This document will explain the analysis on the required grid capacity to fully electrify two-wheelers ride hailing fleet in Greater Jakarta and strategy to incorporate renewable energy sources.

Road Map and Timetable of Two-Wheeler Electrification in Greater Jakarta

Grid Analysis and Renewable Energy Integration Strategy

31/03/2022

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1. Introduction

This report (Task 4.6) is part of a larger plan, namely "Output 4", that aims to provide policy recommendations to support electric two wheelers penetration on a local and national scale, especially for ride-hailing companies. In this task, it specifically focuses on quantifying the impacts to the grid network and local grid infrastructure, and also estimating the optimal solar PV capacity to be integrated to the charging system. The analysis has been especially benefited by the inputs from the state-owned utility - Perusahaan Listrik Negara (PLN) - especially on electricity supply-demand balance.

1.1. Objectives

This task mainly gets its inputs from the previous report (Task 3.3) outputs which are the number of electric two wheelers that will be converted and also the charging network and system that support them, in this case, it will be strictly battery swap stations. Based on that information, the grid and solar PV integration analysis can be done. Specifically, this report aims to deliver the following objectives:

- Estimate the optimal capacity of **solar PV to be installed with the battery swap station**
- Assess the existing and forecasted electricity supply if it can cover the additional load coming from **electric two wheelers charging**
- Determine the required substations capacity and density in areas **where the battery swap stations will be installed**
- List other local electricity infrastructure that needs to be upgraded to cater to the charging load

1.2. Scope of Analysis

The analysis in this task is limited to the following constraints:

- The area investigated is Greater Jakarta, the operational area of ride-hailing companies
- The fleet to electrify in this case is two-wheelers (motorcycles) that are used by the ride-hailing drivers
- The charging strategy used is a combination of overnight and on-the-road charging
- The charging system utilises a network of battery swap stations across the region. They are grouped based on the location that they are installed in
- The battery swap station is assumed to follow one archetype which has designated canopy to install solar PV

- Solar PV capacity for each swap station is determined through techno-financial analysis that aims to suppress cost

1.3. Report Structure

This report is structured as follows:

- **Section 2** shows an overview of electric two wheelers types and charging scenarios that are used as the basis of the analysis
- **Section 3** provides the methodology, assumptions and data input used to run the analysis, including solar PV integration, charging scheduling and requirements, and grid analysis
- **Section 4** presents the results of the solar PV potential assessment, optimal capacity and also the charging load curve
- **Section 5** gives an analysis of the supply and demand condition of the electricity in Greater Jakarta area
- **Section 6** details the local grid infrastructure requirements
- **Section 7** lays out the findings and conclusion of the report

2. Overview on Electric Two Wheelers Charging

This section gives an overview of the charging strategies and the vehicle types available for electric two wheelers deployment. Additionally, this section will also look into the options to integrate solar PV to the charging system and shows a schematic diagram of a swap station that will be used as a benchmark for the analysis.

2.1. Electric Two Wheelers Charging Overview

Charging electric two wheelers can be done in two ways: 1) traditional plug-in, 2) battery swap. Generally, there are two types of plug-in chargers available for electric two wheelers: slow and fast chargers. The former uses an AC power and it takes quite some time to fully charge the batteries. The most common ones are the three-pin plug that can be connected to normal power sockets. They usually contain voltage up to 220 volts and connected on a 1.5A socket, which gives around 350 W of power. Hence, charging an average electric two-wheeler battery will take 3-4 hours at home. Another slow charger type also uses AC power, yet it can support power capacity from 3.7 kW - 7 kW. This one is rarely used in Indonesia currently. The latter type - fast chargers - has been used by several players, namely Ola Electric and Ather Energy. They use CCS (Combined Charging System) type that allow DC power inputs up to 350 kW of power to the batteries. However, not all electric two-wheelers can be charged with this setup in Indonesia.

On the other hand, a battery swap station consists of several battery slots that are equipped with chargers to fully charge the batteries when they are put in the slot. The charging can take around 3-4 hours (assuming slow charging) and when the batteries are charged, they will queue until the drivers swap the batteries. The battery swap stations are seen as more viable especially for ride-hailing drivers that need fast charging for their batteries. While there are fast charging stations available, it will still take more time than replacing the batteries from the slots in the swap stations. Furthermore, the scale of battery swap stations for electric two wheelers is more compact compared to traditional charging stations (plug-in), which is mainly due to the much smaller size of the batteries. Therefore, in this report, the battery swap stations are taken as the only method to charge the electric two wheelers while they are on the road.

2.2. Charging Scheme

Generally, there are two different charging schemes that can be employed to charge an electric two-wheeler, namely overnight charging and on-the-road charging.

2.2.1. Overnight Charging

Overnight charging occurs after operational hours until before the next morning and usually entails slow charging since the users have enough time to fully charge the batteries. In this case, it is taken that the overnight charging is done at the drivers' homes using a low power rating AC charger. Therefore, the next morning it is assumed that all the electric two wheelers used by the drivers are at 100% capacity.

