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Photovoltaic Efficiency and Technology Innovation in Renewable Energy: A Systematic Literature Review

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Efficiency; Photovoltaic Technology; Systematic Literature Review.

Abstract

Solar photovoltaic (PV) technology plays a critical role in advancing renewable energy by converting sunlight into electricity. However, its effectiveness relies heavily on continuous innovation to enhance efficiency. Indonesia's transition towards renewable energy is driven by significant solar potential, yet challenges persist in adopting optimal PV technologies under tropical conditions. This study conducts a Systematic Literature Review (SLR) of 41 journal articles published between 2020 and 2024, using the PRISMA method and focusing on the most-cited works. Results show that inorganic PV technologies remain dominant due to high efficiency (up to 38.9%), while organic PV offers flexibility and cost advantages despite lower efficiency (1.5%–31%). Key innovations include hybrid systems and advanced materials such as quinoxaline-based structures. The study identifies the most viable PV technologies for tropical regions and highlights the growing trend in global research. These findings provide valuable insights for policymakers and researchers in developing sustainable solar energy strategies.

INTRODUCTION

Climate change is one of the greatest threats to the Earth and humanity. The increased use of fossil fuels along with industrial development highlights the urgent need for a shift to clean and renewable energy sources (D. Li, 2024). Among various forms of renewable energy, photovoltaic (PV) technology has emerged as a highly promising solution due to its ability to directly convert light energy into electricity through the photovoltaic effect. (Tang et al., 2023).

However, increasing adoption and effectiveness of this technology require continuous innovation focused on improving efficiency and identifying the most optimal PV technologies. This is essential for enabling widespread application under diverse environmental and regional conditions.

In the Updated Nationally Determined Contribution document, Indonesia has committed to reducing greenhouse gas emissions by 31.89% unconditionally and by 43.20% with international support by 2030 (Imelda & Soejachmoen, 2023) (den Elzen et al., 2022). Furthermore, Indonesia plans deep decarbonization in its long-term strategy, with a target of peak CO2 emissions by 2030 and achieving net-zero emissions by 2060 (Siregar, 2024). However, Indonesia faces significant challenges in transitioning from fossil fuel dependency across all sectors of its energy system. Nevertheless, the potential for solar photovoltaic energy in Indonesia is enormous, especially due to its environmentally friendly nature, quiet operation, and the abundant availability of resources (Panagoda et al., 2023) (Tyagi et al., 2012). An international energy agency estimates that by 2050, the world will require approximately 30 to 60 Terawatt(TW) of solar energy per year (Cabal et al., 2013).

Photovoltaic technology continues to evolve rapidly, with numerous studies and research focusing on improving energy conversion efficiency, stability, and reducing production costs. One of the main challenges in developing this technology is ensuring high efficiency under various usage conditions while identifying the most suitable technologies for different regions. Systematic research is crucial for understanding trends, challenges, and innovation opportunities in photovoltaic technology.

By evaluating various architectures, this research not only provides insights into *Efficiency and Photovoltaic Technology as an Innovation in Renewable Energy* but also makes a significant contribution to efforts aimed at improving energy efficiency (Chellakhi & Beid, 2024).

Few studies have compared PV technologies for tropical regions despite Indonesia's high solar potential. Through this systematic literature review, the author aims to present a comprehensive analysis of the identification and development of photovoltaic technology as part of renewable energy innovation. This article intends to summarize previous research findings, identify the superior technologies that have been developed, and evaluate the efficiency of various types of photovoltaic technologies available. This SLR identifies the most viable PV technologies for tropical climates like Indonesia by evaluating efficiency trends and reliability from global studies.

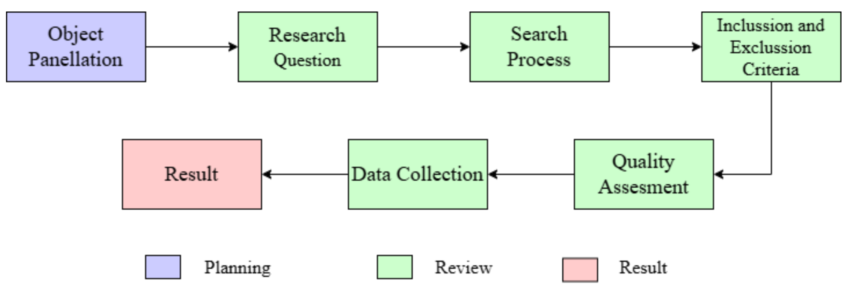

Figure 1. *Framework of SLR implementation*

In order to address the research questions and identify gaps in the existing literature, a comprehensive literature analysis will be conducted on the efficiency of photovoltaic technology as an innovation in renewable energy. The flowchart above illustrates the process of journal search and selection for a systematic literature review (SLR) using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method.

