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The Impact of Electromobility on a Sustainable Ecosystem and an Assessment of the Impact of Optimal Methods for Planning the Location of Charging Stations

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Abstract

The use of electric vehicles has been acknowledged as a crucial technique to slow down global warming, lessen air pollution, and improve energy security. Electric vehicles (EVs) have the potential to dramatically cut greenhouse gas emissions, especially in the transportation industry. However, the development of an infrastructure that can support the shift to a sustainable ecosystem as well as the electrification of vehicles are both necessary for the sustainability of electromobility. The creation of charging stations that are conveniently positioned and easily accessible to satisfy the needs of EV users is a crucial part of this infrastructure. The sustainability of the ecosystem is evaluated in this research together with the effects of the best planning practices for the placement of charging stations. The study concludes that the widespread use of EVs and the creation of a comprehensive infrastructure, including a network of carefully placed charging stations, can lead to a sustainable ecology.

Keywords: electric vehicles, transportation, electromobility, charging stations

Introduction

The internal combustion engine (ICE), which is a component of the transportation system, contributes significantly to air pollution. The use of electric vehicles (EVs) has expanded significantly in the market over the past several years as a result of efforts to minimize air pollution and the transportation sector's reliance on oil. Electric vehicles (EVs) utilise energy from fuel cells, batteries, and ultracapacitors, which are not reliant on fossil fuels and do not produce any harmful gases.

Over the past ten years, researchers in the electrical and transportation industries have studied the optimal location planning of electric vehicle charging stations (EVCS). Transportation-related research has focused on minimizing costs with availability and demand coverage, considering vehicle travel patterns, user behavior, and other constraints imposed by the user or the road network. Nevertheless, as shown in [1], the load margins of the power system are heavily influenced by the EVCS load. The study also demonstrated that the impact of EVCS load on the distribution network can be substantially reduced by utilizing the distribution bus system's optimal location selection. The electricity-based research has therefore concentrated on the optimal EVCS layout to minimize the impact on the distribution grid (DG) while meeting total demand. Other research demonstrates that the extremely stochastic nature of moving EV loads can result in grid-functional uncertainty. This demonstrates the need for a well-equipped central planning charging infrastructure that enables control over the location of charges and enforces power quality requirements at the macro level as opposed to the user level [2]. The purpose of this review is to assess the contributions and viability of prior research on this topic and to identify significant limitations that must be taken into account for an optimal EVCS location planning model.

The EV Market

The EV market is one of the most dynamic sectors in the clean energy globe. According to recent data, sales of electric vehicles (EV) increased by a factor of two in 2021 over the previous year, setting a new record of 6.6 million. Only 120,000 EVs were sold globally in 2012; for comparison in 2021, more than that number was sold per week. In 2021, the market share for electric cars was four times higher than it was in 2019. With this, there are now over 16.5 million electric vehicles (EVs) on the road globally, which is three times as many as there were in 2018. Two million electric vehicles (EVs) were sold globally in the first quarter of 2022, a 75% increase over the same period in 2021.[3]

The People's Republic of China ("China") accounted for half of the increase in electric vehicle sales in 2021. In 2021, China sold 3,3 million more vehicles than the rest of the world combined. After a boom in 2020, sales in Europe continued to develop strongly (up 65% to 2,3 million), while sales in the United States increased after two years of decline (to 630,000). Similar trends were observed in the first quarter of 2022, with sales in China more than doubling compared to the first quarter of 2021 (representing the majority of global growth), the United States increasing by 60%, and Europe increasing by 25%. The IEA Announced Pledges Scenario (APS), which is based on extant climate-focused policy pledges and announcements, assumes that EVs will account for more than 30 percent of all vehicles sold worldwide in 2030 (excluding two- and three-wheeled vehicles). Although remarkable, this is still a far cry from the 60% share required by 2030 to align with a trajectory that would lead to net-zero CO_2 emissions by 2050. Under current policy plans reflected in the IEA Stated Policies Scenario (STEPS), EVs will account for just over 20% of sales by 2030, resulting in a stock increase of 200 million vehicles from the current level. [3]

Global statistics for electric vehicles

To determine the present use of charging stations for electric passenger vehicles and public transportation, as well as the future direction of the technology, it is necessary to analyze the current number of EVs on the road that utilize these charging stations. The following graph compares EV usage around the globe.

