Jurnal Penelitian dan Aplikasi Sistem dan Teknik Industri (PASTI)
Vol. XVIII, No. 1, April 2024, 20-28
p-ISSN 2085-5869/ e-ISSN 2598-4853

Determining The Location of Charging Station Facilities in Surakarta City Using Gravity Location Models

Bekti Nugrahadi[1*], Anita Oktaviana Trisna Devi[2], Nasyita Vivi Amalia[3], Yunita Primasanti[4]
[1,2,4)] Program Studi Teknik Industri, Fakultas Sains, Teknologi dan Kesehatan, Univeritas Sahid Surakarta
Jl. Adi Sucipto No. 154, Jajar, Surakarta 57144
[3)] Program Studi Teknik Industri, Fakultas Sains dan Teknologi, Institut Teknologi dan Sains Nahdlatul Ulama Pekalongan
Jl. Karangdowo No. 9, Kedungwuni, Pekalongan, 51173
Email: bekti.nugrahadi@usahidsolo.ac.id[*], anita.otd@usahidsolo.ac.id, nasyitavivi@gmail.com, yunitaprimasanti@usahidsolo.ac.id

Abstrak

Permasalahan pada lingkungan yang diakibatkan oleh kendaraan bermotor menjadi sorotan di era modern saat ini. Berbagai cara telah dilakukan untuk mengurangi dampak lingkungan akibat kendaraan bermotor. Salah satu cara untuk mengurangi dampak negatif lingkungan yang ditimbulkan akibat kendaraan bermotor adalah dengan menggunakan kendaraan yang ramah lingkungan yaitu kendaraan elektrik. Peraturan Presiden No. 55 Tahun 2019 mendorong adanya elektrifikasi pada kendaraan bermotor di Indonesia. Untuk mendukung regulasi tersebut, perlu adanya infrastruktur untuk kelancaran dan kemudahan dalam penggunaan kendaraan elektrik. Penelitian ini bertujuan untuk menentukan lokasi *charging station* yang optimal di Kota Surakarta dengan menggunakan *gravity location models* untuk mendukung jalannya program pemerintah dalam elektrifikasi pada kendaraan. Berdasarkan perhitungan yang dilakukan, Banjarsari merupakan titik optimal untuk lokasi *charging station*.

Kata kunci: *Charging Station*; *Gravity Location Model*; Infrastruktur; Kendaraan Elektrik; Penentuan Lokasi

Abstract

Environmental problems caused by motorized vehicles are in the spotlight in the modern era. Various methods have been taken to reduce the environmental impact caused by motorized vehicles. One way to reduce the negative environmental impacts caused by motorized vehicles is to use environmentally friendly vehicles, namely electric vehicles. Presidential Regulation No. 55 of 2019 encourages the electrification of motorized vehicles in Indonesia. To support these regulations, there needs to be infrastructure for the smooth and easy use of electric vehicles. This research aims to determine the optimal charging station location in the city of Surakarta using gravity location models to support the implementation of the government program for vehicle electrification. Based on the calculations carried out, Banjarsari is the optimal point for the location of the charging station.

Keywords: *Charging Station*; *Gravity Location Models*; *Electric Vehicle*; *Location Problem*; *Infrastructure*

INTRODUCTION

Globally, the energy crisis and environmental issues are becoming increasingly severe (Li et al., 2020). Environmental challenges, such as global warming, the greenhouse effect, air pollution, and other related problems, are in the news frequently in the modern era. The use of vehicles with Internal Combustion Engine (ICE) technology or oil-fueled vehicles is one of the causes of current environmental problems. The automotive industry is rapidly moving toward zero-emission vehicles (LEVs)(Yuan & Li, 2021). Utilization of ICE-equipped automobiles will impact the utilization of gasoline derived from fossil fuels (Sadeghinezhad et al., 2014). The technology will have an impact on global environmental issues such as the energy crisis and climate change (Hamada & Rahman, 2014). Most transport pollution is caused by road transport (Osieczko et al., 2021). Because cars, trucks, airplanes, ships, and other vehicles account for around 15% of all man-made carbon dioxide, reducing emissions in transportation is a key approach in the fight against global warming(Chen et al., 2018). Many countries have begun to develop policies to promote sustainable and innovative transportation technologies in order to reduce the threat of climate change (Krishnan & Koshy, 2021).

