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Fitriana, Ira
The National Research and Innovation Agency

Niode, Nona
The National Research and Innovation Agency

Anindhita
The National Research and Innovation Agency

Widhiatmaka
The National Research and Innovation Agency

他

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Rooftop Solar Power System for EV Charging Station of Household Customers in Indonesia: A review and an Opportunity for Developing Countries

Ira Fitriana[1], Nona Niode[1], Anindhita[1], Widhiatmaka[1] Arif Darmawan[1,*], Abdul Hamid Budiman[1], Abdul Hadi[1], Agus Nurrohim[1]

[1]The National Research and Innovation Agency, Indonesia

*E-mail: arif.darmawan@brin.go.id

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Abstract: Unlike vehicles powered by internal combustion engines (ICE), electric vehicles (EVs) rely on electricity stored in batteries as their energy source. Its benefits are lower maintenance costs, improved performance, exceptional energy efficiency, and low emissions from renewable energy sources. Research on EV charging has three main areas of focus: charging infrastructure, recommendations for charging stations and charging technology. In contrast to developed countries that have already adopted electric vehicles, developing countries tend to have more significant barriers to massive EV development. This paper reviews the situation of EV deployment in developing countries and Indonesia and the opportunity for solar utilization for charging stations. In addition, regulations regarding the use of rooftop solar PV for charging stations will also be discussed on this occasion, especially in the case of Indonesia. The rooftop PV system can be a solution for future renewable energy supply. Charging stations for household customers are more efficient, making charging easier, saving fuel, and reducing maintenance costs. EV development backed by government regulations will be critical in creating a conducive EV environment to support the net zero emission target.

Keywords: electric vehicle; developing country; charging station; rooftop PV; net zero emission.

1. Introduction

Currently, the net zero emission target launched by many countries will impact strategies for energy utilization. In Indonesia, although the direction of the energy transition strategy is increasingly firm, the pace of energy transition needs to be accelerated to reduce GHG emissions and in line with the path of the Paris Agreement to keep the earth's temperature below 1.5 ºC [1]. Among the national energy roadmap strategies is an alternative approach to minimizing emissions involving fuel switching from hydrocarbon-based fuels to biomass or green hydrogen to replace hydrocarbon fuels completely. The Indonesian government has announced its commitment to supporting the Paris Agreement targets by improving access to clean and smart technologies, energy, and cost-related variables in the energy sectors. Energy transition can be achieved by reducing the use of fossil fuels in all energy-consuming sectors, including industry, transportation, residential, commercial, and others, one of which is by replacing fuel oil-based technology with electricity-based technology. Indonesia was selected as a interest country for this study case because it is the Asia's largest developing country and is located in a tropical environment, making PV applications for implementation. Aside from that, because Indonesia is a very wide archipelago country, it requires a lot of energy in the transportation sector to have access to energy throughout its area. In supporting energy sustainability in the transportation sector, the government currently pushes the development of electric vehicles to support the achievement of clean and environmentally friendly energy [2-3]. Now, electric vehicles are used as alternative solutions that are being developed to support cleaner and environmentally friendly energy and reduce pollution and exhaust emissions due to the use of fossil fuels [5,6].

In contrast to internal combustion engine (ICE) vehicles, EVs' energy source comes from batteries' electricity. Its advantages include low maintenance costs, better performance, excellent efficiency average of 64% less energy [7-9], and low emissions using renewable energy sources [10]. This technology is considered promising for decarbonizing transportation [11-13]. In general, plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs) can be categorized as electric vehicles [14, 15]. Battery systems are an integral part of and essential for all-electric vehicles. Among the battery technologies available are lead-acid, nickel-cadmium, and lithium-ion batteries (Li-ion batteries)[16], each with a wide selection of chemical electrodes.

Nevertheless, Li-ion batteries remain one of the most efficient and reliable battery systems for EVs, especially BEVs, with more advantages than other types of batteries [17]. The Li-ion battery with the greatest energy density is the most promising battery type for Electric Vehicles (EVs) [18]. Nonetheless, the complete substitution of the internal combustion engine in the automotive industry is hindered by significant obstacles, including safety concerns, high expenses, and limited rate capability [19]. In addition, lithium-ion batteries for EVs also require thermal management to maintain optimum EV performance [20]. With the policy direction in the transportation sector toward electric vehicles, the need for battery charging for vehicles will increase massively [21,22]. This condition will radically affect the existing electric power grid due to high power requirements. It is feared that the stability of the electricity network will also be affected [23,24]. Research related to EVs has been carried out worldwide from various aspects. According to Savari et al. [21], there are three main domains related to research involving charging: charging technology, charging infrastructure, and charging station recommendations. It is enough to show the trend of the development of EV research, which is indeed growing rapidly, especially after the joint commitment to reduce emissions.

2. On and off-grid solar vehicle charging stations

Providing reliable and resilient battery charging stations is essential for a sustainable transition to electric vehicle systems. Many researchers have studied the benefits of EVs in balancing the demand and supply of grid power systems; therefore, the relationships between EVs and the grid itself should be deeply understood [22-25]. Although the high electricity demand when charging simultaneously can disrupt the grid system's balance and performance, EVs can also support the network with proper management because they can be considered energy storage on a large scale. It happens when a bidirectional mode is adopted instead of a unidirectional one [26-28]. The utilization of EVs combined with renewable energy sources in power grid management is expected to increase the popularity of the vehicle-to-grid (V2G) concept [29-31]. It is also reported that integrating EVs with the power grid can offer many services, such as peak load reduction, voltage-frequency regulation [32-33], and ancillary services [34]. Huda et al. [10] have studied the feasibility of the vehicle-to-grid (V2G) system in an Indonesian grid and reported the grid supply during peak hours can be reduced by up to 2.8% (for coal) and 8.8% (for gas) by utilizing EVs (Fig. 1).

