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Review

Possibilities and Challenges for the Inclusion of the Electric Vehicle (EV) to Reduce the Carbon Footprint in the Transport Sector: A Review

Aritra Ghosh

Environment and Sustainability Institute (ESI), University of Exeter, Penryn Campus TR10 9FE, UK; a.ghosh@exeter.ac.uk

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Abstract: To combat global climate change moving towards sustainable, mobility is one of the most holistic approaches. Hence, decarbonization of the transport sector by employing electric vehicles (EVs) is currently an environmentally benign and efficient solution. The EV includes the hybrid EV (HEV), the plug-in hybrid EV (PHEV), and the battery EV (BEV). A storage system, a charging station, and power electronics are the essential components of EVs. The EV charging station is primarily powered from the grid which can be replaced by a solar photovoltaic system. Wide uptake of EVs is possible by improving the technologies, and also with support from the government. However, greenhouse gas emission (GHG) saving potential of the EV is debatable when the required power to charge the EV comes from traditional fossil fuel sources.

Keywords: BEV; PHEV; battery; subsidy; charging station; fuel cell; capacitor; solar PV

1. Introduction

Unwanted emissions of greenhouse gases (GHG) from the burning of fossil fuel have now reached a threatening level which needs an immediate action of prevention by implementing environment-friendly climate policy. In 2015, the International Energy Agency (IEA) set a targeted future energy system scenario to limit the increment of average global temperature to 2 °C, which was later modified to 1.5 °C by 2050 [1]. In 2050, the world population is expected to be 9.8 billion, therefore, around 2 billion road vehicles are expected to be on the roads. Currently, over 90% of the global transport sector relies on oil, and 49% of oil production is consumed by the transport sector alone. Accounting for one-quarter of energy-related GHG emissions in 2009, the transport sector is the most rapidly growing energy consuming sector in the world. Hence, road vehicle electrification is essential to overcome environmental issues [2–6].

Electric vehicles (EVs) which emits no greenhouse gases are believed to be a promising solution to combat climate change and environmental pollution challenges. Robert Anderson first invented the EV using nonrechargeable primary cells between years 1832–1839 [7,8]. Later, other prototypes were invented which did not do well, as they lacked practical rechargeable battery and an electrically efficient motor. In the year 1900, EVs constituted 28% of road vehicles in New York City due to the enhancement of the rechargeable lead–acid battery and the DC electric motor. Until about 1918, EVs were popular, however, this popularity died out due to the presence of oil (gasoline). By 1933, the number of EVs fell to zero because of their slow speed and expensive internal combustion engine (ICE) [9]. ICE vehicles emit carbon dioxide, carbon monoxide, hydrocarbon, and sulphur oxides which results in global warming through greenhouse gas effects and pollution which are harmful to both the environment and humans. Hence, zero-emission vehicles (ZEV) are required as a pollution-prevention strategy. ZEV includes fuel cells and electric vehicles. However, the EV is further classified by the hybrid EV (HEV), the plug-in EV (PHEV), the battery EV (BEV) and the vehicle integrated EV, but only BEV satisfy the ZEV criteria [10,11].

Governments around the world are trying to implement policies, e.g., EV purchase cost incentives, developing EV-charging infrastructure, and enchaining public awareness for EV uptake. The aim of this paper is to present a comprehensive review of the following: details of the EV, the development of storage technologies for the EV, the powering of the EV by the photovoltaic system, challenges for EV uptake, and the present EV scenario worldwide.

2. Electric Vehicles and the Charging Station

The term "electric vehicle" counts any electrically powered vehicle, encompassing cars, electric bikes, motorbikes and other battery-powered vehicles. Hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) are common types of EV. For PHEVs and BEVs types, the batteries can be externally recharged [12,13].

2.1. Hybrid EV (HEV) and Plug-In Hybrid

A supplementary electric motor and a gasoline internal-combustion engine power the hybrid electric vehicle (HEV) where the electric motor only participates in starting and accelerating the vehicle. HEVs have limited battery capacity which is charged by deacceleration or braking. HEVs are usually considered twice as fuel-efficient and half as polluting compared to conventional diesel- and petrol-powered vehicles because of their no power consumption from the grid. Series, parallel and series–parallel are the three types of propulsion sources employed for the HEV, as shown in Figure 1. In the series type HEV, an electric motor is the propulsion source and batteries are recharged by regenerative braking, generator and an ICE. The series HEV is appropriate for frequent stops and runs, which makes it suitable for city runs. The parallel HEV electric motor and ICE are both connected mechanically and provides vehicle propulsion by transmitting power. As the ICE and electric motor both complement each other, parallel HEVs are suitable for city driving pattern sand highway driving patterns. The Honda Insight and the Ford Escapes are examples of parallel HEV. The combined series–parallel HEV can be run in series or parallel mode. In this structure, the ICE and electric motor are mechanically coupled to wheels and transmission. This combined structure is costly and complicated. A commercial series–parallel HEV is the Toyota Prius.

A plug-in hybrid electric vehicle (PHEV) is a hybrid electric vehicle (HEV) which has the ability to recharge its electrochemical energy storage with electricity from an electric utility grid (off-board source) [14]. Plug-in hybrid electric vehicles are indicated by a "PHEVx" notation, where "x" typically denotes distance in miles which a fully charged PHEV can drive (all electric range) before it requires to operate its engine. A PHEV20 indicates that it can run 20 miles or 32 km all electrically before its first engine turn on [15]. They are usually equipped with a highly efficient ICE and a large capacity battery pack. The PHEV also has series, parallel and series–parallel power train configuration with an additional on-board battery charger. The PHEV has charge-depleting and charge-sustaining operating modes. The PHEV operates in the charge-depleting mode to start up the vehicle, while a low state of battery charge switches the vehicle into the charge-sustaining mode, consequently causing the ICE to begin operating [16].