The contemporary era's tremendous technological advancement has impacted many facets of daily living. This technology exists to make human existence more convenient and to take environmental factors into account. Electric vehicles are one of the outcomes of technical advancements that will usher in a new transportation trend. Electric vehicles, according to Guerra (2019) can help to reduce greenhouse gas emissions. The use of electric vehicles (EVs) offers the possibility of reducing greenhouse gas (GHG) and pollutant emissions from the road transportation sector, which accounts for almost 25% of global carbon dioxide (CO2) emissions (Teixeira & Sodré, 2018). The GHG emissions of EVs are 46% less than those of traditional-fuel vehicles (Puig-Samper Naranjo et al., 2021). Other advantages of implementing electric mobility include improved urban air quality and significant reductions in acoustic disturbances because EVs do not emit engine noise (Montero Romero et al., 2022). To encourage the adoption of EVs, several governments have implemented new policies that include tax reductions and financial incentives (Taljegard et al., 2019). Governments all over the world have expressed strong support for the development of EVs (Guo et al., 2021). One of the government's efforts to lessen environmental issues caused by oil-fueled vehicles in Indonesia is Presidential Regulation No. 55 of 2019 concerning the Acceleration of the Battery-Based Electric Motorized Vehicle Program for Road Transportation (Presiden Republik Indonesia, 2019). This regulation is the first step in encouraging motorized vehicle electrification in Indonesia. Presidential Instruction No. 7 of 2022 Concerning the Use of Battery-Based Electric Motorized Vehicles as Operational Service Vehicles and/or Individual Service Vehicles for Central Government Agencies and Regional Governments is another document that the government uses to regulate policies regarding the use of electric vehicles (Presiden Republik Indonesia, 2022)

To support the government's plans for motorized vehicle electrification, infrastructure that can support the program's smooth operation and success is required. Electric vehicles require charging stations as infrastructure. One of the primary concerns when implementing EV technology is the lack of public charging stations (Pal et al., 2021). A crucial component used to support electric mobility is widespread charging infrastructure (Acri et al., 2021; Osieczko et al., 2021). Determining the location of good infrastructure can provide future electric vehicle users with smoothness and convenience. Electric vehicle users are concerned about limited mileage, long charging times, and a lack of charging station locations (Haddadian et al., 2015). Currently, the range of electric vehicles ranges from 60 km to 400 km, depending on the type of vehicle, with an average range of 100 km to 160 km (Huang et al., 2016). To deal with such anxiety, the fast charging station could be the greatest solution for the public charging infrastructure (Motoaki, 2019).

According to data from the Badan Pusat Statistik (BPS), there were 20,327 motorcycles and 5,530 four-wheeled motor vehicles in the passenger car category in

Surakarta City. Meanwhile, Surakarta City has 15 electric cars and 400 electric motorcycles, both of which are expected to grow in the coming years. This study aims to identify and evaluate the location of charging stations in Surakarta City in the hopes that people will be motivated to switch to using electric vehicles because they are supported by good infrastructure. Location planning for CS is essential. One of the keys to the success of EVs is having adequate CS facilities (Asna et al., 2023). The distribution network will be negatively impacted by the improper placement of CSs, which will result in increased power losses, unstable voltage, demand-supply imbalances, etc (Deb et al., 2018). Another benefit of a successful electrification program for motorized vehicles is a reduction in carbon dioxide emissions and air pollution in the city of Surakarta.

The following studies have been conducted in order to determine the location of infrastructure:

Research entitled determination of the charging station facility location-allocation model by considering the closest distance: case study in Solo City. This study considers the shortest distance when determining the location of charging station facilities for three-wheeled electric vehicles (Nugrahadi et al., 2020).