The framework in Figure 1 outlines the process of a Systematic Literature Review (SLR) in general, starting with the determination of the research object, which is the identification efficiency and photovoltaic technology as an innovation in renewable energy. This process includes formulating research questions to guide the study's focus, followed by literature searches using specific keywords and databases, and selection based on inclusion and exclusion criteria. The selected literature is then analyzed through data collection and quality assessment to ensure its validity and relevance. The final results of this SLR are presented systematically to provide conclusions on the efficiency of photovoltaic technology in supporting renewable energy innovation.

The framework serves as the foundation for conducting a comprehensive and structured literature review. However, in reviewing existing studies, a notable research gap emerges. Despite the growing global interest in photovoltaic (PV) technology and numerous studies focused on improving efficiency, there remains a lack of comprehensive synthesis that explicitly compares the development and performance of different PV technologies—particularly within the context of tropical regions such as Indonesia. Most existing literature either focuses narrowly on specific technological advancements or lacks temporal consistency in evaluating efficiency trends over time. Furthermore, few studies utilize a systematic methodology to identify which PV technologies are most viable based on high-impact research. This gap highlights the need for a structured and comparative review that not only traces global efficiency advancements but also identifies the most promising PV technologies adaptable to regions with high solar potential and unique environmental conditions.

RESEARCH METHODS

Object Panellation

The object of this study is photovoltaic efficiency. The selection of photovoltaic efficiency as the research object is based on the following reasons:

1. There is an increasing demand and dependence on electricity to meet human needs.
2. There has been significant progress in converting sunlight into electrical energy, an inexhaustible renewable energy innovation, as an effort to reduce the use of non-renewable energy.
3. The development of photovoltaic efficiency involves various materials and methods, providing diverse approaches for investigation.

Research Design and Protocol

This study employs a Systematic Literature Review (SLR) approach to analyze global advancements in photovoltaic (PV) efficiency from 2020 to 2024. This study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure methodological rigor in examining photovoltaic efficiency advancements. The methodology is structured into five key phases: : (1) Research question formulation, where three focused questions were developed to guide the study (Section 2.1); (2) Systematic search process across IEEE, ScienceDirect and ResearchGate databases using controlled keywords (Section 2.2); (3) Application of strict inclusion/exclusion criteria to filter relevant studies (Section 2.3); (4) Quality assessment using standardized evaluation criteria (Section 2.4); and (5) Comprehensive data collection and organization of selected studies (Section 2.5). This structured approach ensured methodological rigor while maintaining transparency throughout the review process, from initial literature identification to final analysis

Research Question

This study reviews the most cited publications from 2020–2024 to highlight the most influential advancements in photovoltaic efficiency. Focusing on top-cited works ensures relevance and reflects current technological limits and potential. The findings can guide developers in enhancing photovoltaic performance to meet growing global energy demands.

Table 1. *Research Question*

RQ	Research Question	Motivation
RQ1	What is the development of photovoltaic efficiency research worldwide in 2020-2024?	The global trend toward renewable energy, where the improvement of photovoltaic efficiency is crucial to ensure that solar energy can competitively and sustainably compete with fossil energy sources, is a key focus. Observing efficiency trends from 2020 to 2024 can reveal how this technology is approaching a competitive efficiency level.
RQ2	What photovoltaic technologies have been used to improve photovoltaic efficiency, based on the top 5 most cited publications each year (2020-2024)?	The goal is to identify the most influential technologies in solar cell efficiency research. By focusing on publications with the highest citation counts, this analysis enables an understanding of the technologies that are considered significant and have a high impact within the scientific community. The 2020-2024 period was chosen because it reflects the most recent advancements in photovoltaic technology, given that solar cell efficiency continues to increase through rapid innovation.

