FEASIBILITY STUDY OF SOLAR-POWERED ELECTRIC VEHICLE CHARGING INFRASTRUCTURE AT SELECTED PETROL STATIONS IN MALAYSIA

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Abstract

The transition from the conventional internal combustion engine (ICE) to electric vehicles (EV) are expected to result in higher total electricity demand in the country. With the introduction of more EVs into the market, the need for charging stations will grow, subsequently increasing power consumption. This research study aims to assess the potential of solar energy production at petrol stations in central region of Peninsular Malaysia and assess the feasibility of solar-powered petrol stations in meeting the energy demands of electric vehicles. Ten samples of existing petrol stations are selected to install a solar-powered DC charging station as a case study. The physical characteristics of the ten sites such as the rooftop area were then analysed by using Google Earth. PVsyst software was then used to design and simulate the solar PV system and the expected solar energy yield can then be found. To study their energy consumption, 90kW DC charger was chosen as the load. As the result, it is found that 90% of the sampled petrol stations are able to generate enough energy to meet the estimated annual energy consumption of the 90kW DC charging system. Naturally, petrol station with larger rooftop area can generate higher amount of solar energy. The results also showed that the cost to install the solar-powered charging system for both power ratings can be recouped in less than 2 years. Overall, this research study offers valuable insights for addressing the rising energy consumption resulting from the increased penetration of electric vehicles in the future. Additionally, the implementation of solar-powered charging infrastructure aligns with the country's renewable energy objectives and efforts to reduce greenhouse gas emissions. However, the assessment of EV penetration and the adoption of charging infrastructure was conducted based on government targets rather than relying on current data regarding the actual numbers and trends of EVs and chargers in Malaysia. The availability of accurate and up-to-date data on the number of EVs, their battery characteristics, chargers, and user charging behaviors in Malaysia would contribute to further enhancing this research work.

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1.0 INTRODUCTION

The transportation sector is one of the major contributors to greenhouse gas emissions globally. To address this issue, the adoption of electric vehicles (EVs) has been considered as an alternative to conventional internal combustion engine (ICE) vehicles. Malaysia, as a developing country, has set a target to have 100,000 EVs on the road by 2030 (MIDA, 2023). However, the widespread adoption of EVs requires a reliable and efficient charging infrastructure (Dimitriadou *et al.,* 2023). According to the Low Carbon Mobility Blueprint 2021-2030, a dedicated council to implement the policy to plan for the EV charging infrastructure is to be established. As more EVs are introduced into the market, the demand for charging stations will increase, leading to an increase in power consumption. Therefore, it is essential to evaluate the impact of EV chargers on power consumption to ensure the stability of the grid.

As more electric vehicles penetrated the Malaysian market, the demand for the EV charging infrastructures will increases. To solve this problem, more EV charging infrastructures has to be built, especially along the existing expressway. However, there are few challenges that must be encountered, where most of the existing EV chargers are powered by unclean electricity from conventional thermal power plants (Shatnawi *et al.,* 2021). These power plants rely on non-renewable resources such as coal and natural gas. As more EV charging stations are to be installed in the future, the electricity demand to power up these stations will be high, therefore requiring more fossil fuels to generate the power. To overcome this problem and avoid future power shortages, a study must be done to support the power consumption of the EV charging stations from the grid to more green and eco-friendly energy resources such as solar energy. A solar-powered EV charging station consists of the typical components of a conventional EV charging station with the addition of solar PV panels and inverter and battery storage system as optional components. This is also in line with the preference of having solar-powered EV charging infrastructure as outlined in the Low Carbon Mobility Blueprint 2021-2030. The huge carbon pollutant reduction potential of solar powered EV compared with traditional gasoline-fueled cars further reinforces the need of this study (Bin Ye *et al.,* 2015). Hence, this paper aims to assess the feasibility of solar-powered petrol stations at selected locations in meeting the energy demands of electric vehicles in Malaysia.

In this research work, it is important to consider the various types of EV chargers available. However, for the purpose of this case study, the focus will be solely on Direct-Current (DC) chargers as the research variable. Additionally, while there are numerous petrol stations across Malaysia, this project research study is specifically limited to 10 petrol stations located along the North-South Expressway in the Central region of Peninsular Malaysia. Furthermore, there are different types of electric vehicles currently available in the market, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs). However, this research project will concentrate solely on studying BEVs. Lastly, this research will only focus on the grid connected PV system, without any additional battery energy storage system.