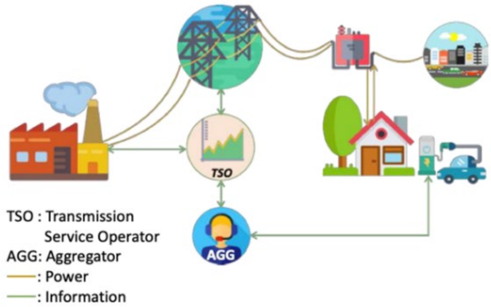

Fig. 1: An integrated system of EVs and power grid [10]

Unfortunately, integrating EV charging into the power grid also has some problems to address. Random EV charging can cause voltage instability [35-37] decreased power quality [38] and efficiency [39], overload of power system components such as cables or transformers [40,37], risk of power loss, and voltage-current transient drops during fault conditions [34]. A significant increase in power load can also affect the peak demand time due to uncoordinated charging. A study conducted in California found that uncoordinated charging methods could raise the peak demand by 11.14% [41]. Uncoordinated EV charging could significantly change the shape of the aggregate residential demand, with impacts on electricity infrastructure, even at low adoption levels[42]. In a low-load week, uncoordinated EV charging at 30% penetration (3% energy penetration) increased the peak load by as much as 27% [43-46]. Therefore, coordinated EV charging is necessary to avoid overloading the grid and ensure efficient use of electricity [47,48].

In addition, matters related to the environment also need to be considered [49]. There are no strict regulations regarding the fuel source because there are no special requirements. The increase in electricity demand for EVs will only create new problems if they are still dependent on fossil-based sources such as coal, petrol, etc. Substantially, it will only move the emission's location, not reduce it. In recent studies, renewable energy utilization has been introduced into the power grid to fulfill EVs power demand, as shown in Fig. 2. The schematic illustrates how the bus is charged using PV solar power or power from the grid. Net-zero energy can be calculated by comparing the total energy generation of distributed rooftop PV with the total energy demand for charging the bus. In the other scheme, the surplus power can also be put into the battery bank instead of the grid, which can later be used to charge EVs if there is solar radiation or very low [50-52].

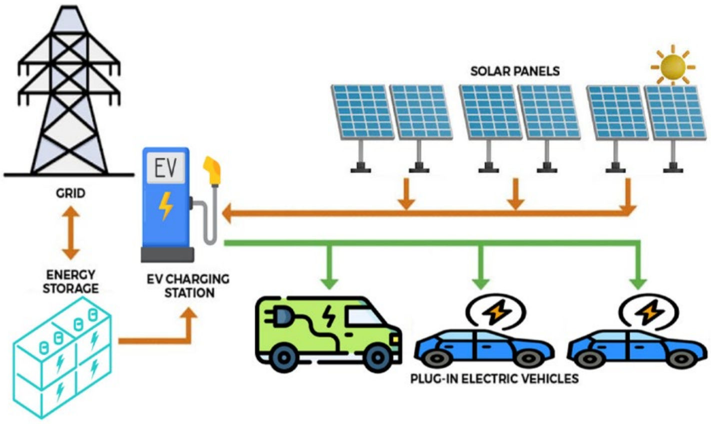

Fig. 2: Schematic of charging station based on renewable energy [53)]

3. EV's research in developing countries and renewable-based charging station

Electric vehicles (EVs) have gained more traction in developed countries due to consumer demand, market prices, availability of charging infrastructure, and government policies, such as purchase incentives and long-term regulatory signals [54-57)]. Countries like China, France, Japan, Norway, and South Korea have dominated the use of EVs. Norway has the highest percentage of EVs on its roads, with 22% of cars being plug-ins in 2021. Europe is well-equipped to sustain electric-fired transportation because of the availability of nuclear and other clean power projects [58-60)]. However, the transition to EVs in developing countries is still in its early stages, and there are challenges such as a lack of charging infrastructure and high upfront costs[61,62)]. Nonetheless, there is potential for EVs to bring development benefits to low-emitting and energy conservation for transportation sector in developing countries [63)], such as improved local air quality and last-mile connectivity in remote places. In some developed countries, EVs are very common and fast-growing in quantity and technology [54)].

The question is, can electric vehicles dominate in developing countries? In developing countries, the presence of electric vehicles will be able to become a special attraction for users in the household sector, although it can be expensive [64-66)]. One of the convenience factors considered by users of this sector is related to charging. Unfortunately, in developing countries such as Nepal, the charging technology is expensive, including installation costs [64)]. They certainly also want to charge the vehicle at a convenient time. With this in mind, there are challenges for Indonesia and other Southeast Asian countries in accelerating electric vehicles.

Sarmad et al. [67)] reported several driving forces for adopting EVs in developing countries, such as emission reduction [68)], energy saving [69)], low operational cost [70)], and affordable price, especially for the scooter with two wheels [71)]. On the contrary, infrastructure costs, high EV prices, lack of policy, resale issues, etc., could be why people avoid EVs [72)]. These driving and resisting factors lead many researchers to perform consumer preferences in developing countries, as reported by Vidhi et al. [73,74)] and Prakash et al. [74)], including Wahab and Karmaker [75)] in Ghana. In Pakistan's case, Rafiq et al. [76)] have addressed development prospects, including statistical analysis, some obstacles, and recommendations. They also provided research and development steps for EVs adaption that may suit Pakistan and other developing countries, as shown in Fig. 3.

Fig. 3: Important aspects for massive EVs development in developing countries [76)]

The charging aspect is among the technical problems related to developing EVs in developing countries. A study on EV charging infrastructure in India identified 11 significant challenges to EV charging infrastructure development, including the lack of charging infrastructure and the need for standardization of charging equipment [77,78)]. Another article discusses the challenges of uncoordinated charging in power systems with minimal and insufficient demand-side management schemes, which can result in electrical distribution network overloads and outages, particularly in small Caribbean Island power systems [79)]. However, there are also articles that propose unique approaches to demand-side management of EV charging in developing countries, such as a prototype device designed for connection to the EV that allows remote modification by the electrical utility of the pilot control signal of the J1772 charge [79)].

Due to infrastructure limitations, EV charging time can be considered relatively long. On four-wheeled electric vehicles, the power outlet requires a minimum of 1 kW (level 1), 7-19 kW or 22 kW (level 2), or more than 50 kW for fast charging (level 3). Level 1 can require more than 40 hours to fill an empty 60 kWh battery. Level 2, 4-10 hours is needed to charge the same capacity battery. Level 1 charging is typically installed in a home, while level 2 is common in the home, workplace, or public area [80)]. Due to environmental considerations, charging stations powered by solar energy have also been widely investigated [81,82)]. K. Hashizaki et al. examined the charge-discharge characteristics to see the declining of lithium battery capacity[83,84)].The researchers want to anticipate the crisis caused by non-renewable fuels [85)]. Spina et al. [86)] solar vehicle design for the Chile case. Barua and Hasan propose a solar PV charging station in Bangladesh[87)], especially for energy savings to minimize electricity consumption. Mahdi et al. also developed [88)] an energy management system to utilize EVs battery as a power backup for the residential sector in developing countries.

