ITDP
Institute for Transportation & Development Policy

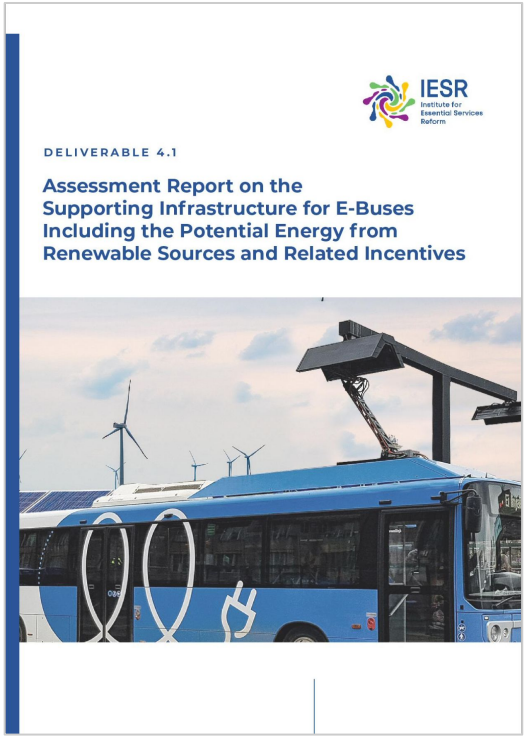
IESR
Institute for Essential Services Reform

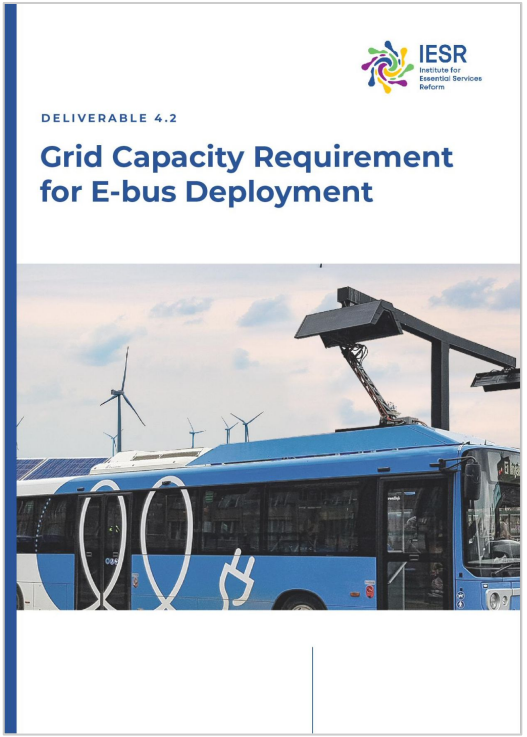
Supporting Jakarta's Transition to E-Mobility:

Feasibility Study of Charging Stations Using Renewable Energy-Based Electricity and Solar PV Systems for Transjakarta

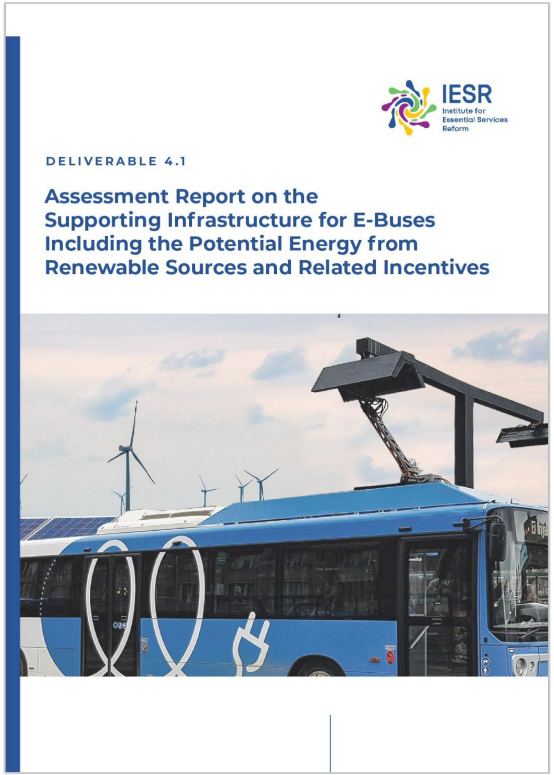
CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

Output 4: Feasibility Study of Charging Stations Using Renewable Energy-Based Electricity and Solar PV Systems for Transjakarta





4.1 Study on integrating solar PV to e-bus charging system



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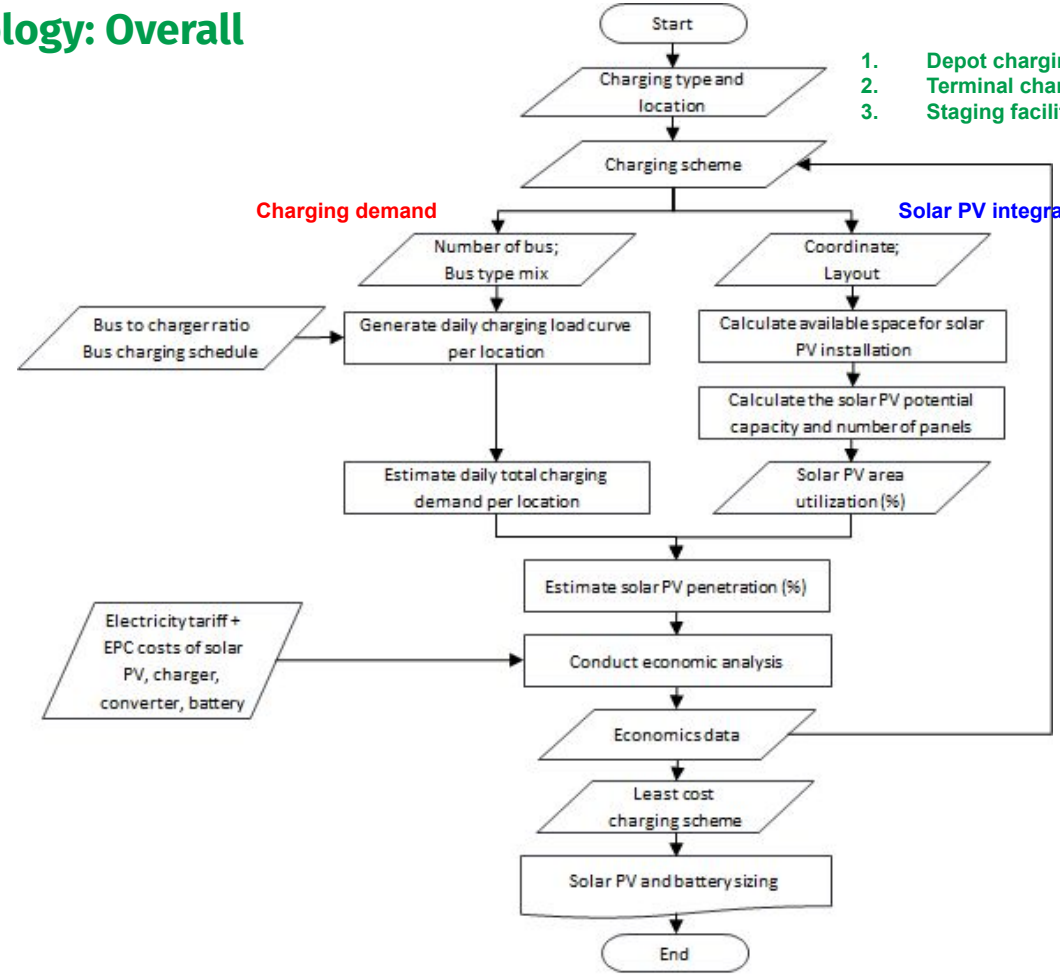
Objectives and scope of work

This report's objective is twofold:

1. To develop **a study on the options for renewable energy for electric buses charging system** by looking at adding solar PV to depots, terminals, and staging facilities
2. To develop **strategies for increasing the share of renewable energy** in the electricity mix for electric buses charging facility

In order to achieve the aforementioned objectives, this report focuses on the assessment to deploy **rooftop solar PV systems** as a support for electric buses charging infrastructure. Furthermore, the analysis is based on three specific locations, namely **Depot Cijantung, Terminal Ragunan and Staging Facility Pejaten**

