SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V12I4P122

Volume 12 Issue 4, 279-288, April 2025

Orinal Article

A Comprehensive Literature Review: Optimization of Photovoltaic Source Placement and Sizing for Enhanced Energy Harvesting

Walid Hilali Najim[1], Mohamed Amine Lakbakbi[1], Oumaima Ben Soultane[1], Rabie Zine[1]*, Houssame Limami[1]

[1]*School of Science and Engineering, Al Akhawayn University in Ifrane, Morocco.*

**Corresponding Author : r.zine@aui.ma*

Received: 17 February 2025 Revised: 19 March 2025 Accepted: 19 April 2025 Published: 29 April 2025

Abstract *- Photovoltaic (PV) systems have seen widespread adoption due to their renewable and sustainable nature. However, their efficiency is strongly influenced by the optimal sizing and placement of PV modules. Inconsistent configurations can result in reduced energy output and lower economic performance. While various optimization techniques have been proposed in the literature, a clear, comparative understanding of these methods remains limited. This review addresses that gap by systematically analyzing and categorizing existing optimization approaches-including mathematical modeling, heuristic algorithms, metaheuristic methods, machine learning, and hybrid techniques-aimed at maximizing energy harvesting efficiency in PV systems.*

Keywords *- Efficiency, Electric distribution network, Optimization, Photovoltaic source, Renewable energy.*

1. Introduction

The escalating demand for electricity, propelled by various factors such as increasing electrification, industrial expansion, urban growth, economic advancement, and technological progress, underscores the pressing need for sustainable power solutions. As societies worldwide continue to develop and modernize, reliance on electricity becomes increasingly critical for everyday activities, from powering homes and businesses to driving innovation and communication networks [1]. 2023 global electricity consumption surged to 30,500 TWh, marking a significant 2.2% increase from the previous year [2]. This growth reflects both the expanding global economy and the rising living standards in many regions [3]. However, this increased demand for electricity also amplifies energy provision and consumption challenges. These challenges are intricately linked to a spectrum of environmental issues that extend beyond just the generation and consumption of electricity. Climate change, driven primarily by the burning of fossil fuels for energy, presents a significant threat to ecosystems, weather patterns, and overall planetary health [4]. This is showcased by the record-breaking carbon dioxide emissions the International Energy Agency reported in 2022. With emissions soaring to a record-breaking 36.8 gigatons, representing a 0.9% increase from the preceding year, the urgency of addressing climate change becomes indisputable [5]. This increase in emissions can be directly linked to expanded global economic activities and rises in energy demands. Furthermore, fossil fuels are responsible for an estimated 74% of all CO2 emissions [6]. Beyond the overarching issue of climate change, the repercussions of these carbon emissions extend to other environmental and public health challenges. Air pollution from power plants and other sources significantly contributes to respiratory illnesses and premature deaths worldwide [7-8]. Acid rain, ozone depletion, and deforestation further exacerbate the environmental impacts of energy production and consumption. The release of hazardous substances, notably radioactive materials from nuclear power plants, introduces an additional dimension of complexity to the environmental landscape. To address the complex challenges posed by our current energy landscape, a transition towards renewable energy sources such as solar, wind, bioenergy and hydroelectric power is becoming necessary by the day [9]. Bioenergy, derived from organic materials such as agricultural residues and woody plants, emerges as a versatile option thanks to its capability to provide renewable electricity, heating, and transportation fuels. Its widespread application is reflected in the fact that around 75% of the renewable energy produced worldwide is derived from biomass sources [10]. Wind energy, which harnesses the kinetic energy of air through turbines, has grown significantly, fulfilling a substantial portion of global electricity demand, particularly in Europe. Significant investments in this sector have propelled its integration into power systems, bolstering its contribution to the overall energy mix. As of 2023, the cumulative installed capacity of wind generation reached 599 GW globally, with an annual addition of 53.9 GW [11]. Projections indicate a continued upward trajectory, with anticipated installed capacity reaching 664.5 GW by the conclusion of 2019, marking an additional capacity of 107.8 GW and a notable increase of 44.9% compared to the previous year [12]. Hydropower, harnessed from the waterfall potential, stands as a prominent renewable energy option, renowned for its high efficiency and significant contribution to global electricity derived from renewable sources [13]. Globally, hydropower facilities exhibit a lower Levelized Cost of Energy (LCOE) compared to fossil-fuel-fired thermal combustion facilities. In 2018, the LCOE of hydropower was recorded at US$0.047 per kWh, positioning it as the most cost-effective electricity source in numerous markets. As of 2022, hydropower accounts for 60% of global renewable energy production, with wind and solar constituting 9% and biomass and other renewables contributing 31% [14]. Ocean energy, encompassing various technologies such as wave and tidal energy, holds the potential for low environmental impact electricity generation, although technological and cost challenges persist.

In addition to offering a workable way to cut greenhouse gas emissions and lessen the effects of climate change, the move to renewable energy sources is essential for supporting environmental preservation initiatives. Moreover, embracing renewable energy sources fosters significant socio-economic benefits across diverse nations, including job creation and economic growth. Recognizing the immense potential of renewables, many countries have embarked on initiatives to capitalize on these resources, driving innovation in technology for energy and encouraging practices of sustainable development on a global scale [15-16]. This concerted effort towards renewable energy adoption not only guarantees a future with cleaner and more sustainable energy but also catalyzes positive socio-economic transformations worldwide.