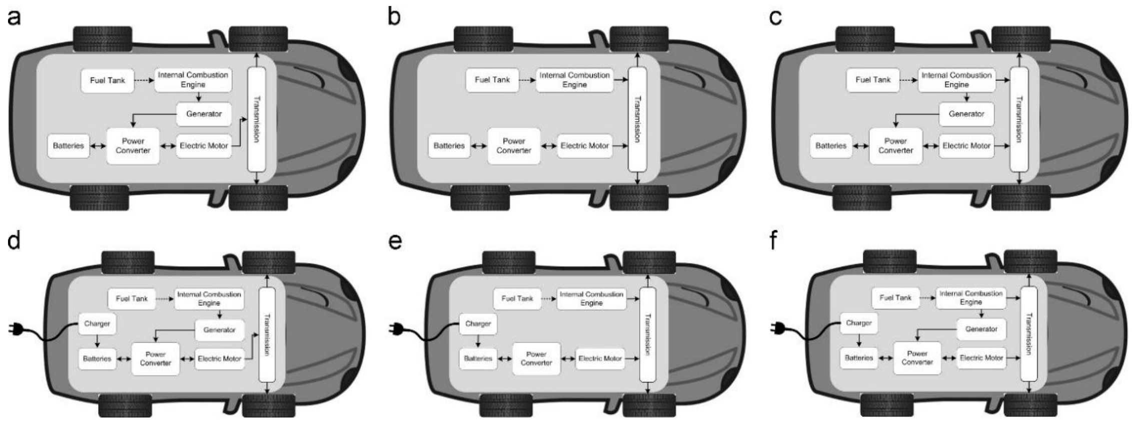


Figure 1. Schematic of typical power train configurations: (**a**) Series hybrid electric vehicle (HEV), (**b**) parallel HEV, (**c**) series–parallel HEV, (**d**) series plug-in hybrid electric vehicle (PHEV), (**e**) parallel PHEV, (**f**) series–parallel PHEV [16].

2.2. BEV

Battery electric vehicles (BEVs) replace the internal combustion engine (ICEV) and the tank with an electric motor powered by a battery, as shown in Figure 2. The BEV is plugged into a charging spot when it is not in use. The BEV does not have conventional engines, fuel tanks, tailpipes and onboard electricity generation provision. Typically, BEVs have a range which is between 60–100+ mi. The absence of a tailpipe allows the BEV to be a tailpipe emissions-free vehicle. Overnight charging using low-cost electricity produced by any type of power station, including renewable, is possible for the BEV. The BEV also possesses sufficient acceleration. However, time consuming battery charging and expensive electricity storage limit the wide range of availability of these vehicles [17,18].

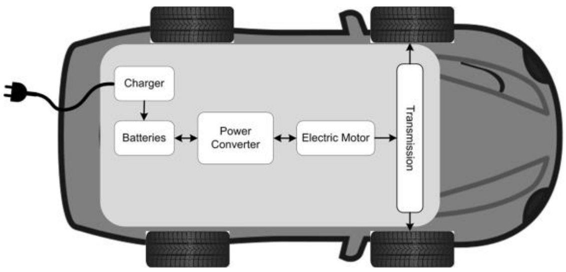


Figure 2. Typical power train configuration of the BEV [16].

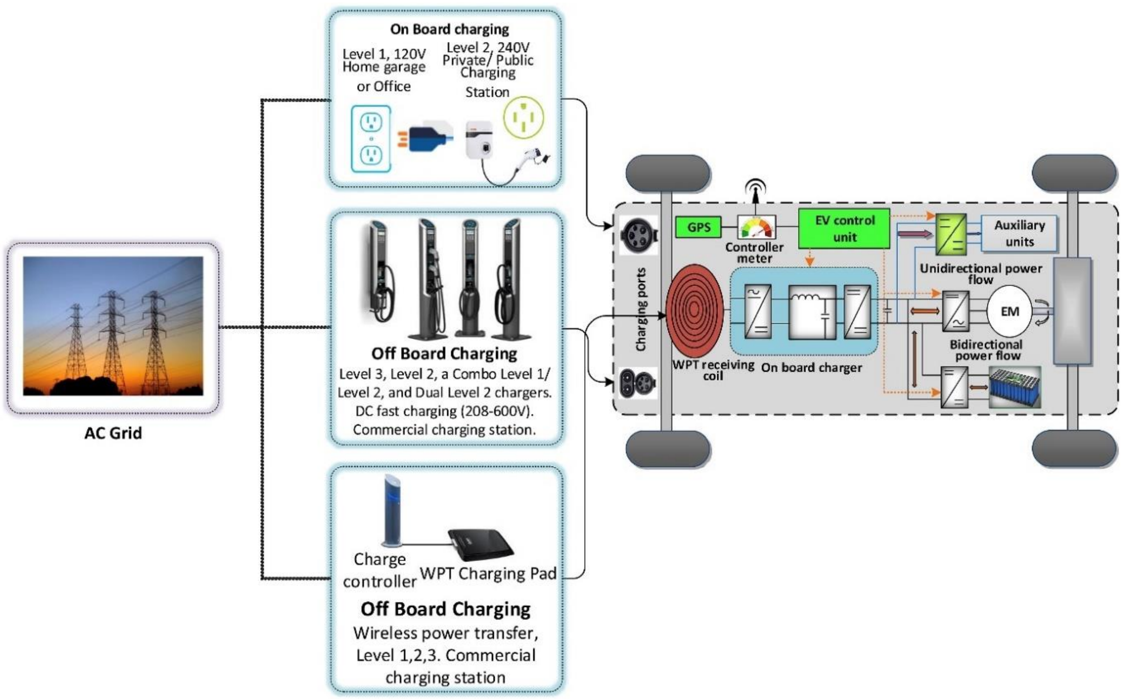
Absence of tail pipe emissions makes the BEV a potential candidate to help to meet the CO_2 reduction targets. However, before implying BEVs as zero-emission vehicles, battery manufacturing and disposal and the carbon intensity of electricity generation must be considered [19–21]. Battery reuse is an effective option and it was found that the carbon emission reduction potential of reusing batteries is similar to that of moving from oiled based vehicles to the EV [22]. Before the wide market penetration, a charging spot infrastructure and the corresponding investment must be in place. A user satisfaction survey shows that the BEV is now gaining interest amongst consumers [23–25].

