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Electric Car Battery Swapping Station Potential Application in Indonesia: A Review

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Abstract. Swapping battery is one of electric car charging mechanism and the place to do it called Battery Swapping Station which is one of kind electric vehicle's infrastructure. In this transition to electric vehicle era, Indonesia is also taking part in this, electric car swapping station is still lack applied in Indonesia, but through some regulations Indonesia is working to increase the number and quality of electric vehicle's infrastructure. This study is giving information and insight about electric car swapping station potential application in Indonesia. Other countries application is discussed to give insight adoption for Indonesia, strategies and suggestions are also presented in this study.

Keywords: *electric car; battery pack; swapping station; charging.*

1 Introduction

There are several charging mechanisms for electric car's battery pack, which are: plug-in charging, inductive charging, and swapping battery, which the illustrations are presented in **Figure 1**. The most common mechanism is plug-in charging or conductive charging, simply by putting charger's plug (connector) on the electric car's socket. Plug-in charging has problem with the charging time, for most cases plug-in mechanism's C-rate is limited about 1-1.5 C due to the battery pack safety acceptance [1], even though there is fast charging ability, it is only achievable up to 80% SOC level therefore the fast charging can be done in 30 up to 90 minutes depending on the temperature rise [1,2] also fast charging tends to decrease battery health faster than slow or normal charging. Inductive or wireless charging, inducing electromagnetic from coil on electricity source to the coil inside electric car then converting it into direct current (DC) which supplying the battery pack. Unfortunately, inductive charging has an issue in efficiency due to the air gap between coil both in stationer and dynamic mode [3][4], therefore it takes complex calculations and designs to develop wireless charging with optimal performance especially for dynamic mode [5-7]. Swapping battery is a promising mechanism compared to plug-in and inductive charging, swapping mechanisms is replacing or changing discharged battery (usually 20% SOC) with charged battery (85%-100% SOC), of course it takes shorter time (2 up to 3 minutes) than plug-in [8] because does not need to wait the battery full charged and also more efficient charging than inductive because the discharged battery pack will be charged using conductive method in slow charging mode [9,10].

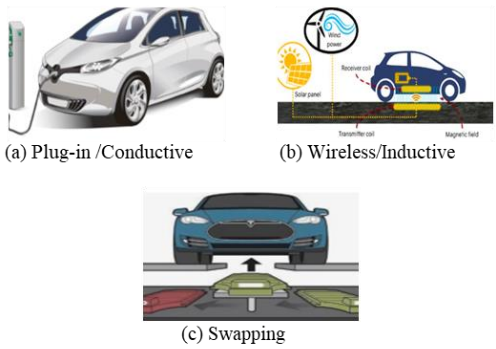

Figure 1 Electric car's charging mechanisms (a) (b) [9] (c) [11].

Government Indonesia issues Presidential Regulation Number 55 of 2019 to speed up the transformation of the use of ICE vehicles into EV therefore, to support this regulation, the number EV's infrastructures must be increased as the usage number EVs. The problem right now, even the number charging stations in Indonesia is not adequate in every main island [12], see **Figure 2**, the green legend indicates public charging stations with 22 kW power capacity and the orange legend indicates the high power charging stations which provide 22 kW, 60 kW, and 200 kW power capacity.

Figure 2 EV's charging stations mapping in Indonesia [12].

Due to electric car BSS in Indonesia that still lack discussed previously and implemented nowadays, the purpose of this study is to give an insight of potential application electric car BSS as one EV's infrastructure in Indonesia that will be needed in the future. This study novelty is giving summarized related BSS study from other country for application in Indonesia also suggesting the BSS preparation steps application in Indonesia. Section 2 presents the mechanisms BSS for electric car and application in other countries with studies those have been conducted by previous researchers. Section 3, technology readiness in Indonesia for BSS application, Section 4 will discuss highlighted aspects on applying BSS in Indonesia, Section 5 summary, presents the suggestions for potential application BSS of electric car and conclusions of this study.

2 Electric Car Battery Swapping Station

2.1 Mechanisms

Battery swapping idea was proposed in 1896 and implemented during 1910-1924 by Hartford Electric Light Company, a subsidiary of General Electric [13], BSS has around 15-50 battery packs available inside [10]. Battery swapping can be implemented for other four-wheel vehicles, such as bus, pickup truck, and van, but it needs to have different techniques and methods, study that has been conducted by [8] summarized several swapping techniques and methods served in **Table 1** below.