Solar energy emerges as a strategic solution for powering diverse sectors, with solar photovoltaic (PV) technology anticipated to dominate the green energy sector in the forthcoming decades. Harnessing solar energy through photovoltaic panels for electricity generation stands as a promising domain within the renewable energy sector, attracting significant attention due to its rapid growth potential and substantial investment opportunities. This trend is evident in the increasingly competitive global photovoltaic market, particularly notable in regions like Europe, China, and the US [17]. In 2020, solar PV energy production surged by an impressive 22%, surpassing 1000 TWh and setting a record growth rate of 179 TWh [18]. This substantial expansion underscores the growing significance of solar photovoltaics, positioning it as the fastest-growing renewable energy technology globally by 2023 [19]. Despite being the second-largest renewable electricity source after hydropower, solar photovoltaics contributed 3.6% to the global electricity output in 2016. This trajectory highlights the escalating potential for widespread adoption of solar PV technology in addressing global energy needs [20]. In addition to its rapid adoption, solar PV presents notable economic and environmental benefits. Economically, the decreasing cost of PV technology has made it increasingly competitive with traditional energy sources, encouraging both utility-scale and decentralized installations. Environmentally, solar PV is a clean energy source that directly supports emission reduction targets because it emits no greenhouse gases while in operation.

These advantages, combined with its modularity and adaptability to different geographical contexts, make solar PV an essential component of global energy transition strategies. Nevertheless, while its growth has been promising, gaps remain in optimizing PV deployment for maximum economic and environmental returns. Addressing this challenge is central to the present study, which investigates [insert your specific research focus here-e.g., “the efficiency of grid-connected PV systems under varying climatic conditions” or “policy implications for PV adoption in emerging markets”. This development reflects a pivotal transition towards sustainable energy solutions and underscores the growing prominence of solar power in the global energy market.

2. Work Related to Placement Optimization of PV

One of the main goals when trying to install a photovoltaic system is to find an optimal location that could help reach all the desired objectives. For this purpose, various papers investigated the use of the optimal mathematical model to get the most optimal results. In [29-31], the main objective was determining the optimal placement and size of photovoltaic sources. The first focuses on minimizing phase asymmetries within the grid [29], while the second addresses PV grid charging systems, considering voltage and current limitations, varying weather conditions, and operational periods [30]. The voltage, current, and thermal line limitations [29], the weather conditions [30], energy prices, and operating periods [30] are considered constraints to these objectives.

By respecting these constraints, electrical phases in the grid are balanced to avoid problems such as power quality problems, and at the same time, make sure that the charging systems or grid can safely handle the maximum voltage and current provided. Moreover, considering factors such as weather conditions and operational periods could be useful in determining when and where solar panels can generate the maximum energy efficiency and reliability. To accomplish these goals the studies, use genetic algorithm techniques [30] and Particle Swarm Optimization (PSO) algorithms [29, 31]. Compared to the losses observed in the cases of TLABC, PFA, and ALOA, respectively, active power losses for PSO algorithms have decreased to 17.50%, 17.48%, and 8.82% [29]. Furthermore, compared to TLABC and ALOA, the cost savings are roughly 15.21% and 6.70% higher, respectively [29]. When using genetic algorithm approaches [30], the grid's strain from EV charging is reduced by 94% to 99%, while the charging price is cut by about 16%. Finally, the results revealed that the optimal PV-Inverter configuration is a total capacity of 2260 kVA [31]. Overall, these findings show significant improvements when it comes to reducing losses and grid burden while optimizing configurations, which consequently offers considerable benefits in terms of efficiency and grid sustainability.

Another parameter that could be taken into consideration for the optimization of photovoltaic sources is the required expenses. The cost could be divided into 2 different categories: the cost needed for the implementation [32-34] and the cost after the utilization of the sources [35, 36]. As mentioned before, the primary objective shared among these papers [32-34] is the minimization of the system's electricity cost. One of these papers introduces parameters representing the optimal number of PV panels, DC/AC inverters, and module placement within the area, respectively [32]. The importance of these parameters remains in determining the most efficient set-up for the power system. However, these objectives are constrained by factors such as PV array size and battery capacity [33]. These constraints show that while the goal is to minimize electricity costs, limitations imposed by the space for panels and the storage capacity of batteries to achieve optimal results should also be considered. To approach these objectives, each of the three papers employs specific techniques: the CPSO algorithm [32], single-variable optimization/two-variable optimizations [33], and genetic algorithms [34]. As a result, the optimal size of the PV array is 89,000 m2, resulting in a total cost of $210M/PV array is considered as cost-effective above an FBCF of $18 /gal ($4.7 /L), and the battery storage is cost-effective above an FBCF of $19 /gal ($5 /L) [33]. These results are considered prominent findings as they suggest that investing in solar panels becomes financially beneficial when the fuel-based charge factor (FBCF) exceeds $18 per gallon, and battery storage becomes economically viable when the FBCF surpasses $19 per gallon. This is an important finding that indicates that adopting the recommended battery and PV system configuration can lead to substantial yearly savings on energy expenses. Finally, for [34], the optimal battery 435 capacity and PV size for a household, the annual energy cost saving is $2457.80.