2.3. Charging Station (CS)

EV charging station controls the energy transfer to the vehicle's battery [26]. Charging is possible based on power levels and charging mode. The Society of Automotive Engineers (SAE) and the International Electrotechnical Commission (IEC) have standardised the EV charger for different power levels and different charging modes [27]. In regard to power level, there are three levels of charging stations that are available to charge EVs. In general, battery capacity varies from 20 to 60 kWh.

Charging level 1 consist a single-phase AC system with up to 3 kW charging power which will take about 7 h to charge a 20 kWh EV battery. For this type charging, the EV connector should have a ground fault interrupter and over current protection. They are commonly located at domestic households and workplace wall boxes. Charging level 2 has a 3-phase AC with up to 24 kW charging power, which needs 1 h to charge a 20 kWh EV battery. For charging level 2, the connector comes under IEC62196-2 type 1, IEC 62196-2 type 2 and GB/T 20234.2 standards. They are located mainly at public charging poles. Charging level 3 has 50 kW DC charging power which provides a fast charging level and charges an EV battery in 20–30 min. Connectors come under SAE J1772, CHAdeMo, and IEC 62196 type 2 standards [28,29]. Fast charging stations which are directly connected to the utility grid also have transformers and rectifiers to produce DC voltage for charging EV batteries in less than 20 min. Hence, a place for a fast charging station can work as an electric fuel station on the motorway (away from the main city) to supply EV energy needed in a short period of time [30,31]. Fast charging station facilities in the public area (main city) are required to spread the wide use of EVs [32]. However fast charging has stronger currents which produce more power losses during transfer and decrease battery lifetime, subsequently reducing the number of total charging cycles. Also, fast DC charging points are more expensive than the AC charger [33].

The location of the charging station for the EV is very essential criteria. Reduction of electric losses from EV charging stations is possible if they are installed near the electric substation [34]. However, most often electric substations are far from EV users (for fast charging, which is the first preference for the consumer). Thus, travel is required to recharge vehicles, which in turn produce EV energy loss. Hence, charging station capacity and the available places to charge a number of EVs are essential parameters in the analysis of economically feasible options [35]. When an EV is connected to a charging station, the control system operates based on several variables, such as the state of charge (SOC) of the battery, current irradiance levels, and the cost of energy from the grid. As EV-CSs are becoming more widespread, other variables such as time spent at the charging location will become important. Figure 3 shows a typical charging facility for EV.



(a)

Figure 3. *Cont.*

(**b**)

Figure 3. (**a**) Complete scheme for an EV charging facility ([27]); (**b**) typical charging stations for EVs in the UK (image courtesy: ROLEC, UK).

2.4. EV Battery

The battery is one of the prime components of the EV, as they work as a source for the propulsion of the HEV and the PHEV, while as the major propulsion component for the BEV. Presently available battery technologies for the EV are lead–acid, nickel-based, and lithium-ion. Allowable temperature for a battery to work properly is about +15 °C to +30 °C, however, ambient temperature can vary between −35 °C to +50 °C due to different climates and regions. Furthermore, in a battery heat generation, heat transport, and heat dissipation are three processes which dominate the battery temperature [36]. Efficient thermal management is essential for an efficient EV battery [37].

The lead–acid battery is the oldest technology, discovered in 1859. In a lead–acid battery, negative terminal lead and positive terminal lead oxide both transform into lead sulphate during charging, and diluted sulfuric acid works as a liquid electrolyte. Lead–acid battery technology is the most mature one and has a low cost (100 USD/kWh). However, they also have low specific energy which varies between 20–40 Wh/kg, and they are not suitable when they discharge over 20% of their rated capacity. When operated at a deep rate of the state of charge (SOC), the battery would have a limited life cycle. The heavyweight lead collector lowers the energy and power density of the battery [38,39].

Nickel-based batteries include Ni-Fe, Ni-Cd, Ni-Zn, Ni-MH, and Ni-H2, where nickel hydroxide works as positive electrode and negative electrode materials. Recently Ni-Cd showed potential for EV application, having life cycles of over 2000 or more and energy density. However, Ni-Cd has a high cost which is ten times that of the price of a lead–acid battery. Environmentally benign nickel-metal hydride (NiMH) batteries are also applicable for BEVs and BHEVs due to their safe operation at a high voltage, flexible size. In addition, they are not very expensive and their energy density varies between 60–80 Wh/kg [40–42].

