Evaluation of Future Battery Electric Vehicles as an Environmentally Friendly Transportation Means: A Review

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Abstract — The climate challenge is an energy challenge. Thus, policymakers around the world are trying to accelerate the adoption of clean energy technologies. The Global Energy Review said that global CO₂ emissions from energy combustion in 2021 reached the highest annual level with an increase of 6% from 2020. The automotive sector is very important to achieve net zero global emissions by 2050 based on the agreement with the world in the Scenario Net Zero Emissions by 2050, in which in 2035 sales of internal combustion engine cars (ICE) will be stopped. In this case, of course, electric vehicles are an alternative to the field of future land transportation that uses batteries as fuel that utilizes renewable energy as a charger for electric vehicles. Electric vehicle charging infrastructure (EVCI) is a key driver of increased electrification mobility shifting away from internal combustion engines, given that the specific geographical distribution of a region and its demographics are factors influencing the adoption of electric vehicles. This paper was written to review the state-of-the-art of Battery Electric Vehicle (BEV), a PV energy source in terms of renewable energy utilization, energy generation, batteries, and charging stations. Several gaps need to be investigated for further research on the availability of real-time measured solar light intensity, placement and capacity of PV power to optimize the performance of PV as a means of charging solar electric vehicles in commercial and residential aspects. This policy is based on the approach of per capita income, market environment, needs and strategic goals, as well as purchasing power based on Popular Commercial BEV Specifications.

Keywords: PV, BESS, and Charging.

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1. Introduction

The climate challenge is an energy challenge. With that in mind, policymakers around the world are trying to accelerate the adoption of clean energy technologies [1]. The Global Energy Review says that global CO₂ emissions from energy combustion in 2021 will reach their highest annual level with a 6% increase from 2020 reaching 36.3 gigatonnes (Gt) as shown in Figure 1 [2]. Then the same world agreement on Scenario Net Zero Emissions by 2050 to limit the temperature increase to 1.5 °C [3]. The automotive sector is critical to achieving net zero global emissions by 2050 towards limiting global warming to 1.5 °C [4], to achieve Net Zero Emissions sales of new internal combustion engine (ICE) cars are discontinued in 2035. It is powered by 90% energy Transportation using fossil fuels relies on oil products based on fossil fuels. In this case, of course, electric vehicles are an alternative in the field of future land transportation that uses batteries as fuel that utilize renewable energy for potential climate change mitigation [5] and global warming [6]. By 2030 electric vehicles represent more than 60% of sold globally and require adequate surge charging installed in buildings [7]. The electric vehicle charging infrastructure (EVCI) is a major driver of increased electrification mobility switching from internal combustion engines [8]. The particular geographical distribution of a region and its demographics are factors influencing the adoption of electric vehicles. Overview of the technology, operation, technical feasibility, and economic feasibility of PV-grid [9] and PV-BESS [10], case studies found that charging PV-BESS grids can be profitable. On the other
hand, self-contained PV may not be economically feasible due to limited PV, but clean energy is the most optimal. It has been found that PV and BESS-based EV charging is more feasible for the EV load profile with a higher correlation coefficient with PV [11]. In addition, PV and BESS-based electric vehicle charging are more suitable in the weakest network areas [12] then [13] proposed a strategy to find out battery capacity and optimize battery operating costs for PV and BESS-based charging stations.

2. Method

The purpose of this paper is to review the state-of-the-art of Battery Electric Vehicle (BEV), a PV energy source in terms of renewable energy utilization, energy generation, batteries, and charging stations. The structure of this paper is as follows: Subsections 3.1 provides an overview of future global CO₂ emissions. Subsections 3.2 describes the Battery Electric Vehicle (BEV). Subsections 3.3 describes the PV. Subsections 3.4 describes Batteries. Subsections 3.5 describes the Vehicle Charging Station Strategy and is followed by a conclusion in Section 4.

3. Result and Discussion

3.1 Future Global CO₂ Emissions

![Figure 1. Total CO2 emissions from energy combustion and industrial processes in 1900-2021.](image)

The automotive sector is very important to achieve net zero global emissions by 2050, to limit global warming to 1.5 degrees Celsius because 65% to 80% of emissions are from the exhaust and indirect emissions come from fuel. In 2050 the volume of oil production is expected to decrease by 55% and gas will decrease by 70% and coal will no longer be produced, the demand for fossil fuel vehicles will drop dramatically to be replaced by electric vehicles which will continue to drop in demand until 2050 [4].

Based on the components grouped related to the use of electric vehicles as an alternative to reducing CO₂ from burning energy in the transportation industry process using fossil fuels by users, there are six factors identified, namely financial factors, vehicle performance factors, lack of charging infrastructure [9], environmental concern, community influence and awareness of electric vehicles [14].
3.2 Battery Electric Vehicle (BEVs).