On the other hand, other research [35-36] focuses on a singular objective, reflected in minimizing the total energy cost while simultaneously maximizing profit for the RDG (Renewable Distributed Generation) owner. These objectives are restricted by the fact that the battery is limited to either charging or discharging, the power Flow, the bus Voltage, the branch Load, and the RDG Capacity. To achieve these objectives, various studies in the literature employ the following techniques two different techniques: MILP (Mixed-Integer Linear Programming) [35] and a hybrid metaheuristic algorithm [36]. These methods take into account various constraints such as bus voltage, power flow, and RDG capacity [36]. In [35], households with both solar panels and batteries (category D) save the most money. This important finding shows the benefits of using solar panels and batteries for household energy systems.

The greatest savings are achieved when households have both solar panels and batteries installed, especially when the solar panels are large. This shows the importance of maximizing the capacity of both solar panels and batteries to get the maximum cost savings. However, if households opt for small or medium-sized solar panel systems, those with only solar panels (category B) record more benefits. This result suggests that the effectiveness of different configurations varies based on the solar panel system's size. On the other hand, households that only have batteries (category C) don't show any advantages. In fact, they end up with slightly lower savings compared to households without any of these technologies. Finally, multiple other research in the literature [37-41] focuses on a central objective of minimizing the cost associated with each unit, resource, microgrid, and operating expense of electric vehicles (EVs).

This objective is pursued while adhering to constraints such as CO2 emissions and LLP (Line Losses Probability) over a year [38], total energy generation, and the overall electricity generation capacity of the plant [40]. To address these challenges, each paper employs specific techniques. These include Particle Swarm Optimization (PSO) combined with the ε-constraint method [38], a hybrid optimization algorithm tailored for energy storage management [40], the utilization of P-graphs [39], and GA, GWO, ALO, and MVO [41]. Using these techniques, the optimal size of the components is 11.4kWp of PV generator, 42kWh of battery bank and 6 kW of diesel generator. The ACS of the optimal system is 8585.14 $, COE is 0.38 $/kWh, and the cost of the battery bank is the dominant cost of the system with 51.4% of the ACS [38]. For [39], the solar panel area is 7.98 m2, the inverter capacity is 527.78 W, and the battery capacity is 6274.96 Wh.

3. Work Related to Size Optimization of PV

Multiple studies address two common and primary objective functions, emphasising maximizing the voltage stability index or network voltage profile and minimizing active electric/power losses. These functions encompass various variables, including the injection of active and reactive power from distributed generators [42] and the presence of photovoltaic (PV) generators at each node in the electrical system (considered as binary variables) [43]. This use of variables suggests that focusing on incorporating renewable energy sources like distributed and PV generators into the system is considered crucial for sustainability. Additionally, these objectives encounter different constraints, such as power flow limitations [42], voltage safety thresholds at the distribution network nodes and geographical constraints [42]. These constraints emphasize maintaining stability and safety within the electrical system while considering factors like power flow and voltage levels.

The number of PV sources (limited to 5) [43], the line thermal limits [44], the RDG capacity, and the total plant cost that should not exceed 50 million INR /MW [45] are also considered as constraints when it comes to the aimed objectives. These limitations on PV sources and cost demonstrate how complex balancing renewable energy integration with financial and technical constraints could be.

To address these objectives, each paper employs a specific technique, including the NSGA-II technique [42], the fuzzy logic [46], the linear programming models (MILP) [43], the hybrid algorithm (BAPSO) [47], the multi-period optimal power flow modeling [48] and genetic algorithms [45]. Following these constraints and methods, the results have differed for each paper. For [43], node 46 has been determined to be the best location, having a peak power of 5760 kWp.

For [46], there was a notable decrease in power losses, and the voltage stability index was improved in the presence of PVS. These results show the importance of photovoltaic systems in decreasing losses and increasing voltage stability, emphasizing the positive impact on the system's performance. Nodes 5, 10, and 12 were chosen using the variable in [43] to best position the three PV sources, which have maximum powers of 779 kVA, 344 kVA, and 664 kVA, respectively, for the Manizales region. This shows that selecting the optimal location has been successful, leading to robustness in addressing local energy needs. For [47], it was found that 10% and 10.825%, respectively, of active power transmission losses could be minimized with and without DG. Finally, [48] concluded that without making several PV changes throughout the course of the operating time horizon, a single ideal PV adjustment reduces losses, enhances the voltage profile, and encourages safe operation. In addition, the energy produced could be considered to determine the optimal size for our photovoltaic sources. In [49], the paper aims to minimize the life cycle cost over the course of a full year, enabling life-cycle cost optimization. To accomplish this, the authors adopted the U.S. National Renewable Energy Laboratory's Renewable Energy Optimization (REopt) approach [49]. Consequently, the battery costs are over $3000 for 3 kWh storage capacity, which is approximately $1060 per kWh. On the other hand, using a smart domestic water heater and a smart AC together costs only $450. Moreover, in [50], the paper introduces a method to optimize battery energy storage system (BESS) sizing in photovoltaic (PV) integrated distribution networks to mitigate voltage rise. An enhanced opposition-based firefly algorithm (EOFA) aims to minimize voltage fluctuations by optimizing BESS output power hourly while considering the state of charge constraints.

The approach enhances the original firefly algorithm with opposition-based learning and inertia weight. This method provides a solution to voltage rise issues in PV-integrated networks, improving system stability and reliability [50]. According to the findings, EOFA is more successful than FA and GSA at determining the ideal BESS size, providing a minimum BESS size of 2.39 MWh and a minimum number of hours (78 hours) at voltage values above 1.05 PU. Overall, these results highlight the success of the optimization efforts in integrating renewable energy sources, particularly photovoltaic systems, into the electrical grid. We've identified optimal locations and capacities for PV installations, significantly reduced power losses, improved voltage stability, and established streamlined strategies for system operation, all of which contribute to a more efficient and sustainable energy infrastructure.