Research entitled integration of supply chain network design model for feasibility evaluation of e-trike vehicle charging station facilities: a case study. This study discusses how supply chain models and feasibility studies can be combined to build three-wheeled electric vehicle charging stations (Nugrahadi et al., 2021).

Research entitled development of location-allocation model of network design for battery swapping station and battery charging station facilities for e-trike and e-motorcycle. This study looks at where charging stations and battery swapping stations for three-wheeled electric vehicles should be located (Wibisono et al., 2022).

METHOD

Electric vehicles are a new motorized vehicle technology that is still uncommon in Indonesia. An electric vehicle is a mode of transportation that is powered by electricity (dynamo/electric motor). The battery, electric motor, and charger are an electric vehicle's primary components. There are several types of electric vehicles that can be used for transportation, including cars, motorcycles, and bicycles. Electric vehicles have several advantages over ICE-type vehicles, including lower ownership and maintenance costs and being more environmentally friendly. Technological advances in electric vehicles and batteries can provide environmentally friendly, energy-efficient transportation solutions with low operating and maintenance costs (Sutopo et al., 2013).

A charging station is a location where electric vehicles can be charged. The charging station can be placed in both public and private spaces. Charging stations are classified into two types: AC and DC. Normal charging is typically done with an AC type, while fast charging with a power range of 22 kW to 150 kW is done with a DC type in public places.

Gravity location models are used to determine the location of a facility that serves as a link between various sources of supply and market locations (Pujawan & Er, 2017). The goal of this model is to find a location with the lowest transportation costs. Several studies have used this method to determine the location of facilities (Dock et al., 2015; khosravi & Akbari Jokar, 2017; Mawadati et al., 2020). The gravity location model makes several assumptions, including that transportation costs increase linearly with volume moved and that the location of supply sources can be determined using the x and y coordinates. This model requires data such as transportation costs per unit, load per unit distance, volume moved, and supply and market location coordinates. The following is the notation used:

C_i : Costs of transportation between candidate facility locations and supply locations, per unit load, per kilometer.
V_i : The load that needs to be moved between the facility and the supply source.
(x_i, y_i) : The x and y coordinates of the supply source i.
J_i : Distance between facility location and supply source i.

In this model, the distance between two points is calculated as the geometric distance between them, which is calculated using the formula below:

$$j_i = \sqrt{(x_0 - x_i)^2} + (y_0 - y_i)^2 \quad (1)$$

(x_0, y_0) is the facility's candidate coordinate. The goal of this model is to find a facility location that has the lowest total shipping cost, which can be expressed as:

$$TC = \sum_i C_i V_i J_i \quad (2)$$

Three steps are required to obtain the optimal (x_0,y_0) value that minimizes the total cost of sending TC:

1. Find the ji distance for each i (i.e. between the candidate facility location and supply source location i).
2. Use the following formula to determine the location coordinates:

$$x_{0n} = \frac{\sum_i \frac{C_i V_i x_i}{j_i}}{\sum_i \frac{C_i V_i}{j_i}} \quad y_{0n} = \frac{\sum_i \frac{C_i V_i y_i}{j_i}}{\sum_i \frac{C_i V_i}{j_i}} \quad (3)$$

This iteration's x and y coordinates are represented by x_{0n} and y_{0n}, respectively.

3. Stop the iteration and choose that coordinate as the location of the facility if two subsequent iterations yield nearly identical coordinates. If not, go back to step 1 and repeat the iteration.

RESULT AND DISCUSSION

The data used in this study include the coordinates of each supply source, transportation costs, load volume, and distance between supply sources. Google Maps was used to obtain coordinate points for supply sources, while secondary data was used for other data. In this study, the supply source is the Surakarta City sub-district. Table 1 shows the coordinates of each sub-district, the load volume, and the transportation costs.