Table 1 Swapping techniques, methods, and applications [8].

No	Technique	Method	Application
1	Top	Chassis	Public busses
2	Bottom	Chassis	Private cars such as Sedan, Hatchback, SUV, Coupe etc.
3	Sideways	Withdrawable	Light Heavy vehicles such as Van, Minivan, Pickup Truck etc.
4	Rear	Withdrawable	Vehicles with batteries placed at the back

From **Table 1** can be concluded that for the electric car, the proper technique and method respectively are bottom swapping and chassis type, this due to the placement of the battery pack is in the bottom for electric car to keep the balance for the it is one of heavy parts on electric car. The advantage of this mechanism is the automation system implementation thus does not need people to change the discharged battery pack with charged one. The disadvantage of this system the complexity in the early design and electric car needs special design especially in the chassis because there is swappable component thus impacts on the number of the bolts those must be placed optimally to make sure the pack is tight enough on the body and easy to be loosen and fasten during swapping process, to give illustration BSS in real implementation, see **Figure 3** on the next sub section.

2.2 Application in other countries and conducted studies

Several countries have applied BSS especially in the countries those have a lot of EV units on-the-road usage, especially three-biggest-population countries in the world India, China, and USA, because they want to decrease air pollution number by switching their usage of ICE vehicle into EV, therefore there is no doubt that they have more advanced EV's infrastructures among other countries. The list of companies and operators those have implemented BSS for their EVs especially car and for India usually 3-wheeler is presented on the **Table 2**.

Figure 3 Blue Park Smart Energy BSS in China [13].

The number of implemented EVs impacting the traffic flow of a city or an area because the placement or allocation of the charging place is following the number of EVs, the more EVs means the more charging places will be needed. Moreover, the demand of electricity for sure is also increasing, thus affecting the electric energy load of grid, therefore supply availability and energy quality needs to be managed well, in **Table 3** is presented summary of studies about electric car BSS those have been conducted by previous researcher.

Table 2 Companies and operators BSS in USA, China, and India [8][13].

Company/Operators	Model	Class	Technique	Operation
Better Place (Israel-USA)	Fluence ZE (Renault)	Compact Sedan	Bottom	2011-2013
Tesla, Inc. (USA)	Model S	Full-size car	Bottom	2012-2015
NIO Inc. (China)	EP9 ES8 ES6 EC6	Sports car Full-size SUV Mid-size SUV Mid-size SUV	Bottom	2018-present 2018-present 2019-present 2020-present
Aulton (China)	-	Taxi	Bottom	2021-present
Blue Park Smart Energy (China)	-	Sedan	Bottom	2021-present
SUN Mobility (India)	eRickshaw	3-Wheeler	Manual	2016-present

Table 3 Studies of BSS conducted previous researchers.

Author-Reference	Objective	Year	Country/City Implementation	Type
Revankar and Kalkhambkar [8]	Grid integration of BSS	2021	Universal	Literatures Review
Cui et.al. [9]	Optimization BSS Operation	2023	Universal	Literatures Review
Verma [10]	Solving vehicle routing problem for BSS	2018	Not specifically defined	Mathematical Model and Simulation
Sindha et.al. [11]	Techno economic feasibility BSS with second life batteries	2023	Sweden	Mathematical Calculation for Study Case
Ibold and Xia [13]	Overview BSS in China	2022	China	Report and Summary
Yang et.al. [14]	Gaining optimal battery allocation model for BSS	2023	China	Mathematical Model and Simulation
Shaker et.al. [15]	Distribution grid with centralized charging and optimal planning BSS	2023	USA	Mathematical Model and Study Case
Wang. Z and Hou [16]	Optimization vehicle to station strategy BSS	2023	China/ Beijing	Mathematical Model, Study Case, and Simulation
Wang. H et.al. [17]	Optimization scheduling EV charging in BSS considering RE accommodation	2021	China/ Beijing	Mathematical Model, Study Case, and Simulation
Yang. X, et.al. [18]	Obtaining method to find key parameters BSS allocation using trajectory data	2021	China/ Beijing	Mathematical Model, Study Case, and Simulation
Yang. Z, et.al [19]	To prove the worthy of promoting BSS from social welfare perspective	2023	China	Mathematical Model and Calculation
Rao, et.al. [20]	Optimizing electric vehicle users' charging behavior in BSS mode	2015	China	Mathematical Model, Study Case, and Simulation
Yang. Z, et.al [21]	Optimizing decisions of automakers and third-party operator of BSS	2022	China	Mathematical Model and Calculation
Wang. S, et.al. [22]	Obtaining deep learning methods for short-term EV battery swapping demand prediction	2023	China/ Beijing	Mathematical Model, AI Model, Study Case and Simulation
Li and Wang [23]	Obtaining onboard health estimation approach with segment warping and trajectory self-learning for swappable lithium battery	2022	Not specifically defined	Mathematical Model, AI Model, and Simulation
Vallera, et.al. [24]	Emphasizing the needs of battery swapping technology	2021	Universal	Literatures Review and Data Analysis