Finally [51, 52] focused on enhancing the reliability of high-power systems and reducing the cost of PV systems. Various factors are considered, such as space availability, system size, budget constraints [51], load requirements [52], and energy limitations. To address these concerns, the papers utilize two distinct approaches: SAPV/GCPV system sizing procedures [51] and MILP (Mixed-Integer Linear Programming) [52]. For [52], It has been demonstrated that the suggested ideal PV system can provide 8672.4 hours of power per year for homes out of 8760 and 10 hours at a cost of 0.437 USD/kWh, which is 29.5% less than the price of the diesel generators that are currently in use. Table 1 represents a summary of previous research investigating PV size and location optimization.

Table 1. Summary of size and location PV optimization techniques

Paper	Objectives	Optimization Approaches
[25]	Minimize the difference between the experimental data and simulated data obtained by estimated parameters.	IJAYA
[29]	Photovoltaic-based distributed generation (PVDG) should be installed in the best possible location and scale to minimize grid phase asymmetries. 5 t reduces power losses, improves the voltage profile, creates symmetry in the system's voltage profile, and offers the most cost savings.	Particle Swarm Optimization (PSO) Algorithm

[30]	Determine the ideal dimensions for the energy storage unit (ESU) and photovoltaic (PV) array for a grid-connected electric vehicle (EV) charging system in an office setting.	PSO
[31]	Determine the optimal size and location of the BESS	Genetic Algorithm technique
[32]	Minimization of the cost of the system	CPSO Algorithm
[33]	The system cost is minimized	Single-variable optimization/TWO-VARIABLE OPTIMIZATIONS
[34]	Minimize the total annual cost of electricity	Genetic algorithm
[35]	Minimize the total energy cost	MILP
[36]	Minimizing the distribution network's overall energy loss while increasing the RDG owner's profit	The suggested hybrid metaheuristic method combines the gravitational search algorithm with the phasor particle swarm optimization.
[37]	To minimize the cost of each unit of electricity generated	
[38]	Minimize total system cost, unmet load, and CO2 emissions	Particle Swarm Optimization (PSO) and ε-constraint method
[39]	Minimize resource use and cost of microgrid	P-Graph
[40]	Minimizing the running costs of EV charging stations that are connected to PV and ESS	An algorithm for hybrid optimization in energy storage management
[41]	Minimize the LCOP	GA, GWO, ALO, and MVO
[42]	Two main objective functions: 1- to minimize the active power losses 2-maximize the voltage stability index	NSGA-II Technique (algorithms for multi-objective optimization)
[43]	Reducing electric power losses during system operation was the primary goal.	Linear programming model (MILP)
[44]	Minimize the active power losses and maximize the voltage stability index.	Non-dominated Sorting Genetic Algorithm NSGA-II
[45]	To minimize the monthly discrepancy between power generation and demand in every Madhya Pradesh district	Genetic algorithm (GA)
[46]	Minimize active power losses and improve the max voltage stability index.	On non-dominated sorting genetic algorithm and fuzzy logic(NSGA-II/FL) algorithm
[47]	The optimal location for the solar power plants such that the overall power loss	The hybrid algorithm (BAPSO), which combines the Bat Algorithm (BA) and Particle Swarm Optimization (PSO), is intended to maximize the capacity and placement of solar generation for a microgrid's effective operation.
[48]	Minimization of energy losses in Distribution Networks (DNS) considering the reactive power control of Photovoltaic Generation (PVG) that can be applied to both short-term and long-term operation planning.	Multi-Period Optimal Power Flow (MOPF) modeling
[49]	Minimize the life-cycle cost of timesteps for a full year to enable the life-cycle cost optimization.	The U.S. National Renewable Energy Laboratory's Renewable Energy Optimization (report)
[50]	The goal of the first optimization is to get the best battery output power on an hourly basis, and the goal of the second optimization is to achieve the best BESS capacity while taking the BESS's state of charge constraint into account.	Firefly algorithm (EOFA)
[51]	High power reliability: reduce cost	SAPV and GCPV systems sizing procedures
[52]	Minimizes the total annual cost of the stand-alone PV systems	MILP

[53]	Minimum field area, minimum plant cost, minimum cost per unit of energy, and maximum yearly incident energy	General programming problem
[54]	Employing the global optimization approach to strategically position solar arrays on the rooftops of buildings on a large scale.	The Differential Evolution (DE) algorithm
[55]	The problem's objective is improving the network's voltage profile and reducing active and reactive power losses.	The suggested hybrid metaheuristic method combines the gravitational search algorithm with the phasor particle swarm optimization.