2.0 METHODOLOGY

At the initial stage of the project, the number of petrol stations as well as their locations along the North-South Expressway will be obtained from the official PLUS Expressway website. As of 26 July 2022, there are up to 100 existing petrol stations along the North-South Expressway (PLUS Expressway, 2023). The petrol stations include Shell, Caltex, Petron, BHP, and Petronas. A sample of 10 petrol stations located in the central region will be calculated and analysed noting that the usage of electric vehicles may be more concentrated in the central region due to its higher population density. Figure 1 shows a sample of a rooftop image of a petrol station at the coordinate of 3.2246017,101.57682758 decimal degrees, which was captured by Google Earth to estimate the net area of the rooftop (Google Earth, 2023). The next step is to use the calculated rooftop area as a parameter to design and size the solar PV system for the selected petrol stations.

The selection of PV modules for the system design was done by taking the modules' efficiency into consideration. Figure 2 illustrates a typical solar-powered EV charging station (Samir, 2020). The efficiency of the PV modules determines how effectively they can convert sunlight into electrical energy. The higher the efficiency of the PV modules, the more energy from the sunlight can be converted into electrical energy. In general, a petrol station operator with the intention to install a solar-powered EV charging station has to decide between monocrystalline or polycrystalline modules as well as whether there is a need for battery storage system within the budgetary constraints. In this paper, a model of monocrystalline PV modules was selected for the design as it has higher efficiency than polycrystalline modules. The specification of the selected module is shown in Table 1 (Shanghai JA Solar, 2021). As for the inverter, it was selected by considering the size of the designed PV system and its expected total power output. According to a previous study, the optimal DC-to-AC ratio should be closer to 1.2 to maximise the specific yield (Kathy, 2018). Table 2 shows the specifications of the selected inverter (Huawei, 2022). Figure 3 shows a sample of the specifications in one of the simulations.

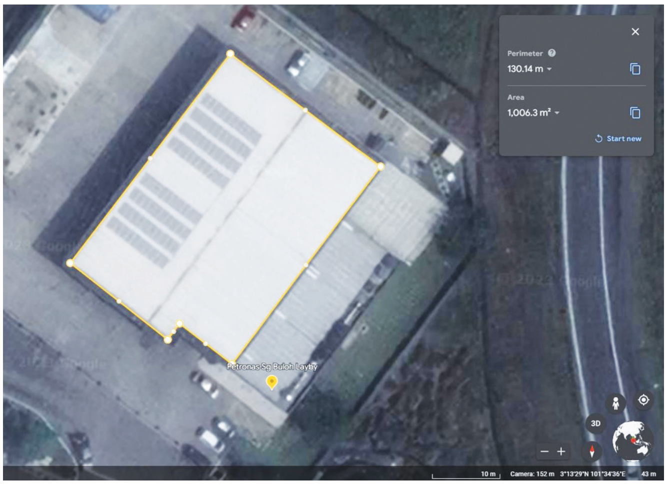

Figure 1: Sample of a rooftop of a petrol station captured by Google Earth (Google Earth, 2023)

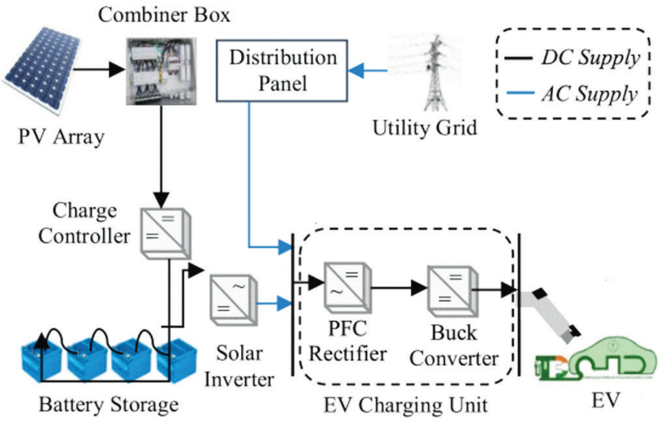

Figure 2: A typical solar-powered EV charging station (Samir, 2020)