Table 3 Studies of BSS conducted previous researchers.

Author-Reference	Objective	Year	Country/City Implementation	Type
Adu-Gyamfi, et.al. [25]	Obtaining intention adoption BSS determinant	2022	China	Questioner Survey and Data Analysis
Adu-Gyamfi, et.al. [26]	Investigating intention adoption BSS	2022	China	Mathematical Model, Study Case, and Data Analysis
Koirala, et.al. [27]	Obtaining planning BSS for faster EV adoption	2022	India	Mathematical Model, Study Case, and Simulation
Yang. J and Sun [28]	Solving BSS location-routing problem	2015	Universal	Mathematical Model, Simulation. and Data Comparisons
Zhang, et.al. [29]	Joint planning BSS services queues	2021	USA	Mathematical Model and Experimental Simulation
Comelli [30]	Collecting information on electrification process, complementary available technologies, and evaluating a BSS project if it could really be implemented under certain assumptions	2020	Italy	Literatures Review, Study Case, and Simulation
Zua and Sun [31]	Locating BSS in urban area	2022	China	Data Analysis, Mathematical Model, and Simulation

3 Technology Readiness

3.1 Electric car’s battery pack

Batteries are often implemented for electric cars are mostly lithium-based batteries, commonly these are LFP, NMC and NCA which have different characteristics [32]. Of the various types of secondary batteries on the market, Li-ion batteries are the better batteries for use in a variety of situations, especially in hot climates, even though they have a higher initial cost, in addition, Li-Ion batteries have higher efficiency compared to other batteries [33]. With these advantages, emphasizing why Li-ion battery is the most suitable for electrical energy storages in EVs.

The Li-ion battery that has a cylindrical shape and a flat positive surface is the 26650 Li-ion battery, it has a capacity of approximately 3500 mAh. There are several things to note about the temperature of the Li-ion battery cells, namely the operating temperature exceeds acceptable tolerances and low temperature uniformity, doing so can cause degradation which shortens battery life [1].

In general, cars use batteries with prismatic and cylindrical types to make setup easier, using this type of battery will make it easier to add BTMS, further BTMS study has been conducted by [34] [35], and make the shape the manufacturer wanted. Car battery standards in Indonesia in general still follow the standards of safety for battery-based vehicles in general, there is a quite unique phenomenon in the process of absorbing car battery technology in Indonesia, the standards for vehicle entering Indonesia which are regional standards for the countries that manufacture it, these have differences between marketing regions.

3.2 Electrification and integration with renewable energy

Installed power plant capacity in Indonesia (2021) is 44.46 GW which is composed of various types of power plants which 70.06% located on Java Island [36] [37], combined with leased power plants, the total capacity of power plants in Indonesia (2021) is 64.55 GW [37] which produced 28947.57 GWh of electricity [37]. PLN played a role in preparing for the EV transformation, which began with research through LIPI in 2010 which produced the Electric Marmot to collaboration with several universities which produced MOLINA in 2012 [36]. PLN's role is to prepare the charging system infrastructure in accordance with Presidential Regulation Number 55 of 2019 which has regulated the categories for Public Charging Stations to 3 levels as shown in **Table 4** below.

Table 4 Public Charging Stations levels by PLN [36].