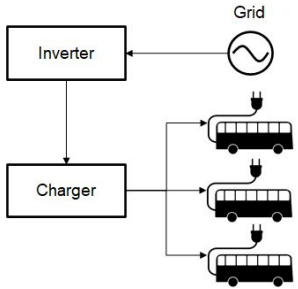
Methodology: Overall



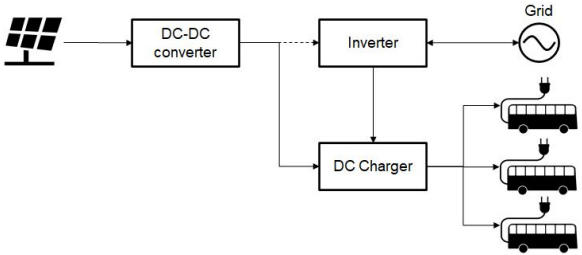
1. Depot charging (plug-in, overnight)
2. Terminal charging (pantograph, opportunity)
3. Staging facility (plug-in + pantograph, mid-day)

Methodology: Charging schemes

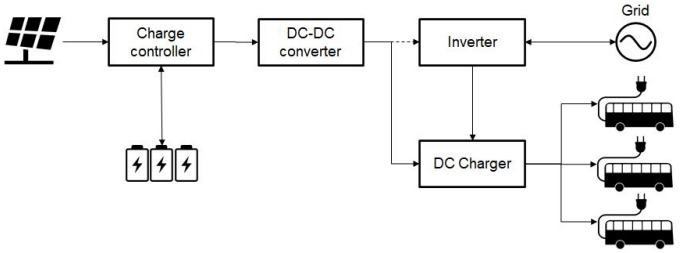
Scenario 1: Grid-only charging (base)



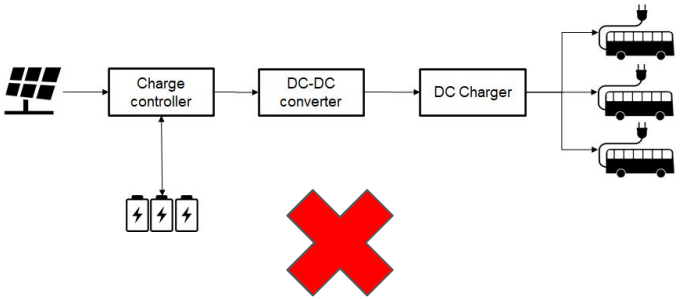
Scenario 2: Grid charging + solar PV



Scenario 3 : Grid charging + solar PV + battery storage



Scenario 4 : Solar PV + battery storage (off-grid)

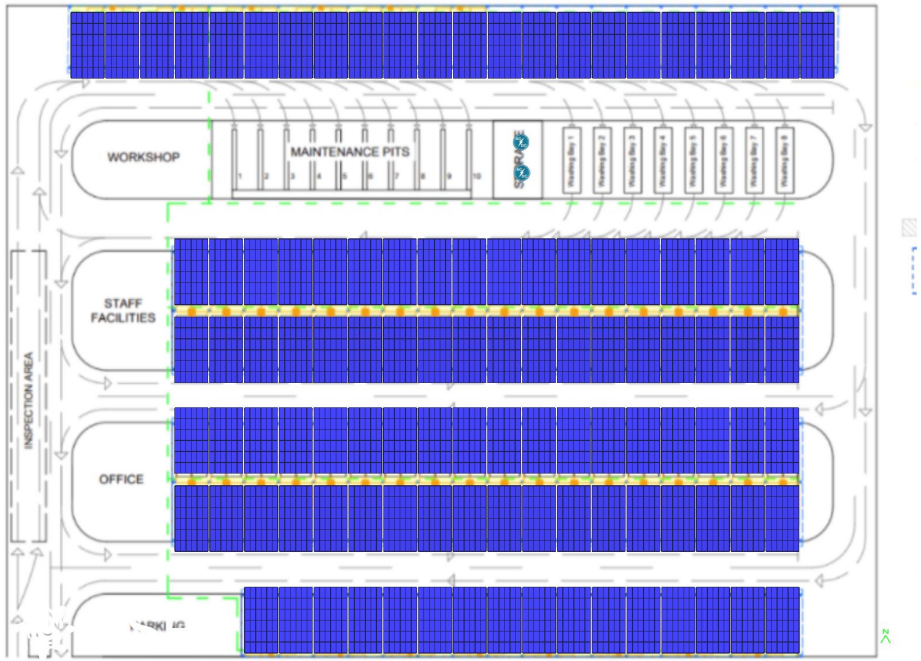


Rooftop solar PV potential assessment

1. Depot Cijantung

Scenario 1: Using generic depot layout

E-bus capacity: 200 + 20 (reserve parking)



Total PV potential: **1,580 kWp**

Design reference: 6 x 6 per 2 buses

Rooftop solar PV potential assessment

1. Depot Cijantung

Scenario 2: Manually-designed

Location coordinate: -6.317722, 106.865131

Rooftop solar potential (**buildings** only): **770 kWp**

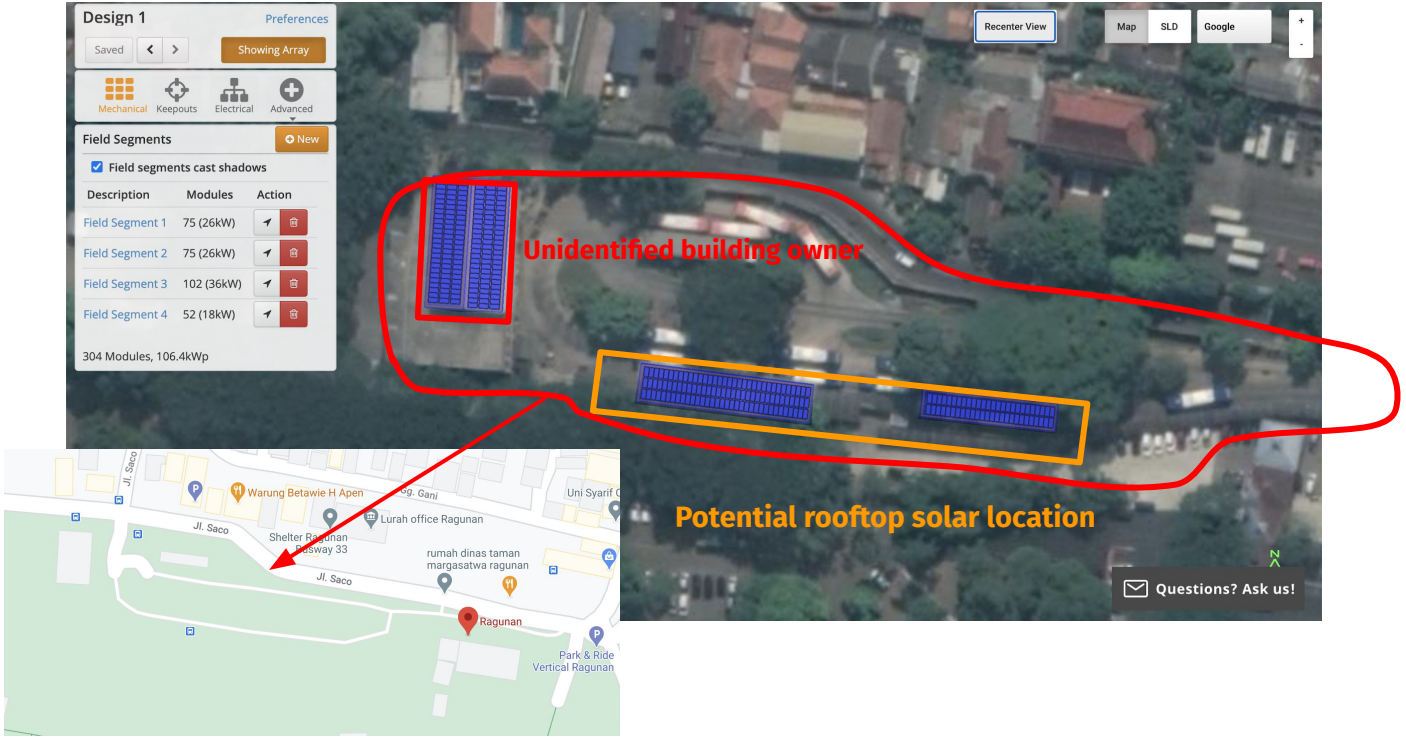
Rooftop solar potential (canopy): **1,493 kWp (1.49 MWp)**

