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A review on current trends on optimal EVCS location

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Abstract

This paper presents a comprehensive literature review aimed at analyzing recent advancements in research concerning the optimal location of Electric Vehicle Charging Stations (EVCS) over the past year. The rapid proliferation of electric vehicles needs a thorough understanding of the strategic placement of charging infrastructure to support their widespread adoption. By examining the latest studies and findings in this field, we aim to synthesize evolving methodologies, technologies, and useful considerations associated with determining the most effective locations for EVCS deployment. This review examines current methodologies assessing economic, environmental, and societal implications of EVCS placement strategies, providing insights to improve energy efficiency and sustainability in transportation ecosystems. Through a critical analysis of 54 published papers published in 2023 and 2024, we explore various factors influencing optimal EVCS placement, including geographical, demographic, and urban planning considerations, as well as emerging trends and research gaps. By analyzing the current state of research in this area, this research aims to inform stakeholders in making informed decisions to support the continued growth and integration of electric vehicles into global transportation infrastructures.

Keywords: EVCS Location, Optimization Techniques, Literature Review

1. Introduction

In the rapidly evolving landscape of transportation and energy, the optimal placement of Electric Vehicle Charging Stations (EVCS) has emerged as a critical topic with far-reaching implications for the global economy. As the world transitions towards sustainable energy solutions, Electric Vehicles (EVs) have gained popularity. However, besides technological advancements, the widespread adoption of EVs heavily relies on the availability and accessibility of charging infrastructure. The strategic positioning of EVCS holds great significance in facilitating the seamless integration of EVs into everyday life, promoting energy efficiency while driving economic growth. In this context, understanding the background of optimal EVCS location is essential in the modern economy and for promoting a sustainable future (Karmaker et al., 2023).

The general goal of this paper is to develop a comprehensive review of relevant works of research on the topic of optimal EVCS location. The following three intermediate objectives will concur to pursue the general goal.

- Leading a systematic literature search, by gathering and identifying peer-reviewed articles, conference papers, and other scholarly publications focused on the optimal placement of EVCS in 2023 and 2024.
- Analyzing and synthesizing existing literature by thoroughly reviewing and evaluating the identified works to extract key insights, methodologies, findings, and trends related to EVCS location optimization.
- Identifying gaps and emerging trends by highlighting areas where further research is needed and innovative approaches could be developed in the field of EVCS location optimization.

The present paper is organized as follows. In Section 2, we conduct a comprehensive literature review by providing: 1) an overview of the problem of EVCS location; 2) a description of the approach herein implemented to develop the review; and 3) a categorization of papers according to their subject areas. Section 3 formalizes the main findings of this research, by synthesizing optimization techniques and relevant aspects or criteria. Section 4 reports the conclusions of this work by exploring potential future lines of development.

2. Literature review

2.1. The problem of EVCS location

The problem of optimal EVCS location is a critical issue that has gained significant attention in recent years due to the growing popularity of EVs (Yuvaraj et al., 2023a). Due to the considerable investment associated with EVCS implementation, identifying appropriate sites is crucial for the advancement of an electric mobility infrastructure (Javanmardi et al., 2024).

One of the central challenges in determining EVCS locations is achieving a balance between accessibility and utilization. Placing charging stations in highly populated areas or along amenities can enhance accessibility and encourage EV adoption by providing convenient charging options for drivers (Rane et al., 2023). However, it is also essential to ensure that these stations are utilized efficiently, reducing network congestion while maintaining EV charging requirements (Chakraborty et al., 2024). Additionally, it is important to address technical considerations such as system reliability (Singhal et al., 2024), which ensures stability to future changes in external conditions, and system security, which includes emergency preparedness including grid safety, fire protection, and resilience against natural disasters.

Beyond logistical and technical challenges, EVCS location optimization also aims to achieve broader objectives related to economic development and social inclusivity (Alanazi et al., 2023). For instance, strategically deploying charging infrastructure in specific areas of developing countries can help reduce transportation-related emissions and facilitate the widespread dissemination of EVs (Mehouachi et al., 2023). Expanding EVCS networks presents opportunities for economic growth while promoting technological innovation with effective energy saving in the network (Abid et al., 2024a).

While significant progress has been made in EV technology and charging infrastructure, several challenges and uncertainties remain, including grid capacity (Mondal et al., 2023a), charging network interoperability (Kumar K et al., 2022), as well as financial operational risks (Haces-Fernandez, 2023). By implementing data-driven approaches, innovative technologies, and stakeholder engagement (Karmaker et al., 2023), it is possible to develop effective plans for optimizing EVCS locations, facilitating the shift towards a greener transportation system.