2.2.2. On-the-Road Charging

Complementing overnight charging, the drivers can make use of on-the-road charging to fill up the battery when it is depleted during daily operation. As mentioned before, this method is assumed to take place in the battery swap stations across the region. The drivers can use this alternative at some period during their working hours, namely lunch breaks, idle time between orders and waiting time at pick up locations. The capacity of a battery swap station is determined by its total number of charging slots, the battery capacity charged, and the charging duration for the batteries. For this task, it is assumed that the swap station consists of 12 slots with average battery capacity of 1.45 kWh. If the batteries in the slots are totally depleted, it will take around 3-4 hours to fully charge them. Therefore, the maximum number of batteries that can be swapped is also constrained by this charging duration.

2.3. Electric Two-Wheeler Type

Based on Task 3.3, there are several types of electric two wheelers commonly used by ride-hailing drivers, such as Selis Mandalika, Viar Q1, Gesits, Niu Gova 03, United T1800, Smoot Tempur, and Volta 401. Using this information and the percentage breakdown of the types of services offered (passenger, food delivery and goods delivery), the necessary variables can be found by using the average of all. From these types, the average battery capacity is around 1.45 kWh. In terms of daily kWh, it is determined by the average fuel economy and distance covered daily across all types of services. The total daily kWh needed is found to be 3.6 kWh to cover around 76.4 km, and the on-the-road daily electricity consumption is estimated to be 2.9 kWh. Since one battery can only cover 1.45 kWh, a driver will need to swap the battery more than once to cater the demand during operation hours. Additionally, it means that the total electricity needed for home charging is around 0.7 kWh per vehicle, which means that the vehicles come home at around 50% SoC (state of charge).

2.4. Adoption of Renewable Power Generation for Electric Two Wheelers Charging

The adoption of renewable energy generation for electric two wheelers charging is generally limited to three options:

- **On-site generation**, this method allows renewable power to be generated at the location where the charging occurs. Several options include biomass, solar and wind power generation. However, these renewable generation will depend on the availability of the sources specifically in the appointed locations. Out of all the options, solar PV is the easiest to integrate to the charging system mainly due its modular characteristic. Whereas wind power will demand more space per generated power and biomass has the issue regarding feedstock availability around the city.

- **Off-site generation**, in the absence of available spaces in the charging locations, this method could be applied. This alternative works to produce power somewhere else and then transmitted to the charging locations. In Indonesia, this can be done via power wheeling and is regulated under the Minister of Energy and Mineral Resources (MEMR) Regulation No. 1 of 2015. As of now, the regulation itself is still under revision to better support implementation. The advantage of this method is that the capacity of renewable power can be increased significantly as more land area is available and more sources (solar irradiation, wind speed, etc) available.

- **Existing grid generation**, apart from installing dedicated renewable power generation, the charging system can also take advantage of the current grid mix. Therefore, the option would be to increase the renewable energy penetration on the local grid network itself. Another opportunity is through renewable energy certificates (RECs), which are credits issued as a proof that a unit of electricity (MWh) has been consumed from renewable sources. While this option does not immediately increase the renewable energy penetration, it can serve as a financial support to building more renewable energy capacity in the future.

This report focuses more on the adoption of renewable energy under the on-site generation scheme, particularly looking at how solar PV can be adopted, or integrated, into battery swap stations charging. In this study, a comparison between electric two-wheelers charging using electricity from PLN's grid only (grid-only charging) and charging that utilises a solar PV system (grid + solar charging) will be made.

For the grid-only charging, the electricity is taken from the grid which is owned by PLN. For the grid + solar PV charging, electric two-wheelers get the electricity from the combination of grid and on-site renewable power generation, which is solar PV. The schematic is shown below.

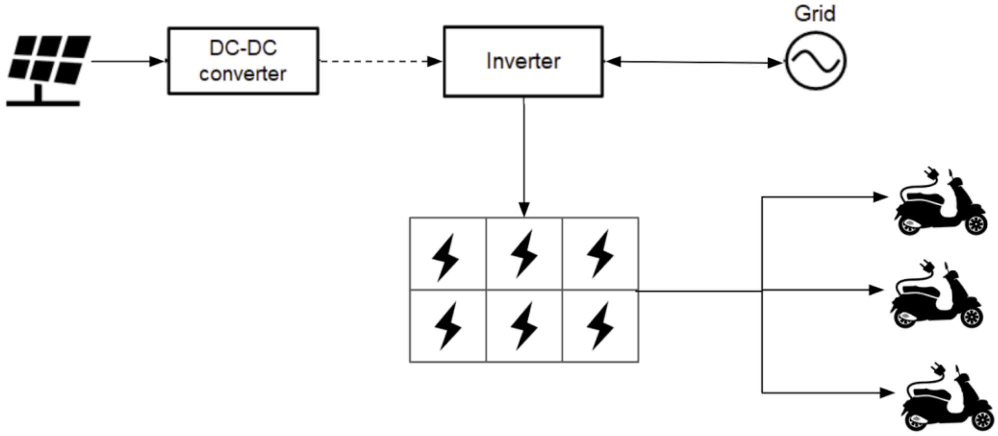

Figure 1 Charging Scheme Representation for Grid + Solar Charging

Integration of solar PV to electric two-wheelers charging can provide cost savings in terms of the avoided electricity cost from grid and also by utilising greener electricity (in terms of emission reduction). The degree on how much solar penetration can enter the mix will vary depending on how much solar potential can be economically integrated into the charging. Rooftop solar utilisation by customers is regulated under the MEMR Reg. 49/2018 including its more recent revisions that now allows 1:1 net metering scheme.

