Optimization of Public Transportation Nodes in the Implementation of Electric Vehicle-Based Green Infrastructure to Realize a Green City in the Nusantara Capital Region Through Implementation of Renewable Energy

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ABSTRACT

Law Number 3 of 2022 is the legal basis for moving the National Capital from DKI Jakarta to Sepaku, East Kalimantan, which is called the Capital City of the Archipelago (IKN). To prevent serious emissions cases from recurring in the capital city of Jakarta, the low emission zone concept needs to be implemented to achieve a smart and green city area in IKN. Community mobility in IKN is directed at 80% to use public transportation with an access time of 10 minutes to public transportation nodes, so that with the large area of IKN it is very necessary to optimize the development of public transportation nodes. This research aims to determine the use of the type of electric vehicle with the lowest emissions and determine the optimal number of bus terminal mapping, so that it can reduce emissions due to transportation activities and create financial savings in the process of installing solar panels as a means of converting renewable energy sources at each bus terminal in the IKN area. This research method was carried out by studying a literature review regarding electric vehicles and using the set covering problem method in determining the optimal number of bus terminals, as well as using the interview method to obtain primary data. BEV type electric vehicles are most suitable for use in IKN, because they emit fewer emissions than other types. In creating optimization, there are six bus terminal construction locations that can serve other areas in IKN.

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KEYWORDS
Optimization,
Electric Vehicle,
Solver,
Set covering problem,
Renewable energy

1. Introduction

Indonesia is one of the developing countries that has quite high levels of greenhouse gas emissions. Law Number 32 of 2009 article 1 paragraph 12 concerning Environmental Pollution explains pollution caused by human activities such as pollution originating from factories, motorized vehicles [1]. Since 2019, the sector that has been the largest contributor to greenhouse gas (GHG) emissions in Indonesia is the energy sector (45.7%), the electricity generation sector contributed 35%, followed by the transportation and industrial sectors with 27% GHG each [2]. Quoting from the world air quality report from IQAir 2021, in the ASEAN region, Indonesia is at the top of the most polluted countries, while if you look at all countries in the world, Indonesia is in 17th place

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with the worst air pollution in the world with the highest concentration of PM2.5 namely 34.3 g/m3. The transportation sector is still a large component in contributing to the greenhouse gas effect due to exhaust gas pollution [3].

Table 1. Number of Motor Vehicle Developments by Type from 2019 to 2021 (Source: Central Statistics Agency of the Republic of Indonesia)

Type of Motor Vehicle	**Development of the Number of Motorized Vehicles by Type (Unit)**		
	2019	**2020**	**2021**
Passenger car	15.592.419	15.797.746	16.413.348
Bus Car	231.569	233.261	237.566
Freight cars	5.021.888	5.083.405	5.299.361
Motorcycle	112.771.136	115.023.039	120.042.298
Amount	133.617.012	136.137.451	141.992.573

Data on the development of motorized vehicles in Indonesia seen from 2019 - 2021 has increased by 6%, this condition results in the still high number of freely circulating emissions from motorized vehicles [4]. DKI Jakarta as the National Capital has very high transportation mobility because it is the center of state government, ownership and use of private vehicles such as motorbikes and cars is a high factor contributing to pollution in the capital area [5]. In connection with the policy of moving the National Capital in accordance with Law Number 3 of 2022 concerning the National Capital (IKN) of the Archipelago, namely moving the national capital from Jakarta to East Kalimantan is a challenge for the government in implementing better transportation policies compared to the transportation system in The capital city is Jakarta because the capital city of the archipelago will be projected as Indonesia's gold transportation with implementation*low emission zone* with optimization*electric vehicle* and use of public transportation [6].