2.2. Methodology adopted for the review

Following the systematic approach proposed by Muka et al. (2020), we develop a systematic literature review on the problem of identifying optimal EVCS locations. The initial step highlighted by Muka et al. (2020) was to check if the topic had been previously reviewed (Yuvaraj et al., 2024; Banegas and Mamkhezri, 2023). However, the rational for this review is to provide a different categorization of papers with a specific focus on the most recent ones. This approach ensures our analysis incorporates the latest insights and advancements in the field of optimal EVCS location. The search for relevant literature was conducted across various scientific databases, as outlined in Figure 1.

Figure 1. Publication items by database

An advanced search was performed between February and March, 2024, by entering the following keywords and selecting fields: "**Optimal**" AND "**EVCS**" AND "**Location**", all of them focusing on the "abstract" category. We narrowed down to this particular section to ensure that the results retrieved would specifically pertain to the keywords within the abstract section of the articles. Results were further refined by specifying the publication year range from 2023 to the present, aiming at capturing the latest developments and insights related to the problem under analysis. It is worth noting that for the search conducted via Google Scholar, broader database, a specific search strategy was employed. Initially, papers from the year 2024 (13 items in total) were selected. Subsequently, the search was expanded to include papers from 2023, sorted by relevance and limited to the second page. This method resulted in a total of 30 items collected from Google Scholar. This approach was implemented deliberately to ensure the analysis remains focused on the most pertinent papers, ensuring thoroughness and synthesis in our review process.

After consolidating all references and abstracts into a single file, we led a screening process to remove duplicates, reducing the number of items for analysis from 70 to 54. Subsequently, we distributed these papers according to their types (journal paper, conference papers, book chapters) and publishers, as illustrated in Figure 2.

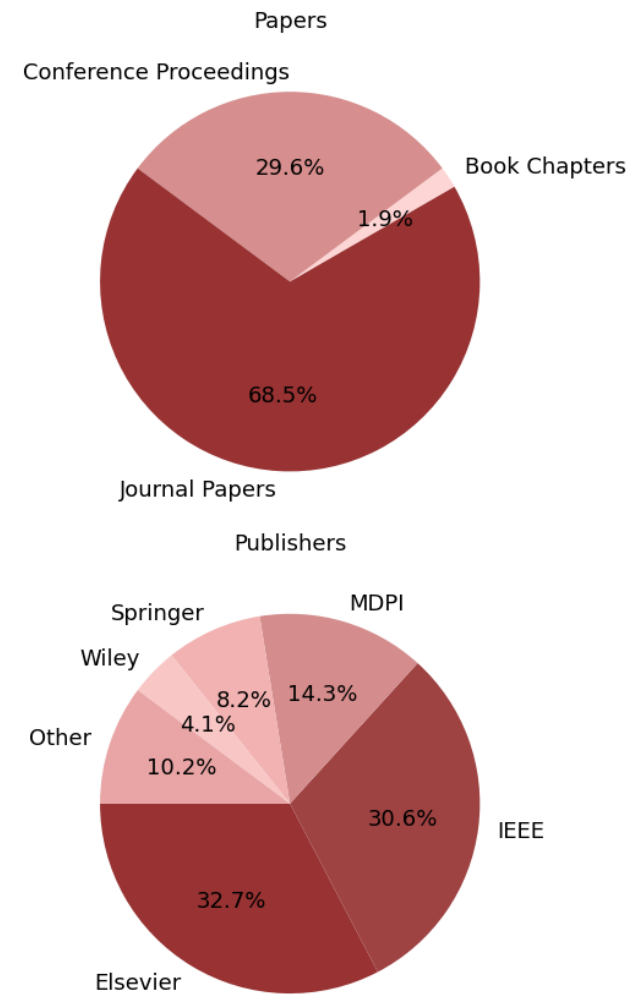

Figure 2. Distribution of the selected 54 papers by types and publishers

Each paper was thoroughly analyzed to identify its main subject matter. During this categorization process, papers were assigned to five distinct topic categories (Figure 3).

