ABSTRACT

The issue of global climate change has driven the energy transition from fossil fuels to more sustainable energy sources, with the transportation sector becoming a primary focus due to its significant contribution to global greenhouse gas emissions. In the national context, Indonesia has committed to achieving Net Zero Emissions by 2060, where the adoption of electric vehicles becomes one of the key strategies to reduce transportation sector emissions. However, at the local level, particularly in Banda Aceh City, the implementation of this transition faces serious infrastructure challenges in the form of limited availability of Public Electric Vehicle Charging Stations (Stasiun Pengisian Kendaraan Listrik Umum - SPKLU). Although data shows positive growth in the number of electric vehicle users in Banda Aceh, limited supporting infrastructure remains a significant barrier to broader adoption. Based on preliminary analysis, the spatial coverage of existing charging stations only reaches 66.04% of the total 53 demand points distributed across the study area, leaving 18 demand points unserved within the optimal 3.3 km radius. This condition creates what is known as range anxiety, which is users' concern about running out of battery power before reaching a charging station, ultimately hindering public intention to switch to electric vehicles.

To systematically and scientifically address this problem, this research integrates three advanced location optimization methods: Improved Set Covering Location Model (ISCLM), Voronoi Graph, and Minimum Covering Circle (MCC). The main objective of this research is to determine the optimal locations and number of new charging stations needed so that all 100% of demand points in Banda Aceh City can be served. The ISCLM approach was chosen over conventional methods such as pure Location Set Covering Problem (LSCP), pure Maximum Covering Location Problem (MCLP), and P-Center due to its ability to minimize the number of required facilities while ensuring complete coverage of all demand. ISCLM outperforms pure LSCP, which has limitations in area division for demand points in terms of proximity between facility construction points and demand points as well as determining the minimum radius of facility construction points; it is better than pure MCLP, which does not guarantee 100% coverage and may leave unserved areas; and it is superior to P-Center, which focuses on minimizing the maximum distance between demand points and the nearest facility without considering comprehensive coverage aspects. ISCLM is inherently highly efficient in resource allocation while considering distance. Furthermore, Voronoi Graph is used as an essential spatial analysis tool to efficiently partition service areas. By dividing the region into Voronoi cells, each demand point can be uniquely associated with the nearest charging station, ensuring that service coverage is based on the most optimal geographical proximity. This approach overcomes the inefficiencies of conventional methods and provides clear visualization of served and unserved areas.

Additionally, this research adopts the concept of Minimum Covering Circle (MCC). MCC functions to determine the optimal coverage radius of each proposed charging station. By identifying the smallest circle that can cover a certain number of demand points, MCC helps in placing charging stations at the most strategic positions to maximize service coverage within an efficient travel distance of 3.3 km.

The implementation of all these models is carried out using the Python programming language, where the ISCLM algorithm iteratively searches for the best locations to place new charging stations, starting with random point initialization and progressively optimizing these positions until all demand points are covered. This process also considers important data such as office locations, universities, hospitals, shopping centers, sports facilities, hotels, ports, terminals, and others.

In addition to spatial analysis, this study incorporates a financial analysis to evaluate the feasibility of the proposed charging station development. The financial assessment includes the estimation of Capital Expenditure *(CAPEX) and* Operational Expenditure *(OPEX), as well as revenue projections under different station utilization scenarios. Cash flow analysis is conducted to assess the long-term economic sustainability of the proposed charging stations. This integrated approach ensures that the recommended locations are not only spatially optimal but also financially viable for practical implementation.*

The results of the ISCLM-based optimization indicate that by adding two new charging stations at coordinates (5.542240, 95.307468) and (5.579886, 95.354833), 100% of the 53 electric vehicle demand points in Banda Aceh City can be effectively covered. Spatial visualization confirms that the newly proposed stations are strategically located to eliminate previous coverage gaps. From a financial perspective, the results indicate that the development of charging stations shows promising feasibility, particularly under moderate to high utilization scenarios, supporting sustainable long-term operation. Overall, this study demonstrates that optimal electric vehicle charging infrastructure planning requires the simultaneous integration of spatial optimization and financial feasibility analysis. The findings are expected to support decision-making for local governments and stakeholders in developing efficient, effective, and sustainable charging infrastructure in Banda Aceh City, while contributing to Indonesia's broader clean energy transition.

Keywords: Electric Vehicle, Public Electric Vehicle Charging Station, Improved Set Covering Location Model, Voronoi Graph, Minimum Covering Circle.