The basic principle regarding the outreach system for public transportation system services by the community in the IKN area is within 10 minutes to each point, so there is a need for optimal mapping in determining the location of public transportation service points. Public transportation will reduce congestion and pollution caused by motor vehicle exhaust gases [7]. Buses are one type of public transportation that is widely used by people as public transportation to move to their destination at a more affordable cost. The development of buses in Indonesia continues to progress with the arrival of electric buses as an effort to reduce high levels of pollution, especially from motor vehicle emissions [8]. The IKN area will be conceptualized as an environmentally friendly city by utilizing renewable energy sources, so the inclusion of public transportation such as electric buses will really support this plan.

2. Method

The following is a flow diagram of the research conducted.

Figure 1. Research Flow Chart

The research method used was a systematic data collection technique, starting from a literature study regarding public issues and regulations*electric vehicle*, solar panels, as well as methods *set covering problem* and*solver*. Next, collect secondary data related to distance data between villages in Sepaku District. Then conduct interviews to obtain primary data. Next, calculate the costs incurred for installing solar panels on the terminal and compare them with the electricity costs using electricity from PLN. Then, the bus terminal mapping optimization calculation is carried out using the method *set covering problem* with *solver excel* and calculation of solar panel installation costs for the entire terminal at IKN.

3. Results and Discussion

The relocation of the new National Capital which was established in the North Penajam Paser Regency area and parts of the Kutai Regency area has the concept of a new city which will become the center of efficient and effective government governance, modern with international standards, smart city, beautiful, green and sustainable and will become a symbol of national identity, as well as becoming an environmentally friendly city (forest city) [9]. One of the aims of moving the country's capital to Kalimantan is because it is a strategic location in the middle of Indonesia. Administratively, the Archipelago Capital region consists of two existing regions, namely Penajem Pasar Utara Regency and Kutai Kartanegara Regency [10].

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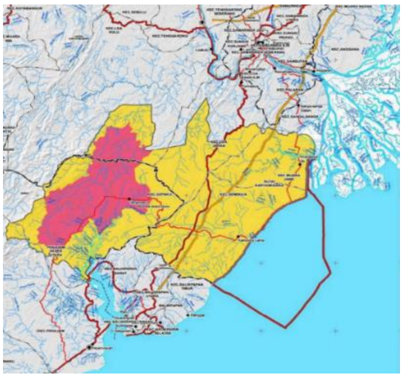

Figure 2. Location map of the Indonesian capital

Presidential Regulation no. 55/2019 concerning Acceleration of the Battery-Based Electric Motor Vehicle Program (*Battery Electric Vehicle*), is the basis for the distribution of electric vehicles in Indonesia with the aim of reducing the high level of pollution in Indonesia, especially in big cities [11]. Currently there are several types of electric vehicles on the market, starting from type*Hybrid Electric Vehicle* (ALL), *Plug-In Hybrid Electric Vehicle* (PHEV), *Fuel Cell Electric Vehicle* (FCEV), *dan Battery Electric Vehicle* (BEV) [12].

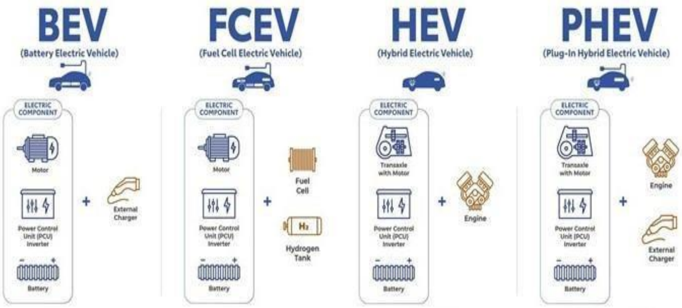

Figure 3. Types of Electric Vehicles

The scheme being proposed in the capital of the archipelago will later implement an area with the creation of an environmental sustainability program of at least 75%, so that all modes of transportation in the IKN in the future must contribute low emissions so that the severity of pollution caused by the current distribution of transportation in the national capital area does not happen again. [13]. Supporting this scheme, the type of electric vehicle that is very suitable for mobility in the IKN area is *Battery Electric Vehicle* (BEV) because according to a study by the Ministry of Energy and Mineral Resources, the pure BEV type is powered by battery-based electricity and emits 5 grams of CO2 per kilometer, while the*hybrid* such as PHEV and HEV use a collaboration between electrical energy and conventional engines so they still cause pollution to the surrounding environment by emitting carbon emissions of around 80 grams of CO2 per kilometer.