Table 1. Sub-district coordinate points in Surakarta

Sub-district	Coordinate Points			
	X	Y	V	C
Laweyan	110.7757168	-7.5608736	40	170
Banjarsari	110.8000438	-7.5471906	160	170
Serengan	110.7989848	-7.5819557	20	170
Jebres	110.8310473	-7.5541726	160	170
Pasar Kliwon	110.8147188	-7.5799066	20	170

Table 2. Iteration 1 with Starting Point (0,0)

Sub-district	X_i	Y_i	J_i	V_i	C_i	$V_iC_iX_i/J_i$	$V_iC_iY_i/J_i$	V_iC_i/J_i
Laweyan	110,7757	-7,5609	111,0335	40	170	6784,213	-463,049	61,24278
Banjarsari	110,8000	-7,5472	111,0568	160	170	27137,12	-1848,46	244,9197
Serengan	110,7990	-7,5820	111,0581	20	170	3392,067	-232,119	30,61461
Jebres	110,8310	-7,5542	111,0882	160	170	27137,04	-1849,64	244,8505
Pasar Kliwon	110,8147	-7,5799	111,0737	20	170	3392,073	-232,023	30,61031
		Total				67842,5	-4625,29	612,2379

To figure out the optimal location for the charging station, the X and Y points as candidate coordinates for the facilities under consideration must be calculated several times. Table 2 shows these iterations. Based on the first iteration with the coordinate (0,0), the new X and Y values are as follows:

$$x_{0n} = \frac{67842,5}{612,2379} = 110,8107$$
$$y_{0n} = \frac{-4625,29}{612,2379} = -7,54473$$

The new X and Y values will be used as the starting point for the coordinates in the second iteration calculation, as shown in Table 3. The coordinates of the X and Y values can be obtained in the second iteration as follows:

$$x_{0n} = \frac{431293342,9}{3892190} = 110,809$$
$$y_{0n} = \frac{-29396319,7}{3892190} = -7,55264$$

Furthermore, the coordinates are used as the starting point in the third iteration, as shown in Table 4. The third iteration generates new X and Y coordinates as shown below:

$$x_{0n} = \frac{455891261,2}{4114209} = 110,809$$
$$y_{0n} = \frac{-31070096,12}{4114209} = -7,5519$$

Table 3. Iteration 2 with Starting Point (110.8107; - 7, 54473)

Sub-District	X_i	Y_i	J_i	V_i	C_i	$V_iC_iX_i/J_i$	$V_iC_iY_i/J_i$	V_iC_i/J_i
Laweyan	110,7757	-7,5609	0,0355	40	170	21219010,54	-1448280,014	191549,3
Banjarsari	110,8000	-7,5472	0,013	160	170	231827784	-15791044,95	2092308
Serengan	110,7990	-7,5820	0,024	20	170	15696522,85	-1074110,391	141666,7
Jebres	110,8310	-7,5542	0,0204	160	170	147774729,7	-10072230,13	1333333
Pasar Kliwon	110,8147	-7,5799	0,0255	20	170	14775295,84	-1010654,213	133333,3
		Total				431293342,9	-29396319,7	3892190

Table 4. Iteration 3 with Starting Point (110,809; - 7,55264)

Sub-district	X_i	Y_i	J_i	V_i	C_i	$V_iC_iX_i/J_i$	$V_iC_iY_i/J_i$	V_iC_i/J_i
Laweyan	110,7757	-7,5609	0,0352	40	170	21399854,38	-1460623,309	193181,8
Banjarsari	110,8000	-7,5472	0,0113	160	170	266704530,2	-18166688,88	2407080
Serengan	110,7990	-7,5820	0,0313	20	170	12035672,47	-823599,0217	108626,2
Jebres	110,8310	-7,5542	0,0212	160	170	142198324,8	-9692145,977	1283019
Pasar Kliwon	110,8147	-7,5799	0,0278	20	170	13552879,28	-927038,9367	122302,2
Total						455891261,2	-31070096,12	4114209

The third iteration's coordinates produce the same point as the previous iteration, so that point is considered the optimal charging station location. Figure 1 below shows the location of the charging station as calculated by the Gravity Location Model.