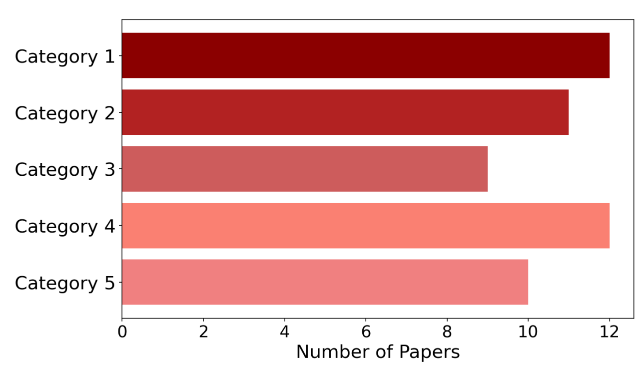

Figure 3. Categorization of papers according to their subject areas

The identified categories covers the following areas:

- **Category 1.** Location strategy and infrastructure planning;
- **Category 2.** Advanced techniques and algorithmic solutions;
- **Category 3.** Techno-economic and environmental assessment;
- **Category 4.** Decision Support Systems and Artificial Intelligence-based applications;
- **Category 5.** Innovative solutions, policy development, and stakeholder engagement.

We specify that certain papers cover topics spanning multiple categories. To address this, each paper is going to be described within the category that most closely aligned with its primary focus, with awareness of potential relevance to other categories. This method ensures that papers are categorized based on their primary theme while recognizing their relevance also to other categories.

2.3. Analysis of papers within the identified categories

2.3.1. Location strategy and infrastructure planning

Narayanan et al. (2024) introduce an optimization framework based on Mixed-Integer Linear Programming (MILP) to identify ideal locations and sizes for EVCS, by retrieving data on EV demand prediction. Through open-source data and advanced analysis, the framework accurately forecasts EV charging demand, while its user-friendly interface enables rapid scenario visualization and analysis, facilitating decision-making processes for businesses.

Venakatakirthiga et al. (2023) propose a method aimed at strategically locating Distributed Generation (DG) units to notably decrease power losses and increase voltage stability in power systems. Their research emphasizes the optimization of EVCS placement and energy management in smart distribution systems, integrating Teaching-Learning-Based Optimization (TLBO) and Particle Swarm Optimization (PSO) for a substantial reduction in Active Power Losses (APL) and an enhancement of voltage profiles across different operational scenarios.

Hisoglu et al. (2023) propose a method for strategically placing Solar-supplied EVCS to address the challenge of insufficient charging infrastructure and promote renewable energy integration in transportation. Combining Geographical Information System (GIS) and Analytic Hierarchy Process (AHP), this study identifies key criteria such as power availability and solar energy potential, offering valuable insights for urban planners and decision-makers in developing sustainable EV charging networks.

Charly et al. (2023) introduces an open-source GIS method to pinpoint optimal sites for community EV charging points, categorized by shared-residential, en-route, and destination charging types to suit end-users. Analysis in Dublin identified 770 priority locations and 3080 potential sites, considering accessibility within five minutes by walking or cycling, offering practical insights for deploying charging stations in similar urban environments worldwide.

Alam et al. (2023) discuss as policymakers in California have proposed transitioning all new vehicles to zero-emission models by 2035, a shift that needs to be supported by strategic infrastructure planning. By integrating EVs into the power distribution system and implementing hybrid charging methods like solar energy, the research aims to reduce environmental emissions and operational costs while evaluating the impact on the PG&E 69-bus distribution system to enhance overall efficiency.

Alanazi et al. (2023) explore the complex factors influencing EVCS placement, analyzing variables such as EV percentage, population density, and energy costs across nine US states. By adopting predictive modeling techniques, the research forecasts EVCS distribution, with Texas emerging as the most favorable state for optimal placement, providing valuable insights to inform policies and strategies for promoting equitable EV adoption.

Islam et al. (2023) focus on selecting optimal EVCS locations to promote sustainable urban mobility in Dhaka, Bangladesh, addressing transportation congestion and air quality concerns. Utilizing the Gravity model integrated with the AHP, this study identifies "Kamalapur" under "Motijheel" as the prime EVCS site, highlighting consistency in meeting the city's charging demands.

Krishnamurthy et al. (2023) analyze a microgrid incorporating solar photovoltaic, wind power, and fuel cells alongside the utility grid to optimize the placement and sizing of EVCSs and Renewable Energy Sources (RESs), aiming to mitigate adverse impacts on the distribution network's operational parameters. This research proposes a multi-objective framework to address such issues as voltage stability, reliability, power loss, and cost considerations, with results indicating significant improvements in voltage profile.