The public transportation sector is very supportive in efforts to create low-emission cities or*green city*, because the public transportation sector can transport dozens of people and goods each way [14]. In accordance with the IKN master plan, the Indonesian capital region will carry out the principle of 80% of people's movements using public transportation or active mobility [15]. The construction of public transportation locations in the IKN area, especially the future bus terminal, is designed based on the use of sustainable clean energy. The concept of a public transportation system in the capital city of the archipelago is to effectively use electric buses.

Figure 4. Skywell Electric Bus Type NJL6129BEV

The Skywell electric bus Type NJL6129BEV is one type of electric bus imported by Indonesia to meet public transportation needs with a low emission concept PT. KLI as the importer and operator of the bus claims that the bus can cover a distance of 352 km if used until the SOC (State of Charge) capacity reaches 0% and uses an LFP (lithium ferrophosphate) battery type with a total battery capacity of 322 kWh which is divided into 10 packs. battery [16].

Table 1. Skywell Electric Bus Battery Specifications Type NJL6129BEV

Battery Specifications	
Battery Type	LiFePO4
Battery Capacity	322 kWh
Battery Model LiFePO4	C10LY4-2P8S
Number of Battery Packs	10 Pack
Voltase Single Pack	153.6 volts/pack
Single Pack Capacity	32,256 kWh

Based on the Decree of the Minister of Energy and Mineral Resources No 188.K/HK.02/MEM. L/2021 of 2021 concerning the Ratification of the Business Plan for the Supply of Electricity of PT. Persero for 2021 to 2030 will support the gradual fulfillment of electricity needs in the IKN area which reaches approximately 900 MVA [17]. The government's policy to supply electricity needs in IKN from clean and renewable energy will be encouraged by the construction of hydroelectric power plants in the North Kalimantan and East Kalimantan areas, the construction of solar panels and the construction of various power plants from clean, renewable energy to supply all electrical current component channels in the IKN area.

Based on data obtained from direct inspection of the Mengwi Terminal, electricity consumption for one month is as follows.

Table 1. Mengwi Terminal Electricity Consumption (Monthly)

	LWBP			WBP		
	Pemk/Kwh	Cost Pemk	Total	Pemk/Kwh	Cost Pemk	Total
A	25,134	1,415.01	35,564,861	4,884	2,122.52	10,366,363
B						
C						
D						

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From the data above, there are twotime categories in determining electricity usage rates, namely LWBP and WBP, where each category will be subject to a different rate [18]. The following is a specific cost calculation for electricity consumption and solar panel use resulting from the application of solar panels as an energy source at each terminal to be built at IKN based on the data in Figure 5.

Operational usage (daily) = LWBP + WBP
= 25,134 kWh + 4,884 kWh
= 30,018 kWh / month
= 1000.6 kWh/day

Figure 6. Mengwi Terminal Type A

Based on the study results, electric buses have a battery capacity of 322 kWh. Then, based on the results of the interview, Mengwi Terminal can accommodate 40 buses per day, so the power requirements are as follows.

Power requirements for 40 electric buses = 332 kWh x 40 bus
= 13,280 kWh / day

Figure 7. Mengwi Terminal Waiting Room Type A

The total electrical power required in the terminal is as follows.

Electricity consumption = operational usage + total power consumption of the electric bus
= 1000.6 kWh/day + 13,280 kWh/day
= 14,280.6 kWh / day

The price of a solar panel with a capacity of 1 kWp which can produce 4 kWh of electricity is IDR. 13,200,000.00 [19]. The following is a calculation of the need for solar panels and their costs.