Parameter	**Level 1**	**Level 2**	**Level 3**	
Phase	**One**	**One or Three**	**Three**	**Three**
Voltage Input (V)	230 Va.b.b	230/400 Va.b.b	400 Va.b.b	400 Va.b.b
Max. Voltage Output (V)	230 Va.b.b	250/400 Va.b.b	250 Va.b.b and 600 Va.s (EE); 480 Va.b.b and 1000 Va.s (FF);	750 Va.s (BB) / 600 Va.s (AA)
Output Current Type	a.b.b	a.b.b	a.b.b / a.s.	a.s.
Max. Current Output (A)	16 a.b.b	70/63 a.b.b	70 a.b.b and 200 a.s (EE); 63 a.b.b and 250 a.s (FF)	200 a.s. (AA) / 600 a.s. (BB)
Connector Type	Type 1 (IEC 62916-2)	Type 2 (IEC 62916-2)	Type EE and FF (IEC 62916-3)	Type AA and BB (IEC 62916-3)

Regarding the number and location of Public Charging Stations and how they are connected to the grid, it is necessary to carry out an estimate and create a roadmap for infrastructure development for EV, thus projections and developments can be created. The increase in the EV population will add to the burden at peak times, thus smart grid infrastructure needs to be built immediately, in Indonesia, the trend for EVs has shown a significant increase from 2011, which only had 5 units, until 2019 has reached 829 units [36]. From this value, projections are made of the growth of EVs until 2024 as shown in **Table 5**.

Table 5 EV's growth projection in Indonesia by PLN [36].

Description	2020	2021	2022	2023	2024
FCEV, HEV	935	1338	5704	10598	14418
PHEV, BEV	689	4014	7130	21196	16020
Total EV (Units)	1624	5352	12834	21196	30438

From this projection, an estimate of the demand for electric power in 2024 can be made as shown in **Figure 4**. Estimation of the growth of electric energy is carried out with the assumption that the average travel distance of an electric vehicle is 8500-18800 km/year, with an average electricity consumption of 0.189 kWh/km [36], then this value is linked to the previously prepared roadmap until 2024, so that the average energy demand for EVs in 2024 is around 99.3 GWh.

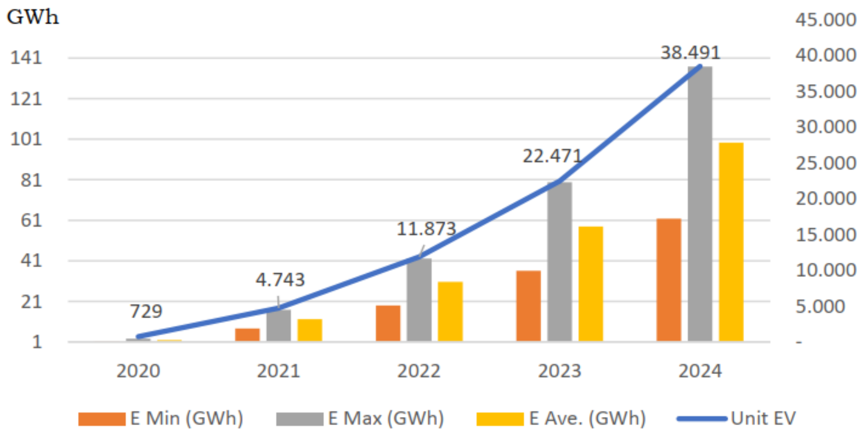

Figure 4 Estimation electricity power for EV [36].

With the Paris Agreement that Indonesia joined to jointly reduce carbon globally to address climate change on earth, the Indonesian government issued various policies that support carbon reduction or commonly called NZE, one example is the use of EV and the use of RE as power plants in Indonesia. One of the great potentials of RE in Indonesia is solar energy which can be utilized as a solar PV. But of course, it's not an easy thing to directly implement RE in Indonesia, there is still a technology gap that occurs in Indonesia for the application of RE [38].

To support the EV usage, the construction of supporting facilities is important, for example the EV-CS and BSS. To support NZE, solar PV as RE with EV-CS and EV-BSS can be combined, thus both EV-CS and EV-BSS can use energy sources from it, therefore the right strategy is needed to be implemented in the BSS work system and services, one of them is PSO to optimize charging time and the number of batteries charged based on the energy capacity generated from PV thus it is capable of charging costs compared to scheduled charging operations [39], the **Figure 5** is the picture of BSS structure using PV.