Singh et al. (2023) underline the existence of challenges related to the problem of EVCS location in India, specifically voltage instability and power loss. To address these issues, the authors observe as strategic placement of EVCS requires effective integration with the power grid, necessitating optimal positioning of DG units. In such a direction, a bat optimization approach is proposed to identify suitable EVCS and DG nodes, offering insights for enhancing the integration of electric vehicles into balanced distribution networks.

Khan et al. (2023) introduce a two-stage problem formulation to optimize the placement of EVCS. In the first stage, suitable indices reflecting accessibility and installation cost are derived. In the second stage, an optimal DG integration is implemented by using the Jaya Algorithm on the IEEE 33-Bus distribution network, and ultimately offering a comprehensive approach capable of minimizing power losses, while enhancing voltage stability.

Again in the context of the IEEE 33-Bus system, Dey et al. (2023) focus on optimizing the problem of EVCS placement by using the Symbiotic Organisms Search (SOS) algorithm. The objective is to minimize active power loss and reduce the annual cost of network loss, thereby enhancing operational efficiency as well as the overall effectiveness of the network infrastructure.

Sarmas et al. (2023) analyze the Greek EV market, highlighting as it presents opportunities for investors seeking to contribute to the country's EV charging infrastructure development. Particularly, their study introduces a robust Multi-Criteria Decision-Making (MCDM) framework to aid stakeholders in identifying optimal charging sites among diverse locations, testing its effectiveness across ten municipalities in Greece and highlighting its value in guiding strategic investment decisions.

2.3.2. Advanced techniques and algorithmic solutions

Zare et al. (2024) make use of a stochastic MILP model for collaborative expansion planning of multi-energy distribution networks, integrating EVCSs amidst uncertainties. The model, designed to minimize investment and operational costs, is validated across various case studies, demonstrating cost reductions through strategic EVCS allocation and highlighting its effectiveness in managing uncertainties for modern energy distribution network expansion.

Yuvaraj et al. (2023b) explore the impact of EV usage on the distribution system's performance in India. Particularly, the authors propose a Bald Eagle Search Algorithm (BESA) and Distribution STATic COMpensators (DSTATCOM) to optimize the allocation of EVCS in practical Indian distribution networks, demonstrating its effectiveness in reducing power loss, enhancing voltage stability, and improving annual net savings compared to traditional optimization methods.

Nugraha et al. (2023) illustrate a technique for minimizing power loss in a distribution network by means of PSO. By focusing on a practical case study, five EVCSs are allocated across designated areas, with each station equipped with various charger types. Power flow analysis demonstrates significant reductions in power loss achieved by strategically situating EVCSs using PSO compared to randomly placed stations, highlighting the crucial importance of strategic planning.

Mehouachi et al. (2023) state as, despite global incentives for electric mobility growth, adoption rates in developing nations remain low. The authors discuss the particular case of integrating EVCS infrastructure with a Photovoltaic (PV) system in congested areas of Tunis, and propose the Multi-Objective Neural Network Algorithm (MONNA). Facilitating EVCS establishment in optimal locations, a 97.8% user demand satisfaction rate and 60% PV exploitation rate can be achieved, while reducing emissions and costs.

Considering the operational challenges posed by stochastic renewable energy generation, Ali et al. (2022) develop a multi-objective planning framework to optimally allocate EVCSs alongside RESs, by specifically considering such aspects as voltage deviations, energy losses, and EV owner satisfaction. Through a two-level approach based on several simulations, the proposed framework achieves significant reductions in total voltage deviation and in energy losses compared to uncontrolled EV charging, ensuring EV owners' satisfaction while addressing grid constraints effectively.

Woo et al. (2023) propose an optimization method considering installation costs, driver preferences, and existing infrastructure. By employing kernel density estimation and Genetic Algorithms (GAs), the proposed approach effectively disperses charging demand while minimizing peak loads, as validated through simulations using real data from Jeju Island, ultimately enhancing the resilience and efficiency of EV charging networks.

Jasmine et al. (2024) apply a hybrid methodology based on the integration between Fire Hawk Optimizer and Spiking Neural Network (FHO-SNN), aimed at mitigating active power losses to enhance system performance. By implementing this approach, significant improvements in voltage profiles and reductions in power losses are observed, promising enhanced stability and efficiency within electric grids, and highlighting the potential for a more resilient transportation infrastructure.

Alabri et al. (2023) underline as the random placement of EVCS leads to increased power losses and voltage imbalances in distribution networks. To address this problem, the authors propose unbalanced load flow calculation and optimization techniques to mitigate adverse grid impacts, stressing the importance of strategic placement for efficient and sustainable EV integration into power grids.