Li-ion technology possesses high energy density, high efficiency and a long lifespan [43,44]. Due to the rapid employment of this technology, battery price reduced to 85% compared to 2010 level and now achievable between 130 USD/kWh [45] and 176 USD/kWh [46]. Lithium-based batteries can be categorised as lithium-ion (Li-ion), lithium-ion polymer (LiPo) and lithium-ion phosphate (LiFeP04). The principle operation of lithium-based batteries is common across each category; positively charged lithium ions move between an anode and cathode through an electrolyte. However, they have a risk of fire and explosion during a malfunction [47–49]. More recently, developments in silicon-air and lithium-air batteries have produced an eco-friendly, nontoxic and, importantly for the EV industry, they are lightweight and low cost, making them substitute for conventional lithium technologies. This technology has the ability to be commercially available within four years [50]. At subzero temperatures (cold climate countries e.g., Canada, Russia and the Scandinavian Peninsula), Li-ion battery performance degrades. Energy and power density both drastically fall at this condition [51]. At low temperatures, charge transfer kinetics and lithium-ion diffusion become very slow, while the electrolyte conductivity also weakens [52–55]. It is also reported that for the same current, a Li-ion cell's available energy at −20 °C is 60% of the room-temperature value [56].

At low temperature, starting the EV is impossible, unless batteries are preheated [57]. The required time to preheat a battery pack can be up to 10–15 min and this preheating process consumes energy from the batteries themselves [58]. The battery management system (BMS) protects a battery from overcharging, overuse and short circuiting. Thus, BMS regulates all engaging activities between the battery and the required load. Overcharging and overuse of the battery can cause excessive heat and can even cause an explosion or flame. BMS for Li-ion batteries are essential as they fail if they are overcharged, causing them to operate outside their safe temperature or completely discharge. Typically, BMS works with multiple responses, where it will initially try to bring back the battery pack voltage by changing power flow in/out from the battery pack. Failure of this step gives authority to BMS to open the battery pack and stop all power flow in/out of it. This step often disables a vehicle, which is an unsafe condition for the vehicle occupants [59–62]. Table 1 listed the details of the different available energy storage facilities for EVs.

Table 1. Details of different available energy storage facilities for EVs [45,63–65].

Storage System	Energy Density (Wh/kg)	Power Density (W/kg)	Energy Efficiency (%)
Lead–acid	20–35	25	70–80
NiCd	40–60	140	60
NiMh	60–80	220	50–80
Li-ion	100–270	300–2000	85–95
Li-polymer	100–200	300–1000	70
Super capacitor	25–75	5000–20,000	90+

3. Hybrid and Alternative Energy Storage

Highly efficient energy storage technologies which can provide a higher range, weight and cost performance are highly required for the widespread use of the EV. Currently available batteries consume a fraction of stored energy, their life span is not high, and they degrade after charging and discharging a number of times. To meet the peak power demand of the EV, high power density batteries are required, which typically have a higher price than their lower power density counterpart. Increasing the battery size can solve the power density issue, but cost still is a problem. Thermal management, e.g., warming up the battery in cold temperature and cooling it down in hot temperature, is also a key challenge for battery storage.

On the other hand, the supercapacitor has a longer life span and a higher power density which makes it a rapid and effective power supplier. The hybrid battery supercapacitor can be a solution due to its better life span [66,67]. In February 2019, Tesla Inc bought Maxwell, the world's largest manufacturer of supercapacitors, to overcome the shortage of batteries.

3.1. Battery/Supercapacitor

Supercapacitors (SC) are 95% energy efficient, have specific power ranges between 1000 and 2000 W/kg, possess the longest durability of up to 40 years, require no maintenance, and are insensitive to temperature. Its high-power density is suitable for rapid acceleration and electric braking [68–70]. Supercapacitors' excellent life cycle can be expected to last as long as the car. Supercapacitors store power as static electricity, hence, power delivery is instantaneous from them [71]. The addition of the battery and supercapacitor storage device improves the EV efficiency. Low rated battery capability can be compensated using SC energy storage suitable for electric vehicle application [72].

The primary challenge for the battery and supercapacitor combination is the connection of the SC and battery to the DC bus. Direct connection of the battery and SC to the DC bus is the simplest method, however, fast charging and discharging currents during regenerative acceleration and braking can degrade the battery life span. Also, the supercapacitor's voltage variation becomes limited as it shares the same terminal with the battery. The battery or supercapacitor connection directly to the DC bus through a DC–DC converter can stop the battery from fluctuation during charging and discharging. Power demand during acceleration and braking is managed by a supercapacitor. High losses due to the inclusion of a converter is the main drawback of this option. Another option is to fully decouple the supercapacitor and battery from the DC bus, making connections exclusively through a DC–DC converter. Additional power losses and costs due to converters are the drawbacks of this system [73]. Connecting SCs directly to the DC bus, without using a power converter, allows one to utilise the SC's energy-usage capability, which is limited by constant DC bus control [74]. The SC and battery combination has the potential to enhance battery life cycle by up to 50% when compared to the battery-only energy storage system [75]. Employing a smaller rated dc/dc converter can control the voltage of the supercapacitor more so than battery voltage, making it useful in maintaining EVs' driving conditions [76].

3.2. Fuel Cell/Battery/Supercapacitor

Fuel cells (which are highly efficient and have a high-power density), without combustion, convert the chemical energy of diverse fuels into electricity. They have no tailpipe emissions when driving (as hydrogen to electricity conversion only produces water), silent operation, high reliability and low maintenance, and thus, are considered to be one of the most promising power generation technologies [77,78]. Based on the type of electrolyte, fuel cells include solid oxide fuel cells (SOFCs), polymer electrolyte membrane fuel cells (PEMFCs), and alkaline membrane fuel cells (AMFCs). However, PEMFCs are considered as the most popular energy source for EVs' engines due to the higher efficiency of the system and the easy accessibility of hydrogen fuel [78–81]. In 2016, Hyundai and Toyota introduced their fuel cell electric vehicles (FCEV) into the market. At the end of 2016, Honda also launched new environmentally benign hydrogen-powered FCEVs. Nissan, General Motor and Daimler are reportedly set to begin commercialization by 2020 [82]. The present FCEV can drive up to 300–500 km. Refuelling is possible within 10 min from a gas station that has a pressurized hydrogen facility [83,84].