2.5. Space Requirements for Charging Infrastructure

Complementing overnight charging, drivers can make use of on-the-road charging to fill up their daily electricity needs. Sufficient space must be provided for vehicle parking and movement, installation of charging points, signage and barriers, and any electrical infrastructure that will be required. The typical space for a motorcycle parking bay is 2.5 x 1.5 metres. This number can be used as the rule of thumb to determine the estimated space required. The typical charging stations in China, with 15 battery packs/stations, requires 8 x 4 metres of space. This charging station allows two motorcycles parked at the same time, which comply with the parking bay space mentioned above.

3. Methods

3.1. Methodology

There are two charging schemes that are assessed in this study, which are overnight and on-the-road charging. For each of these schemes, the electricity load is estimated and then added in the end to calculate the total load. This load is then compared with the available power supply for the Greater Jakarta area. For on-the-road charging, this study goes deeper to plot its daily load curve to see when the peak load occurs and to match it with the reserve capacity of the substations in the vicinity of the swap stations. In doing that, this analysis takes into account solar PV integration. Thus, it simulates two charging scenarios: grid-only charging and grid + solar PV charging.

A typical battery swap station diagram/schematic is utilised to estimate the total power demand from all swap stations across Greater Jakarta. Based on discussions with several stakeholders, including the government, ride hailing drivers, and ride hailing operators, there are three types of preferred locations to build swap stations, namely gasoline stations, government's land or buildings, and commercial areas (mall, shopping centres, etc.). However, it is taken that a 12-slot battery swap station with a specific area will fit to all those locations. Hence, the estimation starts by looking at a single unit of swap station. The analysis includes calculating charging power demand and solar PV potential capacity. In order to estimate the daily total charging power demand and to plot the load curve, the information of number of electric two wheelers, electric two wheelers type (battery size and efficiency), number of chargers, charger capacity, and charging schedule are used. On the other hand, solar PV capacity is estimated based on the available area for solar panels, module specification, and the solar PV array design and spacing. For this study, a standard 500 Wp module with an area of 2 m2 is chosen. The total solar PV capacity can then be calculated by multiplying the number of modules and its capacity.

Next, the solar PV capacity is then fed into the overall charging system analysis to determine the penetration rate. The solar PV integration is then tested through techno-financial analysis to see whether it is less costly compared to grid-only charging. The results will show the prevailing scenario along with its load curve and daily power consumption. Afterwards, the total power demand is gained by multiplying the load for a single unit to the total swap stations needed across Greater Jakarta for ride-hailing electric two wheelers. This number is then compared with the power supply figure from PLN.

Moreover, the load curve will also reveal the peak load on a certain period. This is then added with other battery swap stations and then compared with the daily supply curve of PLN for Greater Jakarta. Lastly, the local grid infrastructure, mainly substations are analysed. The number of substations required is estimated using the reserve capacity range of each substation and the number of battery swap stations in each region. This figure can serve as a benchmark to be compared with the total substations PLN has for each of the regions.