Furthermore, Abdul and Salam[89)] have proposed a system modeling for charging stations powered by solar energy and grid and compared it to the standard EV charging using a grid system. They also proposed a charging station in a remote area and found that utilizing solar power could be economically feasible compared to stand-alone generators[90,91)]. Several studies also investigated the optimization technique of renewable-based charging stations, mainly utilizing solar energy sources [92–98)]. Moreover, due to the nature of grid systems in developing countries, developing off-grid charging stations based on renewable energy could help accelerate EV deployment [99,100)].

4. EV development in Indonesia and proposed rooftop PV system for charging stations in the residential sector

4.1 EV situation in Indonesia

Indonesia is taking steps to decrease its dependence on fossil fuel-based vehicles and encourage the adoption of more eco-friendly means of transportation, particularly electric vehicles (EVs), to tackle climate change and lessen greenhouse gas emissions [101-103]. The development of electric vehicles in Indonesia faces several challenges, including the low adoption rate due to public acceptance and perception issues, the lack of infrastructure such as charging stations, and the high price of electric vehicles compared to internal combustion vehicles [104-106]. The EV ecosystem involves various stakeholders, each playing a crucial role in the development, production, adoption, and support of electric vehicles, as shown in Fig. 4. The number of future electric charging stations based on the growth of electric passenger cars until 2040 has been estimated [107]. The government has implemented various policies, regulations, and incentives to facilitate EV growth and use, including Presidential Regulation No. 55/2019, which provides the framework and legal foundation for developing and using battery-powered EVs for on-road transport[108]. Government agencies have issued additional regulations concerning EVs' production, charging infrastructure, and battery technology [109,110]. These regulations establish transparent standards and guidelines for the production, testing, and certification of EVs, thus creating a conducive environment for the growth of the EV industry while also ensuring the safety and dependability of EVs on Indonesian roads [111,112]. Objectives and guidelines for expanding the local BEV industry using domestic content were also regulated. These regulations offer local manufacturers and suppliers opportunities and help minimize Indonesia's dependence on imported vehicles and components, promote sustainable transportation solutions, and achieve a more sustainable and fair future for all [113,114]. PLN, its largest state-owned electricity provider, to accelerate the preparation of Indonesia's EV infrastructure. PLN is prototyping a location-optimized model to simulate how well its infrastructure design reaches customers, fulfills demands, and generates revenue. Numerical experiments with 11 candidate EV charging station locations and the projected number of electric vehicles in the early penetration phase across 98 sub-districts show that only four charging stations are needed to cover the whole city, given the charging technology PLN has acquired. Still, consumers' time-to-travel is exceptionally high (about 35 minutes), which could lead to poor consumer service and hindrance toward EV technologies [115, 116].

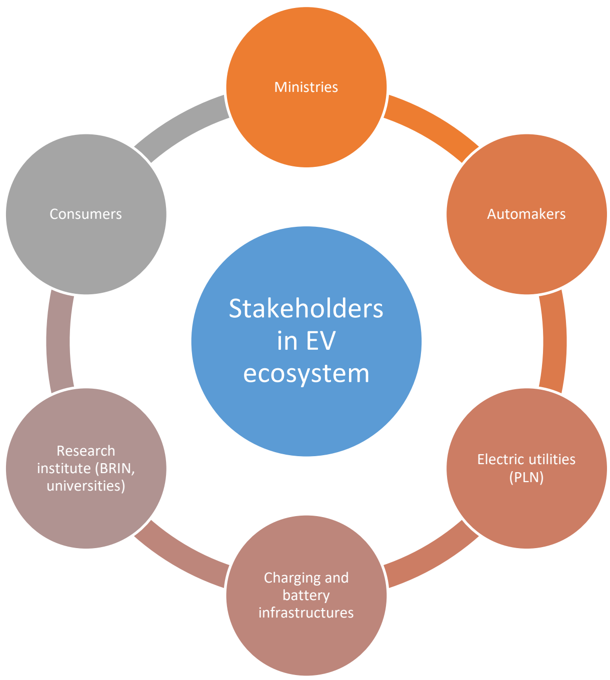

Fig. 4: Illustration of stakeholders of EV in Indonesia.

A study evaluating barriers to EV adoption in Indonesia found that insufficient charging infrastructure is one of the key barriers to EV adoption in the country [117–119]. The Ministry of Energy and Mineral Resources in Indonesia has recently updated its regulations for Electric Vehicle Charging Stations (EVCS) and Battery Swap Stations (BSS) with the release of Ministerial Regulation No. 1 of 2023, which now covers both types of stations. The new regulation outlines important details like business schemes, ID Number Codification, and electricity tariffs. Additionally, it aims to standardize batteries at public

BSS, requiring a minimum capacity of 20 Ampere Hours (Ah) and a rated voltage of 48, 60, or 72 volts, and specific plug and socket types for public EVCS in Indonesia [120)]. To promote domestic nickel smelting, nickel ore exports have been banned, and PT Indonesia Battery Corporation (IBC) has been established to support the development of the EV industry and create job opportunities. Other regulations include the restriction of nickel exports, the restriction of Nickel Pig Iron (NPI) and Ferro Nickel (FeNi) exports, and the distribution of smelter and battery producer industries by region [121, 122)].