The fuel cell work as the main energy source in hybrid electrical vehicles which are equipped with a fuel cell, battery and supercapacitor, while the supercapacitor and battery served as storage and energy support systems [85–87]. During power fluctuations, high power density and dynamic response of the supercapacitor work to relieve stress from the fuel cell and battery. Also, presence of the battery reduces the expense of hydrogen fuel [88]. A fuzzy logic-based control system is beneficial for this combined technology where the logic system will control the charging and discharging of the capacitor bank. This control system has the ability to reduce 14% energy waste [74].

4. Integration of Photovoltaic (PV) in EV

Green power generation from PV technology is extremely promising. In 2017, 500 TWh benign electricity was produced globally from a PV system. In 2019, 500 GW PV was installed, 90 times higher than in 2006 [89]. The use of renewable solar energy is accessible to a wider audience due to the falling cost of the PV systems. Hence, the PV has potential to be source for the EV. A PV powered EV is only suitable for the BEV which can be considered a complete zero emission technology, as nonrenewable and renewable are both still considered as a source.

4.1. PV for EV Charging

The inclusion of the EV into the grid-powered charging station enhances the grid instability [90]. A grid-connected charging station that can supply more than 100 kW to fully charge a 36 kWh battery in 20 min can impose energy losses in the grid if it charges ten vehicles simultaneously (imposing 1000 kW load) with the same capacity [91]. The PV system can supply charging power to EVs as a standalone system. The BEV is a particularly well-suited potential candidate which can be powered directly by the PV. The PV generation system is a complete set where components such as the PV generator, battery, charge controller, inverter, and system load are interconnected and directly convert solar irradiance into electricity. These PV power generation plants are not connected to any utility grid. This system possesses several advantages, for example, grid dependency will be reduced, which in turn reduces the risk of grid failure due to EV penetration; and the EV battery can increase the storage facility and can supply everything in the form of vehicle-to-everything (V2E/V2X) which includes vehicle-to-grid (V2G), vehicle-to-home (V2H), vehicle-to-building (V2B), vehicle-to-load (V2L), and vehicle-to-vehicle (V2V) [92–98].

A standalone PV system can be installed at office buildings, domestic house rooftops, factories, industrial areas, universities, and car parking areas for EV charging (as shown in Figure 4) [99,100]. Generally, employees park their vehicle for a minimum of 8 h during daytime when solar radiations are available and grid electricity demand is also high. Without the need for battery storage, this charging is possible and can mitigate the negative impact of excessive PV-generated power [98]. This "charging while parking" is a very popular concept nowadays [101]. It is also possible to install a PV-powered charging station at a remote location where a large grid is not available [96,97]. A 10.5 kW AC PV array and a 9.6 kWh lithium-ion battery was employed to power lightweight EVs in university campuses [102].

Variability of PV power generation can be an obstacle for a PV–EV combination. Due to the diurnal nature of PV power generation, load charging is often performed during daytime at universities, offices, etc. [103,104]. Using an open source model, it was predicted that nonPV generation may require EV charging to serve the afternoon hours, as only a small portion of transportation demand can be achieved from the high capacity of photovoltaic power generation [105]. Variability can be predicted by employing a probabilistic- or a deterministic-enabled prediction a day ahead of real-time PV output, or a combined state of charge (SOC)-based fair EV charging strategy incorporating a noniterative PV output based on the historical PV ramp data and the real-time measurement [104]. Voltage fluctuation from the PV system was controlled using a large capacity connected in parallel with the PV module [106].

Figure 4. Concept of a solar powered EV charging station [107].

Vehicle to grid (V2G) concept perceives an EV not as load but as a source from where its battery power can be supplied to grid [10,108,109]. Hence, the EV can provide the grid support by regulating voltage and frequency, peak power shaving and spinning reserve [110]. Parked vehicles during grid-connected charging or idle mode can be employed to let active and reactive power flow from the car to the to the grid and power lines. Large-scale deployment of EVs enhances the uncontrolled charging and discharging, significantly influening the power system which can be controlled using a V2G system [111]. For V2H, EV batteries supply energy to a building when the main source of building power cannot meet the building energy demand [112].

A bidirectional converter is an essential power electronics component which allows an EV to be a source for the grid, load, other vehicles and homes. The use of unidirectional converters allows

EVs to charge using the charging station (which is primarily powered from the grid), whereas the bidirectional converter allows vehicle to be a source of power and supply to others (grid, load, homes, etc.), hence electricity can flow in both directions. A new topology was investigated where voltage source converters converted solar farm generated power (200 kWh) and further voltage level was modified using a buck boost converter and harmonics, and transients were removed using a low pass filter. A bidirectional converter between the battery storage and DC microgrid maintained the power flow by charging and discharging the battery power [101,113]. The investigation was also performed using PV system battery storage which was directly connected into a medium voltage direct current bus, and with the grid for EV charging. The medium voltage direct current bus voltage played a key role in controlling the system [114]. For Irish climate, the performance of a 6.65 kW PV to charge four EVs was simulated, and the results indicated that in summer, an EV with 90% SOC using home charging facility can run 100 km daily. The performance was also compared for AC and DC distribution systems which showed that the AC system efficiency was 4.67% lower than the DC system over a year [115]. A highly efficient and power-dense three-port converter was developed to integrate the EV, PV and grid to meet the standard of the combination of the CHAdeMO and the Combined Charging System (CCS) [116].