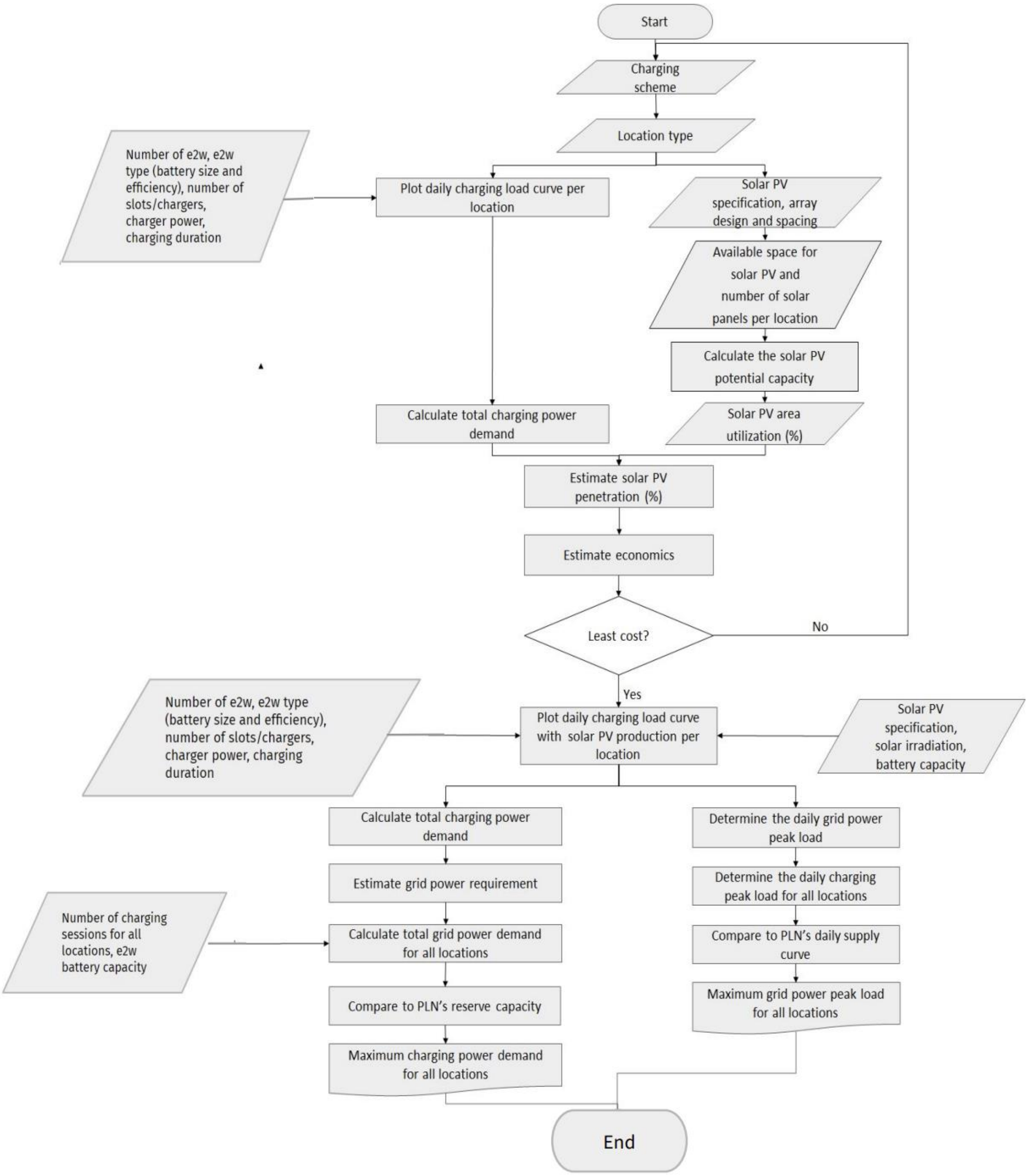

Figure 2 Overall Methodology of The Analysis

Several tools are utilised to support the analysis. First, web-based solar PV design software Helioscope is used to assess the solar PV potential capacity, layout the solar system, and simulate the energy output generation. Second, HOMER Grid is used to model the charging scheme and analyse the economics of the solar PV installations. Finally, Excel is used to manage all of the input and output data.

3.2. Battery Swap Stations Locations

In order to determine the total charging load, load profile, and the solar PV production from the electric two-wheelers battery swap stations, the swap stations are first grouped into several regions. A single typical archetype is used to represent all the battery swap stations. Thus, the total power demand will depend on the total daily kWh figure for each region, which leads to the total number of battery swap stations needed.

Table 1 Breakdown of Number of Battery Swap Stations for Each Region Across Greater Jakarta

City/Regency	Number of Survey Point	18 hrs	14 hrs	Daily kWh	Battery Swapping Station Needed
Central Jakarta City	35	14.16%	14.13%	459,066.26	4,008
South Jakarta City	44	13.16%	13.11%	426,468.00	3,723
East Jakarta City	22	14.15%	14.09%	458,600.57	4,004
West Jakarta City	18	15.41%	15.44%	499,581.24	4,362
North Jakarta City	16	7.13%	7.16%	231,137.17	2,018
Bekasi City	4	5.90%	5.88%	191,087.88	1,669
Bekasi Regency	5	4.06%	4.04%	131,634.87	1,150
Depok City	7	5.92%	5.95%	192,019.26	1,677
Bogor City	9	4.05%	4.07%	131,376.15	1,147
Bogor Regency	5	2.61%	2.63%	84,600.24	739
Tangerang City	13	4.70%	4.72%	152,383.92	1,331
South Tangerang City	11	4.66%	4.68%	151,142.08	1,320
Tangerang Regency	4	4.07%	4.09%	131,997.07	1,153
Total	193			3,241,095	28,295

Then, the total power demand from Greater Jakarta is then found by adding up the power demand from each region. This is also the case when calculating total peak load and solar PV capacity.

3.3. Data Input

As have mentioned above, information on the number of electric two wheelers, electric two-wheeler type (battery size and efficiency), number of chargers, charger capacity, and charging schedule are required to estimate the daily total charging power demand and to plot the load curve. Table 2 summarises the technical data needed to perform the analysis.

Table 2 Technical Data Input for On-The-Road Charging

Route		
Average daily distance	76.4	km
Charging System		
Charging time window	06.00 - 24.00	
Charging duration	3	hours
Number of chargers/slots	12	units
Swap station utilization rate	100	% (percent)
Charging power	0.483	kW
Electric Two-Wheeler		
Battery size	1.45	kWh
Average daily power consumption	3.6	kWh
Average daily on-the-road power consumption	2.9	kWh

4. Solar PV Integration to the Charging System

This section discussed the integration of solar photovoltaic systems as solar canopies into electric two wheelers charging by first assessing its technical potential assessment at an average location in Greater Jakarta and further analysing its financial comparison compared to grid-only charging using HOMER Grid.

4.1. Solar PV Potential Assessment

As discussed in Section 2, the minimum area requirement for the charging infrastructure is 8 x 4 metres. The solar PV potential based on the minimum area requirements will be assessed, hence becoming the typical charging station's solar PV potential in DKI Jakarta Province.