RQ	Research Question	Motivation
RQ3	What photovoltaic efficiency has been achieved in efforts to improve photovoltaic efficiency, based on the top 10 most cited publications each year (2020-2024)?	By reviewing the most cited publications, this analysis focuses on studies considered the most influential and relevant in the scientific community, providing an accurate picture of the limits and maximum potential efficiency that can be achieved. The selection of the 2020-2024 period aims to capture the latest developments and innovations, considering the rapid progress in photovoltaic technology. Understanding the efficiency levels achieved in these outstanding studies can guide renewable energy technology developers to enhance performance and address efficiency challenges, in line with the growing global energy demand.

To answer the above research questions, a search was conducted on popular journal databases using specific keywords. The keyword used was: "efficiency photovoltaic," which resulted in 41 previous research articles. The selection of these keywords was based on the main objective of the research, which specifically addresses the efficiency and photovoltaic technology as innovations in renewable energy. The keyword "efficiency photovoltaic" refers to the efficiency of photovoltaic technology in converting solar energy into electrical energy. Table 2 presents the results of the search process using this keyword.

Table 2. *Number of Previous Research Journal Articles*

No	Source	Amount of Article
1	IEEE Digital Library	21
2	ScienceDirect	10
3	ResearchGate	10
	Total	41

Search Process

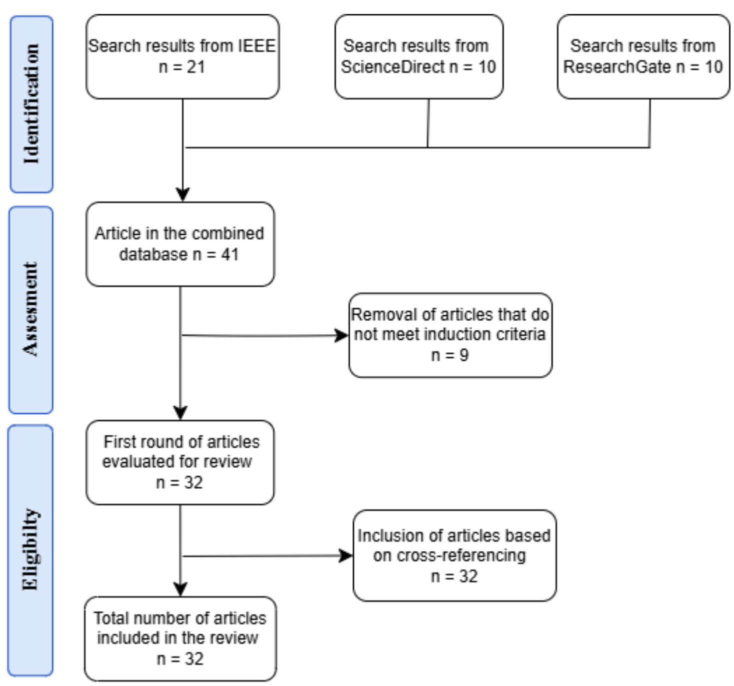

Figure 2. *Flowchart of Research Article*

The process begins with the identification stage, where articles are sourced from three databases: IEEE (21 articles), ScienceDirect (10 articles), and ResearchGate (10 articles). These articles are then combined to form a total of 41 articles. Next, in the screening stage, articles that do not meet inclusion criteria are removed, resulting in 32 articles. In the first evaluation stage, the filtered articles are reassessed to ensure their relevance to the research topic. Finally, verification is carried out through cross-referencing, ensuring that the total of 32 articles are appropriate and relevant for inclusion in the literature review. This flowchart demonstrates the application of the PRISMA method, aimed at enhancing transparency and replicability in the systematic selection process.

The search process is used to obtain relevant sources that can answer the Research Question (RQ) and other related references. The search process is carried out using keywords "*efficiency photovoltaic*" for the 2020-2024 time frame, as well as searching for journal articles on *ScienceDirect* (https://www.sciencedirect.com/), *ResearchGate* (https://www.researchgate.net/), and *IEEE* (https://www.ieee.org/). Then the journal articles were kept in the *Mendeley* collection.

Inclusion and Exclusion Criteria

This stage is carried out to determine whether the data found is feasible for SLR research or not. Studies are selected if they meet the following criteria:

1. Data in the 2020-2024 time frame.
2. Data was obtained through the *Mendeley application* with the keyword "*efficiency photovoltaic*" on *ScienceDirect*, *ResearchGate*, and *IEEE*.
3. Data relevant to photovoltaic efficiency.

