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Comparative Study on Ground and Roof-Mounted Solar PV Systems

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Abstract:** Solar photovoltaic (PV) systems are integral to sustainable energy solutions. The choice between ground-mounted and roof-mounted systems significantly impacts efficiency, cost, and installation feasibility. This study provides a comparative analysis of these two solar PV installation types to inform stakeholders and guide decision-making. This study aims to guide stakeholders, including policymakers, investors, and energy planners, in making informed decisions regarding solar PV system installations. By highlighting the strengths and weaknesses of each approach, this review contributes to the broader understanding of solar PV deployment strategies and their implications for sustainable energy development. A systematic literature review was conducted to gather data from various sources including academic journals, ScienceDirect, Google Scholar, PubMed, SpringerLink, Academia, and research gate. Key criteria for comparison included energy production efficiency, initial and ongoing costs, installation complexity, and long-term maintenance. The review revealed that ground-mounted systems generally offer higher energy production due to optimal tilt and orientation adjustments, and often result in lower maintenance costs due to easier access. Conversely, roof-mounted systems are usually less costly to install as they utilize existing infrastructure and may benefit from lower regulatory hurdles. However, they are constrained by roof space and orientation limitations and may face higher maintenance costs due to accessibility issues. Ground-mounted solar PV systems typically provide greater efficiency and easier maintenance but at higher installation costs. Roof-mounted systems are more cost-effective in terms of installation but may present limitations in energy production and maintenance. The choice between these systems should be guided by specific site conditions, budget constraints, and long-term energy goals.

***Keywords:** Solar Photovoltaic Systems, Ground-Mounted, Roof-Mounted, Energy Efficiency, Cost Analysis, Installation.*

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1. INTRODUCTION

Solar photovoltaic (PV) systems are effective in converting solar energy into electricity through the photovoltaic effect, making them reliable, clean, and versatile for various applications (Sarayu et al., 2023; Samaila et al., 2022). They provide significant benefits, such as low noise, minimal pollution, and easy maintenance, contributing to environmental preservation by reducing carbon dioxide emissions and promoting renewable energy over fossil fuels (Bipin & Asmita, 2020; Urs, 2020). While installation of solar PV systems requires considerable land area, their overall environmental impacts are positive, decreasing greenhouse gas emissions and enhancing energy self-sufficiency.
Two main installation approaches exist: ground-mounted and roof-mounted systems. Ground-mounted systems, discussed by Miguel et al. (2023), attach equipment on pedestals without penetrating roofs, whereas roof-mounted systems secure PV structures to roofs using flashing and brackets, maintaining roof integrity (Ali, 2021). Roof-mounted systems also provide shading benefits, particularly in hot climates, and reduce cooling energy needs (Graboski, 2021; Tayyab et al., 2023). In comparison, ground-mounted systems may face efficiency issues due to self-shading.
Despite the land use impact of ground-mounted systems, innovative structures enhance their versatility by optimizing sunlight exposure for agriculture and reducing noise (Petrachi, 2020). Overall, the research aims to evaluate the comparative performance, cost-effectiveness, installation requirements, and environmental impacts of both system types, contributing to better decision-making in solar PV implementation.

2. RELATED WORKS

A comparative study on ground- and roof-mounted solar photovoltaic (PV) systems offers insights into the performance, efficiency, and cost implications of both configurations. Sabo et al. (2022) conducted a comparative study on ground- and roof-mounted solar photovoltaic (PV) systems, focusing on performance, efficiency, and cost implications. The findings suggest that ground-mounted systems often benefit from optimal placement and orientation, leading to higher energy yields; however, these systems may incur increased installation and land-use costs relative to roof-mounted systems. Jones and Li (2021) found that roof-mounted systems, by leveraging existing structures, can significantly reduce land requirements and installation expenses, though they are sometimes limited by building design and roof space availability.

Yang et al. (2020) highlighted that ground-mounted systems generally experience fewer shading losses, whereas roof-mounted systems contribute to building energy efficiency by insulating roofs, thus reducing cooling demands. Kim and Park (2023) reported that ground-mounted systems, particularly in larger installations, have advantages in terms of accessibility and maintenance, whereas roof-mounted systems are favored in densely populated areas due to limited land availability. Collectively, these findings support the decision-making process for PV system selection, taking into account factors such as environmental impact, spatial constraints, and economic considerations.

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3. MATERIAL AND METHOD

Study Design

This systematic review aims to compare ground-mounted and roof-mounted solar photovoltaic (PV) systems by evaluating their performance, cost-effectiveness, installation requirements, and environmental impacts. The review follows a structured methodology to ensure a comprehensive and unbiased assessment of the existing literature.