Table 1. Different charging modes used in Indonesia [123, 124)]

	Slow Charging	Medium Charging	Fast Charging	Ultra Fast Charging
Location	Private Installation (House)	Private Installation (Office)	Public Charging Station (SPKLU)	Public Charging Station (SPKLU)
Max. current output (A)	16 AC	63 AC	100 AC/250 DC	300 AC/500 DC
Power Output (kW)	≤ 3,7 kW	3,7 kW - 22 kW	22 kW - 50 kW	50-150 kW
Plug-in Connector type	Type 1 and 2 (IEC 62196-2)	Type 2 (IEC 62196-2)	CCS or Chademo (IEC62196-3)	CCS or Chademo (IEC62196-4)

Indonesia's government is promoting the use of electric two-wheeled vehicles and encouraging a program to convert existing vehicles to electric ones [125)]. The program's initial focus is on two-wheeled vehicles, with a target of retrofitting six million motorcycles by 2025. It is expected to result in a significant decrease in oil consumption and CO_2 emissions. The retrofit program is subject to several regulations, including the Regulation of the Minister of Transportation No.65 of 2020, which outlines the certification requirements for retrofit workshops. As of February 2023, there are 21 registered retrofit workshops in Indonesia, and the goal for retrofitted motorcycles in 2023 is 50,000 units. For vehicles other than motorcycles, the retrofit program is regulated by the Regulation of the Minister of Transportation No.15 of 2022, which includes additional provisions for retrofit workshop technicians and registration requirements. The Indonesian government is making a concerted effort to encourage the use of clean energy vehicles, specifically EVs. Presidential Instruction no. 7/2022 requires government agencies to shift their procurement of official and operational vehicles to BEVs. The National Energy General Plan has set ambitious targets for EV usage in Indonesia, and the current number of four-wheeled BEVs has already surpassed the 2025 target. The Indonesian government has implemented a range of incentives to encourage the adoption of electric vehicles (EVs), which can be divided into consumer and manufacturer incentives [126)]. Consumer incentives include lower tax rates, exemptions from vehicle ownership transfer fees and taxes, lower down payment requirements, and reduced electricity tariffs for home charging. EV owners can also enjoy special privileges by displaying special license plates, such as exemptions from traffic rules. Meanwhile, EV manufacturers can benefit from tax holidays, exempting them from paying corporate income tax for a certain period. These incentives promote renewable energy-based vehicles, reduce carbon emissions, and encourage sustainable transportation options [127)]. However, the high EV cost[128)], limited mileage, scarcity of charging stations, and lengthy charging process remain significant barriers to their adoption in Indonesia[66)]. Other alternative vehicle technologies such as FCEVs, biofuel vehicles, and conversion vehicles from ICE[129)] can offer more affordable and environmentally friendly options than BEVs [130)].

Several entities in Indonesia's transportation sector can potentially collaborate in developing and adopting electric vehicles. Transjakarta is leading the way by building electric buses and integrating different modes of transport to provide better services to commuters, including those with disabilities [131,132)]. Electric taxis have been used in the public transportation sector since the early days of EV exploration in Indonesia [133)]. Other electric vehicles also make inroads into delivery services and the police force. The development of EV in Indonesia is gradually progressing, with significant changes already occurring in the air transportation sector. Electrically powered equipment is now being used in the field, and air taxis are also operating, albeit on a limited scale. One of the key challenges is insufficient charging infrastructure, which has been identified as a barrier to EV adoption in the country [134,135)]. The lack of EV infrastructure and strong fossil fuel dependency pose an enormous challenge [136-138)]. The pace of the EV rollout in Indonesia is slow, and the country's low adoption rate of EVs is due to various reasons, including high initial purchase price and a lack of government incentives. The time for consumers to reach EV charging stations is also exceptionally high, which could lead to poor consumer service and hindrance toward EV technologies.

4.2 Total installed capacity of Indonesian power plants

Currently, coal power plants still dominate the national power generation mix, while the government is aggressively pursuing the target of renewable energy utilization set out in the National Energy Policy (KEN). According to government regulation (No. 79 of 2014 (PP 79/2014)) on national energy policy, fossil energy and CO_2 gas emissions are reduced through the energy mix target with a share of new and renewable energy of 23% in 2025 and 31% in 2050. In 2021, coal dominated national power plants with a share of 47%, followed by gas at 31%, oil at 7%, and new and renewable energy (NRE) at 15% (see Fig. 5). The renewable power stations were dominated by hydropower at 8%, Geothermal Power Plant at 3.1%, Minihydro Power Plant at 0.4%, PV and micro-hydro at 0.2%, and the other has a share of 2.9% [139].

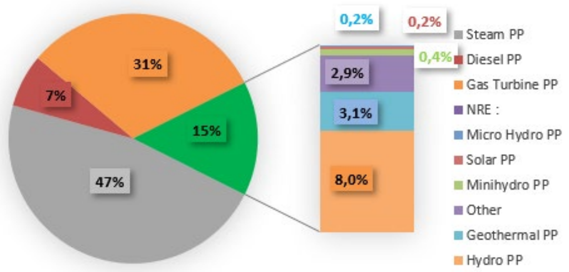

Fig. 5: Primary Power Generation Mix in 2021

Furthermore, through Presidential Regulation Number 22 of 2017 concerning the General National Energy Plan (RUEN), the government strengthens the National Energy Policy PP 79 / 2014. One of the ways to meet the target of NRE is to reach 23% of the total primary energy mix by 2025, with solar power plants expected to be 14% or 6.5 GW of the total 45 GW power generation capacity.

4.3 Total solar power plant and PV rooftop in Indonesia

The potential of solar energy can be used as an alternative energy source to replace petroleum energy[140, 141]. In the last few years, the solar photovoltaic and wind power sectors have undergone significant expansion, propelling the growth of renewable energy[142]. The electricity industry remains the most encouraging market for renewable energy, but the adoption of PV panels in this sector has been hindered by factors such as cost, performance, and atmospheric conditions. At present, only a small portion (15-20%) of the total solar radiation absorbed by a PV panel can be converted into electricity, with the rest being reflected[143,144]. Furthermore, a PV system installed on a rooftop provides not only the ability for households to use energy from the grid, but also allows them to produce it, making them known as prosumers [145-148]. The incorporation of prosumers has been shown to be an effective approach for achieving sustainable energy solutions.

Geographically, Indonesia's potential for solar energy has a tropical climate that gets sunlight throughout the year with an average radiation intensity of 4.8 kWh/m^2/day and a very large solar power potential of 207.9 GW[149-151]. The distribution of solar energy potential in the Indonesian territory is shown in Fig. 6. It can be seen that the potential for solar energy above 10 GW appear across several provinces, there are West Kalimantan at 20.11 GW, South Sumatra at 17.23 GW, East Kalimantan at 13.48 GW, North Sumatra at 11.85 GW, and Java East at 10.34 GW [152, 153].