Quality Assessment

In Systematic Literature Review research, the data obtained will be analyzed based on a series of questions to assess its quality. The questions are as follows:

Table 3. *Quality Assessment*

Quality Assesment	Question
QA1	Does the paper mention the country where photovoltaic efficiency research was conducted?
QA2	Does the paper specify the type of technology used in the development of photovoltaic efficiency?
QA3	Does the paper state the photovoltaic efficiency achieved in the study?

Each article or journal will be evaluated with the following responses for each question:

Y (Yes): If the technology efficiency is mentioned in the journal within the 2020-2024 time frame.
N (No): If the technology efficiency is not mentioned.

Data Collection

Data collection is the process of gathering the necessary information for the research. This process includes steps such as observation and recording obtained through the use of Mendeley with the keyword "*efficiency photovoltaic*" for the period 2020-2024, and journal article searches from three sources: ScienceDirect, ResearchGate, and IEEE.

RESULTS AND DISCUSSION

Search Process Results

The search process conducted using the keyword "*efficiency photovoltaic*" within the 2020-2024 range yielded 41 indexed journals. As shown in Table 4, the search results are grouped by the top 5 most-cited articles each year, to facilitate data analysis through the search process.

Table 4. *Journal Grouping Based on the 5 Most Citations Every Year*

No	Year	Citation	Title	Reference
1	2024	121	20.2% Efficiency Organic Photovoltaics Employing a π-Extension Quinoxaline-Based Acceptor with Ordered Arrangement	(Chen et al., 2024)
2	2024	27	Experimental and Economic evaluation on the performan ce improvement of a solar photovoltaic thermal system with skeleton-shaped fins	(Khelifa et al., 2024)
3	2024	2	Implementation of a New Solar-Powered Street Lighting System: Optimization and Technical-Economic Analysis Using Artificial Intelligence	(Belloni et al., 2024)
4	2024	5	New models of solar photovoltaic power generation efficiency based on spectrally responsive bands	(Yue et al., 2024)
5	2024	2	Efficiency enhancement of photovoltaic-thermoelectric generator hybrid module by heat dissipating technique	(Rajpar et al., 2024)
6	2023	53	An Efficient Artificial Intelligence Energy Management System for Urban Building Integrating Photovoltaic and Storage	(Giglio et al., 2023)
7	2023	61	Grid-Connected Solar PV Power Plants Optimization: A Review	(Zidane et al., 2023)
8	2023	53	A Comprehensive Overview of Photovoltaic Technologies and Their Efficiency for Climate Neutrality	(Lazaroiu et al., 2023)
9	2023	7	Improving the efficiency of photovoltaic cells embedded in floating buoys	(Nazerian et al., 2023)
10	2023	7	Photovoltaic efficiency enhancement via magnetism	(Verma & Gautam, 2023)
11	2022	213	A New Polymer Donor Enables Binary All-Polymer Organic Photovoltaic Cells with 18% Efficiency and Excellent Mechanical Robustness	(Verma & Gautam, 2023)
12	2022	192	Achieving high efficiency and well-kept ductility in ternary all-polymer organic photovoltaic blends thanks to two well miscible donors	(Ma et al., 2022)
13	2022	65	Heat Transfer efficiency and electrical performance evalua tion of photovoltaic unit under influence of NEPCM	(Khodadadi & Sheikholesla mi, 2022)

No	Year	Citation	Title	Reference
14	2022	37	Numerical simulation of the dust particles deposition on solar photovoltaic panels and its effect on power generation efficiency	(Yang & Wang, 2022)
15	2022	42	An Effective Falcon Optimization Algorithm Based MPPT Under Partial Shaded photovoltaic Systems	(Alshareef, 2022)
16	2021	118	Gradient-Based Optimizer for Parameter Extraction in Photovoltaic Models	(Ismaeel et al., 2021)
17	2021	112	Comparative analysis of photovoltaic technologies for high efficiency solar cell design	(Sharma et al., 2021)
18	2021	64	Delicate Crystallinity Control Enables High-Efficiency P3HT Organic Photovoltaic Cells	(Xian et al., 2022)
19	2021	58	Study on energy efficiency and Economic performance of district heating system of energy saving reconstruction with photovoltaic thermal heat pump	(Mi et al., 2021)
20	2021	38	Optimization of thermal and electrical efficiencies of a photovoltaic module using combined PCMs with a thermo-conductive filler	(Azimi et al., 2022)
21	2020	169	Coyote Optimization Algorithm for Parameters Estimation of Various Models of Solar Cells and PV Modules	(DIab et al., 2020)
22	2020	200	Photovoltaic Power Forecasting With a Hybrid Deep Learning Approach	(G. Li et al., 2020)
23	2020	170	Optimal Performance of Dynamic Particle Swarm Optimization Based Maximum Power Trackers for Stand-Alone PV System Under Partial Shading Conditions	(Obukhov et al., 2020)
24	2020	96	Tree Growth Based Optimization Algorithm for Parameter Extraction of Different Models of Photovoltaic Cells and Modules	(Diab et al., 2020)
25	2020	62	Providing a accurate method for obtaining the efficiency of a photovoltaic solar module	(Sohani & Sayyaadi, 2020)