4.2. PV Integrated in the EV (VIPV)

A variety of charging methods utilising PV have been explored suggesting that, subject to local energy tariffs, solar workplace roofs are a favourable solution. However, with the advancement of thin film PV technology, a concept described by Bhatti et al. as a vehicle integrated PV (VIPV) has been suggested as another elegant solution to charging EVs. However, VIPV as the sole power source of a BEV has been shown to be limited due to several factors, including the low power density available. Similarly, [117] deduced that in the study location of Newark which has an array with a peak power of 300 WP and an inverter efficiency of 90%, the VIPV could account for just over 12% of the yearly miles of a Chevy Volt. The study concludes that due to the limited space available on commercial passenger vehicles and subsequent low power density, VIPV may only be considered as a supplement to plug-in charging techniques. The feasibility of VIPV, particularly for large commercial vehicles with big roof surfaces, was conducted using diesel energy equivalent, payback time, potential savings of costs, and CO_2 parameters. It was shown that a 1 m^2 monocrystalline-based VIPV system integrated into a truck can save up to 1100 litters of diesel in a vehicle with a lifetime of ten years [118]. It was predicted that VIPV is a solution but low light condition and rainy season EV still needs power from external charging station which can be grid powered or SPV system [119].

5. Reduction of Greenhouse Gas Emission and Particulate Matter

Traditional diesel and petrol-based cars or ICE vehicles generate pollutant GHG gas which includes carbon dioxide (CO_2), sulphur hexafluoride (SF6), carbon monoxide (CO), hydrocarbons and nitrogen oxides (N_2O) and soot or particulate matter. The prime advantage of the EV is that there is no pollutant emission from the tailpipe. In the EU, the EV can save an average of 50–60% of GHG emissions when compared with ICE-based vehicles [120]. In general, the GHG saving potential of the EV can vary from 10% to 60% depends on the type of EV and geographical location [121]. Hence, it is considered that an EV charged by a battery which takes power from grid can bring environment cleanliness. However, while the EV reduces GHG emission, it also increases the demand for grid electricity. This increased grid power generates GHG, as it still uses fossil fuel as its primary energy source. Usually, GHG measurement metrics of EVs only count direct emission-saving from direct burning of fossil fuels and do not include the indirect emission which is associated during the transmission and generation of the electricity production for grid [122–124]. Thus, electricity generation from alternative sources such as solar, wind, biomass and nuclear are highly recommended [125]. Indeed, it should rightly be pointed out that a definitive or unique comparison of GHG emissions between EVs and ICEs fully depend on the defined system boundaries and the intrinsic assumptions during the calculations process [126]. It was reported that for Macau, the electric public bus cannot save a considerable amount of GHG emissions when compared to the diesel-powered public bus, as power generation comes from traditional sources. Hence, it can be noted that GHG emission benefits of an EV depend on the electric power sources that are being employed to power the EV and its efficiency, range and operating modes. Decarbonization of the transport sector using EVs is not fully certain as they are not the technological solution for all countries [127].

The IEA predicted that in 2040, 16% enhancement of CO_2 emission is possible in the power generating sector when compared to the level in 2014. This emission enhancement is primarily due to the projected 87% surge in global electricity demand. If this production happens through cleaner power generation, the GHG emissions of EVs (particularly BEVs) will be substantially low. However, for the BEV, end of battery life evaluation is also essential. The increasing trend of the BEV enhances the usages of batteries. Recycle of battery is paramount to recover Li and Co which are valuable metals. and to limit Pb, Cd, Cu which are hazardous substances [128].

Traditional diesel and petrol-based cars or ICE vehicles not only generate GHG but also particulate matter. Particles with an aerodynamic diameter less than 10 µm are referred to as PM10, while those with less than 2.5 µm are referred to as PM 2.5. Particulate matter (PM) emission analysis from road traffic shows that 80% of particles are actually PM1 type. PM2.5 and PM10 have adverse impacts on lung disease, acute and chronic bronchitis, asthma attacks, respiratory problems and also possess a risk of inducing lung cancer [129]. According to EU directives, the daily and annual mean of PM10 should be under 50 µg/m3 and 40 µg/m3, respectively. The World Health Organisation's guideline indicates that the PM2.5 level should be 10 µg/m3 [130,131]. Due to the lack of tailpipe emissions, the BEV does not produce PM from exhaust sources. However, PM from nonexhaust sources (road dust resuspension, road wear, brake wear and tyre wear) for EV is still valid. About 50–85% of traffic generated PM10 and PM2.5 comes from nonexhaust emission. The weight of EVs is higher than that of ICE vehicles due to the battery, which subsequently affects tyre wear. Thus, it is also believed that significant reductions of PM from EVs are only possible by further improvement of battery weight [132,133].

6. Challenges in EV Uptake

6.1. Technical

The available range of EVs provided by companies are not true for most cases and often up to 17% lower ranges than predicted mileage also occur [134]. Ultrafast charging facilities are now coming into the scenario. They have 350 kW capacity and can charge a fully drained car within 10 min, providing cars with a 200 km range. However, cars are not ready to receive this high current flow. Long charging time is an obstacle for EV uptake. Long queues in charging stations are an issue which can be diminished by implementing a "battery swap" system where the discharged battery can be exchanged in any of the planned changing stations for this service, which enable the 100% charged battery on board within a few minutes (similar to oil refilling). Thus, EVs' driving ranges will be extended.

The lack of a universal standard for the connector is also an issue with smooth penetration of EVs. The connectors of EV chargers vary with country, EV manufacturer, power level shape, size and pin-out [30], as shown in Figure 5. However, the charging station and the battery employed in the car need to be the same brand or design [3]. Moreover, revenue losses from large investments slow down the growth of the charging infrastructures [135–137]. Figure 4 illustrates the different connectors for EV battery charging [138]. Currently, two global standards are available for fast charging which include SAE International's Combined Charging System (CCS) and the CHAdeMO protocol accepted by German and U.S. industries and Japanese car manufacturers, respectively. To lessen the production cost of software and EV charging parts, harmonized standard in collaboration with the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) are essential [139].