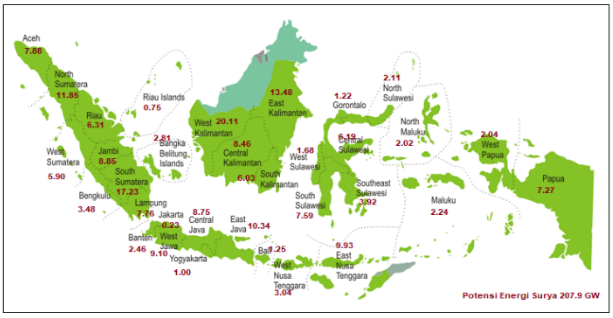

Fig. 6: Distribution of Solar Energy in Indonesia[154]

Solar energy utilization has only reached 0.07% of the existing potential, with an installed capacity for solar power plants of 145.82 MW in 2019, of which 20.97 MW (14%) belongs to The State Electricity Company (PLN). A consumer study found that the main issues for the adoption of solar energy are due to a lack of consumer incentive, lack of clear benefits of electricity reduction, and poor education about how to install solar power on the consumer level [155,156]. The remaining 124.85 MW is owned by private companies, including Independence Power Producers (IPP). Currently, the government is trying to prepare for the development of solar power plants (PV) to target 23% of NRE through three approaches:

1. Until 2019, the capacity of rooftop solar power plants was 19,574 MWp, with 4.927 MWp belonging to PLN's on-grid and the remaining 14,647 MWp belonging to non-PLN. (see Fig. 7)
2. Developing a large-scale solar power plant with

a target of 13,565 MW is still not a priority due to land availability and the high installation cost[157].

3. The program will replace PLN's diesel power plant with PV and batteries as a backup for emergencies [158, 159].

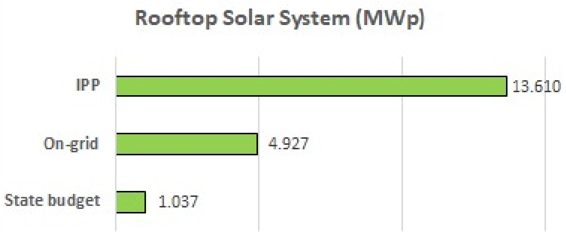

Fig. 7: Installed PV Rooftop Distribution

4.4 Household Customers

According to a study the adoption of rooftop photovoltaic (PV) in Indonesia has become a trend adopted by residential consumers[160]. The study used agent-based modelling (ABM) to predict the rooftop PV adoptions in the future and found that factors inherent in consumer behavior such as the level of adoption to adopt new technologies [161], the number of neighbours who have installed rooftop PV, lifestyle, and intensity of exposure to social media have influenced the rate of adoption. Another study tried to identify the determinants that influence consumers' intention in adopting renewable energy sources and found that only eight variables, including income per month[162], certainty about the efficiency of renewable energy project, and energy tax deduction, are significant statistically[163,164]. A policy study discussed the recent solar rooftop PV system policies in Indonesia, particularly for the implementation of the residential sector [165].

Household customers are individual customers or social entities using electricity for household purposes, including residence houses, groups of rented houses, individual-owned flats, flats owned by National houses (Perumnas), family dormitories for private company employees, and student dormitories. According to PT PLN, as shown in Fig. 8, the types of electricity customers or consumers are classified into several groups, namely social, household, business/business, industry, office/government, and others [166]. The household group has the largest number of electricity customers, namely 69.62 million customers or 92% of the total electricity customers of 75.71 million[167,168].

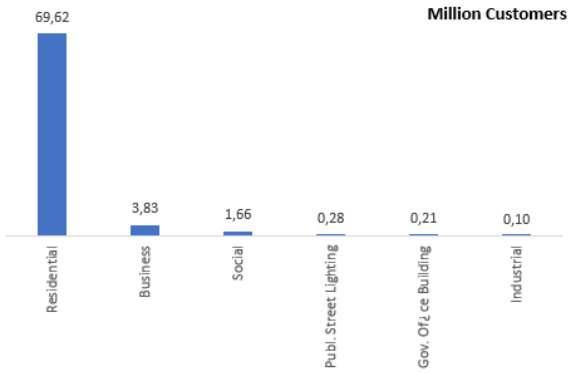

Fig. 8: PLN Customer by Sector Distribution

Household sector customers are categorized into several groups depending on the type of building and the amount of power used. R1 household customers generally have a power range between 450 VA to 2200 VA, namely 68.1 million customers or 97.9% of the total customers with a power of 59.38 GVA. In addition, household customers R2 with a power range between 3500 VA to 5500 VA are 1.2 million customers or 1.8% with a power of 5.11 GVA, and household customers R3 at 6600 VA and above are 0.3 million customers with a power of 3,4 GVA[107], as shown in Fig. 9. Household consumption is generally for lighting, cooking, heating, and other purposes such as fans, air conditioners, mixers, water heaters, refrigerators (refrigerators), water pump motors, TVs, laptops, computers, etc[169]. Each household customer has a different use of electricity. Generally, the peak load of household customers is at night. Power users dominate in the afternoon and will decrease from 22.00 to 6.00. Based on the Ministry of Energy and Mineral Resources Regulation No. 49 of 2018 concerning the use of rooftop solar power generation systems by PLN consumers. The government seeks to accelerate the development of solar PV rooftops through:

- Rooftop PV program on the construction of new houses in collaboration with the Ministry of Public Works and Public Housing (PUPR) and Real Estate Indonesia (REI),
- Rooftop PV installation program at customers' homes for R1 and tariff groups [170].
- The rooftop PV installation program for PLN customers with more than 1,300 VA groups is given an attractive financing scheme incentive and a declaration of the National One Million Solar Roof (GNSSA) movement [171].

