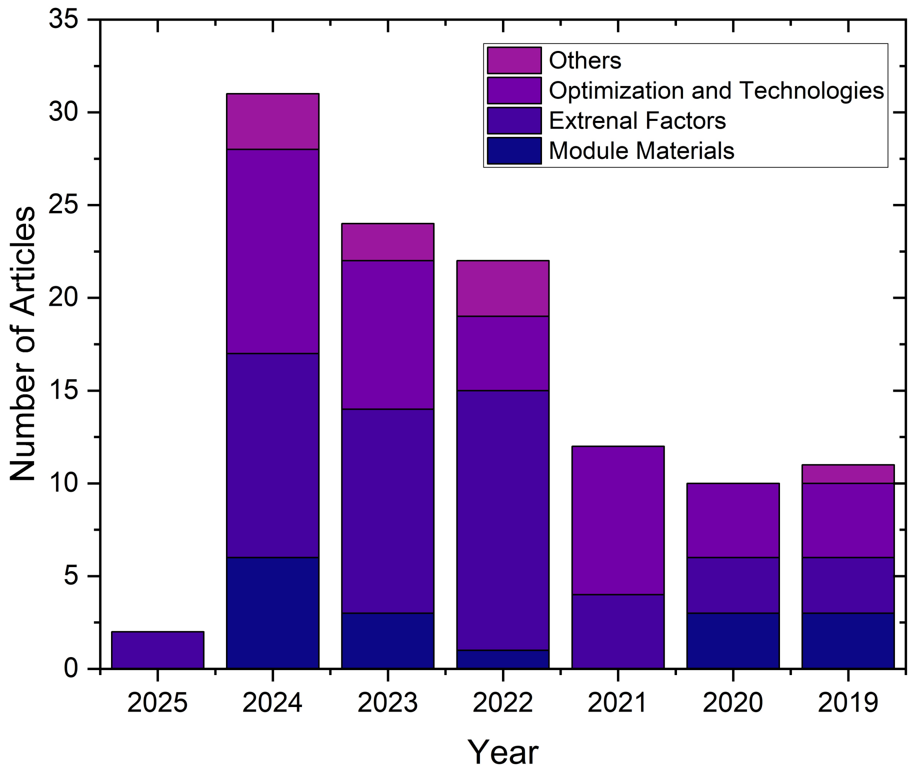


Figure 5. Articles published by year and trend.

While solar module efficiency is primarily influenced by the material type and internal structure [57], recent research trends have shifted away from developing new solar cell materials toward optimization strategies and emerging technologies. The emphasis is now on reducing environmental impact in the operation of solar modules. Notably, the focus on materials research has moved from solar cells to phase change materials.

The analysis of the selected articles reveals the trends and the focus of new studies. Figure 6, illustrates that energy and engineering are the primary fields of scientific production, whereas materials science and chemical engineering are losing influence and falling behind.