Total PV potential: 2,263 kWp (2.2 MWp)


Rece

Rooftop solar PV potential assessment

2. Terminal Ragunan



Rooftop solar potential (existing space): **~50 kWp**

Rooftop solar PV potential assessment

2. Terminal Ragunan

Rooftop solar potential (existing space): **~50 kWp**

Caution: Note for trees, buildings, or other potential shading as it will greatly affect solar PV production

Rooftop solar PV potential assessment

3. Staging Facility Pejaten

Assumed to follow same configuration as bus parking spaces at depot, hence the potential is **1,580 kWp**

Methods: Data input

Technical Data

	Depot	Terminal	Staging Facility	Unit
Charger				
Charging time window	22.00 - 04.00	09.00 - 16.00	09.00 - 16.00	
Charging time	varied	0.05	varied	hours
Charger:bus ratio	1:3.33	-	1:4.05	
Assumed number of e-buses	200	140	81	units
Number of charger(s)	60	1	20	units
Charging power	150	450	180	kW
Number of connectors	2	1	1	unit(s)
Solar PV				
Solar PV potential (canopy only)	1,493	54	1,580	kWp
Solar PV potential (incl. buildings)	2,263	106.4	-	kWp
E-buses (load)				
Proportion of e-buses population (%)	81% -- 180 kWh single bus 10% -- 324 kWh single bus 7% -- 135 kWh medium bus 2% -- 180 kWh low entry bus	100% -- 180 kWh single bus	100% -- 180 kWh single bus	

Economic Data

	Value	Unit
Solar PV		
Solar PV total installed cost (CAPEX)	800/900	USD/kWp
Solar PV module CAPEX (every 25 years)	280	USD/kWp
Inverter CAPEX (every 10 years)	24	USD/kWp
Solar PV system OPEX (O&M)	16	USD/kWp
OPEX escalation per year	2%	USD/kWp
Solar PV degradation rate	0.8%	USD/kWp
Solar PV DC/AC ratio	1.25	USD/kWp
Battery		
Price -- "non-local component" (every 15 years)	300 - 472	USD/kWh
O&M for battery storage	2	USD/kWh/year

Methods: Sensitivity analysis input

Solar PV Utilization	Grid Electricity Tariff	Battery/Storage
100% (all building's rooftop and canopy)	Buy tariff: IDR 1,440/kWh Net metering: 1:0.65	100 kWh Li-ion battery (varying number of units)
66% (100% of canopy area)	Buy tariff: IDR 1,440/kWh (04.00 - 22.00) Buy tariff IDR 1,080/kWh (22.00 - 04.00) Net metering: 1:0.65	1 MWh Li-ion battery (varying number of units)
33% (50% of canopy area)	Buy tariff: IDR 707/kWh (04.00 - 22.00) Buy tariff IDR 495/kWh (22.00 - 04.00) Net metering: 1:0.65	

Results: Economic Analysis

1. Depot Cijantung

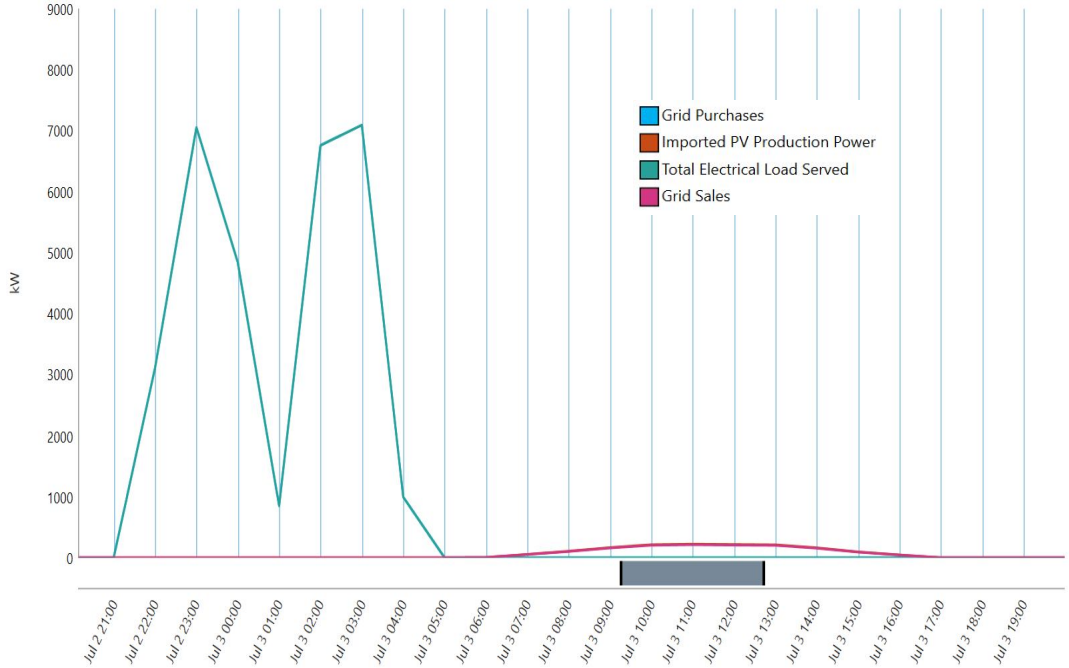
Solar PV capacity: 747 kW

	using IDR 707/kWh electricity tariff			using IDR 1,440/kWh electricity tariff	
	Grid	**Grid + Solar** (747 kWp, 50% canopy)	**Grid + Solar + Storage** (747 kWp,50% canopy; 1 MWh)	**Grid**	**Grid + Solar** (747 kWp, 50% canopy)
NPC (IDR)	72.8 billion	80.5 billion	87.5 billion	148 billion	153 billion
Initial capital (IDR)	-	8.56 billion	13.5 billion	-	8.56 billion
Operation cost (IDR/year)	5.63 billion	5.56 billion	5.73 billion	11.5 billion	11.1 billion
Bill savings (IDR/year)	-	253 million	380 million	-	514 million
ROI (%)	-	-3.2%	-4.8%	-	-0.1%
Simple payback period (year)	-	-	-	-	-

Results: Economic Analysis

1. Depot Cijantung (with 747 kW of solar PV capacity)

Charging load and solar PV production profile



Solar PV penetration and grid sales

	kWh/yr	%
Production		
Imported PV Production	900,190	7.43
Grid Purchases	11,222,346	92.6
Total	12,122,536	100
Consumption		
Grid Sales	855.157	7.08
EV Charged Served	11,222,370	92.9
Total	12,077,527	100
Excess		
Excess Electricity	0	0