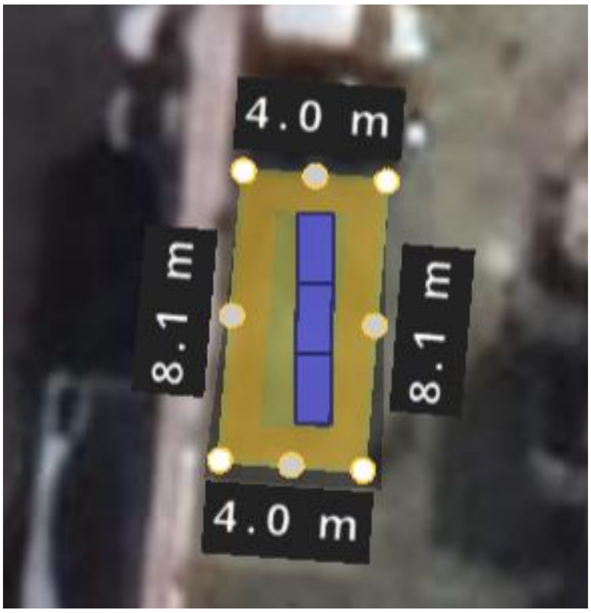

Figure 3 Diagram of Solar PV Panels Placement on A Typical Battery Swap Station

Based on the Helioscope modelling and simulation, the total PV potential of the assessed area is **1 kWp**. Note that the solar PV potential can still be maxed out depending on space availability, but a rather conservative approach is taken to obtain a general benchmark that is more representative when scaled up to a different location.

4.2. Technical and Financial Comparison

In order to estimate the overall supply-demand balance of electricity, the charging load curve and demand have to first be calculated for a single typical battery swap station. In parallel, the viability of solar PV integration is also taken into account when assessing the load curve and power demand. Techno-financial analysis is done through HOMER Grid to compare grid-only and grid + solar PV charging. The main results found are given in NPC (net present cost) and also payback period (in the case of solar PV integration generates cost savings). Three different electricity tariffs are used, the minimum (~IDR 579/kWh), the medium (~IDR 724/kWh), and the maximum (~IDR 1,448/kWh). These numbers come from the formula:

$$707 \ x \ \boldsymbol{Q} \ (IDR/kWh)$$

Where $0.8 \leq \mathbf{Q} \leq 2$

So, the minimum tariff is taken by using 0.8 as Q and maximum is calculated from taking Q = 2. The tariff is also subjected to street lighting tax (PPJ), around 2.4% (disregarding other fees incurred). At night (from 10 p.m. to 5 a.m.), it is also assumed that the charging tariff will be discounted by 30%. Additionally, the electricity produced by solar PV is sold at the same price as the tariff (using 1:1 ratio). Several other assumptions used in this analysis are given below.

Table 3 Project Parameters Assumptions

Variable	Value
Discount rate	8%
Inflation rate	2%
Project lifetime	25 years
Solar PV capital cost	IDR 11,200,000/kW (USD 0.75/kW)
Solar PV O&M cost	IDR 224,000/kW/year (2% of CAPEX)

Overall, the analysis yields that solar PV is the better option financially when the electricity tariff charged for charging is the highest. On the other hand, NPC will go up for solar PV integration as the electricity tariff used goes lower. Nonetheless, the analysis has not counted for government support for solar PV installation. Instruments such as solar leasing and/or bulk procurement can be used to further increase financial viability of solar PV integration. The solar PV production profile itself matches the power consumption period. Therefore, it is generally beneficial to install more solar PV capacity if there are available spaces around.

In the financial aspect, both the ROI and payback period use nominal cash flows, not discounted. The ROI shown is the nominal average annual return of the total initial investment. The payback period is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. Therefore, it indicates the amount of time it would take to recover the difference in investment costs between the current system and the base case system.

This solar PV integrated charging system project has an ROI of 10.5%, 2.2%, and 0.5% from highest to lowest electricity tariff consecutively. The highest ROI implies the fastest **payback period of 7 years**. The financial assessment on each representative of the group is elaborated below.

Table 4 Swap Station Financial Comparison for Three Different Electricity Tariffs

Variable	IDR 579/kWh		IDR 724/kWh		IDR 1,447.9/kWh	
	Grid	Grid + Solar (1 kWp)	Grid	Grid + Solar (1 kWp)	Grid	Grid + Solar (1 kWp)
NPC (IDR)	260 million	265 million	364 million	366 million	728 million	718 million
Cost of Electricity (IDR/kWh)	482.27	491.05	675.52	679.71	1,351	1,332
Initial capital (IDR)	-	11.5 million	-	11.5 million	-	11.5 million
Operation cost (IDR/year)	20.1 million	19.6 million	28.2 million	27.4 million	56.3 million	54.6 million
Avoided electricity cost (IDR/year)	-	0.764 million	-	0.956 million	-	1.92 million
Total return (IDR)	-	9.89 million	-	12.4 million	-	24.8 million
ROI (%)	-	0.5%	-	2.2%	-	10.5%
Simple payback period (year)	-	22	-	16	-	7

On top of the financial assessment, technically it is found that a single swap station will consume 41.680 kWh/year of power with solar PV penetration only amounts to 3.35% of the total load. This is mainly caused by the small area covered by the swap station, thus making the area of the canopy also small.