![Classification of Electric Vehicles](image)

Figure 2. Classification of Electric Vehicles [15].

This paper will only focus on Battery Electric Vehicles (BEVs). BEV cars are more efficient and economical compared to cars with HEV or PHEV technology [16], but the current price of batteries is still very high [17]. However, future work will need to take into account the decline in battery prices to optimally analyze the comprehensive benefits of battery electric vehicles [18], based on reports [19], the electric vehicle market is developing rapidly. Electric car sales accounted for 9% of the global car market in 2021 quadrupling from 2019. Together, China and Europe accounted for more than 85% of global electric car sales as shown in Figure 3.

![Global Electric Car Stock, 2010-2021](image)

Figure 3. Global Electric Car Stock, 2010-2021.

A battery electric vehicle (BEV) runs entirely on batteries and motors without the support of a combustion engine [20], and the use of battery capacity can be recharged from an external power source. Several types of cars with popular BEV technology on the market are shown in Table 1.
Table 1. Popular Commercially BEV Specifications

<table>
<thead>
<tr>
<th>Vehicle Model</th>
<th>Manufacturer</th>
<th>Year</th>
<th>Battery Capacity (Kwh)</th>
<th>Range (Km)</th>
<th>Battery Charger Times (80%) DC Daya (KW)</th>
<th>FC (h)</th>
<th>Battery Charger Times (80%) AC Daya (KW)</th>
<th>C (h)</th>
<th>Battery Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model S</td>
<td>Tesla</td>
<td>2015</td>
<td>100</td>
<td>637</td>
<td>120</td>
<td>0.8</td>
<td>NA</td>
<td>NA</td>
<td>Lithium - Ion (Tesla, 2015)</td>
</tr>
<tr>
<td>Model X</td>
<td></td>
<td>2015</td>
<td>100</td>
<td>535</td>
<td>120</td>
<td>0.8</td>
<td>NA</td>
<td>NA</td>
<td>Lithium - Ion [21]</td>
</tr>
<tr>
<td>Leaf S</td>
<td>Nissan</td>
<td>2022</td>
<td>40</td>
<td>239</td>
<td>50</td>
<td>0.67</td>
<td>6.6</td>
<td>7.5</td>
<td>Lithium - Ion [22]</td>
</tr>
<tr>
<td>Leaf SV Plus</td>
<td></td>
<td>2022</td>
<td>60</td>
<td>341</td>
<td>50</td>
<td>1</td>
<td>6.6</td>
<td>11</td>
<td>Lithium - Ion [22]</td>
</tr>
<tr>
<td>Air EV - Standard</td>
<td>Wuling</td>
<td>2022</td>
<td>17.3</td>
<td>200</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>8.5</td>
<td>Lithium - Ferro-Phosphate [23]</td>
</tr>
<tr>
<td>Range Air EV - Long</td>
<td></td>
<td>2022</td>
<td>26.7</td>
<td>300</td>
<td>NA</td>
<td>NA</td>
<td>6.6</td>
<td>4</td>
<td>Lithium - Ferro-Phosphate [23]</td>
</tr>
<tr>
<td>Mustang Mach-e</td>
<td>Ford</td>
<td>2022</td>
<td>91</td>
<td>505</td>
<td>60</td>
<td>1</td>
<td>19.2</td>
<td>6</td>
<td>Lithium - Ion [24],[25],[26]</td>
</tr>
<tr>
<td>Fokus Electric</td>
<td></td>
<td>2018</td>
<td>33.5</td>
<td>300</td>
<td>6.6</td>
<td>5</td>
<td>Lithium - Ion [27]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kia Jiwa EV</td>
<td>Kia</td>
<td>2019</td>
<td>33</td>
<td>170</td>
<td>50</td>
<td>0.55</td>
<td>6.6</td>
<td>5.5</td>
<td>Lithium - Ion [28]</td>
</tr>
<tr>
<td>Kia Soul EV</td>
<td></td>
<td>2021</td>
<td>64</td>
<td>362</td>
<td>77</td>
<td>0.73</td>
<td>7.2</td>
<td>10.5</td>
<td>Lithium - Ion [29]</td>
</tr>
<tr>
<td>Zoe E-Tech Electric</td>
<td>Renault</td>
<td>2021</td>
<td>52</td>
<td>384</td>
<td>50</td>
<td>1.5</td>
<td>7.4</td>
<td>9.5</td>
<td>Lithium - Ion [30]</td>
</tr>
<tr>
<td>Megane E-Tech Electric</td>
<td></td>
<td>2021</td>
<td>60</td>
<td>400</td>
<td>130</td>
<td>0.5</td>
<td>7.4</td>
<td>8</td>
<td>Lithium - Ion [31]</td>
</tr>
</tbody>
</table>
3.3 PV System

Photovoltaic (PV) is a renewable and environmentally friendly energy source, to get the maximum power from the PV system power optimization strategy plays an important role in the performance of photovoltaic systems [32]. Figure 4 shows the maximum power point of a PV.