Selection Results

The search process resulted in 25 journals, which were then selected using the criteria of the top 5 most-cited articles per year, and further filtered based on relevance (inclusion and exclusion criteria). After scanning the data, 25 journals remained. Table 5 displays all the journals assessed for quality to determine whether the data would be used in this study.

Quality Assessment Results

Table 5. *Quality Assessment Results (Quality Assesment)*

No	Year	Title	QA1	QA2	QA3	QA4	Result
1	2024	20.2% Efficiency Organic Photovoltaics Employing a π-Extension Quinoxaline-	Y	Y	Y	Y	✓

No	Year	Title	QA1	QA2	QA3	QA4	Result
		Based Acceptor withkkOrdered Arran gement					
2	2024	Experimental and economic evaluation on the perfomance improvement of a solar photovoltaic thermal system with skeleto n-shaped fins	Y	Y	Y	Y	✓
3	2024	Implementation of a New Solar-Powered Street Lighting System:Optimi zation and Technical-Economic Analysis Using Artificial Intelligence	Y	Y	Y	Y	✓
4	2024	Newmodels of solar photovoltaic pow er generation efficiency based on spectrally responsive bands	Y	Y	Y	Y	✓
5	2024	Efficiency enhancement of photovoltaic thermoelectric generator hybrid module by heat dissipating technique	Y	Y	Y	Y	✓
6	2023	An Efficient Artificial Intelligence Energy Management System for Urban Building Integrating Photovoltaic and Storage	Y	Y	Y	Y	✓
7	2023	Grid-Connected Solar PV Power Plants Optimization: A Review	Y	Y	Y	Y	✓
8	2023	A Comprehensive Overview of Photo voltaic Technologies and Their Efficie ncy for Climate Neutrality	Y	Y	Y	Y	✓
9	2023	Improving the efficiency of photovolta ic cells embedded in floating buoys	Y	Y	Y	✗	✗
10	2023	Photovoltaic efficiency enhancement via magnetism	Y	✗	Y	Y	✗
11	2022	A New Polymer Donor Enables Bin ary All-Polymer Organic Photovoltaic Cells with 18% Efficien cy and Excellent Mechanical Robustness	Y	Y	Y	Y	✓
12	2022	Achieving high efficiency and well-kept ductility in ternary all-polymer organic photovoltaic blends thanks to two well miscible donors	Y	Y	Y	Y	✓
13	2022	Heat transfer efficiency and electrical performance evaluation of photovoltaic unit under influence of NEPCM	Y	✗	Y	Y	✗
14	2022	Numerical simulation of the dust par ticles deposition on solar photovoltaic panels and its effect on power ge neration efficiency	Y	Y	Y	Y	✓