Madboly et al. (2023) observe as the current volume of EV adoption is insufficient to fully leverage their potential in balancing renewable energy intermittency. Using the Sioux Falls transportation network and IEEE 33-Bus system, the authors employ the Differential Evolution (DE) optimization algorithm to identify optimal charging station locations, highlighting the benefits of co-planning for enhanced distribution network operation.

Ulfa et al. (2023) employ the Flower Pollination Algorithm (FPA) in the East Sumba area of Indonesia. within a set of different planning scenario, the most efficient plan for minimizing power losses and enhancing voltage profiles is selected. The findings underscore the key role of optimization methods in guiding future electricity system development, urging government and utility agencies to consider such approaches for optimal planning.

Altaf et al. (2023) use a Backward and Forward Sweep (BFS) method for load flow analysis and the PSO algorithm for optimal EVCS and DG allocation. The validation stage demonstrates the achievement of superior results, particularly through reduction in power loss, compared to such existing methodologies as Simulated Annealing (SA) and artificial bee colony. The authors affirm as the PSO algorithm overall exhibits enhanced optimization efficiency and computational prowess, presenting a promising avenue in distribution networks management.

2.3.3. Techno-economic and environmental assessment

Turan et al. (2023) focus on nanogrids and EVCS across Istanbul, aiming at minimizing investment costs while optimizing energy efficiency. By exploring different energy system configurations, their study identify cost-effective solutions that also reduced greenhouse gas emissions, emphasizing the importance of balancing economic and environmental considerations in energy planning.

Javanmardi et al. (2024) integrate GIS-based methodology and parametric solar tools to identify the city center and an eastern region as prime sites for EVCS installation in Bilbao, showing potential for charging 16% more electric vehicles without straining distribution substations.

El Hafdaoui et al. (2023) address challenges arising from the rapid growth of EVs with a focus on the Fez-Meknes region in Morocco. By modeling EV battery performance on the basis of such factors as weather and traffic, the authors use a GA-based approach to determine optimal locations considering cost, road width, and autonomy range. Results, presented through interactive GIS maps and node-link networks, highlight the impact of ambient temperature on EVCS placement.

Das et al. (2023) employ the SOS algorithm for strategic placement of EVCS within the Radial Distribution Network (RDN) to minimize power loss while maintaining network stability and meeting charging demands. Results are validated and compared with Grey Wolf Optimizer (GWO) and Whale Optimization Algorithm (WOA) to ensure reliability.

Jeong et al. (2024) explore optimal electricity trading volumes and Energy Storage System (ESS) capacities to enhance the profitability of EVCSs equipped with solar power generation. The research demonstrates as superior profits can be achieved compared to conventional EVCSs through analysis at public parking lots in Seoul, Republic of Korea, considering various factors like ESS lifespan, PV generator peak power, and weather conditions.

Yuvaraj et al. (2020) formulate a multi-objective function to optimize EVCS placement on the basis of their impact on power loss, voltage stability, and reliability. They introduce a novel methodology employing the Spotted Hyena Optimizer Algorithm (SPOA) and comparing results with the Cuckoo Search Algorithm (CSA). Findings suggest strategies to mitigate power losses, regulate voltage, and address reliability concerns, contributing valuable insights into integrating EVCS into RDN.

Haces-Fernandez (2023) sustain the importance of promoting EV adoption in the US, noting the scarcity of public EV charging stations as a major barrier to market penetration. They show how federal incentives drive diverse businesses to integrate EV charging, reducing operational risks and increasing revenue. Through a detailed examination of EVCS placement and operation risks, the study presents a framework for optimal deployment, aiding stakeholders in equipment selection and facilitating EV market growth.

Chen et al. (2024) present a risk-aware framework integrating Monte Carlo simulations for EV charging load estimation and optimization for peer-to-peer Transactive Energy (P2P-TE) trading in urban networks. Additionally, it incorporates a three-phase unbalanced probabilistic optimal power flow for secure operation, resulting in a 26.65% reduction in EVCS operation costs and effective management of uncertainties in trade-off scenarios.

Abid et al. (2024a) introduce an approach to optimize microgrids incorporating RESs by employing a Battery Energy Storage System-based Virtual Synchronous Generator (BESS-VSG) to address frequency instability. Via a Modified Multi-objective Salp Swarm Optimization Algorithm

(MMOSSA), the model allocates PV, wind turbine, BESS-VSG, and EVCS within microgrids, with evaluations conducted on real-world grid networks in Oman and Turkey. Results demonstrate significant improvements in microgrid technical characteristics, with the proposed MMOSSA method outperforming existing optimization strategies.