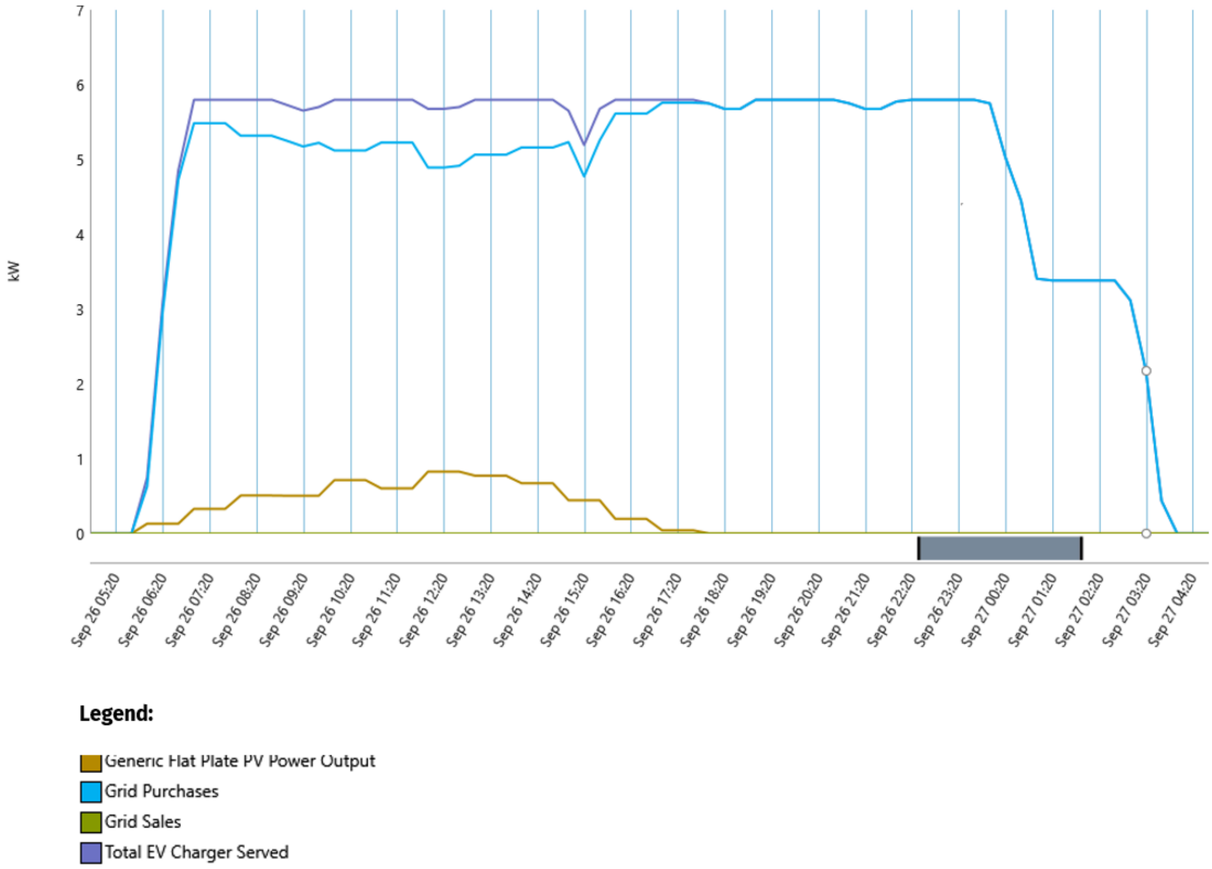

Figure 4 Load and Solar PV Production Profile at Typical Battery Swap Station

When there is more space available, it is advised to install more solar PV capacity since the solar production curve matches the daily power consumption curve. An alternative area might be the rooftop of buildings surrounding the swap station or even vacant land to install ground-mounted solar PV.

Table 5 Swap Station Electricity Supply-Demand Balance

	kWh/yr	%
Production		
Imported PV Production	1,397	3.35
Grid Purchases	40,352	96.7
Total	41,750	100
Consumption		

	kWh/yr	%
Grid Sales	0.354	0.0008
EV Charged Served	41,680	100
Total	41,680	100
Excess		
Excess Electricity	0	0

One charger in this location is utilised 82.1% of the time and gives a peak power of 5.8 kW every 3 hours, that is the recharging time for a single battery. The total charging sessions is 28,767 in a year with an average energy consumed in a session at 1.4 kWh.

Table 6 Swap Station Battery Charging Results

Variable	Value
Sessions per year	28,767
Sessions per day	79.0
Energy per session (kWh)	1.4
Peak power (kW)	5.8
Utilization factor (%)	82.1

5. Analysis of Supply-Demand Balance of Power

5.1. Overnight Charging

In this scenario, the charging of the electric two-wheelers occurs overnight at the drivers' homes using a traditional plug-in charger that goes together with the vehicles. Assuming that the charging power is around 350 W, this means that the drivers' homes need to be at least 900 VA to accommodate home charging. Assuming that every driver will spend 2.9 kWh daily on the road and 3.6 kWh in total for the whole day, it gives around 0.7 kWh to be fulfilled with overnight charging. Therefore, the overnight charging will take around 2 hours.

Summing up the total of each location reveals that overnight charging contributes additional annual power demand of **229,950 MWh/year**. Please note that this is gained for the 900,000 number of ride-hailing drivers in the Greater Jakarta area in 2021.