Results: Economic Analysis

2. Terminal Ragunan

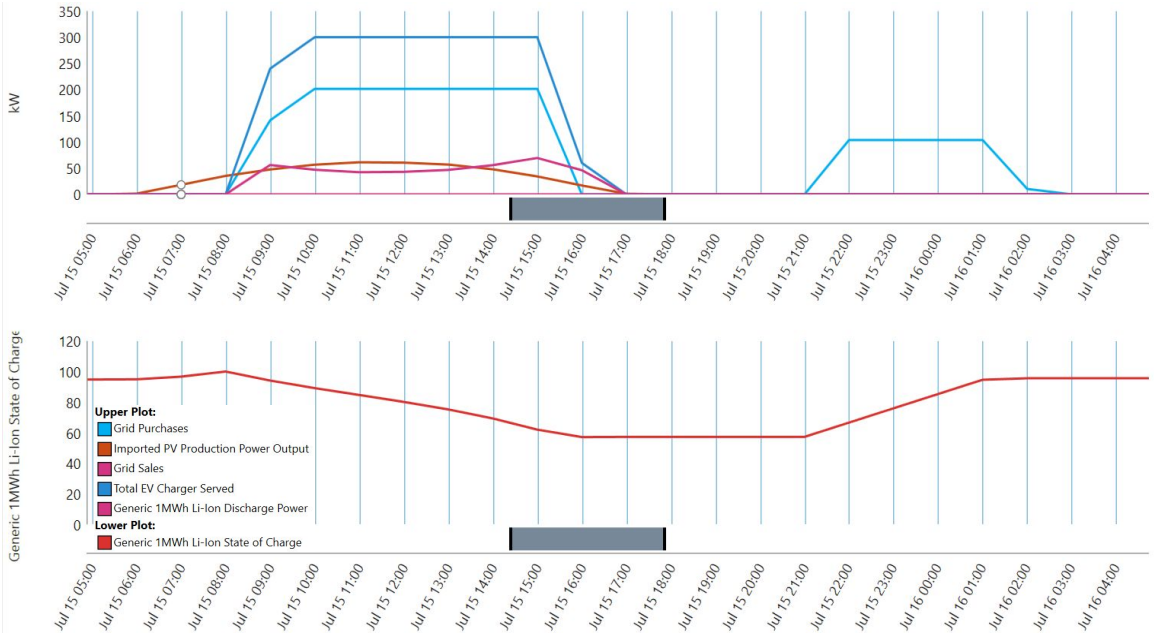
Solar PV capacity: 27 kW ; 106 kWp

	using IDR 707/kWh electricity tariff			using IDR 1,440/kWh electricity tariff	
	Grid	**Grid + Solar** (27 kWp, 50% canopy)	**Grid + Solar + Storage** (27 kWp, 50% canopy; 100 kWh)	**Grid**	**Grid + Solar** (106 kWp, 100% area)
NPC (IDR)	7 billion	7.16 billion	7.85 billion	14.3 billion	13.7 billion
Initial capital (IDR)	0	346 million	836 million	0	1.36 billion
Operation cost (IDR/year)	542 million	527 million	543 million	1.1 billion	956 million
Bill savings (IDR/year)	0	21.9 million	21.9 million	0	175 million
ROI (%)	0	0.3	-4.1%	0	6.8
Simple payback period (year)		24	-	0	9

Results: Economic Analysis

2. Terminal charging (with 106 kW solar PV and 1 MWh battery)

Charging load and solar PV production profile



Solar PV penetration and grid sales

	kWh/yr	%
Production		
Imported PV Production	128,256	16.2
Grid Purchases	663,254	83.8
Total	791,510	100
Consumption		
Grid Sales	19,179	2.44
EV Charged Served	765,915	97.6
Total	785,094	100
Excess		
Excess Electricity	2.82	0.0004

Results: Economic Analysis

3. Staging Facility Pejaten

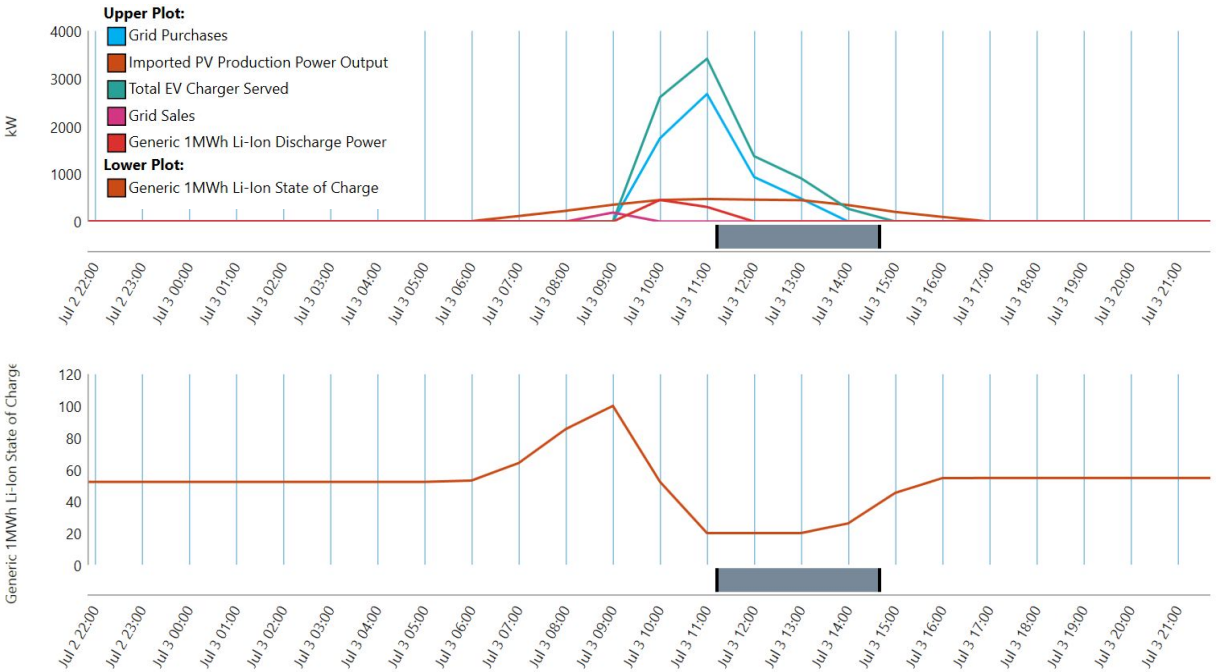
Solar PV capacity: 521 kWp ; 1.58 MWp

	using IDR 707/kWh electricity tariff			using IDR 1,440/kWh electricity tariff	
	Grid	**Grid + Solar** (521 kWp, 50% canopy)	**Grid + Solar + Battery** (521 kWp, 50% canopy; 1 MWh)	**Grid + Solar** (1.58 MWp)	**Grid + Solar + Battery** (1.58 MWp; 1 MWh)
NPC (IDR)	28.6 billion	30.7 billion	37.6 billion	47.5 billion	55.2 billion
Initial capital (IDR)	0	5.94 billion	10.8 billion	18 billion	22.9 billion
Operation cost (IDR/year)	2.21 billion	1.91 billion	2.07 billion	2.28 billion	2.5 billion
Bill savings (IDR/year)	0	421 million	421 million	2.6 billion	2.56 billion
ROI (%)	0	1%	-2.7%	8.3%	4.7%
Simple payback period (year)	0	20	-	8.2	11

Results: Economic Analysis

3. Staging facility charging (with 1,580 kW solar PV and 1 MWh battery)

Charging load and solar PV production profile



Solar PV penetration and grid sales

	kWh/yr	%
Production		
Imported PV Production	1,904,551	49.2
Grid Purchases	1,966,518	50.8
Total	3,871,069	100
Consumption		
Grid Sales	612,166	16.4
EV Charged Served	3,126,225	83.6
Total	3,738,391	100
Excess		
Excess Electricity	18,490	0.478

Strategy to increase renewable energy mix

1. **Submit proposals for incentives to the government (local and national) for promoting the use of solar PV in public transportation**
2. **Open the charging facilities at staging facilities for private users**
3. **Adopt alternative business model (i.e., solar lease) for adopting rooftop solar**
4. **Purchase renewable energy certificates (RECs) from PLN**
5. **Source renewables-based electricity using power wheeling**