Search Strategy

A comprehensive literature search was conducted across several academic databases, including: ScienceDirect, Google Scholar, PubMed, SpringerLink, Academia, and research gate. Keywords and phrases used in the search included: ground-mounted solar PV systems, roof-mounted solar PV systems, performance comparison of solar PV systems, cost analysis of solar PV installations, environmental impact of solar PV systems and efficiency of solar panels on rooftops vs. Ground. The search was limited to studies published between January 2010 and August 2024.

Inclusion and Exclusion Criteria

Studies comparing ground-mounted and roof-mounted solar PV systems, Peer-reviewed journal articles, conference papers, research papers review articles and technical reports were included in the research. Studies providing data on performance metrics, cost analysis, and environmental impact were included. Non-English language publications, Studies that do not provide enough data or focus on non-solar PV technologies and Articles not meeting quality standards for scientific rigor and relevance were excluded.

Study Selection

Initial screening of titles and abstracts was conducted to identify potentially relevant studies. Full-text articles were then reviewed to determine final inclusion based on eligibility criteria. A standardized form was used to document the selection process, ensuring consistency and transparency.

Data Extraction and Synthesis

Two independent reviewers extracted data from the selected studies using a standardized data extraction form. Discrepancies were resolved through discussion or consultation with a third reviewer. A narrative synthesis was performed to summarize the findings from the included studies.

4. RESULTS AND DISCUSSION

The choice between these two systems ultimately depends on the available space, project scale, environmental considerations, and financial goals. Combining the strengths of both systems, such as using roof-mounted systems in urban areas and ground-mounted systems in rural or commercial settings, can contribute to a diversified and efficient renewable energy strategy.

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The table below show the summary of the comparisons. The subsections was made to discuss more on comparisons as shown below the table

Table 1: An overview of findings on comparison

Category	**Ground-Mounted Solar PV Systems**	**Roof-Mounted Solar PV Systems**	**Discussion**
System Efficiency	Typically, higher due to the ability to adjust the tilt angle for optimal sun exposure (Sharma et al., 2022; Nair & Reddy, 2019).	Generally lower due to fixed angles that follow the roof's structure (Lopez & Baker, 2021; Ahmed et al., 2022).	Ground-mounted systems offer flexibility in orientation and inclination, improving efficiency, especially in regions with varying sun exposure. Roof-mounted systems are limited by the roof's design but are still effective in urban settings.
Space Requirements	Requires large open spaces, making it suitable for rural or large commercial installations (Patel et al., 2023; Smith & Johnson, 2018).	Ideal for urban areas with limited ground space, as it utilizes the existing rooftop infrastructure (Smith et al., 2021; Lee & Park, 2020).).	Ground-mounted systems need more space, which may limit their feasibility in crowded urban areas. Roof-mounted systems efficiently use existing structures but might not accommodate large-scale installations.
Installation Costs	Higher installation costs due to land acquisition, site preparation, and additional mounting structures (Kumar et al., 2023; Aydin & Çakır, 2020).	Lower installation costs since the roof serves as the mounting base, reducing the need for extra materials (Nguyen et al., 2022; González et al., 2021).	Ground-mounted systems incur higher upfront costs, including land and labor. Roof-mounted systems are more cost-effective for small and medium installations due to reduced structural requirements.
Maintenance and Accessibility	Easier to access for cleaning, repairs, and system upgrades (Ahmed et al., 2022; Wang et al., 2019).	More challenging to access, especially for sloped roofs or high buildings, increasing maintenance complexity (Bauer & Fischer, 2023; Brown et al., 2021).	Ground-mounted systems provide easier access for regular maintenance, while roof-mounted systems, though harder to reach, reduce the risk of accidental damage due to restricted access.
Environmental Impact	May disrupt the landscape and require more land modification,	Minimal environmental impact as it does not require land modification,	Ground-mounted systems can lead to habitat disruption, while roof-mounted systems have a lower environmental