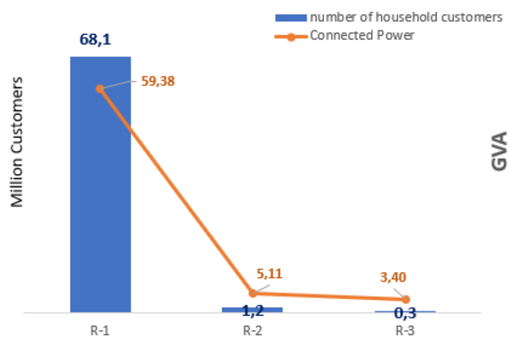

Fig. 9: Ratio of PLN customers in the household sector by type [167,168)]

4.5 Rooftop PV mini-grid household customers

As of December 2020, the installed capacity of Rooftop PV reached 21,404 MWp (Megawatt peak) with 3007 customers, an increase of 8.6 times from Rooftop PV mini-grid customers in January 2018 of 351 subscribers (Fig. 10). This is because rooftop PV systems can save up to 30% of the use of PLN electricity[172)], component costs, and installation of Rooftop solar panels for low kWp, which are easy to maintain. The lifespan of solar panels is about 25 years[173)].

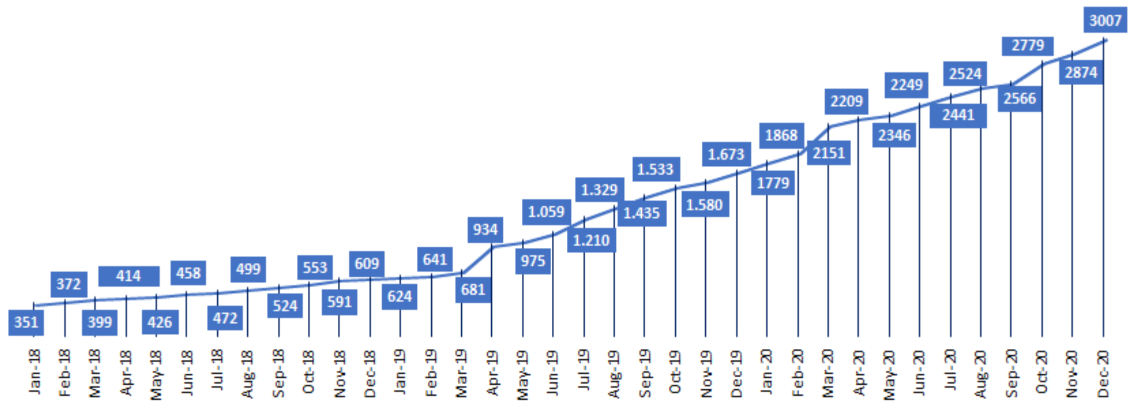

Fig. 10: Growth of rooftop installation

Since household customers are the most dominant, the potential for rooftop PV for household customers can be seen in the size of the tariff group for household customers [174, 175)]. In this case, the data used is from 2019 because it is the most complete and available (source of PLN 2019 Statistics & Ministry of Energy and Mineral Resources). Rooftop PV customers by tariff group are still dominated by household customers, with 1,463 customers, as shown in Fig. 11.

As of December 2019, PLN's installed Rooftop PV with capacity per tariff class reached 3,176 MWp (Megawatt peak) with 1,463 household customers or 0.002% of 69.6 million household customers. The most customers are in Jakarta, with the number of customers reaching 479 with a capacity of 1,140 MWp, followed by Banten with 398 customers with a capacity of 0.723 MWp, West Java with 385 customers with a capacity of 0.648 MWp. It can be seen that there are only 50 customers in Bali. Still, the capacity is 0.337 MWp, greater than the 0.209 MWp capacity in East Java, which has 105 households from customers in Bali, Central Java, and Yogyakarta, 39 customers with a capacity of 0.094 MWp, Riau and Riau Islands with the capacity of 0.009 MWp, East Kalimantan 2 customers with a capacity of 0.008 MWp, and S2JB 1 customer with a capacity of 0.009 MWp.

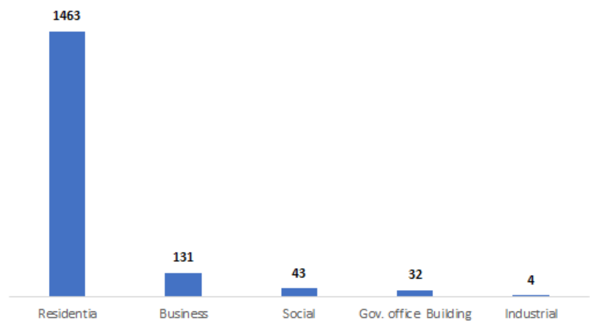

Fig. 11: Number of PV Rooftop Customers by Tariff Rate

4.6 Rooftop PV concept for household charging station

4.6.1 The concept of rooftop PV combined with the power grid in household

Among the factors affecting the performance of a rooftop PV is the quality of sunlight and intensity—the higher radiation intensity results in higher power generated[176-178)]. Generally, sunlight can produce maximum electrical energy in Indonesia ranges from 4 to 5.5 hours a day from 9.30 to 2 pm [179)]. The intensity of sunlight received by household PV will be low when the sky is cloudy or rainy[180)]. The presence of shading and dust accumulation also causes reduced efficiency and losses in the PV system [181,182]. According to the regulation, a rooftop solar power system generates electricity using photovoltaic modules installed on roofs, walls, or other parts of household customers, as well as distributing electrical energy through the electrical connection system of household customers[183,184]. The installation of the rooftop PV system should also have an SLO (Certificate of Eligibility for Operation) to make it sustainable and work properly[185-187], as shown in Fig. 12 as a standard installation.

Sunlight is renewable energy received (captured) by the solar panel. A solar panel produces electric current with direct current entering DC (direct current)[188]. The inverter converts DC direct current into electricity, so alternating current AC (alternating current) can run household appliances using alternating current electricity, such as electronic devices, such as TVs, refrigerators, fans, water pumps, and washing machines[189,190]. If the power generated by the rooftop PV system is greater than self-consumption, the remaining power will be exported to PLN, according to the regulation. If we export 1 kWh, we can import 0.65 kWh for free, and PLN calculates the excess energy[191, 192], which means that PLN will reduce the bill for the next month. PV on-grid does not have battery storage and only operates at noon. On the other hand, if the rooftop PV power is less than household demand, the additional power will be imported from PLN's grid system. In addition, PLN provides electricity tariff discounts of up to 30% from 22.00 to 5.00 am; PLN also waives the cost of increasing household electric power.