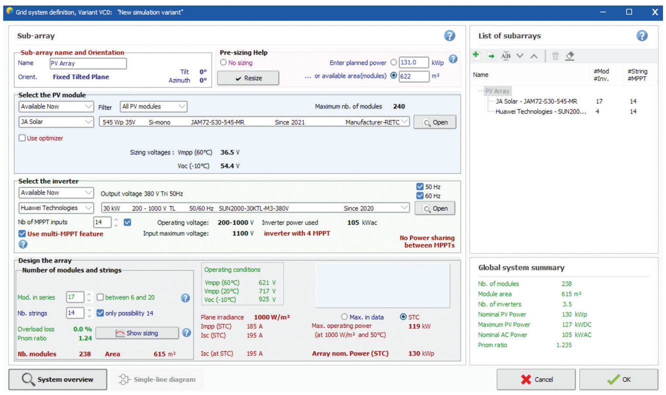

Figure 3: Sizing of PV systems in PVsyst software

Table 1: Electrical parameters of the monocrystalline PV module

Rated Maximum Power (Pmax) [W]	545
Open Circuit Voltage (Voc) [V]	49.75
Maximum Power Voltage (Vmp) [V]	41.8
Short Circuit Current (Isc) [A]	13.93
Maximum Power Current (Imp) [A]	13.04
Module Efficiency [%]	21.1
Power Tolerance	0~+5W
Temperature Coefficient of Isc(α_Isc)	+0.045%/°C
Temperature Coefficient of Voc (β_Voc)	-0.275%/°C
Temperature Coefficient of Pmax (γ_Pmp)	-0.350%/°C

Table 2: Technical specification of the inverter

Max. Input Voltage	1100 V
Max. Current per MPPT	26 A
Max. Short Circuit Current per MPPT	40 A
Start Voltage	200 V
MPPT Operating Voltage Range	200 V - 1000 V
Rated Input Voltage	600 V
Number of Inputs	8
Rated AC Active Power	30000 W
Max. AC Apparent Power	33000 VA
Rated Output Voltage	230 Vac / 400 Vac / 480 Vac, 3W/N+PE
Rated AC Grid Frequency	50 / 60 Hz
Rated Output Current	43.3 A
Max. Output Current	47.9 A
Max. Total Harmonic Distortion	< 3%

Once the rooftops' area has been obtained and the types of solar module and inverter have been selected, the next step is to design and simulate the PV systems based on the design parameters using PVsyst software (PVsyst, 2023). The design parameters that were obtained will be used to size the PV system, which the PVsyst software will prompt the user to enter the rooftop area, types of solar modules, and types of solar inverters. The power ratings of DC chargers for electric vehicles can vary depending on the specifications of the charger model. However, there are several common power ratings for DC chargers that are currently being installed in Malaysia. Based on official websites of TNB Electron, Shell, and Petronas (TNB Electron, 2023), (Shell Recharge, 2023), (PETRONAS, 2023). DC chargers with power ratings of 90kW and 180kW are quite commonly installed in petrol stations along the expressway. It is important to note that the power ratings of the DC chargers can vary further based on the technological advancements and individual charger manufacturer. Nevertheless, the research was focused more on the 90kW power ratings as it is more common along the expressway compared to other power ratings.

The next step in this research work is to calculate the estimated energy consumption of those 90kW DC chargers' power ratings. The equation to calculate the estimated daily energy consumption of the DC chargers is shown in Equation 1 below:

$$Daily\ energy\ consumption = P \times t \times N \tag{1}$$

where:
P = Power rating of DC charger (kW)
t = charging time (hours)
N = Number of EVs charged per day

The parameter N in Equation (1) was obtained by determining the number of EVs and charging points available in Malaysia. The Malaysian government has set a target to have 100,000 EVs on the road by 2030 (MIDA, 2023). As for the charging points, the Ministry of Natural Resources, Environment, and Climate Change (KASA) aims to set up 10,000 EV charging points in Malaysia by 2025 under the Low Carbon Development Plan 2021-2030 (Ministry of Environment and Water, 2021). Since there are no well-established data regarding the number EVs and the charging points that are currently available in Malaysia, this information was used to estimate the number of EVs per charging point. Therefore, based on the government targets, the estimated ratio of EV-to-charging points approximates 10 EVs per charging points.

The total cost of the entire system for each petrol station was calculated based on the number of units of PV modules, solar inverters, and DC chargers installed. The market prices for each component unit are shown in Table 3 (Secondsol Solar Panel, 2023), Secondsol Inverter, 2023), (Tonghe, 2023). Note that the installation costs are excluded from this study as the rate may vary significantly.