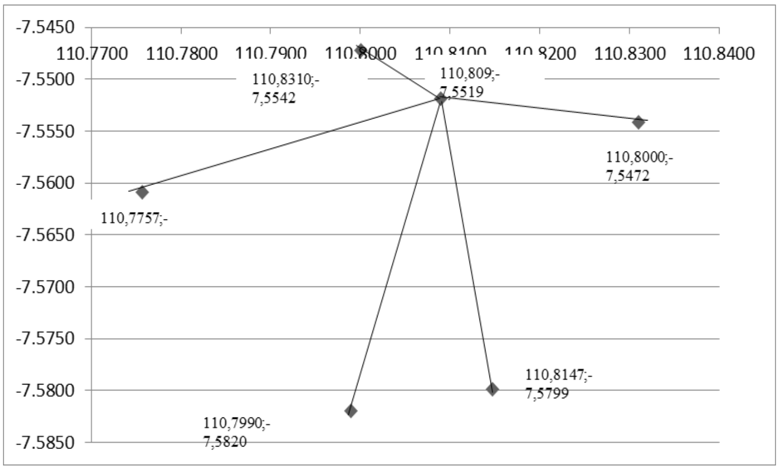

Figure 1. Charging Station Location Points Calculation Results Using the Gravity Location Model

The coordinates (110.808; -7.5519) are obtained using the Gravity Location Model and indicate the location in Banjarsari District. Figure 2 shows the charging station's location.

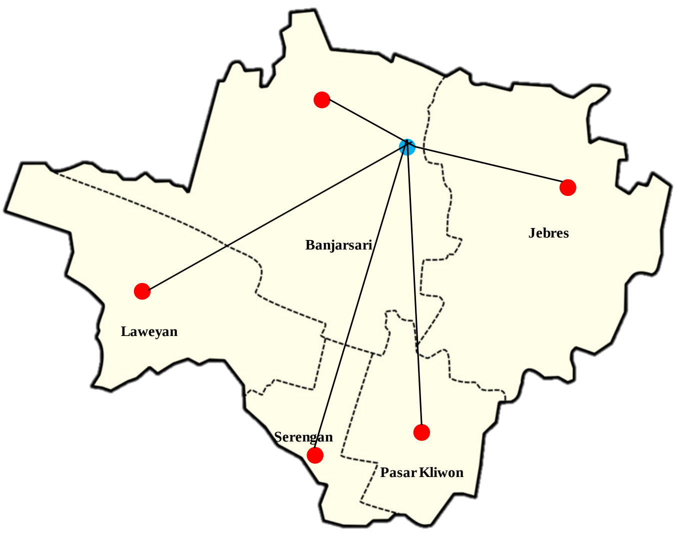

Figure 2. Location of Charging Station

CONCLUSION

Using the gravity location model, this study obtained the coordinates for the construction of a charging station in Surakarta City; the optimal charging station location is at point (110.809, -7.5519). The data used include the coordinates of Surakarta's five sub-districts, the volume of loads moved, and transportation costs. The third iteration of the coordinate point iteration is considered optimal as the coordinate point for the charging station construction site.

REFERENCES

Acri, R. A., Barone, S., Cambula, P., Cecchini, V., Falvo, M. C., Lepore, J., Manganelli, M., & Santi, F. (2021). Forecast of the demand for electric mobility for rome–fiumicino international airport. *Energies*, *14*(17). https://doi.org/10.3390/en14175251

Asna, M., Shareef, H., & Prasanthi, A. (2023). Planning of fast charging stations with consideration of EV user, distribution network and station operation. *Energy Reports*, *9*, 455–462. https://doi.org/10.1016/j.egyr.2023.01.063