Figure 1 – Global statistics for electric vehicles [3]

According to the most recent Consumer Mobility Index, more than fifty percent of prospective car buyers will opt for a wholly electric, plug-in hybrid, or hybrid vehicle. [4] As the European Union moves closer to banning the sale of new gasoline and diesel vehicles by 2035, the transition to electric vehicles may soon become mandatory for many residents.[5] According to the Electric Vehicle Database, the current average EV battery range is a comfortable 332 kilometers, which is sufficient to alleviate so-called range anxiety in daily use. Included in the survey are all electric vehicles arranged by range. The numbers are derived from genuine values. The list of EVs with the greatest range is displayed in Figure 2.

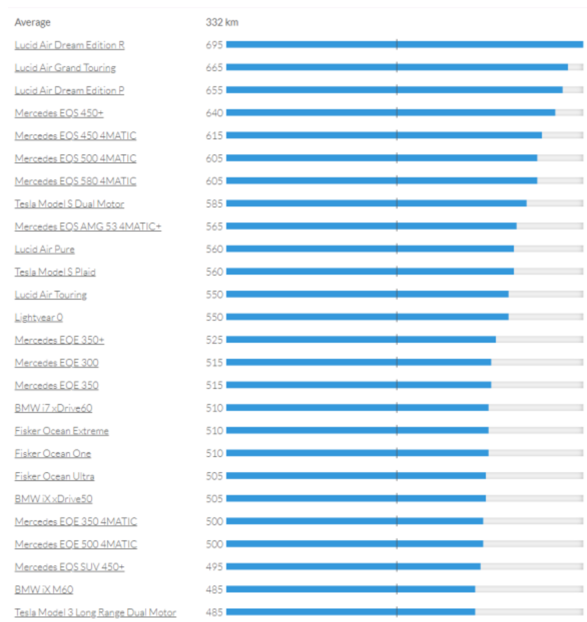

Figure 2 – Range of fully electric vehicles [6]

EU charging infrastructure

With the current range of entirely electric vehicles, cross-continental infrastructure remains inconsistent in many areas, making the use of EVs for cross-border travel still quite problematic. Not only are charging stations distributed unevenly, but so are providers and payment systems. In the European Union, there are over 330 000 publicly accessible charging stations, and the number is expanding. A recent audit by the European Court of Auditors found, in their Special Report No 5/2021 available at [7], that despite successes such as enforcing a common EU standard for plugs and improving access to various charging networks, electric vehicle travel within the EU still faces obstacles. The availability of charging stations varies from country to country, there are no standardized payment systems in place that meet minimum requirements, and there is insufficient information available to users. In the absence of a comprehensive infrastructure deficit analysis, the Commission has been unable to direct EU funding where it is required most. The EU is still a long way from attaining the Green Deal goal of opening one million charging points by 2025, and it lacks a comprehensive electro-mobility strategy. The purpose of this audit was to evaluate the efficacy of Commission support for the deployment of publicly accessible EV charging infrastructure in the EU.

The European Commission has a goal of one million charging stations or points by 2025, but the EDA report warns that this goal may not be met if deployment continues at its present rate. It is estimated that 150,000 new points per year, or nearly 3,000 per week, will be required to close the disparity, which seems quite unrealistic at this time. Figure 3 shows the publicly available charging infrastructure across the EU.