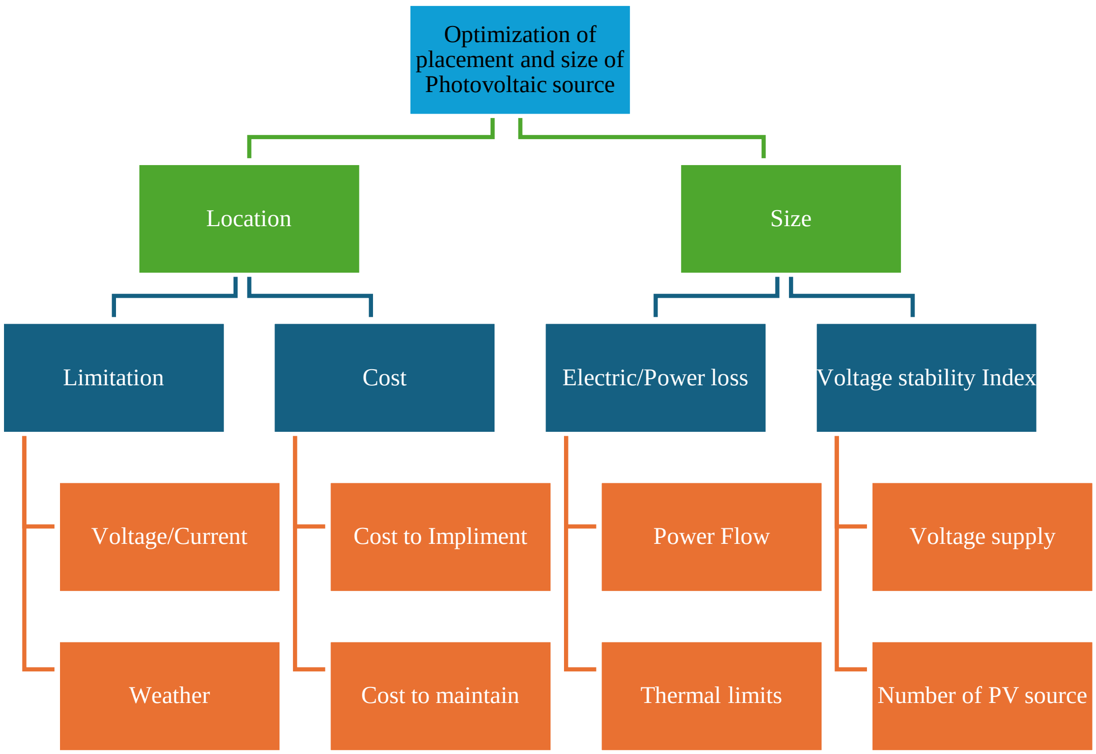

Fig 1. Optimization of placement and size of photovoltaic source parameters

4. Key Factors Influencing the Location and Size of PV Installations

Factors impacting the positioning of PV installations are primarily solar irradiation, proximity to substations, terrain slope, road accessibility, distance from urban zones, and land utilization.

The size of a PV system impacts its efficiency and performance, with factors such as shading, distance between panels, and the placement of PV plants affecting the effectiveness of the PV power plant [56, 57]. When determining the location of PV installations, environmental considerations include the solar resource's temporal and spatial fluctuation, protected natural areas, climate, and proximity to other facilities [58, 59].

The economic implications of the size and location of PV systems are influenced by the costs related to both the installation and the operation of the power plants, as well as the energy prices [56, 60].

4.1. Key Factors Influencing the Location of PV Installations

SelecChoosing optimal sites for solar PV power plants is influenced by various factors. These factors include solar irradiation, distance to substations, terrain slope, road accessibility, proximity to urban centers, and land usage. Researchers have employed advanced techniques such as Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) to identify prime locations for large-scale photovoltaic installations. This approach emphasizes the significance of factors such as solar irradiation and proximity to substations in assessing potential sites [61]. Furthermore, the latest modifications to solar application support programs have led to shifts in the spatial distribution of photovoltaic installations. New installations are increasingly concentrated in built-up areas, reflecting evolving policy incentives and preferences [58].

4.2. Impact of Size on Efficiency and Performance

The effectiveness of PV power plants is attributed to several crucial factors. These factors include shading, the spacing between panels, and the specific location of PV installations [58]. Evaluating the performance of PV systems is crucial for their continual optimization and maintenance. This assessment ensures that photovoltaic systems operate at peak efficiency consistently, underscoring the significance of regular adjustments and upkeep [57]. Choosing the appropriate combination of PV modules and inverters is essential in sizing PV systems, and software tools are available to streamline this process. However, integrating sizing with optimization methods can enhance the design outcomes [62]. As the demand for high performance, reliability, and economic viability of PV-battery systems grows, sizing procedures with minimal input data requirements and low complexity have become increasingly prominent [64].

4.3. Environmental Considerations

When determining the location of PV installations, environmental considerations are pivotal. This includes climatic factors, closeness to other facilities, and the existence of protected environmental areas [58]. Additionally, conducting geographic analyses of PV performance factors across extensive regions can empower stakeholders to make well-informed decisions. This process highlights the significant influence of climatic variables on characteristics like module temperature coefficients, mounting configurations, and coatings [59].

4.4. Economic Implications

The impact of location extends beyond determining the solar irradiation received by solar modules; it also significantly influences the costs related to both installing and operating power plants [60]. Moreover, the economic performance of various PV power plant topologies is shaped by solar technology, with location playing a critical role in determining the expenses linked to installation and ongoing operation [59, 62, 64]. Recent shifts in support schemes for solar applications are reshaping the spatial distribution of PV installations, with a notable trend towards concentrating new installations within built-up areas. This phenomenon underscores the significant impact of regulatory changes on the placement of PV systems [59]. To summarize, the location of PV installations is influenced by factors such as solar irradiation, substation distance, and land use, while the size of a PV system impacts its efficiency and performance. Environmental considerations include climatic aspects and the existence of protected environmental areas, and the economic implications of the size and location of PV systems are influenced by installation and operation costs.