Solar panel costs $= \left(\frac{Total\ electricity\ demand\ at\ the\ terminal}{The\ power\ produced\ is\ 1\ kWp\ of\ solar\ panels}\right)\ x\ price\ 1\ kWp$

$= \left(\frac{14.280,6\ kWh}{4\ kWh}\right)\ x\ Rp.\ 13,200,000.00$

= 3,570.15 kWp rounded to 3,571 kWp
= 3,571 kWp x Rp. 13,200,000.00
= Rp. 47,137,200,000.00

Below we will compare the use of solar panels with the use of electricity from PLN for 25 years. This is because the usage period of solar panels reaches 25 years, so comparisons must be made for 25 years as well [20]. The calculation is as follows.

Operational electricity costs (monthly) = LWBP costs + WBP costs
= Rp. 35,564,861 + Rp. 10,366,363
= Rp. 45,931,224 / month

The scheme applied for charging electricity on buses is within the LWBP time which is in the time range from 22.00 to 18.00. However, based on observations made at the Gor Ngurah Rai bus stop, the operating hours for the Trans Metro Dewata bus start at 04.30 WITA. So, if you use LWBP time for charging electric buses, there will be time from 22.00 to 04.30 which is equivalent to 6 hours 30 minutes to charge several buses so they are ready for use. The following is the calculation of charging time for an electric bus with a capacity of 322 kWh [21].

Bus battery charging time $= \frac{bus\ battery\ capacity}{SPKLU\ capacity}$
$= \frac{322\ kWh}{200\ kW}$
$= 1{,}61\ jam$

To charge 40 electric buses and provide 8 SPKLUs in the bus terminal, each SPKLU will handle 5 buses. Then, with the charging time for one bus being 1.61 hours, at 04.30 there will be 32 fully charged electric buses available. This is the basis that the process of charging electricity on buses is carried out during LWBP. The calculation of electric power consumption and costs for 40 electric buses per day is as follows.

Electricity requirements and costs for buses = 40 buses x 322 kWh x Rp. 1,415.01/kWh
= Rp. 13,668,996.6 / day
= Rp. 410,069,898.00 / month

Therefore, the total costs for 25 years are calculated as follows.

Total cost = Operational electricity costs + Electricity costs for buses
= Rp. 45,931,224.00/month + Rp. 410,069,898.00/month
= Rp. 456,001,122.00/month
= Rp. 456,001,122.00 x 300 months
= Rp. 136,800,336,600.00

From these calculations, the savings in using solar panels are as follows.

Cost difference = total cost of using conventional energy from PLN - total cost use of solar panels
= Rp. 136,800,336,600.00 -Rp. 47,137,200,000.00
= Rp. 89,663,136,600.00

Solar panels provide savings of Rp. 89,663,136,600.00. After getting the cost of using solar panels at one station, the total costs incurred will be calculated if all eleven villages in Sepaku District have terminals built. The total cost calculation is as follows.

Total cost = number of terminals x solar panel installation cost for one terminal
= 11 x Rp. 47,137,200,000.00
= Rp. 518,509,200,000.00

Innovation in the use of solar panels will be implemented based on the principle of optimization, so that it will produce more optimal savings from the use of solar panels in each terminal, while still paying attention to policies in accordance with the IKN Master Plan in the Appendix to the IKN Law which has been drafted, where the planning of time to access the bus terminal is maximum 10 minutes from residential areas. Then the area within the IKN is an urban area, so movement activities that occur within the city will pass through roads in the urban area. According to the Minister of Transportation Regulation Number PM 111 of 2015 concerning Procedures for Determining Speed Limits, the speed limit for roads in urban areas is 50 km/hour [22]. Based on these benchmarks, the maximum distance from residential areas to the planned location for the bus terminal is as follows.