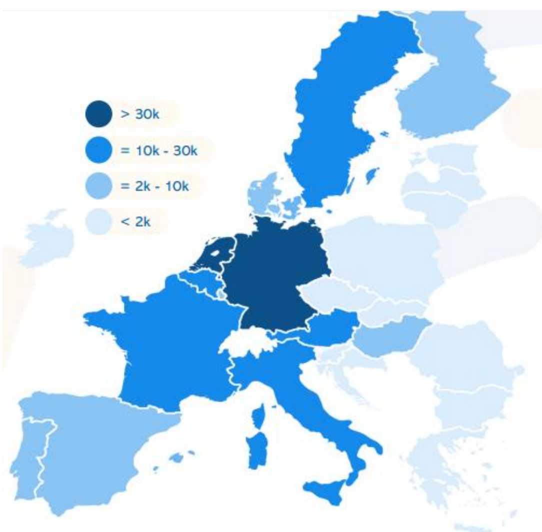

Figure 3 – publicly accessible charging infrastructure across the EU [8]

Figure 4 shows the significant disparities in the number of charging stations between Member States. There are disparities between the North and the West and the South and the East. There is a significant possibility that countries with a high proportion of charging stations or cities will outpace other nations, resulting in a two-speed Europe.

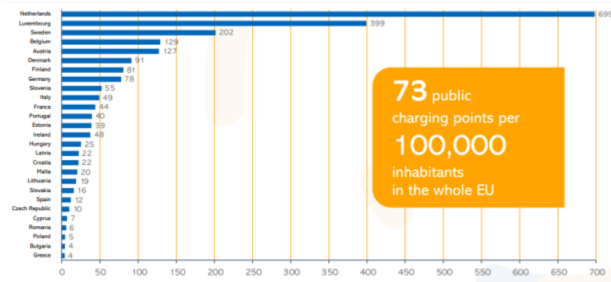

Figure 4 – The number of electrical vehicle charging facilities in EU Member States [8]

Review research of methods for determining the location of charging stations.

In the early phases of EVCS position optimization research, the optimization models were based on precise methodological approaches, such as Branch and Bound [9], [10], Mixed Integer Linear Programming [11], [12], Voronoi Diagram [13], [14] etc., which provided precise solution points. These methods demanded that the input data be preprocessed in order to identify the shortest paths, feasible combinations, etc., and required a great deal of computational time to obtain them. Several researchers have also determined that it is nearly impractical to even pre-generate combinations for actual systems with large and complex datasets, and that it is even more difficult to solve the optimization model. Linear models are also concerned with minimizing/maximizing each objective function within a constraint, which may not result in a global optimum with a non-ideal objective combination. Heuristic algorithms are implemented in this context. In contrast to exact methods, heuristic algorithms have been shown to solve large and sophisticated optimization models in a reasonable amount of time [15].

Genetic Algorithms, as implied by their name, imitate the evolutionary aspect of a candidate population in order to improve the present selection set. In order to apply a genetic algorithm to a problem, it is necessary to make meticulous design decisions to adapt the algorithm to the problem. The crossover mechanism and fitness functions of the genetic coding scheme have a direct impact on the algorithm's ability to discover the optimal outcomes. A large quantity of heterogeneous data is also required to prevent the algorithm from becoming stuck in local minimums. Typically, this is accomplished by randomly selecting genes for crossover, resulting in a delayed convergence rate for ensuring exploration. Although increasing the population size enhances the solution of the genetic algorithm, it dramatically increases the computation time, even if the solution improvement is marginal. In papers [16-19], the authors discuss their research on this subject.

NSGA-II (Non-Dominated Sorting Genetic Algorithm) [20] is a powerful meta-heuristic multi-objective genetic algorithm used to solve multi-objective optimization problems in a variety of applications, including facility allocation [21], supply network design [22], and congested facility location [23].

Particle Swarm Optimization (PSO) is a popular and effective algorithm that utilizes the randomness of real numbers and global communication between particles to optimize its performance. The outputs of potential solutions (particles) search the search space for optimal solutions while communicating and updating the best personal and global solutions in real time. At the beginning of each iteration, each particle moves in the direction of the vector derived from its personal and global best solution, eventually convergent on the global optimal solution [2].

Improved Particle Swarm Optimization (IPSO) [24], and Binary Particle Swarm Optimization (BPSO) with the so-called ,,Taboo," mechanism [25] have demonstrated better convergence rates without compromising the search for the global optimum. It is demonstrated that PSO-based algorithms are superior for solving multi-objective optimization problems.