Table 3: Market price for each component unit

Item	Price per unit
PV module	RM883.00
Solar inverter	RM9,200.66
90kW DC charger	RM71,495.00

The return on investment (ROI) and payback period for the whole system on each petrol station was calculated using Equation 2 and Equation 3, respectively. The annual profit in Equation 2 refers to the profit generated from the whole investment. The profit for each petrol station was calculated based on the charging rates of the DC chargers. According to TNB Electron, the charging rate for the 90kW DC charger is RM2.20/min (TNB Electron, 2023).

$$ROI = \frac{Annual\ Profit}{Total\ Cost\ of\ the\ System} \times 100\% \tag{2}$$

$$Payback\ Period = \frac{Total\ Cost\ of\ the\ System}{Annual\ Profit} \tag{3}$$

4.0 RESULTS AND DISCUSSIONS

Table 4 shows the simulated solar energy production from each of the 10 selected petrol stations in this study. The average irradiance level received by the Central region is 1778 kWh/m^2. Higher irradiance levels result in a greater amount of energy generation. However, the net area of the rooftops also plays an important role in maximizing the energy harvest from the solar PV system. Based on the obtained results, it can be observed that a larger rooftop area at a petrol station allows for the installation of more PV modules, resulting in higher power generation.

The energy consumption of the 90kWDC chargers' power ratings was calculated using Equation 1. It is important to note that the charging time for an electric vehicle (EV) depends on the EV's specifications and its built-in battery capacity. Based on the assumption of 10 EVs per charging point, as discussed in previous section, if each EV is charged for 30 minutes regardless of the state-of-charge, the estimated daily energy consumption for the charger is 450 kWh. The annual energy consumption of the DC charger was obtained by multiplying the daily energy consumption by 365 days. Thus, the annual energy consumption for the 90kW DC chargers is 164,250 kW.

As observed in Table 4, 9 out of 10 petrol stations can meet the annual energy demand of the 90kW DC charger. The petrol stations with rooftop areas below 510 m^2 could not generate enough energy to support the annual energy demand of the charger. Specifically, Petron Dengkil which has rooftop areas of less than 510 m^2, resulting in insufficient energy generation to meet the energy demand of the 90kW charger.

The number of EVs that can be charged per year for each charger was determined by dividing the annual energy generation by the energy consumption of each EV. Table 5 presents the number of EVs that can be charged per year for each type of charger. Note that the analysis was made based on the assumption of 30 minutes of charging time, regardless of the state-of-charge of the EVs.

Table 4: Designed PV system simulation results in central region

Stations	Area (m²)	Annual Average Irradiation (kWh/m²)	Performance Ratio	Annual Energy Produced (kWh)
Shell Tapah NB	894.84	1757.3	0.848	275808
Petron Behrang Layby SB	936.69	1754.7	0.847	288995
Petronas Ulu Bernam SB	817.63	1758.3	0.846	247892
Petronas Rawang NB	683.51	1772.4	0.846	208150
Petronas Sg Buloh Layby SB	1006.46	1775.2	0.847	311367
Petron NKVE	995.8	1783.1	0.846	307303
Caltex Elite USJ	603.02	1794.1	0.845	185057
Petron Dengkil Elite SB	495.79	1800.8	0.847	155394
Shell Dengkil Elite SB	713.37	1801.1	0.846	225736
Petronas Damansara NKVE	1381.85	1783	0.842	435328
Average	**852.896**	**1778**	**0.846**	**264103**

Table 5: Comparison on the annual charging capacity of the systems

Stations	Annual Energy Produced (kWh)	90kW Power Consumption (kWh)	No. of EVs can be charged by 90kW
Shell Tapah NB	275808	45	6129
Petron Behrang Layby SB	288995	45	6422
Petronas Ulu Bernam SB	247892	45	5509
Petronas Rawang NB	208150	45	4626
Petronas Sg Buloh Layby SB	311367	45	6919
Petron NKVE	307303	45	6829
Caltex Elite USJ	185057	45	4112
Petron Dengkil Elite SB	155394	45	3453
Shell Dengkil Elite SB	225736	45	5016
Petronas Damansara NKVE	435328	45	9674