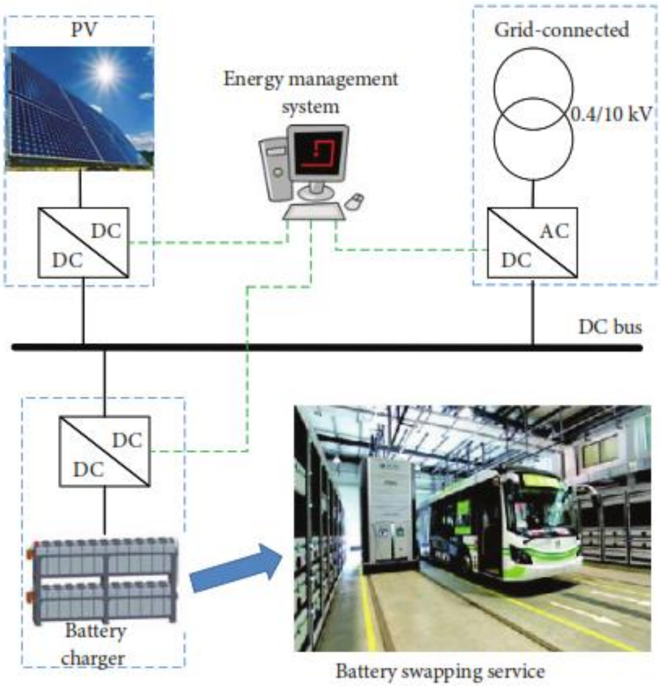

Figure 5 BSS using PV On-Grid system [39].

However, to support the use of RE technology such as PV in Indonesia's electricity network system, it still cannot be done optimally. A long-term plan is needed thus the implementation of the planned programs can run in synergy to achieve the energy mix, both from electric vehicles and from the supply of electrical energy from RE. The government's role is urgently needed to issue more detailed policies related to RE and EV so that public awareness of clean energy will also increase [40].

The presence of a BSS to support the presence of EV has had various positive and negative impacts on various sectors and fields, one of which is the electric power distribution system. Of course, the presence of BSS will increase the load that must be met for the electric power distribution system so that additional capacity and more reliability are needed for the distribution system to be able to meet load demand. However, the characteristics of this BSS are not the same as other electrical loads because they have various influencing factors such as battery type and user behavior. Based on the results of studies conducted from this study [41], BSS has several positive impacts if it is equipped with V2G capabilities so that it can increase the reliability of the electric power distribution system. In addition, negative impacts on the reliability of the electric power distribution system can also arise if EV resources are not properly managed and exploited, such as uncoordinated battery charging activities.

4 Highlighted Aspects on Electric Car BSS Application

Based on presented information and studies from Section 2 and Section 3 in this study, there are several main aspects to be highlighted for preparing electric car's BSS implementation in Indonesia, those are : electrification readiness, EV infrastructure readiness, stake holders' readiness, policy making and standardization, see **Figure 6** below.

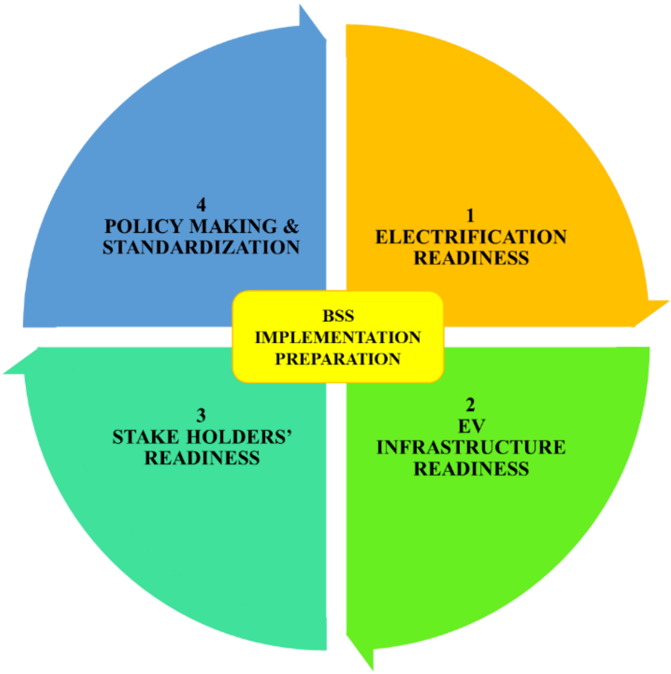

Figure 6 Main aspects electric car's BSS implementation in Indonesia.