5.2. On-the-Road Charging

As have been discussed previously, this scenario happens during the operational hours of ride-hailing drivers. Realistically, the drivers will most likely swap batteries during lunch break (assumed 75 minutes duration) and when they are waiting for orders. However, in this study, it is modelled that a single battery swap station is utilised to its maximum capacity, which means it is only constrained with the recharging duration of all the battery slots. Hence, it is assumed that every 3 hours (recharging duration), there will be 12 electric two-wheelers that come and do the swapping. This happens along the operational hours of the swap station, which is 18 hours (from 06.00 - 24.00). An important note is that the location distribution of the swapping stations needs to be inspected. Thus, making sure that each driver will have access to the swap station (e.g., gas stations, commercial areas, and government buildings).

Table 7 Annual Power Demand for Overnight Charging of Ride-Hailing Drivers in Greater Jakarta

City/Regency	Daily Kwh	Battery Swapping Station	Annual Power Demand (MWh/year)	Peak Load (MW)
Central Jakarta City	459,066	4,008	167,053	23.2
South Jakarta City	426,468	3,723	155,175	21.6
East Jakarta City	458,601	4,004	166,887	23.2
West Jakarta City	499,581	4,362	181,808	25.3
North Jakarta City	231,137	2,018	84,110	11.7

City/Regency	Daily Kwh	Battery Swapping Station	Annual Power Demand (MWh/year)	Peak Load (MW)
Bekasi City	191,088	1,669	69,564	9.7
Bekasi Regency	131,635	1,150	47,932	6.7
Depok City	192,019	1,677	69,897	9.7
Bogor City	131,376	1,147	47,807	6.7
Bogor Regency	84,600	739	30,802	4.3
Tangerang City	152,384	1,331	55,476	7.7
South Tangerang City	151,142	1,320	55,018	7.7
Tangerang Regency	131,997	1,153	48,057	6.7
Total	**3,241,095**	**28,295**	**1,179,336**	**164.1**

To calculate the power demand, the annual electricity demand per charging session of one swap station is conducted. The annual electricity demand is found to be 41,680 kWh/year. The number of charging sessions for this station is 79 (maximum capacity). Therefore, the annual electricity demand per charging session is to divide the annual electricity demand with the number of charging sessions. Accumulation of annual power demand for all swap stations yields a significant figure, **1,179,336 MWh/year**. This figure is much higher than overnight charging, it is 5 times bigger than overnight charging power demand.

5.3. Comparison of Total Power Demand with Available Supply from Greater Jakarta's Grid

Total annual electricity demand from both scenarios is 1,409,286 MWh/year. The average power demand for the entire fleet of electric two-wheelers (overnight and on-the-road charging) comes up to around 1,392 MW. From PLN's data, it is shown that in March 2021, the average electricity supply (power capability) is around 13,895 MW and average power demand of 6,385 MW. This shows that there is 7,510 MW of excess supply capacity (around 54% of total supply power capability). This reserve margin shows that the additional demand from electric two-wheelers charging adds around 18.5% of the available margin. This shows that the grid is more than capable to handle the additional power demand.

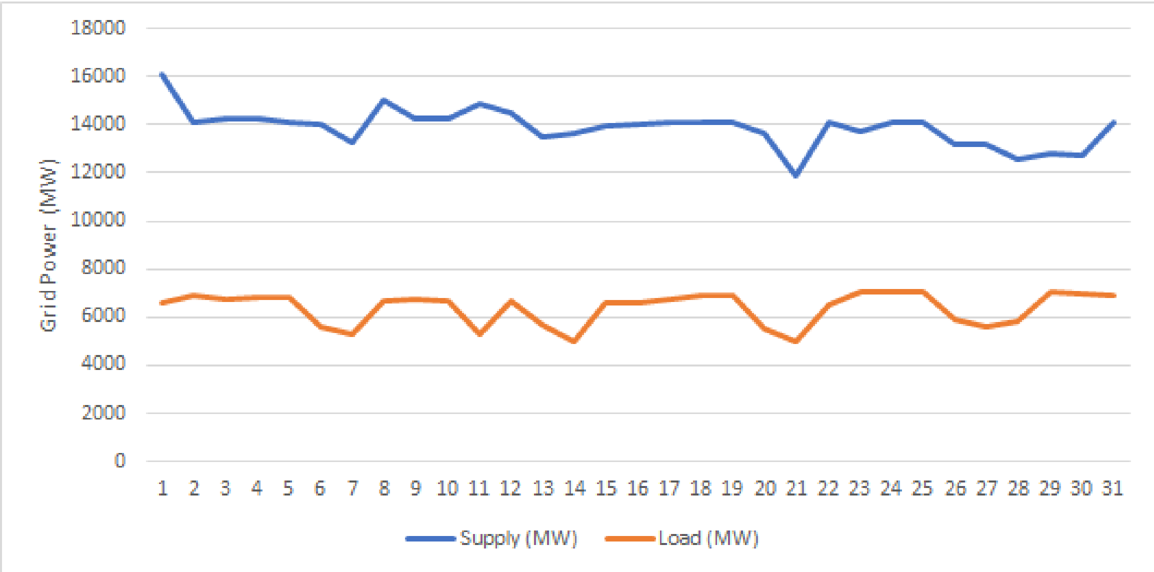

Figure 5 Supply and Load Curve of Jakarta Recorded in March 2021

With regard to peak power, PLN's data also shows that in February 2021, Jakarta's peak demand occurs during the afternoon at 4,493 MW. On the other hand, the additional peak power from two wheelers opportunity charging is estimated at around 164 MW from all swapping locations. Therefore, this only contributes to around 3.65% of the most recent peak power recorded. This also shows a very minimal impact to the grid as it does not create a significant power spike.