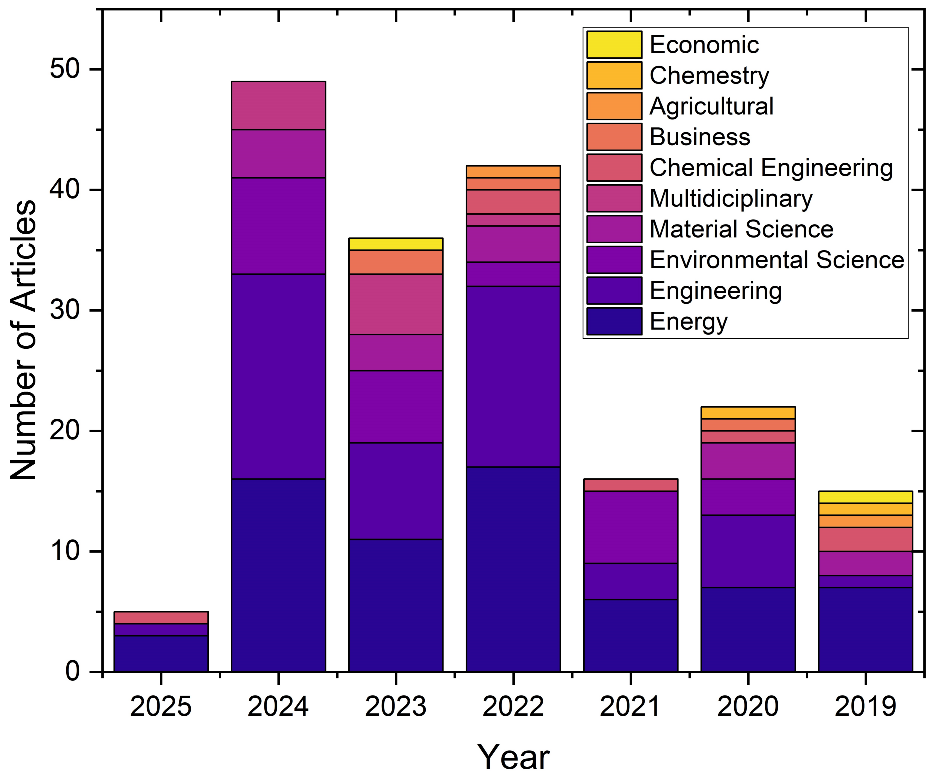


Figure 6. Articles published by topic and year.

4.2. Trends in the Sizing and Projection of PSS

The methodology proposed for installing PSS (see Figure 7) considers the main factors affecting efficiency, adopting an integrated approach that ensures both technical feasibility and economic viability. To this end, an energy analysis is developed to identify savings and consumption optimization opportunities, establishing an energy performance indicator. In addition, structural assessments of the building are carried out to evaluate the infrastructure resistance and to design adequate support for the solar panels, considering environmental factors. The characteristics of the current electrical system are analyzed to ensure efficient integration with the existing infrastructure [96–99].

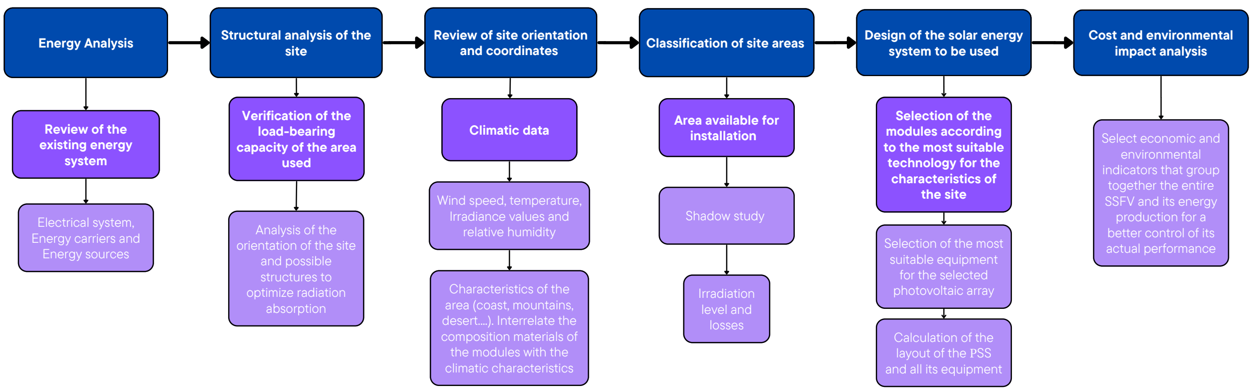


Figure 7. Proposed process diagram for PSS sizing.

From a feasibility perspective, this methodology incorporates optimization techniques to enhance system performance and maximize economic profitability. The sizing and optimization process evaluates both economic and environmental impacts, ensuring long-term viability. The methodology uses manual calculations and simulation tools to define design criteria that can serve as references for future implementations in similar buildings.

In this way, the methodology not only seeks to guarantee an efficient operation of the system but also to lay the foundations for its replicability in subsequent projects [100–102].

The current trend in photovoltaic system sizing focuses on achieving greater accuracy and efficiency, leveraging advanced simulation and analysis tools, and to optimize energy performance. The evolution of these systems has led to the integration of predictive models based on artificial intelligence (AI) and optimization algorithms that allow the design to be adjusted to specific site conditions, maximizing solar energy capture and reducing energy losses. In addition, battery storage integration with smart demand management is becoming a priority and enhances autonomy and stabilizes electricity supply in buildings.

In line with these developments, the proposed methodology aligns with contemporary trends by incorporating optimization models that integrate PSS within existing infrastructure while adapting to user energy needs. This approach ensures technical and economic feasibility and flexibility to adapt to emerging technologies and changing conditions. This methodology prioritizes long-term energy efficiency, supporting sustainable solutions.