Various algorithms of maximum power point tracking (MPPT) techniques were carried out [33], such as the Perturb and Observe (P&O) Algorithm maximizing solar productivity through the movement of the PV modules on the trajectory of the sun from east to west [34], a new enhanced P&O algorithm has been proposed with control two-step variable voltage to integrate MPPT photovoltaic system performance, two-step voltage guarantees fast tracking response, and at the same time guarantees low oscillation in output power performance during steady-state working [35], then simulation comparison between two different MPPT techniques of system PV that implements the Salp swarm optimization (SSO) and P&O algorithms, where the SSO algorithm can achieve MPP faster than the P&O technique [36], the simple and efficient DC-DC Boost Converter is used as the MPPT algorithm for advanced algorithms (P&O), the converter can overcome the inconsistency of the solar panel output to produce out maximum power put from the PV[38], then the working mode of the converter is validated from various atmospheric conditions [37]. Figure 5 shows the schematic of the PV system and Table 2 shows the characteristics of the MPPT technique.

![Figure 4. PV Maximum Power Point](image)

![Figure 5. PV System Schematic Diagram](image)
Table 2. The main characteristics of the MPPT technique

<table>
<thead>
<tr>
<th>Ref</th>
<th>MPPT Technique</th>
<th>PV System</th>
<th>Converter Type</th>
<th>Analog or Digital</th>
<th>Convergence speed</th>
<th>Sensor Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>[39]</td>
<td>PSO</td>
<td>PV Panel</td>
<td>Boost Converter</td>
<td>Digital</td>
<td>High</td>
<td>V and I</td>
</tr>
<tr>
<td>[40]</td>
<td>P&amp;O</td>
<td>PV Panel</td>
<td>Boost Converter</td>
<td>Analog</td>
<td>Medium</td>
<td>V and I</td>
</tr>
<tr>
<td>[41]</td>
<td>Incremental-Fuzzy Logic</td>
<td>PV Array</td>
<td>Boost Converter</td>
<td>Digital</td>
<td>High</td>
<td>V and I</td>
</tr>
<tr>
<td>[42]</td>
<td>P&amp;O</td>
<td>PV Panel</td>
<td>Buck Converter</td>
<td>Digital</td>
<td>High</td>
<td>V and I</td>
</tr>
<tr>
<td>[36]</td>
<td>Neural Network</td>
<td>PV Panel</td>
<td>Boost Converter</td>
<td>Analog</td>
<td>Medium</td>
<td>Irradiance</td>
</tr>
<tr>
<td>[43]</td>
<td>RCC</td>
<td>PV Panel</td>
<td>Boost Converter</td>
<td>Analog</td>
<td>Medium</td>
<td>V and I</td>
</tr>
<tr>
<td>[44]</td>
<td>PSO</td>
<td>PV Array</td>
<td>Buck-Boost Converter</td>
<td>Digital</td>
<td>Medium</td>
<td>V and I</td>
</tr>
<tr>
<td>[45]</td>
<td>Fuzzy Logic</td>
<td>PV Panel</td>
<td>Buck-Boost Converter</td>
<td>Digital</td>
<td>Medium</td>
<td>V and I</td>
</tr>
</tbody>
</table>

3.4 Battery

The demand for lithium-ion (Li-ion) batteries for electric vehicles continues to increase [46] in line with the demand for battery electric vehicles [47]. This increase was driven by an increase in electric passenger cars [17] and the battery capacity of battery electric vehicles (BEV). 2020 to 14 kWh in 2021. The average battery capacity for BEV electric vehicles is changing regionally, with more than 10% increases occurring in Korea and some European countries. Global battery demand will double by 2021 [17], driven by sales of electric cars in China.

![Figure 6. Global Market Battery Demand](image)

The projected demand for battery metal in Net Zero Emissions in the 2050 Scenario is much higher than the current demand. Demand under this scenario in 2030 is projected to increase by 30% per year for lithium, 11% for nickel, and 9% for cobalt. In comparison, the supply of lithium in the last five years has increased by 6% per year, nickel by 5%, and cobalt by 8% [8]. Therefore, the mineral intensity of the battery and the average battery size per vehicle must be minimized [48]. Battery charge
efficiency and battery discharge efficiency are assumed to be 95% each, to infer the state of charge (SoC) of the battery and its changes lead to approximately 6% loss in charge [20], a Lithium-ion degradation model used to accurately assess and optimize operating costs for electric vehicles and BESS on real-time charging is more optimal [47][49].