2.3.4. Decision Support Systems and Artificial Intelligence-based applications

Abid et al. (2024b) investigates the integration of Multi-Agent Deep Reinforcement Learning (MADRL) and Multi-Objective Optimization (MOO) for EV charging scheduling and microgrid optimization. They propose a novel planning framework, Multi-Objective Artificial Vultures Optimization Algorithm based on Multi-Agent Deep Deterministic Policy Gradient (MOAVOA-MADDPG), which optimizes RESs, BESSs, and EVCSs to minimize costs, emissions, and power losses while enhancing system stability. Validation on real-world networks confirms its effectiveness in improving EV state of charge and outperforming existing techniques across various metrics.

Polisetty et al. (2023) develop a novel Dove-based Recursive Deep Network (DbRDN) for optimal EV charging station placement in the context of smart cities, integrating hybrid renewable sources like wind, solar, and hydropower, and assessing system efficiency under various conditions. The system's effectiveness is validated by comparing outcomes with existing techniques, demonstrating improvements in power loss, harmonic distortion, voltage imbalance, error, and accuracy.

Rene and Fokui (2024) develop a strategy leveraging artificial intelligence to optimize EV, accounting for factors such as load voltage deviation and distributed solar photovoltaic systems. They employ a hybrid GA-PSO approach to pinpoint optimal locations for EVCSs integrated with photovoltaics, achieving superior performance in minimizing power loss and enhancing voltage compared to conventional methods.

Li et al. (2023) present a three-level location model integrating dynamic pricing and the Soft Actor-Critic (SAC) reinforcement learning algorithm to optimize pricing strategies for EVCSs. Case studies in a Chinese industrial park validate its efficacy in making economically and scientifically informed location decisions, while the dynamic pricing method based on reinforcement learning offers valuable insights for EVCS establishment and operation.

Mohanty et al. (2023) propose a synthetic dataset approach for EV charging infrastructure planning, illustrated with a case study in Berhampur, India. This dataset enables the optimal placement of charging stations and informs future infrastructure planning, providing valuable assistance to city planners in predicting energy usage and enhancing charging services.

Herjuna et al. (2023) adopt the K-Nearest Neighbour (KNN) algorithm considering geographical assets, population density, and Point Of Interest (POI) data to predict optimal EVCS locations. This study develops the Manyala App, a user-friendly decision support system for EVCS placement in Ternate and Ambon, Indonesia.

Mishra et al. (2024) introduce a novel MCDM approach, combining the COmplex PRoportional ASsessment (COPRAS) and q-Rung Orthopair Fuzzy Sets (q-ROFSs) to improve the accuracy and efficiency of EVCS site selection under uncertain scenarios. The robustness of the proposed approach is evaluated through numerical examples and sensitivity analysis, demonstrating its superiority over existing MCDM approaches in the field.

Balu and Mukherjee (2023) propose a novel strategy to optimize the placement of EV Battery Swapping Stations (EVBSS) in RDN. The study introduces a Chaotic Student Psychology-Based Optimization (CSPBO) algorithm for sizing and siting renewable DG units, such as solar PV and wind turbines, to improve system reliability and efficiency.

In their study, Venkata Prasanth et al. (2023) combine Virtual Anticipation (VA) and Chemical Reaction Enhancement (CRE) techniques to effectively manage uncertainty in the design and management of electronic vehicle payment station networks. Their innovative method is aimed at developing a dependable model for selecting optimal locations for EVCS, assessing power supply line hazards and managing power demand entropy, while considering various factors such as power network type, charging station location, and operational hours.

The research conducted by Deeum et al. (2023) employs GA-based optimization for load flow analysis to strategically locate, scale, and optimize EVCSs within a distribution grid integrated with distributed PV and BESSs. Their findings reveal notable reductions in power losses observed across various zones within the distribution grid.

Lin et al. (2023) propose an innovative planning framework integrating a Fuzzy Inference System (FIS) to optimize EVCS locations and capacities alongside PV systems and energy storage units, considering multiple off-site factors to simultaneously minimize electricity cost and emission pollutants. Through numerical simulations on a coupled distribution and transportation system, the proposed FIS-based approach efficiently simplifies optimization problems and generates realistic outcomes reflecting practical system conditions.