4.3. Comparison Table of Review Articles on Solar Photovoltaic Systems: Efficiency Factors and Technology Trends

The comparative review presented in Table 9 highlights the distinct approach of this study compared to the existing literature on photovoltaic module (PM) systems. While previous studies focus on specific aspects of solar PV technology, this review provides a holistic perspective, addressing multiple dimensions, including technical performance, environmental impact, and interconnected technological advances. Several key differences emerge when comparing this study to prior reviews: Khalid et al. [103] focus on the development of perovskite solar cells, while Breyer et al. [104] analyze historical efficiency trends in photovoltaic systems. However, neither study includes a comprehensive evaluation of sustainability factors, literature review correlations, or system integration approaches.

Table 9. Review articles on solar photovoltaic systems and their focus on efficiency factors and technology trends.

Works	Main Focus	Methodology	Strengths	Limitations	Our Work
[103]	Focus on perovskite cells and their material properties.	Review of experiments and simulations.	Technical detail on crystal structures and stability strategies.	It does not address full systems integration or environmental impact.	It addresses a broader perspective of technologies, environmental factors, and whole systems.
[104]	Analysis of historical trends in photovoltaic efficiency.	Bibliographic analysis of historical data.	Multiple technologies (Si, CIGS, CdTe) and their advances	Limited to energy efficiency; does not include sustainability.	Integrates elements such as recycling and sustainability
[105]	Effects of temperature, dust, shading, and climate on efficiency.	Case studies and literature review.	Climatic analysis and specific solutions, such as self-cleaning systems.	Does not analyze emerging technologies or advanced cell designs.	It includes technology trends such as tandem cells and solar tracking systems.
[106]	Focus on renewable energies: solar thermal and photovoltaic.	Interdisciplinary review.	Holistic coverage of multiple energy technologies.	Surface analysis of efficiency factors for photovoltaics.	Analyzes photovoltaic systems and discusses specific efficiency factors.
[15]	Efficiency and advantages of bifacial panels.	Comparative analysis of experimental studies.	Detailed analysis of bifacial configurations in various geographic locations.	Exclusive to bifacial technology without comparison to other technologies.	It includes more diverse technologies and considers storage systems.
[107]	Analysis of environmental impacts and recycling strategies in PM systems.	Life cycle assessment and environmental analysis.	It brings a focus on sustainability and recycling.	Does not include PM recycling analysis	It incorporates sustainability aspects, in addition to considering trends in cell design.

Similarly, Kartikay et al. [105] provide a detailed analysis of environmental factors affecting PM efficiency, but they do not extensively cover emerging solar technologies or long-term sustainable approaches. Kazem et al. [106] present a broad global perspective on renewables, yet their study lacks a specific focus on PM technologies and system advancements. One of the main strengths of this review is its ability to integrate technical elements, such as bifacial systems, tandem designs, and energy storage innovation, with critical aspects of sustainability, including solar panel recycling and lifecycle impact.

This multidimensional approach contrasts with specialized studies such as Vodapally et al. [15], which focuses exclusively on bifacial panels, and Chau et al. [107], which prioritizes sustainability and recycling but omits technological innovations in efficiency and system design.

Table 10 offers a comprehensive and balanced comparison of different reviews on solar PM systems, identifying gaps in the literature and guiding future research directions. By linking specialized technical studies with broader reviews, this study serves as a bridge between niche technical advancements and high-level renewable energy analyses. This approach facilitates the identification of research priorities, such as the following: integrating innovative solar materials with sustainable lifecycle strategies, developing policies that encourage the widespread adoption of PM technology, and enhancing system design for greater efficiency and environmental compatibility. By addressing these gaps, this review contributes to a more comprehensive understanding of photovoltaic systems, supporting their technological evolution and sustainable adoption.

Table 10. Comparison of this work against state-of-the-art reviews.

Works	Complete Systems	PM Energy Efficiencies	Cell Designs	Storage Systems	Solar Tracking Systems	PSS Sizing Analysis	Period Search
[103]		X	X				-
[104]	X			X			2011–2024
[105]	X				X		-
[106]		X		X			-
[15]	X			X			2009–2021
[107]			X		X		-
Our Work	X	X	X	X	X	X	2019–2025

5. Conclusions

One of the main challenges in photovoltaic (PV) systems is the continuous development of highly efficient and sustainable technologies. Achieving this goal requires careful material selection and advanced installation techniques. This systematic review highlights the importance of choosing durable, low environmental degradation, and ecological properties while optimizing factors such as module orientation, site location, and energy demand to maximize efficiency.