Chen, Y. W., Cheng, C. Y., Li, S. F., & Yu, C. H. (2018). Location optimization for multiple types of charging stations for electric scooters. *Applied Soft Computing Journal*, *67*, 519–528. https://doi.org/10.1016/j.asoc.2018.02.038

Deb, S., Tammi, K., Kalita, K., & Mahanta, P. (2018). Impact of electric vehicle charging station load on distribution network. *Energies*, *11*(1), 1–25. https://doi.org/10.3390/en11010178

Dock, J. P., Song, W., & Lu, J. (2015). Evaluation of dine-in restaurant location and competitiveness: Applications of gravity modeling in Jefferson County, Kentucky. *Applied Geography*, *60*, 204–209. https://doi.org/10.1016/j.apgeog.2014.11.008

Guerra, E. (2019). Electric vehicles, air pollution, and the motorcycle city: A stated preference survey of consumers' willingness to adopt electric motorcycles in Solo, Indonesia. *Transportation Research Part D: Transport and Environment*, *68*(July), 52–64. https://doi.org/10.1016/j.trd.2017.07.027

Guo, S., Qiu, Z., Xiao, C., Liao, H., Huang, Y., Lei, T., Wu, D., & Jiang, Q. (2021). A multi-level vehicle-to-grid optimal scheduling approach with EV economic dispatching model. *Energy Reports*, *7*, 22–37. https://doi.org/10.1016/j.egyr.2021.10.058

Haddadian, G., Khodayar, M., & Shahidehpour, M. (2015). Accelerating the Global Adoption of Electric Vehicles: Barriers and Drivers. *Electricity Journal*, *28*(10), 53–68. https://doi.org/10.1016/j.tej.2015.11.011

Hamada, K. I., & Rahman, M. . (2014). an Experimental Study for Performance and Emissions of a. *International Journal of Automative and Mechanical Engineering (IJAME)*, *10*(December), 1852–1865.

Huang, K., Kanaroglou, P., & Zhang, X. (2016). The design of electric vehicle charging network. *Transportation Research Part D: Transport and Environment*, *49*, 1–17. https://doi.org/10.1016/j.trd.2016.08.028

khosravi, S., & Akbari Jokar, M. R. (2017). Facility and hub location model based on gravity rule. *Computers and Industrial Engineering*, *109*(April), 28–38. https://doi.org/10.1016/j.cie.2017.04.005

Krishnan, V. V., & Koshy, B. I. (2021). Evaluating the factors influencing purchase intention of electric vehicles in households owning conventional vehicles. *Case Studies on Transport Policy*, *9*(3), 1122–1129. https://doi.org/10.1016/j.cstp.2021.05.013

Li, J., Hu, D., Mu, G., Wang, S., Zhang, Z., Zhang, X., Lv, X., Li, D., & Wang, J. (2020). Optimal control strategy for large-scale VRB energy storage auxiliary power system in peak shaving. *International Journal of Electrical Power and Energy Systems*, *120*(November 2019), 106007. https://doi.org/10.1016/j.ijepes.2020.106007

Mawadati, A., Purba, J. S., & Simanjutak, R. A. (2020). Penentuan Lokasi Fasilitas Gudang dengan Metode Gravity Location Models. *Journal of Industrial and Engineering System*, *1*(2), 121–126. https://doi.org/10.31599/jies.v1i2.354

Montero Romero, A., Di Martino, A., Longo, M., Barelli, L., & Zaninelli, D. (2022). Full Implementation of Electric Mobility in a Countryside Region of Spain. *Energies*, *15*(17), 1–19. https://doi.org/10.3390/en15176336

Motoaki, Y. (2019). *Location-Allocation of Electric Vehicle Fast Chargers — Research and Practice †*. 10–16. https://doi.org/10.3390/wevj10010012

Nugrahadi, B., Sutopo, W., & Hisjam, M. (2020). Determination of the Charging Station Facility Location-Allocation Model by Considering the Closest Distance: Case Study in Solo City. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3429789.3429848

Nugrahadi, B., Sutopo, W., & Hisjam, M. (2021). *Integration of Supply Chain Network Design Model for Feasibility Evaluation of E-Trike Vehicle Charging Station Facilities : A Case Study*.