Chakraborty et al. (2024) employ a Multi-Objective Particle Swarm Optimization (MOPSO) for strategically placing fast-charging EV infrastructures across the distribution system, aiming at minimizing power loss and voltage deviations. Through time-series analysis and cost-benefit evaluations, the proposed approach effectively identifies optimal locations, enhancing system performance while maximizing operator profits.

2.3.5. Innovative solutions, policy development, and stakeholder engagement

Yuvaraj et al. (2024) explore optimal EVCS locations by using BESA and CSA methodologies, aiming to evaluate the impact of the transition from fossil fuel vehicles to EVs on charging infrastructure, highlighting challenges like inadequate facilities and high costs. The study evaluates multiple scenarios to demonstrate the effectiveness of different energy sources in addressing the challenges associated with EV charging on distribution systems.

Banegas and Mamkhezri (2023) lead a systematic review on EVCS site selection techniques, focusing on GIS and decision-making variables used. Findings highlight the prevalence of map algebra and data overlay methods in GIS-based analysis, as well as the importance of geographic and demographic variables in site selection. This underscores the need for MCDM approaches to ensure the sustainability and efficiency of EVCS deployment, offering valuable insights for policymakers.

Muthuvinayagam et al. (2023) introduce a hybrid technique, based on the Reptile Search Algorithm (RSA) and the Honey Badger Algorithm (HBA), for designing EVCS networks in urban areas. The approach optimizes EVCS design considering factors like distance from home, driver behaviors, and traffic patterns. Computational experiments and related results offer insights for addressing challenges in large-scale EVCS network design.

Singhal et al. (2024) provide an review on charging infrastructure deployment challenges, discussing factors like installation costs, land availability, and operational considerations, alongside different methodologies and algorithms for optimal charging station location planning, aiming to guide young researchers in this field.

Karmaker et al. (2023) emphasize the importance of including diverse stakeholder perspectives in placing and scheduling EVCS to promote transport electrification. By assigning different weights to stakeholders and analyzing case studies, this research presents a focus on EVCS owners when developing placement and scheduling strategies, urging for comprehensive consideration of other stakeholders, especially in suburban and remote areas.

Shahbazi et al. (2023) address the optimal location and sizing of EVCSs to mitigate their adverse effects on the network, considering uncertain loads through probabilistic modeling using Monte Carlo simulations. MATLAB simulations show a 10% increase in peak-hour power losses but reduces losses during low-load times, while minimizing voltage deviations to within 8% of the nominal value, emphasizing the importance of strategic placement for network impact mitigation.

Grimaccia et al. (2023) employ the evolutionary algorithm known as Social Network Optimization (SNO) to determine optimal EVCS positioning, considering factors like residential density, showcasing its flexibility in deployment strategies for cities like Genoa and Turin, Italy.

Mondal et al. (2023a) propose a modified FBS to determine the Maximum Additional Load (MAL) of each RDN node during EV charging, aiding in optimal EVCS installation without compromising voltage security. The authors use the same MFBS algorithm in another research (Mondal et al., 2023b) to determine the Maximum Permissible Load (MPL), integrating solar DG to mitigate energy loss.

Terkes et al. (2024) conduct optimal sizing and feasibility analyses of an EVCS, considering daily, hourly, and hybrid demand variations, alongside multi-year sensitivity analyses for different energy storage system technologies. The study also considers the effects of solar irradiation, wind speed, and electricity prices, alongside power quality concerns, within a cost-focused optimization approach.

3. Formalization of results

We now synthesize relevant approaches and aspects emerged for each topic category through Tables 1 to 5. This formal synthesis aims to offer insights into the evolving research landscape addressing optimal EVCS location. While existing studies cover a wide range of methodologies and applications, a gap appears in addressing the socio-economic and environmental aspects of EVCS placement.