So far for electrification readiness, Indonesia through PLN has made significant progress by doing projection of EV's growth and its energy estimation [36], in 2021 case. The total production of electricity energy is 28947.57 GWh [37], it is more sufficient than the needed for the maximum energy EV, which is only around 20 GWh, even for 2022, 2023, and 2024 which respectively 41 GWh, 80 GWh, and 140 GWh (see **Figure 4**) but further study is still needed because the electricity sufficiency also must look on other electricity demands number from factories, housing, etc. The equal electricity distribution is the main problem in the electrification readiness, 70.06% power plants located on Java Island whereas EVs will be implemented not only in there, but also in other islands, such as Sumatera, Kalimantan, Sulawesi, Papua, Bali, Nusa Tenggara, Maluku, etc., therefore power plants number on other islands must be increased especially for RE power plants, to fulfil electrification readiness aspects.

For EV’s infrastructure readiness mainly talking about grid distribution management for EV, BSS optimization allocation, and integration with RE. Grid distribution and BSS allocation is corelating each other, the usage of EVs in an area is affecting the electricity load demand also traffic flow. The number of charged batteries in BSS, its type, BSS location, and swapping frequency determine the electricity load fluctuation thus needs reliable grid performance to ensure BSS can work properly without disturbing other demands, several researchers conducted study about grid distribution for electric car BSS [8] [9] [15] [41] and for BSS batteries allocation conducted by [14]. Traffic flow of EV and users’ charging behaviors affecting the BSS operation therefore, in determining BSS placement needs to analysis the EVs’ routing to achieve its optimal performance, several studies using optimization algorithms to solve EV’s routing to BSS are [10] [16] [20] [22] [28] [29] and for BSS studies allocation are conducted by [18] [27] [30] [31]. RE integration with BSS is needed as supporting electricity source thus increasing grid performance, but this integration needs complex design and configuration, the studies about RE integration with BSS are [17] [39] [41].

Besides government of Indonesia and PLN, EV manufactures, online mobility service provider, and BSS operators are also part of the stake holders [8] [13] [21]. Government as the highest decision maker and taker should promoting the worthy of BSS [19] and emphasizing the importance [24] of BSS implementation in Indonesia to the people of Indonesia, the promotion can be done by giving some incentives or subsidies of EV and its infrastructure usage, but to do that and make faster implementation, feasibility and intention adoption study of BSS [11] [13] [25] [26] [27] need to be done. Several automobile companies in Indonesia, such as Hyundai and Wuling, are on the way to shift ICE car into the electric, this also supported by online mobility service provider, such as Grab and Gojek, to start using electric car for their operation, but for now swappable electric car is not yet implemented by them due to the low frequency operation of electric car for now.

Policy making and standardization are important to accelerate EV and its infrastructure adoption in Indonesia. From this study [13] in China policy support from government come first, with this other stake holders can plan and take decision about what must they do. Due to a lot of automobile manufacturers, thus there are so much variation of electric cars and its charging methods, if this condition is not regulated well, it will make unstandardized EV usage and charging, therefore needs third party authorization to regulate the BSS [21], in Indonesia PERTAMINA can take this part as replacement of oil and gas regulator those will be shifted to electric in the future, also through IBC, battery pack of swappable electric car can be standardized, thus automobile manufactures and online mobility service provider can adjust with those standards.

5 Summary

The transformation of the use of electric vehicles in Indonesia has begun. Through Presidential Regulation Number 55 of 2019 concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program for Road Transportation, the government is trying to establish an electric vehicle ecosystem that involves many parties [42]. This policy has been responded to by various levels of government agencies to attract people's interest in switching to electric vehicles [43]. In addressing the government's commitment, the community has shown different responses [44]. The transition of vehicles by the people of Indonesia since the presidential decree was issued is still too little. Asfani et al. stated that one of the factors influencing this is the supply-demand of electric vehicles in Indonesia [45]. Even though the government has issued strategic strategies to attract public interest, the supply is still small which makes the price of electric vehicles expensive, making the penetration of electric vehicles in Indonesia still lacking [45]. In addition, even though electric vehicle charging facilities have been built by the government in busy locations such as rest areas, crowd centers, shopping centers, and others, these conditions are not evenly distributed in Indonesia, so far, they are still concentrated in big cities.

Several studies have been conducted to determine the optimal location for placing charging stations or swapping stations for vehicles. An important characteristic that is needed is to be in a location that has a dense population and workers [46]. This location is suitable because parked vehicles will be controlled naturally, effectively, and efficiently economically and with other resources. In addition, the location selection must also pay attention to requests from users, because this will affect the termination of existing charging stations [47]. As summary closing of this study, SWOT analysis of potential application BSS for electric car in Indonesia is presented on **Figure 7.**

Figure 7 SWOT analysis electric car's BSS potential application in Indonesia.