Maximum distance traveled (D_c) = speed x maximum travel time (5)

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= 50 km/h x 0.167 hours
= 8,5 km

From the calculation above, the maximum distance covered in 10 minutes at a speed of 50km/hour is 8.5 km. Because the maximum distance traveled is 8.5 km, to find out the number of transportation node locations, it is necessary to determine the distance between villages in Sepaku District which is covered by the IKN Area. Based on determining the distance on*google maps*, below is the distance matrix between villages in Sepaku District.

Table 2. Distance Matrix Between Villages in Sepaku District (Kilometers)

	Telemow	Binuang	Bumi Harapan	Bukit Raya	Karang Jinawi	Sukaraja	Tengin Baru	Suko Mulyo	Argo Mulyo	Semoi Dua	Wonosari
Telemow	0	4,1	25,9	27,5	67	26,8	36,6	48,8	45,8	45,6	53,4
Binuang	4,1	0	20,4	25,5	53,7	35,5	37,9	48,7	43,9	50,9	49,5
Bumi Harapan	25,9	20,4	0	5,2	50,7	21,1	23,5	32,4	29,5	36,5	35,1
Bukit Raya	27,5	25,5	5,2	0	45,4	25,4	19,1	32,4	29,5	36,5	35,1
Karang Jinawi	67	53,7	50,7	45,4	0	11,5	33,1	55,1	52,2	59,2	57,8
Sukaraja	26,8	35,5	21,1	25,4	11,5	0	11,1	10,8	21	28	26,6
Tengin Baru	36,6	37,9	23,5	19,1	33,1	11,1	0	8,2	7,8	21	18,9
Suko Mulyo	48,8	48,7	32,4	32,4	55,1	10,8	8,2	0	15,7	28,9	20,7
Argo Mulyo	45,8	43,9	29,5	29,5	52,2	21	7,8	15,7	0	14,2	13
Semoi Dua	45,6	50,9	36,5	36,5	59,2	28	21	28,9	14,2	0	8
Wonosari	53,4	49,5	35,1	35,1	57,8	26,6	18,9	20,7	13	8	0

Based on this distance matrix, the distance between villages can be determined below or equal to 8.5 km. The determination is done automatically using a function*if* in Excel by creating a new table that has the same format and comparing the same cells in the distance between villages from table 2 with the new table. If the distance between villages is below or equal to 8.5 km, then the value in the table will change to 1. However, if the distance between villages exceeds 8.5 km, then the value in the table is 0. Next, the parameters will be determined in*solver* in solving the problem.

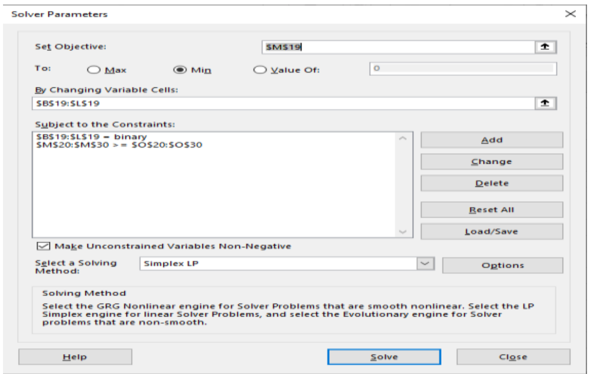

Figure 9. Parameters on*Solver*

Based on formula (2), *set objective* or the objective function is the minimum number of bus terminals obtained from the sum of each X_j Which values 1 and 0 on the row*select*, where is index*j* is an element of the set of numbers J [23]. *By changing variable cells* is a select line that works to minimize the amount of X variables$_j$ which was selected as a bus terminal in accordance with the principle of optimization. Next, the logic of determining the constraint function or*constraints* on*solver* is based on formulas (3) and (4). In accordance with formula (3), cells M20 to cell M30 must be greater than cells O20 to O30, which means that each location is at least served by one other location and mathematically it will ensure that the value of the amount$_j$, with index*j* is an element of the set of N numbers$_i$ must be in a condition with a value greater than or equal to 1, so that each location can be reached by a bus terminal that can be accessed within 10 minutes. To implement formula (4) into the problem, cells B19 to cell L19 are rows*select* which determines whether on X_j whether a bus terminal will be built or not, so it uses binary numbers with values 1 and 0. This binary number will help determine the decision whether a bus terminal will be built at that location or not. Because the bus terminal optimization problem is a form of linear programming problem to find the minimum number, the solution can be solved using a method*simplex LP* [24].