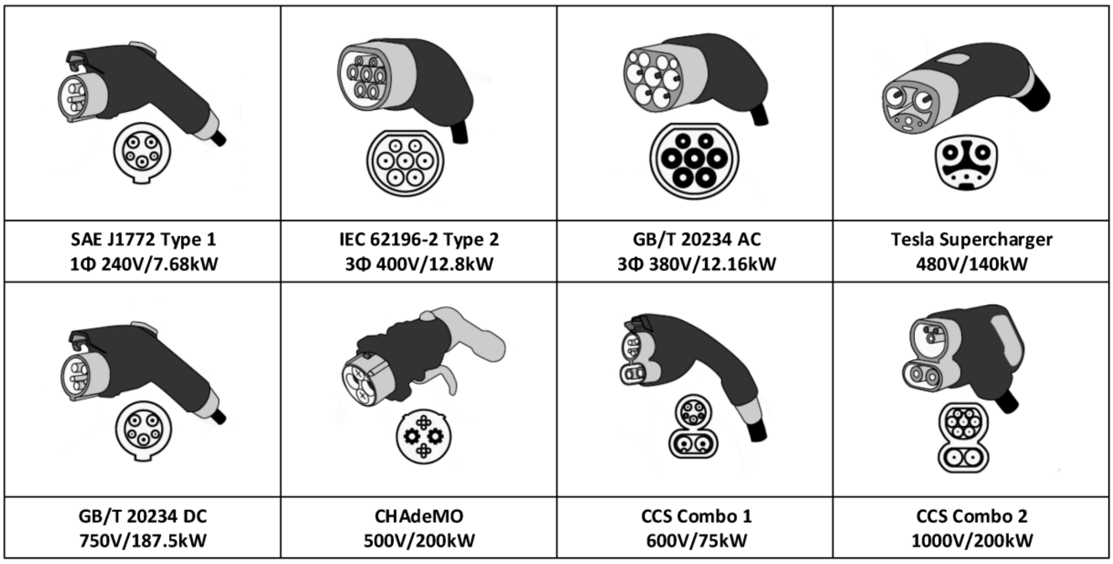


Figure 5. Global male and female battery charger connectors (Ronanki et al., 2019).

6.2. Consumer Behaviour in the Context of Socio-Technical Factors

Widespread unavailability of EVs depends primarily on the behaviour of consumers [140]. The intention of purchase and use, consumer readiness and willingness to pay and accept are some factors which limit the widespread implementation of EVs. How customers' gender, age, education level, income and occupation have an impact on EV purchase is still a debatable topic. From literature-based studies, it is evident that well-educated young and middle-aged male consumers have stronger intentions to adopt EVs [141–144]. Those educated in technical fields or those engaged in technical professions are more likely to consume EVs [145]. Advanced BEV technologies are easy to understand for technophiles [142,146]. Currently, EV users, irrespective of geography, are primarily well-educated males who have a medium–high income. They use their cars for private purposes and charge them at home during the night [147]. This is confirmed for Austria [148], Canada [149], Germany [145,150], Norway [151], United Kingdom [152], United States [144,153] and Sweden [147]. Nonearly adopters have a tendency to prefer the PHEV due to their lack of knowledge of EV technologies. It is evident that the price of the BEV is higher than conventional ICE-based vehicle. However, while it is reported that the consumer thinks less about the price when they consider purchasing an EV in some literature [143,154], other literature finds that they do consider the high price [155,156].

The EV's driving range issue is also an obstacle for drivers who are not willing to proceed with the BEV option once they experience the same due to its short range [157]. The limited driving range, the limited availability of public charging stations, and the length of time it takes to charge an EV, especially in a hilly area, causes range-anxiety [158]. A residential charging station may solve this issue [159].

Additionally, diversity in the EV model can attract a range of audiences. The current EV market is not able to excite people from different backgrounds due to lack of EV models. Hence, variation in EV range, style, appealing features and functionality can attract more consumers [139]. The number of cars and number of available members in the family possess a considerable amount of influence on EV consumer. However, it is still not clear whether having more than one vehicle eventually impresses the consumer to buy an EV or not [160].

6.3. Government Support and Policy

Lucrative government policy and incentives can promote the EV in the global market. Upfront initiatives such as tax reduction and subsidies are attractive during the purchase of an EV. In spite of this, the EV can only compete if the tax on ICE vehicles are higher than EVs, which is the case for Norway and Denmark. Norway is a global forerunner for the use of BEVs. In Norway, seventy thousand BEVs were registered, which accounted for approximately 18% of new car sales in 2015. Total BEV and PHEV purchases were 10,000 in 2012, which became 50,000 in 2015 [154]. Some consumers prefer toll exemption and the privilege of being allowed to drive in the bus lane [154]. EV uptake in some countries such as Singapore is low due to the heavy government taxes on vehicles, which include both the ICEVs and EVs [161].

Hence, a government policy which includes financial subsidies, free parking, driving privileges and preferential tax demonstrates a positive influence on consumers' intentions to purchase EVs [162–164].

7. EV Status Worldwide

In 2017, more than 3 million EVs were on the road, and in 2018 this figure reached to 5.2 million, while just ten years ago there were only hundreds [87]. Figure 6 shows the list of countries leading the sales of EVs in 2018. Current global deployment of EVs shows that China has the highest figure with 45%, followed by Europe and the United States with 24% and 22%, respectively [165]. By the end of 2018 1.1 million EVs were added to China s transport sector. Table 2 indicates the EV status and targets for different countries. Data were compared to the year of 2010. Table 3 shows the reason for the global growth of EVs.