Despite significant advancements, gaps remain in the literature, particularly in the adaptation of PV systems to local conditions and scalability considerations. Additionally, few studies systematically integrate material selection, system sizing, and module optimization. This review underscores the need for future research to bridge these gaps by proposing new methodologies that enhance both energy efficiency and sustainability in PM systems. With proper material selection and optimal system design, it is possible to maximize the use of solar resources while minimizing environmental impact. This approach contributes to the advancement of cleaner and more efficient energy technologies. As a result, the following outcomes were achieved:

- A systematic review was conducted, leading to the selection of 113 high-impact articles after exclusions.

- Critical aspects such as materials, technologies, and system sizing processes were analyzed, evaluating the ideal working ranges of key system variables.
- In PSS sizing, the trend is shifting toward AI-driven optimization, enabling the integration of more variables, ranges, and achieving higher efficiency.
- The development of new materials in photovoltaic systems improves energy efficiency but raises cost and potential toxicity concerns. The trend indicates minimal growth in new material adoption.
- Technological advancements, including perovskite cells, bifacial panels, and tandem configurations, have significantly increased energy yields and economic feasibility.
- In contrast, the development of intelligent energy storage and management systems has optimized their integration into power grids.
- Sustainability efforts now focus on recyclable materials and circular economy strategies, reducing the environmental impact of photovoltaic technology.
- With evolving regulatory policies and government incentives, the adoption and optimization of photovoltaic technology are expected to grow, reinforcing their role as a key renewable energy source.

Contribution to Scientific Knowledge:

- Innovative Synthesis and Analysis of Photovoltaic Materials: This research provides a comprehensive and novel perspective on the most commonly used materials in photovoltaic systems, emphasizing their impact on efficiency, durability, and long-term performance. Integrating recent advancements offers a fresh outlook on material selection for next-generation solar technologies.
- Advanced Evaluation of Design and Operational Variables: Going beyond conventional approaches, this study explores cutting-edge methodologies for optimizing photovoltaic system performance. Assessing key design parameters under diverse conditions introduces new insights into enhancing energy yield, reliability, and adaptability to various environmental scenarios.
- Pioneering Exploration of Emerging Solar Technologies: This work delves into the state-of-the-art innovations in tandem and bifacial solar cells, highlighting their unprecedented potential in the global energy transition. Bridging the gap between theory and real-world application provides a forward-looking perspective on their feasibility, scalability, and transformative impact on the photovoltaic industry.

Author Contributions: Conceptualization, L.A.I.C., C.D.C.-R. and M.G.G.-B.; methodology, L.A.I.C., C.D.C.-R. and M.G.G.-B.; software, L.A.I.C., C.D.C.-R. and M.G.G.-B.; validation, J.M.Á.-A., Y.C.-A. and J.R.-R.; formal analysis, Y.C.-A., L.A.I.C. and J.R.-R.; investigation, Y.C.-A. and L.A.I.C.; data curation, L.A.I.C., J.M.Á.-A. and J.R.-R.; writing—original draft preparation, L.A.I.C., C.D.C.-R. and M.G.G.-B.; writing—review and editing, J.M.Á.-A. and J.R.-R.; visualization, Y.C.-A. and J.R.-R.; supervision, J.R.-R. and J.M.Á.-A. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funding was associated with this research.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be made available upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
η_{panel}	Photovoltaic Panel Efficiency
P_{out}	Electrical Power Generated by the Panel
P_{in}	Solar Power Incident on the Panel
G	Solar Irradiance
A	Panel Surface Area
η_{system}	Photovoltaic System Efficiency
E_{AC}	Electrical Energy Measured at the Inverter Output
t	Solar Exposure Time
PR	Performance Ratio
η_{total}	Total System Efficiency
PM	Photovoltaic Module
PSS	Photovoltaic Solar Systems
MPPT	Maximum Power Point Tracking
PCM	Phase Change Materials
PERC	Passivated Emitter and Rear Cell
IR	Infrared
Isc	Short-Circuit Current
Voc	Voltage at Open Circuit
XRD	X-ray Diffraction
SEM	Scanning Electron Microscopy
LPS	Lightning Protection Systems
I-V	Intensity-Voltage
IR	Infrared
QE	Quantum Efficiency
LoT	Internet of Things
TIR	Total Internal Reflection
PSS	Power System Stabilizers
SWNT	Single-wall Nanotube
Uv	Ultra-violet
AI, IA	Artificial Intelligence

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