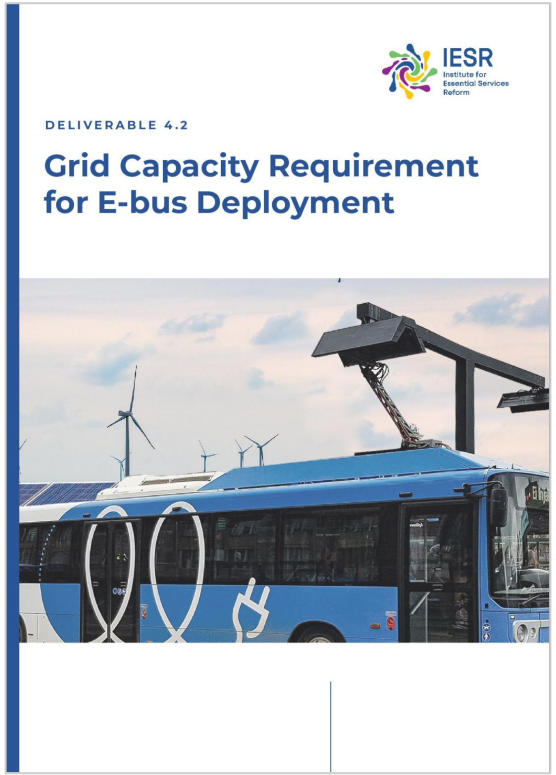
Conclusions

1. **Grid-only charging is the least cost option** for all charging locations if electricity tariff is lower than national average cost of electricity generation (IDR 1,100/kWh).
2. **Rooftop solar integration is the most optimum for staging facility charging,** where the charging load and solar PV production match and that there are available spaces to install solar PV.
3. Integration of s**olar PV for terminal charging** is also found **to be cost-effective only when the tariff is higher** (> IDR 1,100/kWh)
4. Our analysis on **depot (overnight) charging** finds that it **does not present a good economics for integrating solar PV** (or with additional energy storage)
5. **The use of batteries** to store solar PV generation and/or grid power (when the tariff is lower at night) **generally results in higher total cost**

Recommendations

1. Transjakarta should **aim for the lowest electricity tariff possible when negotiating with PLN**
2. If the electricity tariff is set to be the same as or above national average cost of power generation (IDR 1,100/kWh), Transjakarta should **opt for installing solar PV particularly for staging facility and terminal charging** scenarios.
3. Transjakarta should **consider installing solar PV due to other benefits** aside from financial perspective, **such as security and branding**
4. Transjakarta can **find a low-cost EPC that sources its solar PV from low-cost vendors.** It is also suggested to **deploy large solar PV capacity** to get bulk discount
5. Transjakarta could **propose to the government to provide incentives** for solar PV procurement to **cut 35% of the total installation cost**
6. **Opening the charging location also for private users** is recommended, especially for staging facilities
7. As a strategy to increase renewable energy mix, Transjakarta could **consider using the "solar lease" business model**
8. To further increase the renewable energy mix for charging, Transjakarta should **consider purchasing renewable energy certificates (RECs) from PLN and use power wheeling scenario** when it is available **for longer term**

4.2 Grid Capacity Requirement for E-bus Deployment



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Objectives and scope

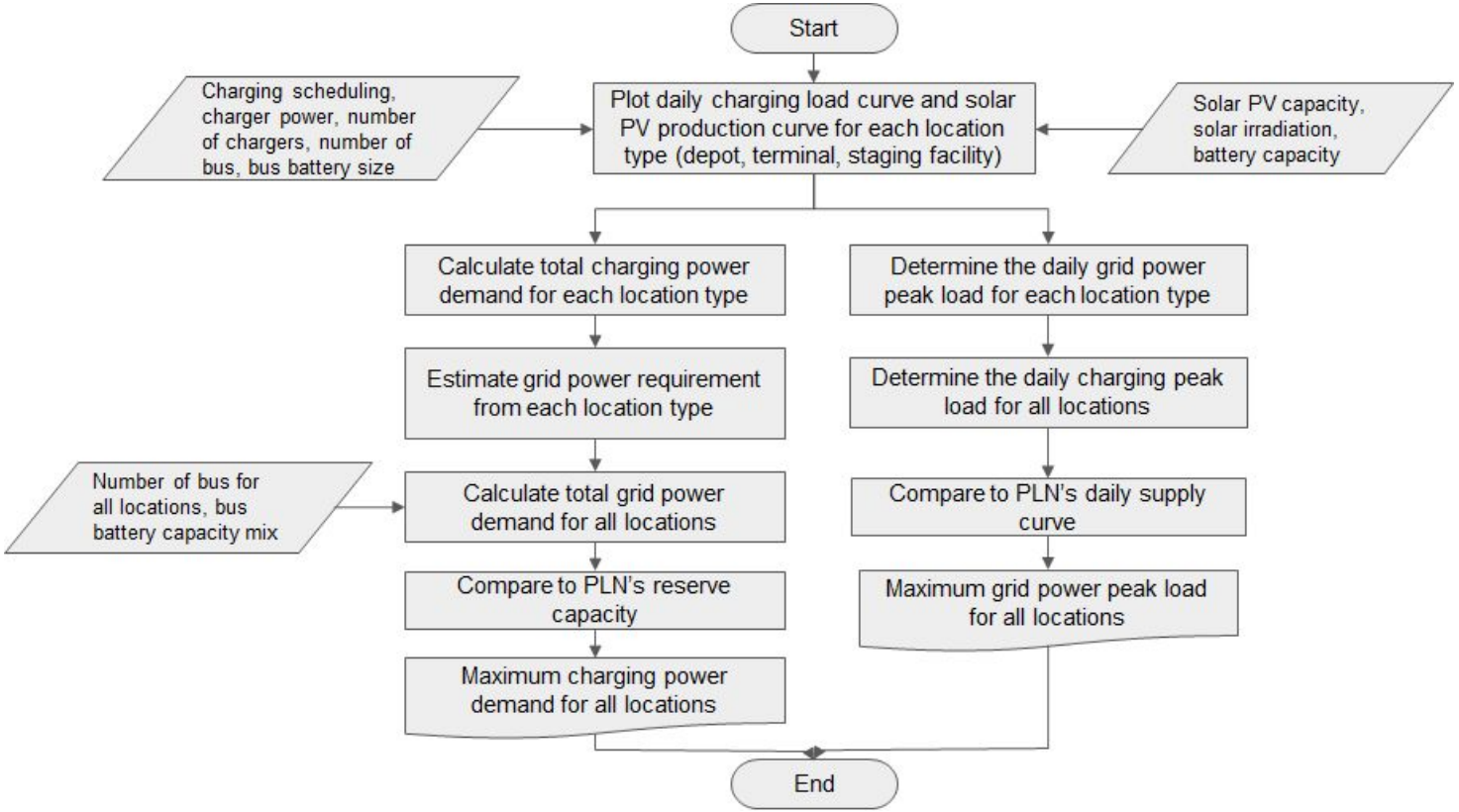
The main objective of this report are:

1. To **analyze the current (local) grid capacity**, especially in Jakarta region, and to analyze **the electricity demand for electric buses charging**, load increase each year by looking at the supply–demand balance of power given Transjakarta's e-buses deployment plan
2. To **identify the required electrical power infrastructure** at different charging locations (i.e., bus depots, terminals, and staging facilities) to cater the electric buses charging demand

This report looks at the charging demand depending on the previously proposed charging scenarios and to analyze the impact of this charging demand to the local power grid (Jakarta region)

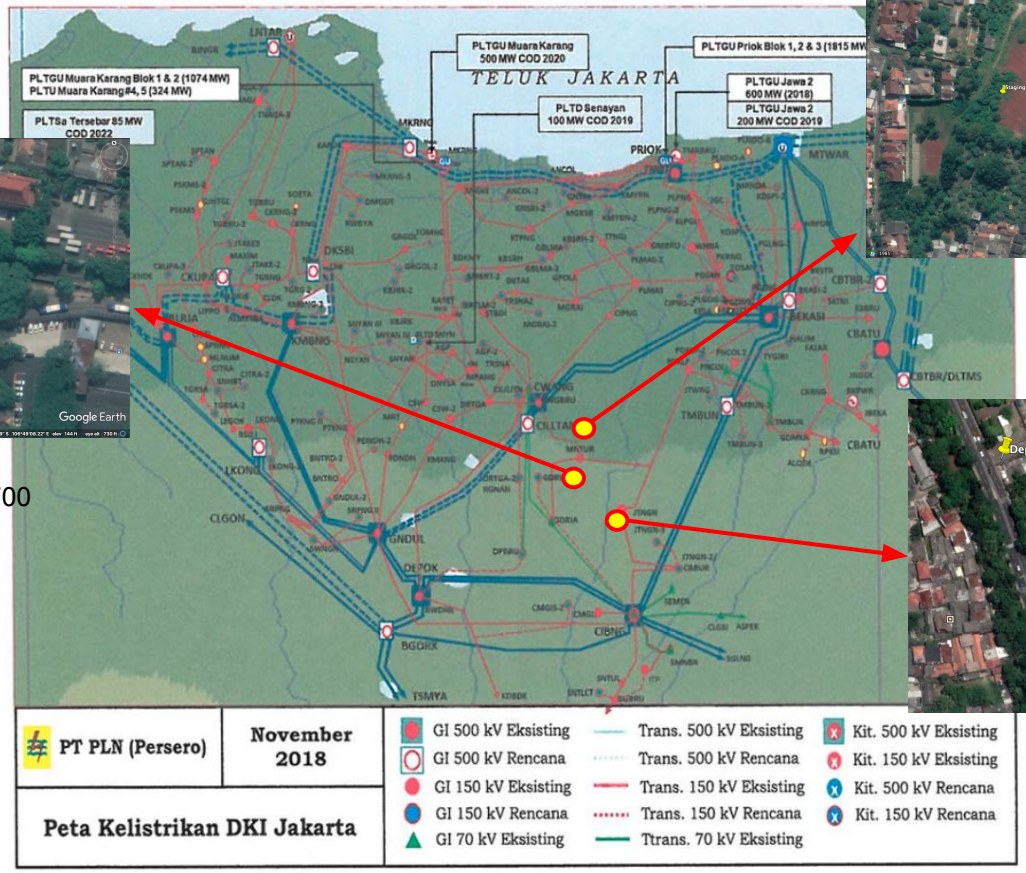
- Current charging location types (Depot Cijantung, Terminal Ragunan, Staging Facility Pejaten)
- Impact of electric bus charging load to local grid