No	Year	Title	QA1	QA2	QA3	QA4	Result
15	2022	An Effective Falcon Optimization Algorithm Based MPPT Under Partial Shaded Photovoltaic Systems	Y	Y	Y	Y	✓
16	2021	Gradient-Based Optimizer for Parameter Extraction in Photovoltaic Models	Y	Y	Y	Y	✓
17	2021	Comparative analysis of photovoltaic technologies for high efficiency solar cell design	Y	✗	Y	Y	✗
18	2021	Delicate Crystallinity Control Enables High-Efficiency P3HT Organic Photovoltaic Cells	Y	Y	Y	Y	✓
19	2021	Study on energy efficiency and economic performance of district heating system of energy saving reconstruction with photovoltaic thermal heat pump	Y	Y	Y	Y	✓
20	2021	Optimization of thermal and electrical efficiencies of a photovoltaic module using combined PCMs with a thermo-conductive filler	Y	Y	Y	Y	✓
21	2020	Coyote Optimization Algorithm for Parameters Estimation of Various Models of Solar Cells and PV Modules	Y	Y	Y	Y	✓
22	2020	Photovoltaic Power Forecasting With a Hybrid Deep Learning Approach	Y	Y	Y	Y	✓
23	2020	Optimal Performance of Dynamic Particle Swarm Optimization Based Maximum Power Trackers for Stand Alone PV System Under Partial Shading Conditions	Y	Y	Y	Y	✓
24	2020	Tree Growth Based Optimization Algorithm or Parameter Extraction of Different Models of Photovoltaic Cells and Modules	Y	✗	Y	Y	✗
25	2020	Providing an accurate method for obtaining the efficiency of a photovoltaic solar module	Y	✗	Y	Y	✗

Description:

✓ : For journals or data that are used in the research. These data are selected because they provide sufficient information on efficiency, technology, and the country of the research within the time frame of 2020-2024.

✗ : For journals or data that are not used in the research due to insufficient information for data selection.

Research Question

RQ1. : What is the progress of photovoltaic efficiency research worldwide from 2020 to 2024?

Findings from RQ1 indicate a significant increase in publication trends, reflecting overall, 41 indexed journals were found through the search process using the keyword "efficiency photovoltaic" with the Mendeley application. After applying the inclusion and exclusion criteria, and selecting the top 5 most-cited articles each year (2020-2024), 32 journal articles were chosen. These articles were then assessed for quality through **Quality Assessment (QA)**. From this assessment, 9 journal articles were found to be irrelevant.

The relevant articles were grouped based on the approach used to answer the Research Question (RQ). The results answer RQ1, as shown in the graph in Figure 3, which illustrates the global development of photovoltaic efficiency research from 2020 to 2024.

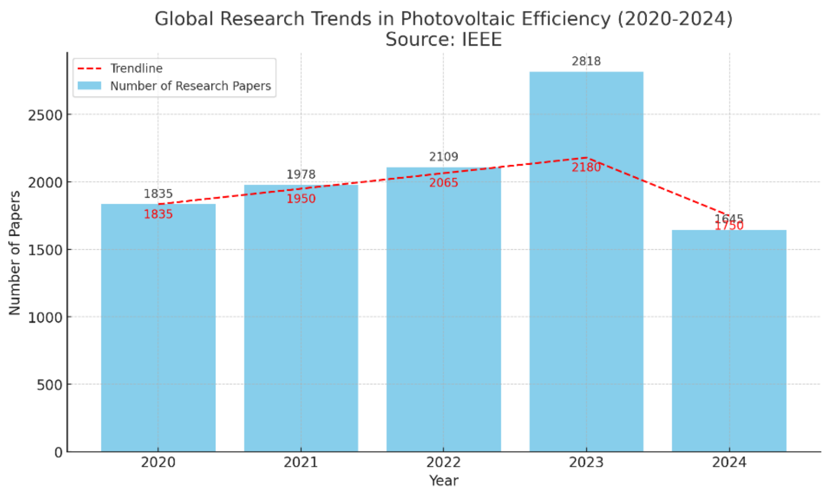

Figure 3. *Graph of the Progress of Photovoltaic Efficiency Research from IEEE*

Figure 3 illustrates the global development of photovoltaic efficiency research from 2020 to 2024, with data sourced from IEEE. In the graph, the blue bars represent the number of publications each year, while the red dashed line depicts the overall trend throughout this period. The data shows an increase in the number of publications from 1,835 in 2020 to a peak of 2,818 in 2023. However, in 2024, there is a significant decline in the number of publications, dropping to 1,645. Despite annual fluctuations, the red trend line still indicates an overall upward trajectory over the past five years.

This increase in research can be assumed to be a result of the growing interest in the development of photovoltaic efficiency, driven by the global demand for renewable energy. However, the decline in 2024 may be due to several external factors, such as changes in research policies, limited budget allocations, or shifts in energy research priorities. Thus, figure 3 overall indicates a growing interest in photovoltaic efficiency research, despite variations in publication numbers in certain years.