5. Conclusion

In conclusion, this paper has presented a comprehensive review of optimization techniques for enhancing energy harvesting efficiency in PV systems through optimal location and size of modules. The literature reveals a rich diversity of approaches, including heuristic algorithms, mathematical modeling, and emerging machine-learning techniques, each contributing unique strengths to the optimization process.

The analysis underscores that no single method universally outperforms others; rather, effectiveness is highly context-dependent, influenced by variables such as geographical location, solar irradiance variability, shading profiles, and system design constraints. This highlights the importance of hybrid and adaptive optimization models that can dynamically respond to site-specific conditions.

Key findings from the review suggest that integrated frameworks-combining environmental data, predictive analytics, and real-time system feedback-hold significant promise for pushing the boundaries of PV efficiency. Moreover, the synergy between technological advancements in data acquisition (e.g., IoT, GIS) and intelligent optimization algorithms marks a compelling frontier for future exploration.

Looking ahead, future research should focus on developing standardized performance metrics for comparing optimization techniques across different scenarios, enhancing model generalizability, and reducing computational costs for large-scale implementations. Additionally, exploring the integration of PV optimization with smart grid technologies and energy storage systems presents a critical avenue for supporting resilient and decentralized energy infrastructures. Ultimately, advancing the science of PV optimization is not only a technical challenge but also a strategic imperative for accelerating the global transition to sustainable energy.

References

[1] Catia Cialani, and Reza Mortazavi, "Household and Industrial Electricity Demand in Europe," *Energy Policy*, vol. 122, pp. 592-600, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] World Energy Outlook 2024, International Energy Agency, 2024. [Online]. Available: https://www.iea.org/reports/world-energy-outlook-2024

[3] Mohammad Mafizur Rahman, "Environmental Degradation: The Role of Electricity Consumption, Economic Growth and Globalisation," *Journal of environmental management*, vol. 253, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Asif Raihan et al., "The Dynamic Impacts of Economic Growth, Financial Globalization, Fossil Fuel, Renewable Energy, and Urbanization on Load Capacity Factor in Mexico," *Sustainability*, vol. 15, no. 18, pp. 1-21, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Iftikhar Muhammad et al., "Does Environmental Sustainability Affect the Renewable Energy Consumption? Nexus Among Trade Openness, CO2 Emissions, Income Inequality, Renewable Energy, and Economic Growth in OECD Countries," *Environmental Science and Pollution Research*, vol. 29, no. 60, pp. 90147-90157, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[6] Abdullah Muratoglu, and Mehmet Ishak Yuce, “World Energy Outlook and Place of Renewable Resources,” *International Journal of Scientific and Technological Research*, vol. 1, no. 7, pp. 10-17, 2015. [Google Scholar] [Publisher Link]

[7] Ling Tang et al., “Air Pollution Emissions from Chinese Power Plants Based on the Continuous Emission Monitoring Systems Network,” *Scientific Data*, vol. 7, no. 1, pp. 1-10, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[8] Gabriel-Petrică Bălă et al., “Air Pollution Exposure-The (in) Visible Risk Factor for Respiratory Diseases,” *Environmental Science and Pollution Research*, vol. 28, no. 16, pp. 19615-19628, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] Mohammed Abdul Sattar et al., ”Renewable Energy and Its Industrial Applications,” *International Research Journal of Engineering and Technology*, vol. 7, no. 6, pp. 6042-6046, 2020. [Google Scholar] [Publisher Link]

[10] George E. Halkos, and Eleni-Christina Gkampoura, “Reviewing Usage, Potentials, and Limitations of Renewable Energy Sources,” *Energies*, vol. 13, no. 11, pp. 1-19, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Shakir D. Ahmed et al., “Grid Integration Challenges of Wind Energy: A Review,” *IEEE Access*, vol. 8, pp. 10857-10878, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Renewables 2023: Analysis and forecast to 2028, International Energy Agency, 2023. [Online]. Available: https://www.iea.org/reports/renewables-2023

[13] Hydropower Explained, U.S. Energy Information Administration, 2023. [Online]. Available: https://www.eia.gov/energyexplained/hydropower/

[14] Asphota Wasti et al., “Climate Change and the Hydropower Sector: A Global Review,” *Wiley Interdisciplinary Reviews: Climate Change*, vol. 13, no. 2, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Souvik Sen, and Sourav Ganguly, “Opportunities, Barriers and Issues with Renewable Energy Development-A Discussion,” *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 1170-1181, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[16] Jerry L. Holechek et al., “A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050?,” *Sustainability*, vol. 14, no. 8, pp. 1-22, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] Priscila Gonçalves Vasconcelos Sampaio, and Mario Orestes Aguirre González, “Photovoltaic Solar Energy: Conceptual Framework,” *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 590-601, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] Girma T. Chala, and Shamsa M. Al Alshaikh, “Solar Photovoltaic Energy as a Promising Enhanced Share of Clean Energy Sources in the Future-A Comprehensive Review,” *Energies*, vol. 16, no. 24, pp. 1-39, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[19] D. Gayen, R. Chatterjee, and S. Roy, “A Review on Environmental Impacts of Renewable Energy for Sustainable Development,” *International Journal of Environmental Science and Technology*, vol. 21, no. 5, pp. 5285-5310, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[20] Cimetrics Anlytika, The Future of Energy Efficiency Trends and Innovations, 2024. [Online]. Available: https://analytika.com/energy-efficiency/