Methodology



Charging locations:

Terminal Ragunan
-6.305720, 106.818700



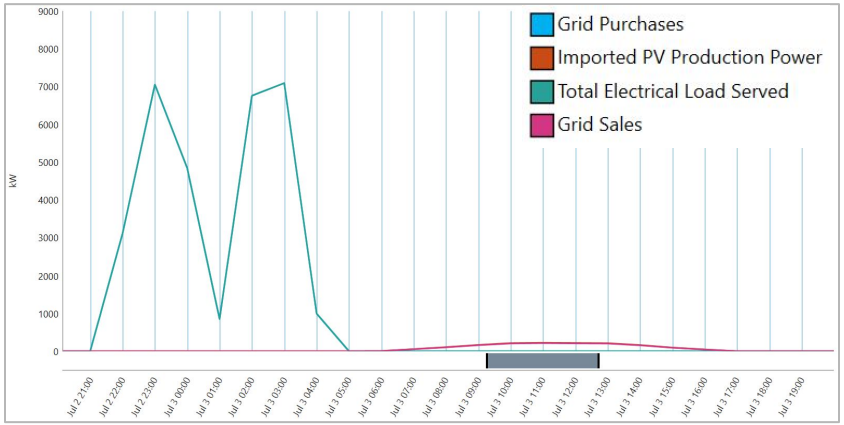
Staging Facility at Pejaten
-6.269253, 106.835925

Depot Cijantung
-6.317722, 106.865131

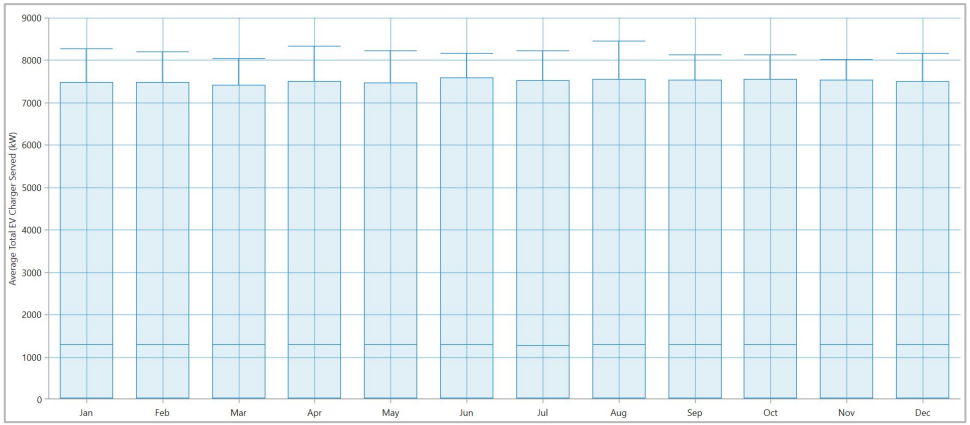
Charging demand results:

1) Depot Cijantung

Daily load profile for depot charging



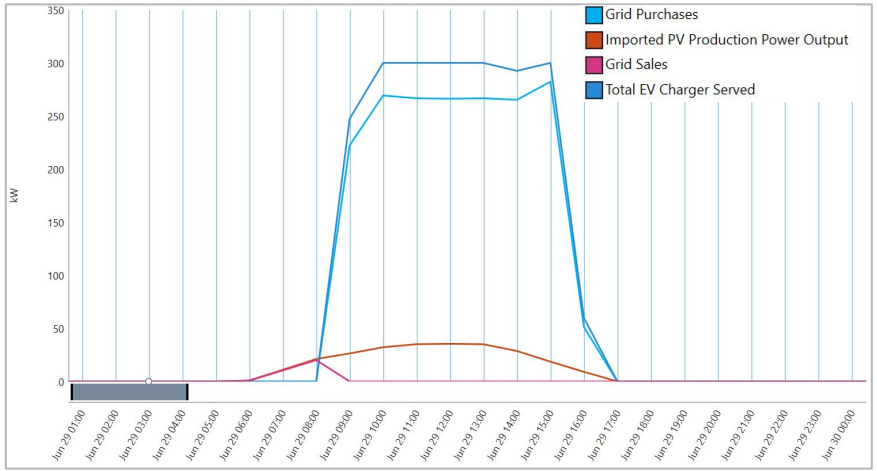
Load profile seasonality for depot charging



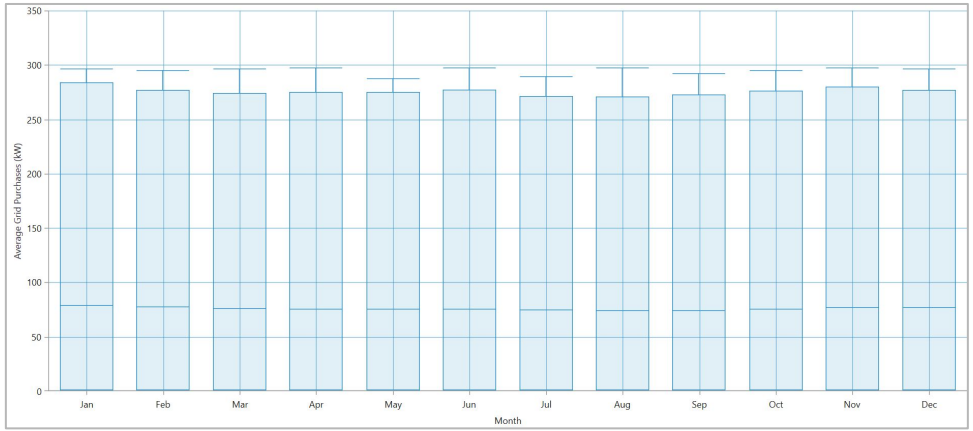
- The **daily average charging power load** for this depot totals **4,392 kW**
- With 7 hours of daily operational hours, **total electricity demand** reaches **30,746 kWh/day**, or **11,222 MWh/year**
- There are **two peaks** (load) observed, both reaching **8,457 kW** at 23.00 and 03.00, due to different schedules of electric buses arriving
- **Minimum required installed power connections** is **9.40 MVA** (assuming a PF of 0.9)