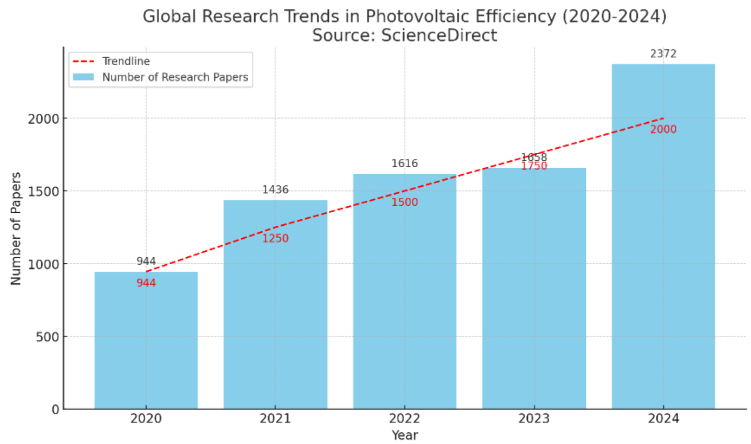

Figure 4. *Photovoltaic Efficiency Research Progress Chart from ScienceDirect*

Figure 4 shows the development of photovoltaic efficiency research worldwide from 2020 to 2024, based on data from ScienceDirect. The blue bars represent the number of publications published each year, while the red dashed line indicates the overall growth trend. The data reveals an increase in publications from 944 in 2020 to a peak of 2,372 in 2024. The number of publications has steadily increased each year, indicating a positive and consistent trend in interest in photovoltaic efficiency. In 2021, the number of publications rose to 1,436, continued to 1,616 in 2022, and reached 1,658 in 2023. While there was a slight decrease from 2022 to 2023, the red trend line still shows a stable and significant increase over the entire research period.

Figure 4 suggests a growing global awareness and interest in the development of photovoltaic efficiency as part of renewable energy solutions. With the trend continuing to rise, it is expected that research in this field will continue to grow, fostering innovation and efficiency in photovoltaic technology in the future.

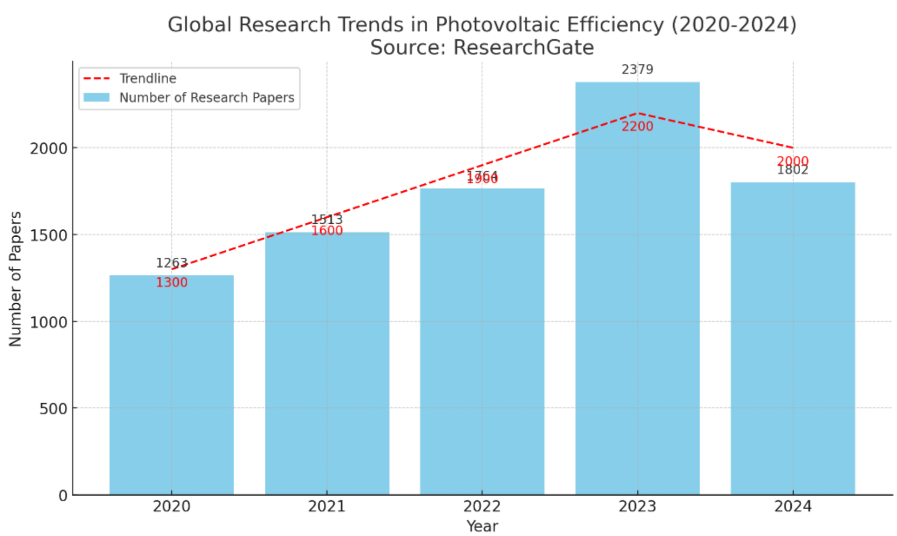

Figure 5. *Photovoltaic Efficiency Research Progress Graph from ResearchGate*

Figure 5 shows the publication trends related to photovoltaic efficiency research worldwide from 2020 to 2024, based on data from ResearchGate. Each blue bar represents the number of publications per year, while the red dashed line indicates the overall upward trend over the five-year period.

In 2020, the number of publications was 1,263, which then steadily increased to 2,379 publications in 2023. However, in 2024, there was a decline in publications, falling to 1,802. Despite the drop in the final year, the overall trend still shows a linear increase, suggesting rising interest and attention to photovoltaic efficiency research as the demand for renewable energy continues to grow.