In addition to optimization algorithms for planning the location of charging stations, the system under investigation is modeled mathematically, which is a fundamental and essential component of optimization problems. Complex multilevel mathematical models frequently represent real systems with multiple decision variables and optimization objectives. These models are reformulated as a single-level model using linearization techniques and solved using heuristic or exact methods [26] for simplicity of implementation. The required input data are origin-destination distances, spatial distribution of Vehicle Miles Traveled (VMT), road network map data using GIS [27] [28], etc., as the majority of the research centers on optimizing setup cost, ease of access, and quality of service. When analyzing the impact on the power distribution network, one of the standard IEEE bus systems is taken into account. In the studies, GIS-based tools were utilized to overlay the road network with the power distribution system network in order to identify the optimal location of EVCS by minimizing the cost of laying conductors [29] and assessing the impact on the network's stability [28]. In addition, researchers have attempted to develop mathematical models to provide service providers with a ladder-based solution to facilitate implementation and maintenance [30].

Conclusion

On the basis of these EVCS placement optimization studies, it can be concluded that simpler exact optimization methods are not applicable to actual systems with multiple optimization objectives and large, complex data sets. However, heuristic approaches provide reasonably accurate solutions in a fraction of the time required by deterministic approaches.

In addition, it is evident that site planning studies that consider the effects on the power distribution system are rarely considered, despite the fact that a number of studies have highlighted the repercussions of ignoring these effects. Methods integrating the spatial distribution of electricity DG and traffic flows are required to find optimal locations with minimal impact on DG and simple access for users in order to find more viable and sustainable solutions.

Unless the industry, infrastructure, and supporting network of services catch up to the rapid acceleration of electromobility, this goal is in risk of failing. The availability and dependability of charging facilities are key obstacles. Administrative and operational obstacles delay deployment. In turn, the effects of unmanaged charging have consequences for power quality, investment costs, and driver confidence in a completely charged battery. Each of these components is dependent on the others. One cannot advance without destabilizing the other parties. Getting the fundamentals correct is crucial. Today, we are designing a road transportation system that will serve us well into the distant future.

It is essential that the emerging sector's entire ecosystem consisting of municipalities, local authorities, urban planners, electromobility service providers (eMSPs), vehicle manufacturers, and network companies serve customers more effectively. Distribution network operators play an absolutely crucial position within this ecosystem.

Real-time information will be decisive. This data will enable energy companies to provide the market with information on the condition of the grid, allowing the connected ecosystem to govern its use and ensure the grid's reliability for users. They can ensure the influx of electric vehicles and the health of the entire ecosystem in this manner. This is the vision for the future of connected electromobility that is entirely integrated and automated.

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References

[1] C. H. Dharmakeerthi, N. Mithulananthan and T. K. Saha, "Modeling and planning of EV fast charging station in power grid", IEEE Power Energy Soc. Gen. Meet., pp. 1-8, 2012, [Online], Available : https://ieeexplore.ieee.org/document/6345008 [Accessed 25 4 2023]

[2] C. H. Dharmakeerthi, N. Mithulananthan and T. K. Saha, "Planning of electric vehicle charging infrastructure", IEEE Power Energy Soc. Gen. Meet., pp. 1-5, 2013, [Online], Available : https://ieeexplore.ieee.org/document/6672085 [Accessed 25 4 2023]

[3] IEA (2022), Global EV Outlook 2022, IEA, Paris, [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2022. [Accessed 25 4 2023]

[4] R.Miller, M. Cardell, G.Batra, Why consumers are charging toward electric vehicles, EY Global Mobility, [Online]. Available: https://go.ey.com/3wM3onu [Accessed 25 4 2023].