Table 6: Total cost of the whole system for petrol stations

Stations	Units of PV Module	Units of Inverter	Total Cost of 90kW System (RM)
Shell Tapah NB	340	5	417718.30
Petron Behrang Layby SB	357	6	441929.96
Petronas Ulu Bernam SB	306	5	387696.30
Petronas Rawang NB	255	4	333462.64
Petronas Sg Buloh Layby SB	380	5	453038.30
Petron NKVE	374	6	456940.96
Caltex Elite USJ	224	4	306089.64
Petron Dengkil Elite SB	187	3	264217.98
Shell Dengkil Elite SB	272	4	348473.64
Petronas Damansara NKVE	532	8	614856.28

Table 7: Annual profit for petrol stations

Stations	No. of EVs Charged per Year (90kW)	Charging Duration (min)	Annual Profit for 90kW (RM)
Shell Tapah NB	6129	30	404518.40
Petron Behrang Layby SB	6422	30	423859.33
Petronas Ulu Bernam SB	5509	30	363574.93
Petronas Rawang NB	4626	30	305286.67
Petronas Sg Buloh Layby SB	6919	30	456671.60
Petron NKVE	6829	30	450711.07
Caltex Elite USJ	4112	30	271416.93
Petron Dengkil Elite SB	3453	30	227911.20
Shell Dengkil Elite SB	5016	30	331079.47
Petronas Damansara NKVE	9674	30	638481.07

The total cost for the whole system for each petrol station was calculated by considering the number of units of PV modules, inverter, and chargers used to design the system and is as per Table 6.

The annual profit for each system was obtained by calculating the profit gained from the number of EVs that can be charged with the annual energy generated. With the charging rates for the 90kW chargers being RM2.20/minute and with the assumption of 30 minutes charging time for each EV as discussed previously, the annual profit for all petrol stations can be found in Table 7.

The total cost and annual profit obtained for every designed system previously were used for the calculation of return on investment (ROI) and their payback period. The ROI and payback period for each system were calculated using Equation 2 and Equation 3. The results for all the systems are displayed in Table 8. Again, it is to be noted that the ROI and payback period are estimated without considering the cost of installation.

While this study seems to strongly suggest that solar powered 90 kW EV chargers is highly feasible, do note that there could be practical implementation issues and challenges in ensuring maximization of solar PV being installed at the available space of the petrol stations. Hence, strategies for beneficial charging such as those outlined in (Zachary *et al.*

2023) can be considered. Due to the constraints of low wind speed in general, small wind turbine can be considered for additional renewable energy harvesting to supplement the potential drop in solar energy yield during cloudy or stormy days (Lim *et al.,* 2019).

Table 8: Return on investment and payback period of the systems

Stations	ROI for 90kW System	Payback Period for 90kW System (Year)
Shell Tapah NB	96.84%	1.03
Petron Behrang Layby SB	95.91%	1.04
Petronas Ulu Bernam SB	93.78%	1.07
Petronas Rawang NB	91.55%	1.09
Petronas Sg Buloh Layby SB	100.80%	0.99
Petron NKVE	98.64%	1.01
Caltex Elite USJ	88.67%	1.13
Petron Dengkil Elite SB	86.26%	1.16
Shell Dengkil Elite SB	95.01%	1.05
Petronas Damansara NKVE	103.84%	0.96

5.0 CONCLUSION

In a nutshell, 90% of the petrol stations considered in this study can meet the energy demand of EV charging as per the assumptions made. On the average, the simple payback period for the investment made to install solar PV system to power the charging of EVs is slightly more than one year for most of the petrol stations considered in this study. However, it must be acknowledged that the actual yield of solar energy is dependent on environmental factors such as partial shading due to buildings or trees, accumulation of dusts and dirt on the solar modules just to name a few. Moving forward, more petrol stations from the Northern and Southern regions will be studied to provide a more comprehensive overview of the feasibility of solar powered EV charging stations in Malaysia. ■

REFERENCES

[1] Dimitriadou, K., Rigogiannis, N., Fountoukidis, S., Kotarela, F., Kyritsis, A. and Papanikolaou, N. (2023). Current Trends in Electric Vehicle Charging Infrastructure; Opportunities and Challenges in Wireless Charging Integration," Energies, vol. 16, no. 4, p. 2057, Feb. 2023, doi: 10.3390/en16042057.