2) Terminal Ragunan

Daily load profile for terminal charging



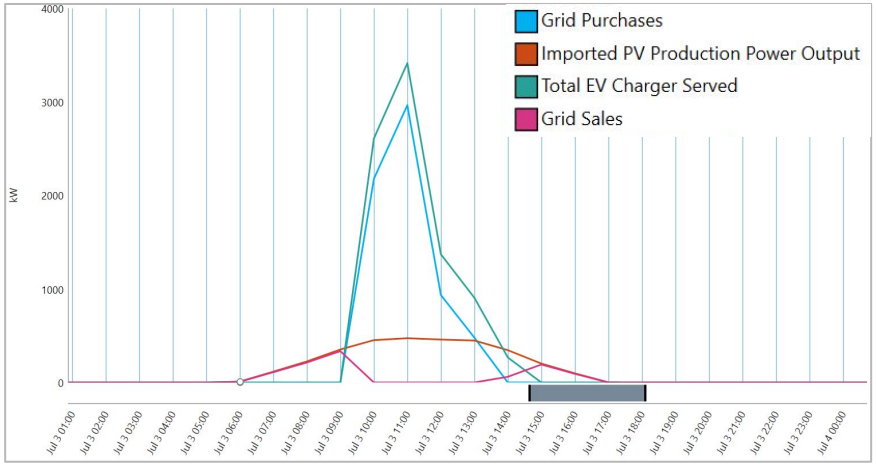
Load profile seasonality for depot charging



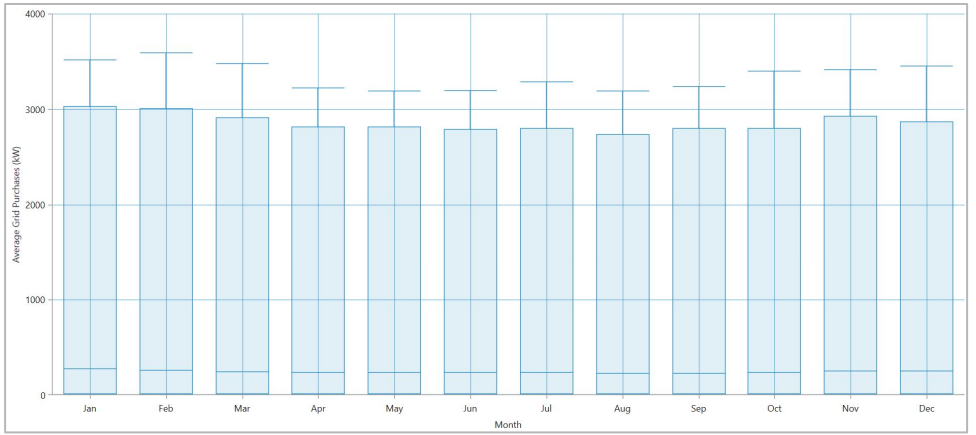
- The **daily average load** for 20 electric buses charged hourly in the Terminal Ragunan is **262 kW**
- With **total electricity consumption** of **2,098 kWh/day**, or **765,915 kWh/year**
- **With direct full utilization of solar PV production**, **grid electricity purchases would be reduced 13%** to **1,817 kWh/day**
- The **peak load** occurs for four hours from 10.00 - 13.00 at **300 kW**
- **Minimum required installed power connections** for Terminal Ragunan is **0.33 MVA** (assuming a PF of 0.9)

3) Staging Facility Pejaten

Daily load profile for staging facility charging



Load profile seasonality for staging facility charging



- Daily charging are divided into 3 batches with a total of around 4 hours and require **1,713 kW of average power demand**
- Without PV, **total electricity consumption** would be **8,565 kWh/day** (or 3,126 MWh/year)
- **With solar PV**, **grid electricity purchases would be reduced 37%** to **5,387 kWh/day** (or 2,118 MWh/year)
- The **peak load** is observed to be 4,000 kW at 11.00
- **Minimum required installed power connections** is **4.44 MVA** (assuming a PF of 0.9)

Summary: overall charging system and full deployment

Table 1. Total charging demand for each charging location type

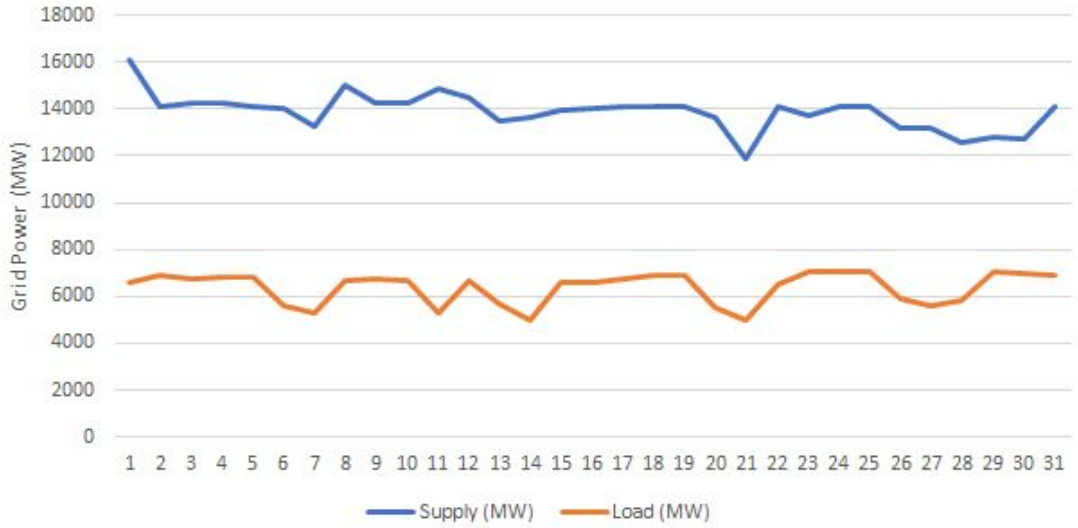
Charging location type	PV Capacity (kWp)	Average Power Demand (kW)	Electricity Demand (kWh/day)		Peak Load (kW)
			With PV	Without PV	
Depot Cijantung	747	4,392	30,746	30,746	8,457 (03.00; 23.00)
Terminal Ragunan	106	262	1,817	2,098	300 (10.00 - 15.00)
Staging facility Pejaten	1,580	1,713	5,387	8,565	4,000 (11.00)

Table 2. Total charging demand for all charging locations

Charging location type	Total number of location	Total number of bus	Power demand (MW)	Total Electricity Demand (MWh/day)		Peak load (MW)
				With PV	Without PV	
Depot	19	3,800	83.45	584.18	584.18	160.68 (02.00; 03.00; 23.00)
Terminal	12	210*	2.75	19.08	22.03	3.6 (10.00 - 15.00)
Staging facility	4	344	7.27	22.87	36.37	16 (11.00)
Total			93,44	626.13	642.58	160.68 (02.00; 03.00; 23.00)

Supply-demand of power analysis results

Supply and load curve of Jakarta recorded in March 2021



Average capacity

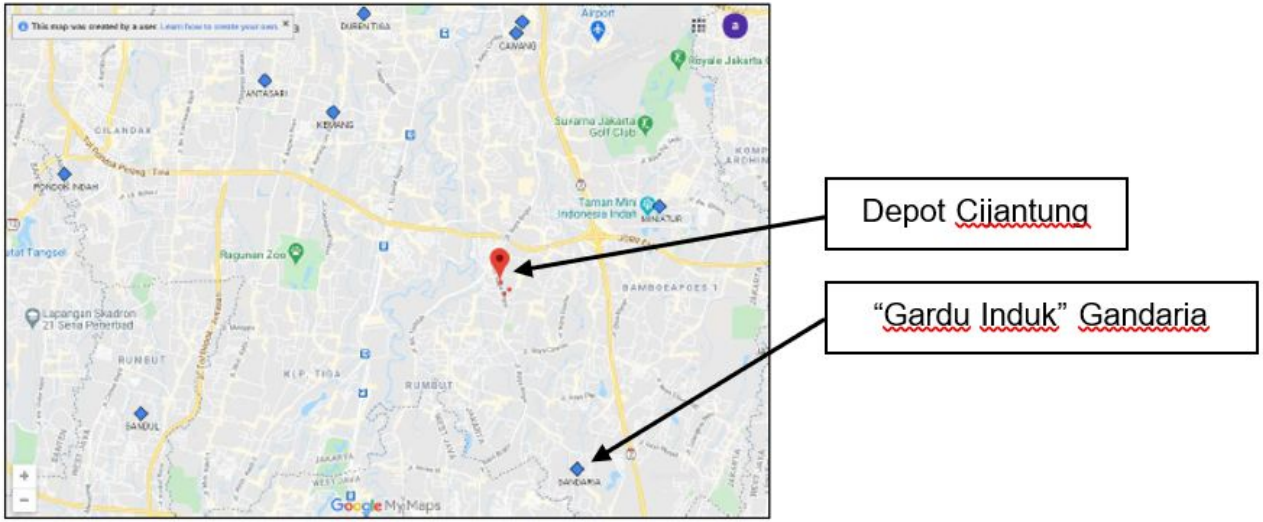
- Jakarta's gap capacity is around 50%, that is 7,510 MW
- The total charging load only contributes around 1.3% of margin capacity