Osieczko, K., Zimon, D., Płaczek, E., & Prokopiuk, I. (2021). Factors that influence the expansion of electric delivery vehicles and trucks in EU countries. *Journal of Environmental Management*, *296*(April). https://doi.org/10.1016/j.jenvman.2021.113177

Pal, A., Bhattacharya, A., & Chakraborty, A. K. (2021). Placement of Public Fast-Charging Station and Solar Distributed Generation with Battery Energy Storage in Distribution Network Considering Uncertainties and Traffic Congestion. *Journal of Energy Storage*, *41*(April), 102939. https://doi.org/10.1016/j.est.2021.102939

Presiden Republik Indonesia. (2019). Peraturan Presiden Nomor 55 Tahun 2019 Tentang Percepatan program Kendaraan Bermotor Listrik Berbasis Baterai (Battery Electric Vehicle) Untuk Transportasi Jalan. *Republik Indonesia*, *55*, 1–22.

Presiden Republik Indonesia. (2022). *Instruksi Presiden Nomor 7 Tahun 2022 Tentang Penggunaan Kendaraan Bermotor Listrik Berbasis Baterai (Battery Electric Vehicle) Sebagai Kendaraan Dinas Operasional dan/atau Kendaraan Perorangan Dinas Instansi Pemerintah Pusat dan Pemerintahan Daerah*. *141403*, 2. https://jdih.setneg.go.id/

Puig-Samper Naranjo, G., Bolonio, D., Ortega, M. F., & García-Martínez, M. J. (2021). Comparative life cycle assessment of conventional, electric and hybrid passenger vehicles in Spain. *Journal of Cleaner Production*, *291*, 125883. https://doi.org/10.1016/j.jclepro.2021.125883

Pujawan, I. N., & Er, M. (2017). *Supply Chain Management Edisi 3*. ANDI.

Sadeghinezhad, E., Kazi, S. N., Sadeghinejad, F., Badarudin, A., Mehrali, M., Sadri, R., & Reza Safaei, M. (2014). A comprehensive literature review of bio-fuel performance in internal combustion engine and relevant costs involvement. *Renewable and Sustainable Energy Reviews*, *30*, 29–44. https://doi.org/10.1016/j.rser.2013.09.022

Sutopo, W., Astuti, R. W., Purwanto, A., & Nizam, M. (2013). Commercialization model of new technology lithium ion battery: A case study for smart electrical vehicle. *Proceedings of the 2013 Joint International Conference on Rural Information and Communication Technology and Electric-Vehicle Technology, RICT and ICEV-T 2013*. https://doi.org/10.1109/rICT-ICeVT.2013.6741511

Taljegard, M., Göransson, L., Odenberger, M., & Johnsson, F. (2019). Impacts of electric vehicles on the electricity generation portfolio – A Scandinavian-German case study.

Applied Energy, *235*(March 2018), 1637–1650. https://doi.org/10.1016/j.apenergy.2018.10.133

Teixeira, A. C. R., & Sodré, J. R. (2018). Impacts of replacement of engine powered vehicles by electric vehicles on energy consumption and CO2 emissions. *Transportation Research Part D: Transport and Environment*, *59*, 375–384. https://doi.org/10.1016/j.trd.2018.01.004

Wibisono, I. B., Maret, U. S., Nugrahadi, B., Surakarta, U. S., Sutopo, W., Engineering, I., & Maret, U. S. (2022). *Development of Location-Allocation Model of Network Design for Battery Swapping Station and Battery Charging Station Facilities for E-Trike and E-Motorcycle*.

Yuan, X., & Li, X. (2021). Mapping the technology diffusion of battery electric vehicle based on patent analysis: A perspective of global innovation systems. *Energy*, *222*, 119897. https://doi.org/10.1016/j.energy.2021.119897