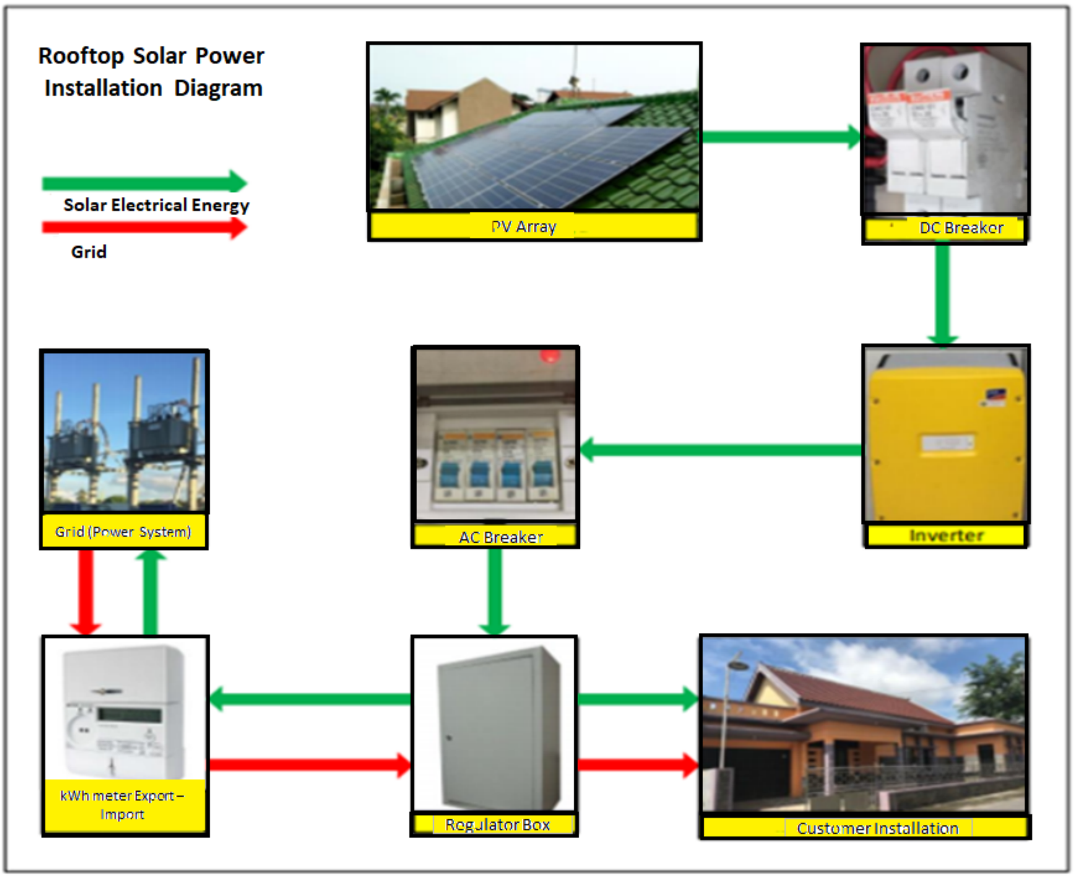

Fig. 12: Installation Diagram of the Rooftop PV mini-grid system according to MEMR Regulation No 49 of 2018

4.6.2 On-grid rooftop PV Concept for household charging stations

The rooftop PV system PLN is proposed based on the procedure in Fig. 12. However, the performance would depend on various factors such as weather, clouds, shading[193], and air pollution. The power required depends on the type and location of the house, namely the PLN tariff class for household customers (R1, R2, and R3) to which panel solar will be installed. Meanwhile, the power output of the rooftop PV system peaks during the day between 9.30 am to 2 pm hours and is zero at night when the maximum demand occurs. It assumes that the tariff group for household customers is R2 in the power range between 3500 VA to 5500 VA. They are using charging station mode 3, which uses a special charging station as a wall box installed in households to charge EVs, adopting fast charging with strict safety protection. They are using alternating current

AC or DC direct current[194]. Mode 3 chargers are limited to less than 22 kW and can be used for 4-wheeled and 2-wheeled vehicles[195].

In current conditions in Indonesia, the installation of rooftop solar PV is generally 1-2 kWp per household[196]. This power is sufficient for charging electric cars using a range of 1,000-2,500 W with a charging time of 7-8 hours. For fast charging, 7,700 W of power is used because the charging device is bundled when purchasing a new electric car, and the charging time is between 3-4 hours faster. With the support of 2 kW of rooftop solar PV, it can save electricity consumption from PLN by up to 30%. It is recommended that the kWh meter for charging electric cars be separated from household appliances to determine electricity consumption, especially when charging electric cars. Currently, initiatives are being attempted to develop wireless power transfer (WPT) to facilitate the process of charging, allowing energy to be transferred without any physical contact. EVs that are capable of charging systems up to kilowatts can benefit from this technology. When using a cable would be difficult, risky, or impossible, it is helpful for powering electrical devices [197]. Consequently, it is essential to establish an EV charging station network similar to the gas stations seen in places where lengthy commutes are common. Nevertheless, the planning and implementation of an EV charging infrastructure is challenging, including the evaluation of competing industry standards, grid implications, current technology, as well as additional policy and technical difficulties[198,199].

4.6.3 Off-grid rooftop PV concept for EV charging stations

The off-grid rooftop PV consists of several panels arranged in a series, parallel, or parallel series combination placed on the roofs of household customers that convert sunlight into direct current electricity. Compared to the installation diagram in Fig. 12, the off-grid system charging station is not connected to the PLN's grid, and 100% of the power comes from the rooftop PV system. Consequently, the system requires a battery to store the electrical energy generated during the day to meet electricity demand at night [200, 201]. However, the off-grid system requires significant battery capacity, estimated to be expensive. The installation cost for the solar panel system will be 2 or 3 times more expensive than the on-grid system [202-205]. It is assumed that the tariff group for household customers is R3 at a power of 6000 VA and above that can use charging station mode 4. This off-grid is only recommended for remote locations.