5.1 Suggestions

Before the conclusion of this study, suggestion steps from preparation until application electric car BSS in Indonesia are presented on **Figure 8** below :

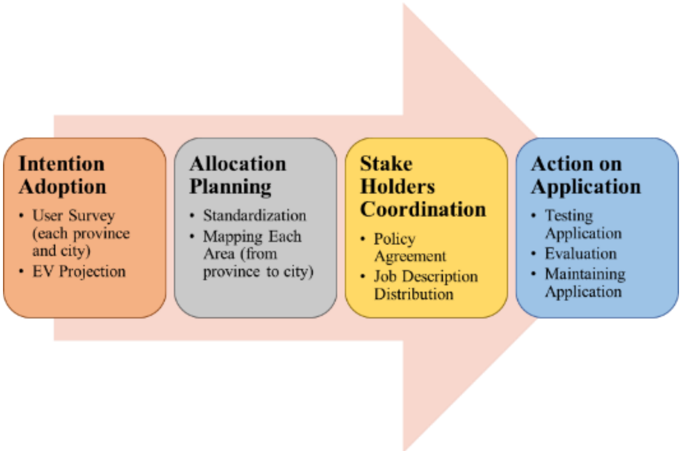

Figure 8 Steps of electric car BSS application in Indonesia.

Intention Adoption consists of user survey specifically for each province and derived until city level to gain accurate survey results also doing EV projection based on the conducted survey results. Allocation planning is doing standardization of correlated infrastructure and technology for EV such as vehicle specification, battery pack, and grid distribution, after that doing mapping for each city about BSS allocation. Coordination inters stake holders need to be done to clarify and emphasize policy that has been made thus agreement is achieved, the rest is ensure each job description is distributed properly. Application testing is a must to ensure the system works properly, next is evaluation, and lastly maintaining the BSS system.

5.2 Conclusions

BSS for electric car is promising technology in the future of EVs era, several countries have implemented it, Indonesia is on the way shifting from ICE vehicle into EV usage, therefore for now, EVs' especially electric car usage number is still little thus the BSS is not implemented yet, but by considering EV's growth future projection of Indonesia, BSS for electric car of course will be needed. Preparation for its implementation in Indonesia is better to be done from now, because many aspects take a lot of time to be fulfilled. Equal electrification distribution must be accomplished before implementation of this electric car BSS. Further and more specific study about BSS allocation in every area of Indonesia is important, to make the implementation accurate thus the effort to do it will be efficient.

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Nomenclature

Abbreviations

DC	=	Direct Current
AC	=	Alternating Current
C-rate	=	Charging rate
SOC	=	State of Charge
ICE	=	Internal Combustion Engine
EV	=	Electric Vehicle
BSS	=	Battery Swapping Station
USA	=	United State of America
SUV	=	Sport Utility Vehicle
RE	=	Renewable Energy
Li-Ion	=	Lithium Ion
LFP	=	Lithium Ferro Phosphate
NMC	=	Nickle Manganese Cobalt
NCA	=	Nickle Cobalt Aluminum
BTMS	=	Battery Thermal Management System
PLN	=	Perusahaan Listrik Negara
LIPI	=	Lembaga Ilmu Pengetahuan Indonesia

MOLINA	=	Mobil Listrik Nasional
FCEV	=	Fuel Cell Electric Vehicle
HEV	=	Hybrid Electric Vehicle
PHEV	=	Plug-in Hybrid Electric Vehicle
BEV	=	Battery Electric Vehicle
NZE	=	Net Zero Emission
PV	=	Photo Voltaic
EV-CS	=	Electric Vehicle Charging Station
PSO	=	Particle Swarm Optimization
V2G	=	Vehicle to Grid
PERTAMINA	=	Perusahaan Tambang Minyak Negara
IBC	=	Indonesia Battery Corporation
SWOT	=	Strength Weakness Opportunity Threat

Units

kW	=	Kilo Watt
GW	=	Giga Watt
GWh	=	Giga Watt Hour
(V)	=	Volt
(A)	=	Ampere
kWh	=	Kilo Watt Hour
km	=	Kilometer

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