[2] Google Earth. (Version 9.189.0.0). Google. Accessed: Feb. 6, 2023. [Online]. Available at: https://earth.google.com/web/

[3] Huawei, SUN2000-30/36/40KTL-M3 Smart PV Controller, Huawei. [Online]. Available at: https://solar.huawei.com/download?p=%2F-%2Fmedia%2FSolar%2Fdatasheet%2FSUN2000-20303640KTL-M3.pdf

[4] JA Solar Technology, JAM72S30 525-550 MR, Shanghai JA Solar 6Technology Co., Ltd. [Online]. Available at: https://www.jasolar.com/uploadfile/2021/0706/20210706053524693.pdf

[5] Kathie, Z, "Why Array Oversizing Makes Financial Sense," Solar Power World, Feb. 12, 2018. Accessed: 5/4/2023. [Online]. Available at: https://new.abb.com/docs/librariesprovider117/default-document-library/solar-inverters/solar_power_world-article.pdf?sfvrsn=80a7614_4

[6] Lim, S.C., Meng, T.J., Palanichamy, C., and Eng, G. T. (2019). Feasibility Study of Wind Energy Harvesting at TELCO Tower in Malaysia. International Journal of Energy Economics and Policy vol. 9, no. 6, pp. 277-282, 2019.

[7] Malaysian Investment Development Authority (MIDA). "Rapid chargers, battery swapping can accelerate EV adoption" mida.gov.my. https://www.mida.gov.my/mida-news/rapid- chargers-battery-swapping-can-accelerate-ev-adoption/ (Accessed Mar. 15, 2023).

[8] Ministry of Environment and Water. Low Carbon Mobility Blueprint 2021-2030: Decarbonizing Land Transportation" 1st edition, Putrajaya, Malaysia: KASA, 2021.

[9] PETRONAS. "EV Charging Station" mymesra.com.my https://www.mymesra.com.my/for-consumer/ev-charging-station (Accessed Feb. 14 2023).

[10] PLUS Expressway. Petrol Station along PLUS Highway. Available at: https://www.plus.com.my/index.php?option=com_content&view=article&id=152&Itemid=143&lang=en (Accessed Jan. 5, 2023).

[11] PVsyst. (Version 7.3.1). PVsyst Photovoltaic Software. [Online]. Available at: https://www.pvsyst.com/download-pvsyst/. (Accessed: Feb. 6, 2023).

[12] Shariff, S. M., Alam, M. S., Ahmad, F., Rafat, Y., Asghar, M. S. J., and Khan, S. (2019). System Design and Realization of a Solar-Powered Electric Vehicle Charging Station. IEEE Systems Journal, 14(2), 2748-2758.

[13] Secondsol.Inverter–Huawei. Available at: https://www.secondsol.com/en/anzeige/28396/inverter/string/huawei/sun2000-30ktl-m3 (Accessed May. 10, 2023).

[14] Secondsol.SolarPanel–JA Solar. Available at: https://www.secondsol.com/en/anzeige/31298/ja-solar/ja-solar/ja-solar-jam72s30-545mr-545w-solar-panel (Accessed May. 10, 2023).

[15] Shatnawi, M., Ari, K. B., Alshamsi, K, Alhammadi, M., and Alamoodi, O. (2021). Solar EV Charging. 2021 6th International Conference on Renewable Energy: Generation and Applications (ICREGA), 2021, pp. 178-183, doi: 10.1109/ICREGA50506.2021.9388301.

[16] Shell Recharge.Shell Recharge HPC Locations. Available at: https://www.shell.com.my/motorists/shell-recharge/shell-recharge-hpc.html (Accessed Feb 14. 2023).

[17] TNB Electron. Electric Vehicles (EV) Charging Platform. Available at: https://www.tnbx.com.my/ev-charging-platform (Accessed Feb. 14, 2023).

[18] Tonghe. Tonghe 90kW DC Charger. Available at: https://tonghe-ev-charger.en.made-in-china.com/product/

CKHQvfVEhlYS/China-90kw-All-in-One-DC-Fast-Charger.html (Accessed May. 10, 2023).

[19] Ye, B., Jiang, J., Miao, L., Yang, P., Li, J., and Shen, B. (2015). Feasibility Study of A Solar-Powered Electric Vehicle Charging Station Model. Energies, 8(11), 13265-13283.

[20] Zachary, N., Wei, W. and Trancik, J. E. (2023) Strategies for Beneficial Electric Vehicle Charging to Reduce Peak Electricity Demand and Store Solar Energy." Cell Reports Physical Science vol. 4, no. 3, pp. 1-16, 2023.

PROFILES

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