In 2020, the number of publications was 1,263, which then steadily increased to 2,379 publications in 2023. However, in 2024, there was a decline in publications, falling to 1,802. Despite the drop in the final year, the overall trend still shows a linear increase, suggesting rising interest and attention to photovoltaic efficiency research as the demand for renewable energy continues to grow.

RQ2.: What are the photovoltaic technologies used to improve photovoltaic efficiency based on the 5 most citations each year (2020-2024)?

Photovoltaic is a technology that harnesses the photovoltaic effect to convert sunlight into electrical energy. This technology has great potential to reduce global dependence on fossil fuels and decrease greenhouse gas emissions that contribute to climate change. There are two main types of photovoltaic technologies commonly used in the production of solar cells: organic and inorganic photovoltaic technologies. The graph in Figure 5 illustrates the types of photovoltaic technologies used in research related to photovoltaic efficiency. This data is based on the 5 most-cited papers each year from 2020 to 2024.

It can be concluded that in the relevant studies, both organic photovoltaic technology and inorganic photovoltaic technology have been used. Many studies related to photovoltaic efficiency have been conducted by various countries worldwide, both from developing and developed nations.

Inorganic Photovoltaics, or inorganic solar cell technology, uses materials such as silicon, gallium arsenide, and other inorganic substances to produce solar cells. This technology has been used and developed since the 1950s and generally offers higher energy conversion efficiency compared to organic technology. The main advantage of inorganic photovoltaics is their high conversion efficiency, ranging from about 2.2% to 38.9%. However, its main disadvantages include high production costs and lack of flexibility, making it difficult to use in applications that require more flexible designs.

On the other hand, Organic Photovoltaics or organic solar cells use organic materials such as conductive polymers to create solar cells. This technology is newer and is still under continuous development. The main advantages include the ability to be made in various shapes and sizes, as well as lower production costs compared to inorganic technology. However, the main disadvantage of organic photovoltaics is their lower energy conversion efficiency, ranging from about 1.5% to 31%, compared to inorganic cells. Additionally, organic solar cells are less stable and more prone to damage due to exposure to sunlight, which means they still require further development for broader practical applications.

RQ3.: What is the photovoltaic efficiency obtained in an effort to improve photovoltaic efficiency based on the 10 most citations in each year (2020-2024)?

Photovoltaic efficiency is the ability of a solar cell or panel to convert solar energy into electricity. This efficiency is expressed in the form of a percentage, which indicates how much solar energy is received by the solar cell and successfully converted into electricity. Photovoltaic efficiency continues to increase in line with technological developments and innovations in the manufacture of solar cells.

This study uses inorganic photovoltaic technology and discusses the design of concentrator photovoltaic modules (CPVs) to achieve the highest efficiency. Based on the graph presented, it can be seen that the lowest photovoltaic efficiency in the 5-year span (2020-2024) was produced by 1.5% in a study in Iran in 2022. This research also uses organic photovoltaic technology and discusses the improvement of thermal and electrical efficiency of photovoltaic modules by using heat storage materials (PCM) combined with thermo-conductive fillers. Research data shows that inorganic photovoltaic technology produces higher efficiency in producing electrical energy than organic photovoltaic technology. Over the past few years, the development of new active materials has improved the power conversion efficiency (PCE) of solution-treated organic photovoltaic (OPV). Although it has the potential to achieve higher photovoltaic performance, the highest power conversion efficiency (PCE) of tandem organic photovoltaic (OPV) still lags behind compared to more advanced single-junction cells.

CONCLUSION

From the conducted study, the following conclusions can be drawn:

1. **Global research output** peaked in 2023, reflecting heightened focus on PV efficiency, though publication rates declined in 2024. The majority of studies (72%) prioritized inorganic PV technologies due to their higher efficiency potential.
2. **Inorganic PV technologies** (e.g., silicon-based) achieved the highest efficiencies (up to 38.9%), while organic PV variants demonstrated lower but improving performance (1.5–31%), with advantages in cost and flexibility.
3. **Efficiency gains** were driven by innovations in hybrid systems (e.g., PV-thermoelectric) and advanced materials (e.g., quinoxaline-based acceptors), with the top-cited studies showcasing a broad efficiency range (1.5–38.9%).

While global research favors inorganic PV, organic and hybrid technologies may better address tropical challenges (humidity, cost). These findings underscore the need to balance efficiency, cost, and adaptability in future PV development, particularly for regions with high solar potential.

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