In the case where in 2030 more fleets will be electrified (1,469,663 electric two-wheelers), it will still create an insignificant impact to the grid as it will only increase the average power demand requirement to around 267 MW during the day and 514 MW at night. This will impact the current grid by 3.5%-6.8% from its margin. Additionally, in 2030 the grid might have more power margin to dispose depending on the circumstances.

5.4. Substation Requirements for Each Location Group

Each battery swap station needs to be connected to the grid network via a substation (150/20kV). In Jakarta, there are around 59 substations that exist. In order to assess which substation to be connected to for every swap station, several factors must be considered. The first one being the reserve capacity of the substations, and also the proximity of the substations to the swapping locations. The reserve capacity of a substation depends on the remaining capacity of each of its transformers. On average, it ranges from 0 – 700 MW in Jakarta. Therefore, since the peak load of a swapping station only gives 5.8 kW, it will have almost negligible impact to the transformers. However, when there are a lot of swapping stations accumulated in an area, it might give rise to a bigger peak load. As shown in Table 7 above, the total peak load for each region is still insignificant when compared to the average reserve capacity of a single transformer in a substation.

Technically, a single substation will be able to hold for all of the battery swap stations considered in the study. However, there is also geographical constraint, which makes the distance from swap station to a specific substation relevant.

6. Local Grid Infrastructure to Charge Batteries at Swap Stations

Battery swap stations owners should provide required technical and administrative data on the electric two-wheelers charging demand to PLN UID Jakarta in order for PLN to check the existing local power grid capability to cover the demand. Additionally, the owners would also need to follow regulation under MEMR Regulation 13/2020 (Article 25) on electric vehicles charging safety and operation-worthiness requirements. On the other hand, PLN UID Jakarta is responsible to ensure the power supply, grid stability, and electrical connection.

The necessary infrastructure depends on the charging power demand. According to PLN, for electricity load under 197 kVA is considered as low-voltage connection, and the customers are not required to build additional infrastructure. Therefore, this is applicable for all of the battery swap stations analysed in the study. This will only require cable connection from PLN's nearest substations to low-voltage (220/380 V) network (*Jaringan Tegangan Rendah*, "JTR"). If there is any infrastructure needed, it will be covered by PLN, thus the customers will not need to bear any cost.

This also opens opportunities for a joint connection to the substation if there are more than 1 swap stations clustered in a single location. Based on the previous assumption that the average swap station will create 5.8 MW of power spike, a maximum of 34 battery swap stations could be accommodated in a single location together under one connection before needing an additional local electricity infrastructure. Hence, a single location could afford around 408 battery slots before upgrading the electrical infrastructure.

7. Conclusion

A detailed study on two wheelers charging including its charging demand impact to the electrical power system has been conducted to accommodate two wheelers electrification plan. Renewable energy adoption in the form of solar PV has also been considered in the techno-financial analysis for two wheelers charging, looking at typical space requirements for charging infrastructure. Impact to local power grid infrastructure and its associated cost have also been analysed. Lastly, the environmental impacts of two wheelers electrification such as greenhouse gas emissions, air pollution, and oil import reduction have also been discussed. The study finds that:

1. **Solar PV can be easily integrated to two wheelers charging to generate cost savings**.
   - Solar PV can accommodate for about 3.35% (on an annual basis) of the charging demand. However, it is still dependent on the solar PV potential and charging profile at each location. From the typical space requirements for the charging infrastructure, the solar power potential is about 1 kWp.
   - As the electricity tariff charged by PLN increases, the financial viability of integrating solar increases. This is because more cost savings could be realised per kWh of imported solar PV production. The highest electricity tariff assessed, IDR 1,447.9, is estimated to incur an ROI of 8.4% with payback period of 8 years.
2. **Total additional charging power demand from the two-wheelers electrification incur insignificant impact to PLN's electrical power system**.
   - The total electricity demand coming from two wheelers overnight charging is **229,950 MWh/year**. For opportunity charging, the total power demand is coming at around **1,179,336 MWh/year**.
   - Additional power demand to charge the two wheelers has insignificant impact to PLN's grid. The average charging power demand for all fleets is 1,392 MW. Compared to PLN's supply and demand balance, this number merely corresponds to 18.5% of the available reserve margin.
   - Likewise, additional peak power from two wheelers opportunity charging brings negligible impact to the PLN's grid. Total peak power from charging the two wheelers, which is around 164 MW at 12.00, only contributes to 3.65% of grid's power peak (referring to PLN data in February 2021).
   - Nearest substations to all representative locations have been identified and are able to accommodate the charging power demand. However, when there are a lot of swapping stations accumulated in an area, it might give rise to a bigger peak load.

3. **Local grid infrastructure requirements are relatively simple, since the electricity load is low**.

    - According to PLN, for electricity load under 197 kVA is considered as low-voltage connection, and the customers are not required to build additional infrastructure.
    - It only requires cable connection from PLN's nearest substations to low-voltage (220/380 V) network (*Jaringan Tegangan Rendah*, "JTR"). If there is any infrastructure needed, it will be covered by PLN, thus the customers will not need to bear any cost, except to provide the location (about 3–5 m2 piece of land).

8. References

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