[21] Arsalan Muhammad Soomar et al., “Solar Photovoltaic Energy Optimization and Challenges,” *Frontiers in Energy Research*, vol. 10, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Adel Mellit, “Sizing of Photovoltaic Systems: A Review,” *Journal of Renewable Energies*, vol. 10, no. 4, pp. 463-472, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[23] Alejandra Paz-Rodríguez et al., “Optimal Integration of Photovoltaic Sources in Distribution Networks for Daily Energy Losses Minimization using the Vortex Search Algorithm, *Applied Sciences*, vol. 11, no. 10, pp. 1-18, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[24] Oscar Danilo Montoya et al., “Optimal Placement and Sizing of PV Sources in Distribution Grids using a Modified Gradient-Based Metaheuristic Optimizer,” *Sustainability*, vol. 14, no. 6, pp. 1-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[25] Samir H. Oudjana et al., “Multi-Objective Optimization for Optimal Photovoltaic Source Placement and Size in Distribution Network using Metaheuristic Approach,” *The 5th International Seminar on New and Renewable Energies*, vol. 5, pp. 1-6, 2018. [Google Scholar] [Publisher Link]

[26] Andrés Felipe Buitrago-Velandia, Oscar Danilo Montoya, and Walter Gil-González, “Dynamic Reactive Power Compensation in Power Systems through the Optimal Siting and Sizing of Photovoltaic Sources,” *Resources*, vol. 10, no. 5, pp. 1-17, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[27] Muhammad Zulqarnain Zeb et al., “Optimal Allocation and Sizing of Solar Panels Generation Via Particle Swarm Optimization Algorithm,” *2nd International Conference on Computing, Mathematics and Engineering Technologies*, Sukkur, Pakistan, pp. 1-5, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[28] Sajjad Ahmadnia et al., “Optimal Placement and Sizing for Solar Farm with Economic Evaluation, Power Line Loss and Energy Consumption Reduction,” *IETE Journal of Research*, vol. 68, no. 3, pp. 2175-2190, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] Muhammad Abid Ali et al., “Optimal Location and Sizing of Photovoltaic-Based Distributed Generations to Improve the Efficiency and Symmetry of a Distribution Network by Handling Random Constraints of Particle Swarm Optimization Algorithm,” *Symmetry*, vol 15, no. 9, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[30] Abdul Rauf Bhatti et al., "Optimized Sizing of Photovoltaic Grid-Connected Electric Vehicle Charging System using Particle Swarm Optimization," *International Journal of Energy Research*, vol. 43, no. 1, pp. 500-522, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[31] Riad Chedid, and Ahmad Sawwas, "Optimal Placement and Sizing of Photovoltaics and Battery Storage in Distribution Networks," *Energy Storage*, vol. 1, no. 4, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[32] Reza Alayi et al., "Energy/Economic Analysis and Optimization of On-Grid Photovoltaic System using CPSO Algorithm," *Sustainability*, vol. 13, no. 22, pp. 1-16, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[33] Torrey Wagner et al., "Photovoltaic System Optimization for an Austere Location using TimeSeriesData," *IEEE 7th World Conference on Photovoltaic Energy Conversion, A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, Waikoloa, HI, USA, pp. 1239-1243, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[34] Jiaming Li, "Optimal Sizing of Grid-Connected Photovoltaic Battery Systems for Residential Houses in Australia," *Renewable Energy*, vol. 136, pp. 1245-1254, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[35] Su Nguyen et al., "Optimizing Rooftop Photovoltaic Distributed Generation with Battery Storage for Peer-To-Peer Energy Trading," *Applied Energy*, vol. 228, pp. 2567-2580, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[36] Jordan Radosavljević et al., "Optimal Placement and Sizing of Renewable Distributed Generation using Hybrid Metaheuristic Algorithm," *Journal of Modern Power Systems and Clean Energy*, vol. 8, no. 3, pp. 499-510, 2020. [CrossRef] [Google Scholar] [Publisher Link]
[37] F. Fodhil, A. Hamidat, and O. Nadjemi, "Potential, Optimization and Sensitivity Analysis of Photovoltaic-Diesel-Battery Hybrid Energy System for Rural Electrification in Algeria," *Energy*, vol. 169, pp. 613-624, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[38] Angel Xin Yee Mah et al., "Optimization of Photovoltaic-Based Microgrid with Hybrid Energy Storage: A P-Graph Approach," *Energy*, vol. 233, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[39] Kalpesh Chaudhari et al., "Hybrid Optimization for Economic Deployment of ESS in PV-Integrated EV Charging Stations," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 1, pp. 106-116, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[40] Rahul Dubey, Dheeraj Joshi., and Ramesh C. Bansal, "Optimization of Solar Photovoltaic Plant and Economic Analysis," *Electric Power Components and Systems*, vol. 44, no. 18, pp. 2025-2035, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[41] Maawiya Ould Sidi, Mustafa Mosbah, and Rabie Zine, "Optimization of the Placement and Size of Photovoltaic Source," *CMC-Computers, Materials & Continua*, vol. 74, no. 1, pp. 1855-1870, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[42] Juliana Jiménez, John E. Cardona, and Sandra X. Carvajal, "Location and Optimal Sizing of Photovoltaic Sources in an Isolated Mini-Grid," *TecnoLógicas*, vol. 22, no. 44, pp. 63-82, 2019. [CrossRef] [Google Scholar] [Publisher Link]
[43] M. Mosbah et al., "Optimal Location and Size of Shunt Capacitor in Distribution Using Metaheuristic Method," *International Conference on Artificial Intelligence in Renewable Energetic Systems*, Tipasa, Algeria, pp. 111-120, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[44] Manoj Verma, Harish Kumar Ghritlahre, and Surendra Bajpai, "A Case Study of Optimization of a Solar Power Plant Sizing and Placement in Madhya Pradesh, India Using Multi-Objective Genetic Algorithm," *Annals of Data Science*, vol. 10, no. 4, pp. 933-966, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[45] Samson Ademola Adegoke et al., "Optimal Placement of Distributed Generation to Minimize Power Loss and Improve Voltage Stability," *Heliyon*, vol. 10, no. 21, pp. 1-28, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[46] Ahmad Almadhor et al., "A Hybrid Algorithm (BAPSO) for Capacity Configuration Optimization in a Distributed Solar PV Based Microgrid," *Energy Reports*, vol. 7, pp. 7906-7912, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[47] Cícero Augusto de Souza et al., "Multi-Period Optimal Power Flow with Photovoltaic Generation Considering Optimized Power Factor Control," *Sustainability*, vol. 15, no. 19, pp. 1-20, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[48] Eric O'Shaughnessy et al., "Solar Plus: Optimization of Distributed Solar PV Through Battery Storage and Dispatchable Load in Residential Buildings," *Applied Energy*, vol. 213, pp. 11-21, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[49] Ling Ai Wong et al., "Optimal Battery Sizing in Photovoltaic Based Distributed Generation Using Enhanced Opposition-Based Firefly Algorithm for Voltage Rise Mitigation," *The Scientific World Journal*, vol. 2014, pp. 1-11, 2014. [CrossRef] [Google Scholar] [Publisher Link]
[50] Samer Alsadi, and Tamer Khatib, "Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools," *Applied Sciences*, vol. 8, no. 10, pp. 1-30, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[51] Chiemeka Onyeka Okoye, and Oğuz Solyalı, "Optimal Sizing of Stand-Alone Photovoltaic Systems in Residential Buildings," *Energy*, vol. 126, pp. 573-584, 2017. [CrossRef] [Google Scholar] [Publisher Link]
[52] A. Aronescu, and J. Appelbaum, "Design Optimization of Photovoltaic Solar Fields-Insight and Methodology," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 882-893, 2017. [CrossRef] [Google Scholar] [Publisher Link]
[53] Niko Lukač et al., "Optimisation for Large-Scale Photovoltaic Arrays' Placement Based on Light Detection and Ranging Data," *Applied Energy*, vol. 263, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[54] Saeed Alizadeh, Mehdi Mahdavian, and Ehsan Ganji, "Optimal Placement and Sizing of Photovoltaic Power Plants in Power Grid Considering Multi-Objective Optimization Using Evolutionary Algorithms," *Journal of Electrical Systems and Information Technology*, vol. 10, no. 1, pp. 1-17, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[55] Willy Stephen Tounsi Fokui, Michael Saulo, and Livingstone Ngoo, "Optimal Placement and Sizing of a Photovoltaic System into Nairobi Distribution Network: Case of Embakasi," *Proceeding Of the Sustainable Research and Innovation Conference*, JKUAT Main Campus, Kenya, pp. 27-32, 2021. [Google Scholar] [Publisher Link]