[5] Directorate General for Communication, European Parliament, EU ban on the sale of new petrol and diesel cars from 2035 explained, 2023, [Online], Available: https://www.europarl.europa.eu/pdfs/news/expert/2022/11/story/20221019STO44572/20221019STO44572_en.pdf [Accessed 25 4 2023]

[6] Electric Vehicle Database, 2023, [Online], Available: https://ev-database.org/cheatsheet/range-electric-car [Accessed 25 4 2023]

[7] European Court of Auditors, Special Report 05/2021: Infrastructure for charging electric cars is too sparse in the EU, [Online], Available: https://op.europa.eu/webpub/eca/special-reports/electrical-recharging-5-2021/en/ [Accessed 25 4 2023]

[8] ChargeUp Europe based on P3 analysis , [Online], Available : https://www.chargeupeurope.eu/ [Accessed 25 4 2023]

[9] Y.-W. Wang, "An optimal location choice model for recreation-oriented scooter recharge stations", Transportation Research Part D: Transport and Environment, vol. 12, no. 3, pp. 231-237, May 2007, [Online] Available: https://www.sciencedirect.com/science/article/pii/S1361920907000223 [Accessed 26 4 2023]

[10] Y.-W. Wang, "Locating battery exchange stations to serve tourism transport: A note", Transportation Research Part D: Transport and Environment, vol. 13, no. 3, pp. 193-197, May 2008, [Online], Available : https://www.sciencedirect.com/science/article/pii/S1361920908000059 [Accessed 26 4 2023]

[11] Z. Lin, J. Ogden, Y. Fan and C.-W. W. Chen, "The fuel-travel-back approach to hydrogen station siting", Int. J. Hydrogen Energy, vol. 33, no. 12, pp. 3096-3101, Jun. 2008, [Online], Available : https://www.sciencedirect.com/science/article/pii/S0360319908001171 [Accessed 26 4 2023]

[12] Y.-W. Wang and C.-C. Lin, "Locating road-vehicle refueling stations", Transportation Research Part E: Logistics and Transportation Review, vol. 45, no. 5, pp. 821-829, Sep 2009, [Online], Available: https://www.sciencedirect.com/science/article/pii/S1366554509000313 [Accessed 26 4 2023]

[13] X. Yin and X. Zhao, "Planning of Electric Vehicle Charging Station Based on Real Time Traffic Flow", 2016 IEEE Veh. Power Propuls. Conf. VPPC 2016 - Proc., pp. 1-4, 2016, [Online], Available: https://ieeexplore.ieee.org/document/7791751 [Accessed 26 4 2023]

[14] L. Luo, W. Gu, Z. Wu and S. Zhou, "Joint planning of distributed generation and electric vehicle charging stations considering real-time charging navigation", Appl. Energy, vol. 242, pp. 1274-1284, March 2019, [Online], Available : https://www.sciencedirect.com/science/article/pii/S0306261919305707 [Accessed 26 4 2023]

[15] S. Lim a M. Kuby, "Heuristic algorithms for siting alternative-fuel stations using the Flow-Refueling Location Model", European Journal of Operational Research , zv. 204, č. 1, s. 51-61, 2010, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0377221709006717 [Accessed 26 4 2023]

[16] S. Lim and M. Kuby, "Heuristic algorithms for siting alternative-fuel stations using the Flow-Refueling Location Model", European Journal of Operational Research, vol. 204, no. 1, pp. 51-61, 2010, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0377221709006717 [Accessed 26 4 2023]

[17] Z. Zhu, Z. Gao, J. Zheng and H. Du, "Charging station location problem of plug-in electric vehicles", JTRG, vol. 52, pp. 11-22, 2016, [Online], Available : https://www.sciencedirect.com/science/article/pii/S0966692316000156 [Accessed 26 4 2023]

[18] P. Sadeghi-barzani, A. Rajabi-Ghahnavieh and H. Kazemi-Karegar, "Optimal fast charging station placing and sizing", Appl. Energy, vol. 125, pp. 289-299, 2014, [Online], Available : https://www.sciencedirect.com/science/article/pii/S0306261914003171 [Accessed 26 4 2023]