Table 1. Category 1. Location strategy and infrastructure planning

Methodological approaches	Relevant aspects
MILP-based framework	EVCS location and size
TLBO and PSO integration	DG units, losses, stability
GIS and AHP integration	Power availability, solar potential
Open-source GIS method	Accessibility, walk/cycle range
Hybrid charging methods	Emissions, operational costs
Predictive modeling	EVCS distribution, energy costs
Gravity model and AHP integration	Urban charging demand
Microgrid optimization	Voltage stability, reliability, cost
Bat optimization approach	DG units, instability, loss
Jaya algorithm	DG integration, accessibility, cost
SOS algorithm	Active power loss, network cost
MCDM framework	Investors planning process

Table 2. Category 2. Advanced techniques and algorithmic solutions

Methodological approaches	Relevant aspects
Stochastic MILP model	EVCS allocation, costs
BESA and DSTATCOM integration	Power loss, stability, net savings
PSO for power loss minimization	EVCS siting, charger types
MONNA Neural Network	Demand satisfaction, PV use
Multi-objective planning	Voltage, losses, owner satisfaction
kernel density estimation and GAs	Charging dispersal, peak loads
FHO and SNN integration	Voltage profiles, power losses
Unbalanced load flow optimization	Power losses, voltage imbalances
DE optimization algorithm	Energy intermittency, co-planning
FPA algorithm	Power losses, voltage profiles
BFS and PSO integration	Load flow analysis, DG allocation

Table 3. Category 3. Techno-economic and environmental assessment

Methodological approaches	Relevant aspects
Nanogrid exploration	Investment, efficiency, emissions
GIS and parametric solar tools	Charging efficiency
GA modelling weather and traffic	Cost, road width, autonomy range
SOS algorithm	Power loss, network stability
Electricity trading volumes	Profitability, EVCS capacity
SPOA algorithm	Loss, stability, reliability
Risk assessment framework	Operational risks, revenue
Monte Carlo simulations	EV charging load
MMOSSA algorithm	BESS-VSG, frequency instability

Table 4. Category 4. Decision Support Systems and AI-based applications

Methodological approaches	Relevant aspects
MADRL and MOO integration	Costs, emissions, losses, stability
DbRDN deep network	Harmonic distortion, accuracy
GA and PSO integration	Power loss, voltage, cost
Dynamic pricing-based SAC	Economic decision-making
Synthetic dataset approach	Energy usage
KNN algorithm	Geography, population density
COPRAS and q-ROFSs integration	Uncertainty affecting input data
CSPBO algorithm	DG units sizing and siting
VA and CRE integration	Supply hazards, demand entropy
GA optimization	Load flow analysis, power loss
FIS planning framework	Electricity cost, emission pollutants
MOPSO algorithm	Loss, voltage deviations, profit

Table 5. Category 5. Innovative solutions, policy development, and stakeholder engagement

Methodological aspects	Relevant criteria
BESA and CSA integration	Inadequate facilities, transition cost
Systematic review	GIS, geography, demography
RSA and HBA integration	Network design, drivers' behavior
Charging infrastructure review	Installation costs, land availability
Stakeholder perspective analysis	Different weights, EVCS owners
Monte Carlo simulations	Peak losses, voltage shifts
SNO evolutionary algorithm	Res. density, urban deployment
MFBS algorithm	MAL and MPL determination
Optimal sizing and feasibility	Demand, storage technologies

Even if some studies touch upon stakeholder engagement and policy development, there is a need for more in-depth analysis regarding the socio-economic impact of EVCS deployment on local communities, businesses, and overall urban development. Understanding how EVCS placement decisions affect job creation, property values, and economic disparities could provide valuable insights for policymakers and urban planners striving to promote equitable and sustainable transportation electrification. Moreover, further attention is required to address environmental considerations in the location of EVCS. Assessing such factors as, for instance, air quality improvement, reduction in greenhouse gas emissions, along with the potential ecological impacts resulting from the development of necessary infrastructure can provide a comprehensive understanding of the wide-ranging and interconnected environmental implications associated with the deployment and expansion of EVCS.

4. Conclusions and future lines

This paper provides a comprehensive review of recent research on the problem of optimal EVCS location. Analyzing 54 papers published in 2023 and 2024, we synthesize evolving methodologies and factors influencing placement, including economic and technical considerations. The findings aim to formalize the identified works to extract key insights as well as potential gaps and emerging trends. However, a limitation of this review is its narrow focus on recent publications, which may overlook valuable insights from earlier research that could still be relevant in understanding the evolution of EVCS location strategies.

Future work could aim to broaden this review by extending the scope to include a wider range of publication dates for evaluation. Furthermore, we plan to develop a deep learning approach for optimal EVCS location prediction, incorporating novel criteria related to socio-economic and environmental implications of stations deployment in local communities, with a specific focus on underserved regions, so as to offer urban planners insights for promoting equitable and eco-conscious transportation networks. Additionally, exploring the integration of real-time data analytics and predictive modeling could enhance the responsiveness and adaptability of EVCS placement strategies to dynamic urban environments, thereby optimizing their effectiveness and sustainability.

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