[56] Graciele Rediske et al., "Determinant Factors in Site Selection for Photovoltaic Projects: A Systematic Review," *International Journal of Energy Research*, vol 43, no. 5, pp. 1689-1701, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[57] Krzysztof Łowczowski, and Jacek Roman, "Techno-Economic Analysis of Alternative PV Orientations in Poland by Rescaling Real PV Profiles," *Energies*, vol. 16, no. 17, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[58] Mustapha Adar et al., "Performance Analysis of PV Grid-Connected in Fours Special Months of the Year," *International Renewable and Sustainable Energy Conference*, Tangier, Morocco, pp. 1-5, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[59] Jaroslav Hofierka, Ján Kaňuk, and Michal Gallay, "The Spatial Distribution of Photovoltaic Power Plants in Relation to Solar Resource Potential: The Case of the Czech Republic and Slovakia," *Moravian Geographical Reports*, vol. 22, no. 2, pp. 26-33, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[60] Marcel Suri et al., "Geographic aspects of photovoltaics in Europe: contribution of the PVGIS website," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 1, no. 1, pp. 34-41, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[61] Andrés Honrubia-Escribano et al., "Influence of Solar Technology in the Economic Performance of PV Power Plants in Europe. A Comprehensive Analysis," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 488-501, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[62] Graciele Rediske et al., "Multi-Criteria Decision-Making Model for Assessment of Large Photovoltaic Farms in Brazil," *Energy*, vol. 197, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[63] Monika Sandelic, Ariya Sangwongwanich, and Frede Blaabjerg "Robustness Evaluation of PV-Battery Sizing Principle Under Mission Profile Variations," *IEEE Energy Conversion Congress and Exposition*, Detroit, MI, USA, pp. 545-552, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[64] Jacek Kusznier, and Wojciech Wojtkowski, "Impact of Climatic Conditions and Solar Exposure on the Aging of PV Panels," 15^{th} Selected Issues of Electrical Engineering and Electronics, Zakopane, Poland, pp. 1-6, 2019. [CrossRef] [Google Scholar] [Publisher Link]