[19] J. A. Domínguez-Navarro, R. Dufo-López, J. M. Yusta-Loyo, J. S. Artal-Sevil and J. L. Bernal-Agustín, "Design of an electric vehicle fast-charging station with integration of renewable energy and storage systems", Int. J. Electr. Power Energy Syst., vol. 105, no. March 2018, pp. 46-58, Feb. 2019, [Online] Available : https://www.sciencedirect.com/science/article/pii/S0142061518308019 [Accessed 26 4 2023]

[20] K. Deb, A. Member, A. Pratap, S. Agarwal a T. Meyarivan, "A fast and elitist multi-objective genetic algorithm: NSGAII", vol. 6, č. 2, str. 182-197, 2002, [Online], Available: https://ieeexplore.ieee.org/abstract/document/996017 [Accessed 27 4 2023]

[21] KF Doerner, WJ Gutjahr a PC Nolz, "Multi-criteria location planning for public facilities in tsunami-prone coastal areas", OR Spectr., zv. 31, č. 3, str. 651-678, 2009, [Online], Available: https://link.springer.com/article/10.1007/s00291-008-0126-7 [Accessed 27 4 2023]

[22] JG Villegas, F. Palacios a AL Medaglia, "Solution methods for the bi-objective (cost-coverage) unconstrained facility location problem with an illustrative example", Ann. Oper. Res. , zv. 147, č. 1, str. 109-141, 2006, [Online], Available: https://link.springer.com/article/10.1007/s10479-006-0061-4 [Accessed 27 4 2023]

[23] V. Hajipour, P. Fattahi, M. Tavana a D. Di Caprio, "Multi-objective multi-layer congested facility location-allocation problem optimization with Pareto-based meta-heuristics", Appl. Matematika. Model. , zv. 40, č. 7–8, s. 4948-4969, 2016, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0307904X15008227 [Accessed 28 4 2023]

[24] A. Awasthi, K. Venkitusamy, S. Padmanaban, R. Selvamuthukumaran, F. Blaabjerg and A. K. Singh, "Optimal planning of electric vehicle charging station at the distribution system using hybrid optimization algorithm", Energy, vol. 133, pp. 70-78, Aug. 2017, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0360544217308514 [Accessed 28 4 2023]

[25]] H. Xu, S. Miao, C. Zhang and D. Shi, "Optimal placement of charging infrastructures for large-scale integration of pure electric vehicles into grid", Int. J. Electr. Power Energy Syst., vol. 53, no. 1, pp. 159-165, 2013, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0142061513001907 [Accessed 28 4 2023]

[26] J. He, H. Yang, T. Q. Tang and H. J. Huang, "An optimal charging station location model with the consideration of electric vehicle ' s driving range", Transp. Res. Part C, vol. 86, no. December 2016, pp. 641-654, Jan. 2018, [Online], Available:

https://www.sciencedirect.com/science/article/pii/S0968090X17303558 [Accessed 28 4 2023]

[27] A. Shukla, J. Pekny and V. Venkatasubramanian, "An optimization framework for cost effective design of refueling station infrastructure for alternative fuel vehicles", Computers & Chemical Engineering, vol. 35, no. 8, pp. 1431-1438, 2011, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0098135411001086 [Accessed 28 4 2023]

[28] J. Liu, "Electric vehicle charging infrastructure assignment and power grid impacts assessment in Beijing", Energy Policy, vol. 51, pp. 544-557, Dec 2012, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0301421512007562 [Accessed 28 4 2023]

[29] Y. Zhang, Q. Zhang, A. Farnoosh, S. Chen and Y. Li, "GIS-Based Multi-Objective Particle Swarm Optimization of charging stations for electric vehicles", Energy, vol. 169, no. 2019, pp. 844-853, Feb. 2019, [Online], Available: https://www.sciencedirect.com/science/article/pii/S0360544218324289 [Accessed 28 4 2023]

[30] S. Davidov and M. Pantoš, "Optimization model for charging infrastructure planning with electric power system reliability check", Energy, vol. 166, pp. 886-894, Jan. 2019, [Online], Available : https://www.sciencedirect.com/science/article/pii/S0360544218321467 [Accessed 28 4 2023]