3.5 Vehicle Charging Station Strategy

From the literature [50] to support the large-scale adoption of electric vehicles, efficient charging requires an integrated electric vehicle charging system infrastructure in Figure 7 and Figure 8, namely, planning optimal charging stations because it requires coordination between planning transportation activities and distribution of electricity networks include; integrated modeling approach [51], taking into account the detailed modeling of charging demand [52] measure of the charging capacity of electric vehicles [53], the need to consider different types of renewable energy electric vehicle charging options such as fast charging [16] PV generating capacity [54] and Public charging stations [55]. The method of charging electric vehicles is shown in Table 3.
charging in Figure 7 above. The effect of EV charging on the distribution network must be studied to optimize the BESS configuration. The effects of the EV charging load on power grids peak-load shifting is used to replace the large electricity consumption during peak hours with energy storage.

Table 3. Electric vehicle charging method

<table>
<thead>
<tr>
<th>Ref</th>
<th>Electric vehicle charging method</th>
<th>Software / Implementation</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>[56]</td>
<td>PV and BESS</td>
<td>Matlab Simulink</td>
<td>1) the filling strategy is based on the method used in real-time decision-making and not on optimization; 2) the main goal is to ensure the availability of the BESS service, which guarantees the EV to swap batteries quickly without excessive waiting; 3) the second goal is to maximize self-consumption of PV energy and BESS operating profit; 4) charging power is calculated dynamically in real time according to PV power and service availability constraints. the availability of BESS services can still be reached (more than 99.9%) if BESS is connected to the Grid at night.</td>
</tr>
<tr>
<td>[57]</td>
<td>PV and BESS</td>
<td>Matlab Simulink</td>
<td>The main contribution of this research is the combination of PV, BESS, and EV. BESS starts working when PV is insufficient for EV charging and starts charging when the PV generator is in surplus. the combination of EV charging, PV generation, and BESS improves the stability and reliability of the power grid. The simulation results show that the efficiency can be increased by 5.67%, 4.46%, and 6.00%, respectively, for the PV-to-EV mode, PV-to-BES mode, and BES-to-EV under conditions of nominal operation.</td>
</tr>
<tr>
<td>[13]</td>
<td>PV and BESS</td>
<td>ANSYS TwinBuilder</td>
<td>The main contribution of this study is to propose a strategy to determine battery charging capacity and optimize battery operating costs for solar PV-based charging stations.</td>
</tr>
<tr>
<td>[58]</td>
<td>PV</td>
<td>Matlab Simulink</td>
<td>The main contribution of this research is to reduce the electricity peak load demand for electric vehicle charging. with scenario: 1) Electric vehicles are slated for no future energy demand forecast. 2) Electric vehicles are scheduled with a forecast of arriving future energy demand based on average values. 3) Electric vehicles are scheduled across a wide range of possible future energy demands.</td>
</tr>
<tr>
<td>[59]</td>
<td>PV</td>
<td>Matlab Simulink</td>
<td>The main contribution of this research is about the optimal size of PV for charging electric vehicles in the workplace. Self-consumption and independence i.e. SC (Self-consumption) and SS</td>
</tr>
</tbody>
</table>
(Self-sufficiency) are proposed to determine the optimal combined PV-EV size. The optimal framework based on self-sufficiency balance i.e. SCSB (Self-consumption-sufficiency balance) can be used to determine how large a PV system should be installed if there are several charging ports.

<table>
<thead>
<tr>
<th>[60]</th>
<th>PV - BESS</th>
<th>Implementation</th>
<th>Implementasi</th>
</tr>
</thead>
</table>

The main contribution of this research is the design of the PV system as a charging facility for AC E-Bike Charging electric vehicles, DC E-Bike Charging, Wireless E-Bike Charging, and Renault Twizy electric vehicles.

### Conclusion

In most countries around the world, utility-scale solar PV is the cheapest option for adding electrical energy capacity, especially amid rising natural gas and coal prices. Utility-scale solar projects continue to provide more than 60% of all solar PV additions worldwide. Meanwhile, policy initiatives in China, the European Union, and India are driving the deployment of commercial and residential PV projects. IEA (2021). Electric vehicles and power plants based on renewable energy are promising solutions for reducing global CO₂ emissions. This paper presents a comprehensive up-to-date overview of modeling a BESS-connected EV-PV charging system. Several gaps need to be investigated for further research on the availability of real-time measured solar light intensity, placement and capacity of PV power to optimise the performance of PV as a means of charging solar electric vehicles in commercial and residential aspects. Currently, each region/country has a policy to promote the use of electric vehicles, supported by charging infrastructure that is accessible to the public, especially the use of clean energy generators. Regulations for the use of battery electric vehicles as an environmentally friendly means of transport will evolve based on the policies of each country's government. This policy is based on the approach of per capita income, market environment, needs and strategic objectives, and purchasing power based on popular commercial BEV specifications.

### REFERENCES


installed-in-buildings