Peak load

- The peak load is 160.68 MW that occurs at midnight (22.00 - 04.00), when power demand surplus occurs in the grid
- Charging peak load will not shift the overall peak load of the grid

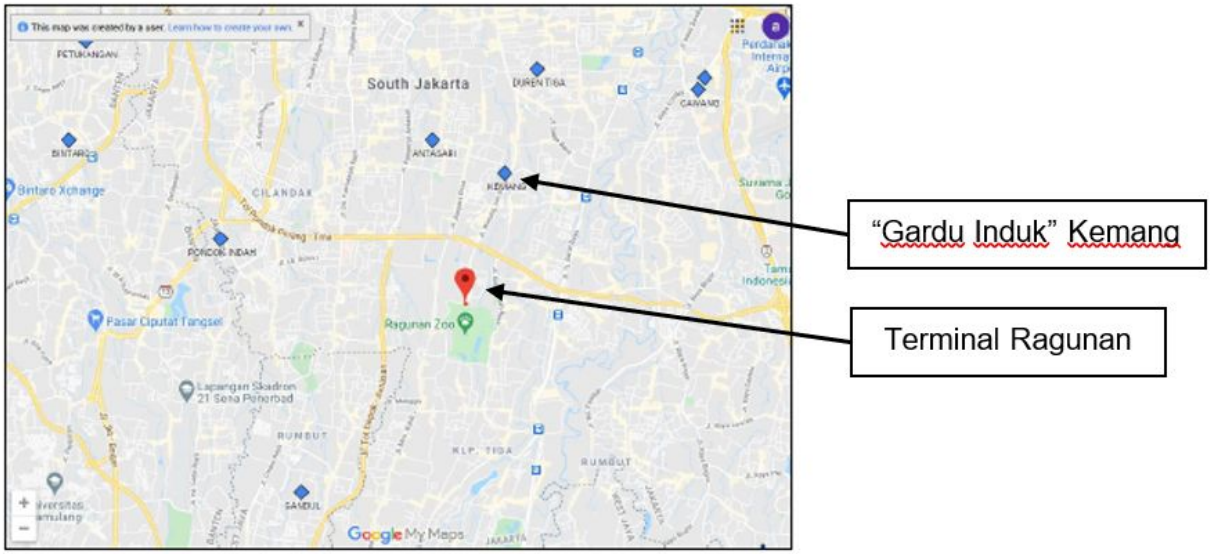
Local grid connection results

1) Depot Cijantung



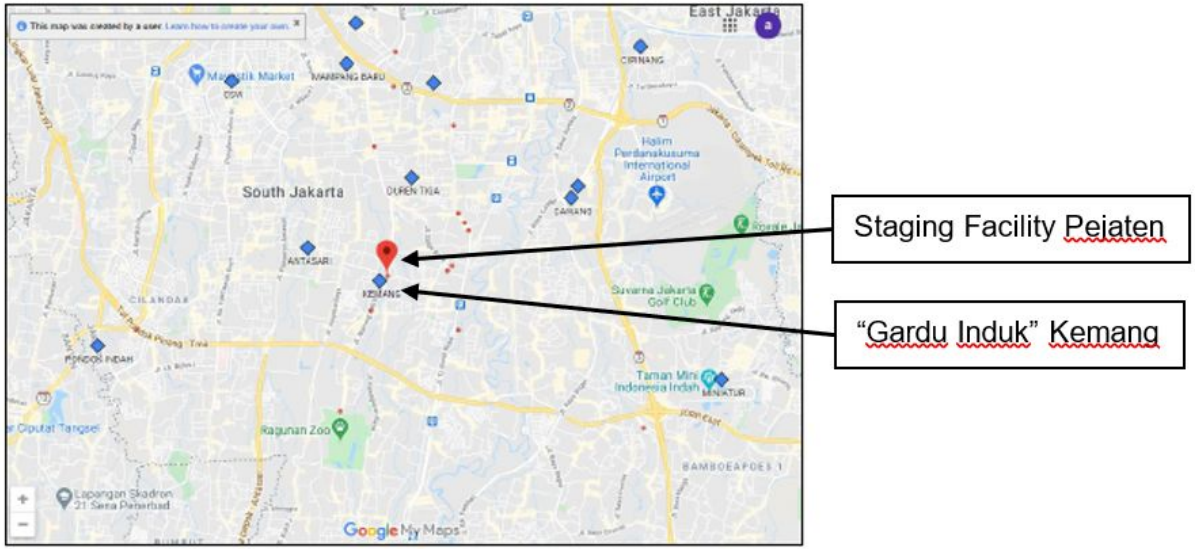
- “Gardu Induk” Gandaria has two substation transformers with each has **maximum load of 1,732 MVA** and **average load between 1,452-1,571 MVA**
- Minimum required installed power connections is only **9.40 MVA**

2) Terminal Ragunan



- "*Gardu Induk"* Kemang has three substation transformers with each has a **maximum load of 1,732 MVA** and **average load between 760-1,322 MVA**
- Minimum required installed power connections is merely **0.33 MVA**

3) Staging Facility Pejaten



- "*Gardu Induk"* Kemang has three substation transformers with each has a **maximum load of 1,732 MVA** and **average load between 760-1,322 MVA**
- Minimum required installed power connections is **4.44 MVA**

Power connection cost assessment

	Depot (Cijantung)	Terminal (Ragunan)	Staging (Pejaten)
Power connection (MVA)	9.40	0.33	4.44
Connection fee (IDR)	5,929,296,666	210,333,333	2,804,444,444
Subscription guarantee fee (IDR)	1,879,333,333	66,666,666	888,888,888
SLO certification fee (IDR)	7,000,000	4,000,000	7,000,000
Total estimated cost (IDR)	**7,815,629,999**	**280,999,999**	**3,700,333,332**

By scaling up the estimated connection costs for the overall charging system for Transjakarta's e-bus fleet deployment linearly **the total estimated connection cost would amount to a total of IDR 166.67 billion,** which is broken down into:

- 19 bus **depots** (a total of **IDR 148.5 billion**),
- 12 **terminals** (a total of **IDR 3.37 billion**),
- 4 **staging facilities** (a total of **IDR 14.8 billion**).

Note: **Connection fee** for a three-phase medium-voltage (> 197 kVA) connection is I**DR 631/VA** (MEMR 27/2017). **Subscription guarantee fee** is calculated based on PLN's rate (https://web.pln.co.id/pelanggan/uang-jaminan-langganan), in this case, all three charging location is considered to have a B-3 (> 200 kVA) tariff class, giving a rate of **IDR 200/VA**.

Conclusions

1. The **total average charging power demand** for all charging locations is **93.44 MW** (with **total peak load of 160.68 MW**)

2. **With solar PV utilization, the total electricity demand** for all locations is **626.13 MWh/day. By relying only on the grid**, the total electricity demand will increase by 2.6% to **642.58 MWh/day**

3. **Determination on** which **substation** needs to be connected to each charging location depends on **proximity to the charging location** and **adequacy of reserve capacity**

4. **A connection to a 20 kV medium-voltage network (JTM) is required** to cater the electricity demands at the three charging locations

5. The **required infrastructure** to cater the electric bus charging demands on each charging scenario will generally include **building a medium-voltage main distribution panel (MVMDP)** on the customer side and **building (or upgrading) a low-voltage main distribution panel (LVMDP)** to distribute power supply to the EV chargers

6. Overall, the required **power connection costs** for **Depot Cijantung is the highest given its peak demand, amounting to IDR 7.8 billion**. Meanwhile, Staging Facility Pejaten and Terminal Ragunan connection costs are estimated at IDR 3.7 billion and IDR 281 million respectively