5. Conclusions and Recommendations

The government's policy to meet the renewable energy target of 23% of the total primary energy mix in 2025 is equivalent to a PV of 6.5 GW of the total renewable power capacity of 45 GW. One of the efforts to encourage the program to be more progressive is to deploy a rooftop PV system. The power generated can also be used as electric vehicle charging stations. The advantages that customers can obtain in the household sector include:

- Rooftop solar power plant saves on monthly electricity bills.
- Rooftop PV mini-grid systems are not subject to a capacity charge and the cost of purchasing emergency electrical energy, which is part of the parallel fee.
- The rooftop PV system is one of the best solutions for future renewable energy supply
- Charging stations for household customers are more efficient, making charging easier, reducing time spent figuring out where to charge, and saving fuel and maintenance costs

Some recommendations are provided related to rooftop PV development in Indonesia:

- Reduction of PV mini-grid investment costs for household customers
- The government should provide incentives for the amount of energy generated from rooftop solar panels installed in households through Certified Emission Reduction (CER).
- Increase the export-import regulation related to power generated from the residential PV system

Table 2. Studies of EV Policies in Several Countries

References	**Country**	**Policies**							
		Convert 2-wheeled vehicles to electric	Using domestic content (TKDN)	Tax deductions for electric vehicles	Emission standard	End of Life and battery directive	Public charging station (SPKLU)	Odd-even free for enter the big city	Fund innovation for EV Batteries
L.Peiseler [4]	European Union (EU)	x	x	x	v	v	v	x	x
	Germany	x	x	v	x	x	v	x	x
C.B. Agaton et.al [54]	Philippines	x	v	v	v	x	v	x	x
R. Vidi and P. Shrivastava[72]	India	x	x	v	v	x	v	v	v
Lukuman Wahab and Haobin Jiang[74]	Ghana	x	x	v	x	x	v	x	x
F. Razi et.al[133]	Canada	x	x	x	v	x	v	x	x

Table 3. Charging Stations

References	**Type of Charging Station (CS)**	**Charging Technology - Source of Electricity**	**Location of CS**	**Study case**
Mangipinto et.al [22]	Smart Charging	Vehicle To Grid – RE Power Generation	Public Charging Station	Europe (28 countries)
Clement-Nyns et.al [23]	Coordinate Charging (Smart Metering)	Plug-In Hybrid – Grid	Residential	Belgium
Benedetto et.al [24]	EVCS	Vehicle To Grid – MV and LV Grid (non-dispatchable renewable energy)	Car Parking	Global
Amani et.al [25]	EVCS	Vehicle To Home - PV and BESS	Residential	Australia
Tan et.al [26]	EVCS	Vehicle to Grid – RES with Multi-MicroGrid	Public Charging Station	Hainan - China
Zhang et.al [27]	Fast Charging Station	Third Generation Prospect Theory (PT3) – PV & BESS	Public Charging Station	China
Falahati et.al [28]	Smart Charging	Vehicle to Grid – Grid and PV System	Electric Buses	US

Inci, et.al [29)]	Integrating EV as a Virtual Grid Integration (VGI)	Vehicle to Grid – Virtual Power Plant	Public Charging Station	Turkey
Shi et.al [30)]	EVCS - Slow Charging	Vehicle to Grid – Renewable Energy as Microgrid	Residential	Global
Shuoya et.al [31)]	EVCS	Vehicle to Grid – Wind and PV Powerplant	Public Charging Station	China
Huda et.al [10)]	EVCS	Vehicle to Grid – Power Grid	Home and Commercial Building	Jawa – Madura – Bali (Indonesia)

Tabel 4. Solar PV system for Charging Station

References	Location	Solar PV system	Typical use
Muhammad Azis et.al [14)]	Japan	Offgrid PV and Power Conversion System (PCS)	Building
Wajahat Khan et.al [89)]	India	PV to grid and PV to vehicle	Urban
Hassan E.Eldeeb et.al [91)]	USA	PV uses battery energy storage system (BESS)	Urban
Abdulla Al Wahedi and Yusuf Bicer [97)]	Qatar	Concentrated PV-Thermal for hydrogen production and hydrogen fuel cell	Hot region

Table 5. Research on Electric Vehicle Application in Developed and Developing Countries

References	Case Study	Technology Type	Implications of EV Application
Agaton et.al [54)]	Phillipines	Electric Vehicle	Reduction of greenhouse gas emissions, lowering the reliance on imported fossil fuels, more sustainable public transport system
Boschert et.al [56)]	America	Plug In Hybrid, Electric Vehicle	Save drivers money, reduce pollution, increase US security by reducing dependence on imported oil,
Haugneland et.al [58)]	Norway	Electric Vehicle	High taxes on cars with high emissions and zero tax for zero emissions cars, reduce emissions and traffic noise, strong incentives to move to EV
Kramer et.al [59)]	Germany	Electric Vehicle	CO2 emission reduction, driven energy-efficiently by using in-vehicle eco-features and by adapting eco-driving behaviors, switching on EV systems reduces energy consumption
Hasan et.al [60)]	Norway	Electric Vehicle	EV reduces local air pollution, traffic noise, and saves money in the long term, cost aspects have the strongest effects on manipulating overall satisfaction to EV use.
Künle et.al [61)]	France, Germany, Norway	Electric Vehicle	Direct incentives in Germany do not offset the higher EV price lists and taxes. In France, the direct incentive is higher than in Germany, but EV remain slightly more expensive than the same

			class internal combustion engine (ICE). In Norway, EV are cheaper than the equivalent ICE with current direct incentives
Murugan et.al [62]	India	Electric Vehicle	Identify the barriers to implement EV: Higher initial purchase cost of a vehicle, Many EV manufacturers are new companies, Technical specification of the vehicle (power, acceleration, etc.), Less Mileage on a full charge of a battery, Non-Reliable battery technology, Lesser Adaptive competitive vehicle design, Limited availability of local technician, Limited availability of public charging stations
Mali et.al [64]	Nepal	Electric Vehicle	Nepal posed to have excess power production from the development of new hydropower projects, pathway for Nepal's EV sector has been developed. The introduction of precise and investment-friendly regulations will incentivize various companies to extend PV business in Nepal.
Vidhi et.al [73] and Prakash et.al [74]	India	Electric Vehicle	NOx emissions caused by vehicles can be reduced by 7–25%, depending on charging energy source, while CO and CO2 can be reduced by up to 85%, if the charging energy were to come from renewables, the government incentives and consumer characteristics are most crucial areas of concern to improve the EV penetration in mass market
Asghar et.al [76]	Pakistan	Electric Vehicle	The move from ICE to EVs would not only strengthen Pakistan's economic structure through the expansion of different markets; they will also provide costeffectiveness for car manufacturers as many models have similar battery packs and EM

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