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	which could affect local ecosystems (Jones et al., 2021; Green et al., 2018).	only structural reinforcements on the roof (Khan et al., 2023; Jones & Miller, 2020).	footprint, making them more suitable for eco-sensitive areas.
Energy Production	Higher energy production potential due to better positioning and larger scale installations (Palmer et al., 2022; Huang et al., 2022).	Limited energy production based on roof size and shading from nearby structures (Wei & Zhou, 2021; Taylor et al., 2019).	Ground-mounted systems allow for larger solar arrays, maximizing energy production, whereas roof-mounted systems are constrained by the available roof space and shading effects.
Aesthetic Impact	Can be visually intrusive, especially in residential areas (Zhang et al., 2022; Johnson & Adams, 2019).	Less visually disruptive, as the panels blend into the building's structure (Taylor et al., 2021; Smith et al., 2022).	Ground-mounted systems may face opposition due to their visual impact, while roof-mounted systems generally have a more discreet appearance, making them more acceptable in urban and residential environments.
Installation Time	Longer installation time due to groundwork (Kumar & Singh, 2021).	Faster installation as it uses existing infrastructure (Patel et al., 2021).	Ground-mounted systems require a longer installation time due to the need for groundwork, whereas roof-mounted systems can be installed more quickly as they utilize existing structures.
Flexibility and Scalability	Easier to scale up with additional panels (Choi et al., 2021).	Limited by roof size; expansion may require additional roofs (Evans & Smith, 2020).	For ground-mounted systems, scaling up with additional panels is easier due to the flexibility of land use. In contrast, roof-mounted systems are constrained by the available roof space, and expanding capacity might necessitate additional rooftops.
Heat Dissipation	Better heat dissipation due to airflow around the	Roof installations often face heat buildup due to	Ground-mounted systems benefit from improved airflow, reducing thermal

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	panels, which can enhance performance (Davies & Kim, 2021).	reduced airflow, potentially lowering efficiency (Hassan & Li, 2022).	losses. Roof-mounted systems may experience heat buildup, particularly in hot climates, which can negatively impact system performance.

Performance and Efficiency of Ground and Roof Mounted Solar PV System

The performance and efficiency of solar photovoltaic (PV) systems are influenced by their installation type, either roof-mounted or ground-mounted, with each configuration offering distinct advantages and challenges. Taddy et al. (2024) investigated the efficiency of roof-mounted PV systems, finding that elevated installations on stone-coated roofs reached performance levels of up to 96.16%. This high efficiency is attributed to reduced heat absorption and improved airflow around the panels, which helps in heat dissipation. In Malaysia, Govindarajan et al. (2024) studied a large-scale rooftop PV installation that demonstrated an efficiency of 11.86% with a performance ratio of 0.78. This system contributed to significant energy production while also reducing CO_2 emissions, underscoring the environmental benefits of roof-mounted PV systems. Sudirman et al. (2024) compared ground-mounted PV systems in Indonesia to those in the UK, showing that the Indonesian installations performed better due to higher solar resource availability. These systems are advantageous because they allow for optimal solar exposure without the limitations of roof angles or structural load. Furthermore, González-Moreno et al. (2024) found that bifacial modules in ground-mounted setups could increase power generation by 2-15% over monofacial modules due to their ability to capture sunlight from both sides of the panel. Economic analyses reveal that, despite lower solar resources, UK rooftop installations tend to be more profitable than Indonesian ground-mounted ones due to favorable policy incentives (Sudirman et al. 2024). Rus et al. (2024) highlighted that in roof-mounted setups, an east-west orientation can minimize structural load while optimizing energy capture. Conversely, ground-mounted installations, while effective in energy production, require more land and can have broader environmental impacts. Roof-mounted PV systems generally offer high efficiency, especially with favorable designs that enhance cooling and airflow. Ground-mounted systems, on the other hand, excel in energy output due to better solar exposure and are well-suited for large-scale installations where land is available. Each installation type has unique advantages in efficiency and economic viability depending on local environmental conditions, solar resources, and policy incentives.

Impact of Tilt Angle and Orientation on Electricity Generation

Research has shown that the tilt angle and orientation of photovoltaic (PV) systems are vital factors affecting electricity generation. Merisa (2023) and Aloys et al. (2022) highlighted that optimizing tilt angles based on solar radiation and geographical considerations enhances PV energy yield. For example, Hasanuzzaman (2022) and Victor et al. (2022) demonstrated that optimal tilt angles maximize exposure to solar radiation and improve peak power output. These findings suggest that angle adjustments are essential for maximizing system efficiency and sustainable energy production.

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Ground-Mounted Systems and Tilt Adjustability

Ground-mounted PV systems provide better adjustability for achieving optimal tilt angles, which can increase energy production and revenue. Silvestro et al. (2021) and Sudhakar et al. (2023) analyzed ground-mounted configurations like gable structures with inverter oversizing, which allow precise land use, stability, and efficiency improvements. Systems featuring leveling modules and adjustable heights further enhance construction efficiency and reduce costs by optimizing the angle for maximal energy capture.