Figure 10. Location Mapping Results and Optimal Number of Bus Terminals

	Telemow	Binuang	Bumi Harapan	Bukit Raya	Karang Jinawi	Sukaraja	Tengin Baru	Suko Mulyo	Argo Mulyo	Semoi Dua	Wonosari	jumlah optimal	Setiap lokasi minimal terlayani oleh 1 lokasi lainnya	
select	1	0	1	0	1	1	1	0	0	1	0	6		
Telemow	1	1	0	0	0	0	0	0	0	0	0	1	≥	1
Binuang	1	1	0	0	0	0	0	0	0	0	0	1	≥	1
Bumi Harapan	0	0	1	1	0	0	0	0	0	0	0	1	≥	1
Bukit Raya	0	0	1	1	0	0	0	0	0	0	0	1	≥	1
Karang Jinawi	0	0	0	0	1	0	0	0	0	0	0	1	≥	1
Sukaraja	0	0	0	0	0	1	0	0	0	0	0	1	≥	1
Tengin Baru	0	0	0	0	0	0	1	1	1	0	0	1	≥	1
Suko Mulyo	0	0	0	0	0	0	1	1	0	0	0	1	≥	1
Argo Mulyo	0	0	0	0	0	0	1	0	1	0	0	1	≥	1
Semoi Dua	0	0	0	0	0	0	0	0	0	1	1	1	≥	1
Wonosari	0	0	0	0	0	0	0	0	0	1	1	1	≥	1

From the calculation results*solver* above, number 1 on the line*select* shows locations that are suitable for construction based on the maximum distance traveled, namely 8.5 km. So, it can be determined that the optimum number of planned bus terminals needed is in six locations, namely in Telemowo Village, Bumi Harapan Village, Karang Jinawi Village, Sukaraja Village, Tengin Baru Village, and Semoi Dua Village. If the optimal number of bus terminals to be built is known, then calculations will be made regarding the cost of installing solar panels at the six terminals, which are as follows.

Total cost = number of terminals x solar panel installation cost for one terminal
= 6 x Rp. 47,137,200,000.00
= Rp. 282,823,200,000.00

The savings obtained from the optimization scheme are as follows.

Savings = total cost of solar panels for 11 stations - total cost of solar panels for 6 stations
= Rp. 518,509,200,000.00 - Rp. 282,823,200,000.00
= Rp. 235,686,000,000.00

So, savings can be obtained by applying the concept of optimizing bus terminal mapping with methods*set covering problem* is IDR. 235,686,000,000.00.

4. Conclusion

Planning for mapping the optimal number of bus terminals using the method*set covering problem* can support regional achievement*green city* by carrying out the concept of efficiency and effectiveness of green infrastructure development in IKN, especially in Sepaku District, so that it can support the goals of developing the use of existing renewable energy sources. This is because;

a) Application of transportation*electric vehicle* based on electric buses to support the use of public transportation will be a solution to the current case of high emissions from motorized vehicles, especially in the IKN area.
b) The use of solar panels as an application of renewable energy provides cost savings of IDR.

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89,663,136,000.00 when compared to the use of electrical energy from non-renewable energy sources produced by PLN.

c) Based on the planning results obtained, bus terminals can be built in six village locations, namely Telemowo Village, Bumi Harapan Village, Karang Jinawi Village, Sukaraja Village, Tengin Baru Village, and Semoi Dua Village, and from the calculation results, the implementation of the optimization scheme provides cost savings amounting to Rp. 235,686,000,000.00.

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