Potential Shading Effects on the System

Roof-mounted PV systems often face shading from nearby structures, such as chimneys or walls, which can reduce energy generation. Aronescu & Joseph (2020) noted that shading rates peak in winter months, making proper design essential to mitigate losses (Christian, 2023). Additionally, shading can reduce the thermal resistance of mounting structures, impacting overall performance (Priya et al., 2023). Considering shading in roof-mounted PV setups is therefore crucial for achieving optimal system efficiency.

Temperature Effects on Panel Efficiency and Energy Output

Temperature influences PV efficiency, with increased panel temperatures resulting in lower output due to thermal losses, as studied by Taner et al. (2022), Panagiotis & Yashwant (2023), and Syed (2023). While cooling techniques can mitigate these effects, ground-mounted systems are generally more susceptible to temperature-related power losses. Comparatively, rooftop systems offer benefits like reduced urban heat impact. Studies indicate that both rooftop and ground-mounted systems can contribute substantially to energy production, but temperature management remains a key factor for efficiency across installations.

Cost and Economics

Initial Installation Cost

Ahmed et al. (2020) found that ground-mounted PV systems incur higher initial costs due to the need for larger land areas and increased interrow spacing, affecting the levelized cost of energy (LCoE). However, Ali (2021) and El et al. (2021) noted that roof-mounted systems can mitigate land costs, especially in urban settings, while also lowering cooling energy needs. In Oman, grid-connected rooftop systems proved more cost-effective, demonstrating lower initial costs and energy costs than ground-mounted alternatives (Ahmed, 2019). Environmental life cycle analyses further indicate that the ecological impact varies by installation type and proximity to grid connections.

Maintenance Cost Considerations

Xubin et al. (2022) highlighted that ground-mounted systems may have higher maintenance costs due to land usage and shading challenges. Conversely, Elieser (2023) noted that roof-mounted systems benefit from reduced maintenance costs through better access and lower cooling needs. Additionally, optimizing the ground coverage ratio in rooftop PV systems can boost performance and decrease maintenance expenses (Ahmed et al., 2023), making it a favorable choice in terms of maintenance efficiency.

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Government Incentives for Installations

Government incentives remain pivotal in promoting PV installations worldwide. Despite incentives from the Ministry of Energy and Mineral Resources (MEMR) in Indonesia, installation rates have lagged (Dianing et al., 2020). In contrast, the U.S. and other countries, such as Malaysia and Turkey, have achieved notable installation rates through favorable Feed-in Tariff (FiT) schemes, which have enhanced financial returns on PV investments (Ryan et al., 2020; Bilal et al., 2016). Such policies, including FiT and extended purchase agreements, have been instrumental in driving solar adoption (John et al., 2015).

Levelized Cost of Electricity (LCOE)

LCOE varies significantly between PV types due to design, site, and financial factors. Bhatti et al. (2024) reported that ground-mounted systems in California achieved an LCOE as low as 5.03 cents/kWh, benefiting from economies of scale, while roof-mounted systems were higher, reaching 7.09 cents/kWh. Similarly, Zainali et al. (2023) observed a 1.02 SEK/kWh LCOE for rooftop systems in Sweden, influenced by local policies. Ground-mounted PV systems are advantageous for large-scale, flexible installations but incur high initial costs and potential environmental impacts. Roof-mounted systems, while constrained in space and orientation flexibility, offer cost savings and are ideal for residential settings due to minimal land use and lower aesthetic impact.

5. CONCLUSION

The comparison between ground-mounted and rooftop solar PV systems highlights their distinct strengths and challenges in terms of energy production, cost, and environmental impact. Ground-mounted systems typically generate more energy due to optimal positioning and minimal shading, making them suitable for areas with abundant space and high solar potential, like Indonesia. In contrast, rooftop systems, while constrained by space, are efficient in urban settings with limited land, as they leverage existing structures and require lower initial investment. For instance, in the UK, rooftop PV installations are economically viable due to supportive policies, despite their lower energy output compared to ground-mounted setups.
Rooftop systems, often oriented south for maximum yield, reduce environmental impact by up to 50% compared to ground-mounted systems by minimizing land use. Ground-mounted systems, while potentially more energy-efficient, need substantial land, which is less feasible in dense urban areas. Budget constraints also influence choice; ground-mounted installations incur higher initial costs due to land and setup expenses, while rooftop systems are more affordable, particularly in cities. Ultimately, selecting between these systems should consider site conditions, budget, and environmental goals to achieve optimal energy production and cost-effectiveness.

Ethical Considerations

As this study is a systematic review of existing literature, no ethical approval is required. However, all sources of information will be appropriately cited to acknowledge the original authors and avoid plagiarism.

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