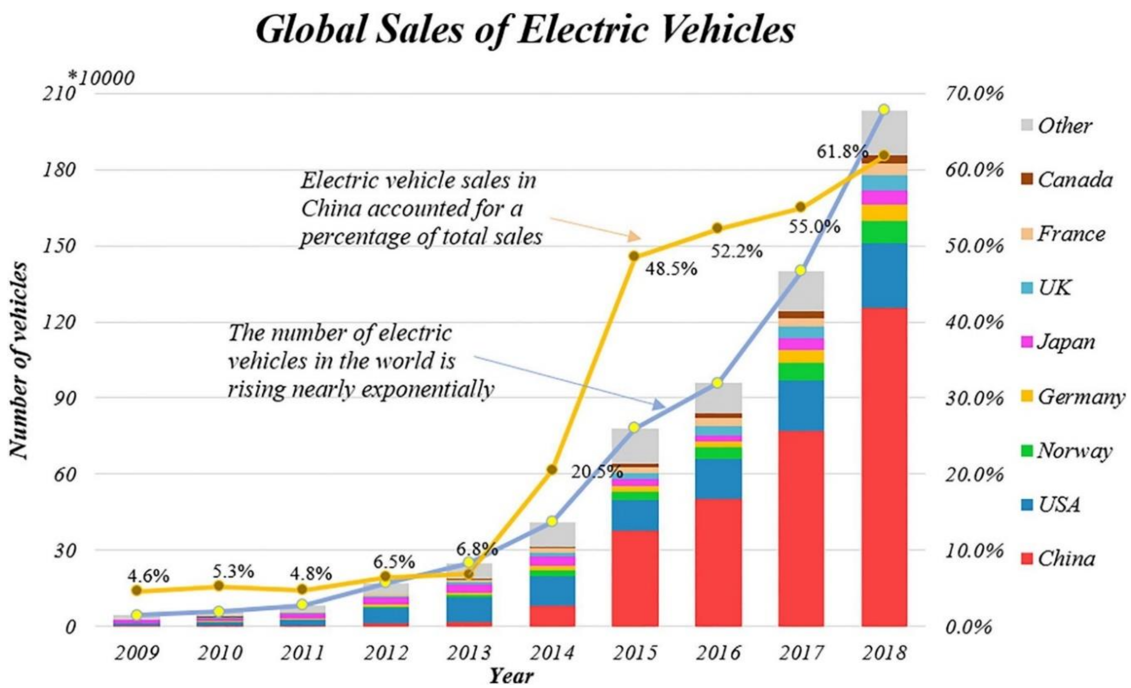


Figure 6. The growing sales of EVs since 2009 [87].

Table 2. EV targets for different countries by 2050 and comparison with past commitment.

Country	Target (Published in 2010 [30])	2020 Present Status	Target for 2050
Austria	2020: 100,000 EVs deployed	2018: ~25,000 2020: in Feb 6.7% EV sales	
Australia	2012: first cars on road, 2018: mass deployment, 2050: up to 65% of car stock	2019:1277 EVs sold 2018: 670 EVs sold	2030: 50% of new cars to be EVs
Canada	2018: 500,000 EVs deployed	2019: 93,091 EVs on the road, EV sales grew by 125% compared to 2017	New light-duty zero-emission vehicle sales by 2025: 10%; 2030: 30%; 2040: 100%

Table 2. *Cont.*

Country	Target (Published in 2010 [30])	2020 Present Status	Target for 2050
China	2011: 500,000 annual production of EVs	2011: 8159 EVs and in 2015, 331,092 EVs were sold. 2020: 15,000 EV charging stations to accommodate 5 million EVs	2400: 40% global EV sales
Denmark	2020: 200,000 EVs	2019: 4618 BEVs and 3623 PHEVs are sold.	2050: Transport sector will be independent of fossil fuel
France	2020: 2,000,000 EVs	2018: 2% sold card was either a PHEV or a BEV	2040: ban on fossil fuel car and Paris will follow this from 2030.
Germany	2020: 1,000,000 EVs deployed	2019: 24,000 public charging stations	2030: 1 million charging stations
Ireland	2020: 10% EV market share	2019: 4825 EVs on the road and another 4054 were registered	2030: 1 million EVs
Israel	2011: 40,000 EVs, 2012: 40,000 to 100,000 EVs	2025: 177,000 EVs on road	2030: full switch to EV
Japan	2020: 50% market share of next generation vehicles	2017: EVs account for 0.4% of market share	2030: 20-30% BEV and PHEV market share
New Zealand	2020: 5% market share, 2040: 60% market share	2021: 64,000 electric vehicles	2030: EVS constituting100% of new vehicles 2050: 100% all lightweight vehicles are EV
Spain	2014: 1,000,000 EVs deployed	2018: 8000 EVs	2040: Banning of diesel, gasoline, hybrid vehicles sale 2050: Permanent ban
Sweden	2020: 600,000 EVs deployed	2019: PHEVs account for 11% of market share	2030: Halt fossil fuel car 2045: carbon neutral
UK	No target figures, but policy to support EVs	Transport sector accounts 27%GHG emission	Zero emission
USA	2015: 1,000,000 PHEV stock	2011: 9750 EVs were sold 2015: 71,044 EVs were sold	Los Angeles targets 100% EVs

Table 3. Subsidy for EVs in different countries.

Country	Subsidy
Austria	• EUR 3000 for BEV price of up to 50,000 euro for private use, EUR 60,000 for commercial use • EUR 400 for cargo bike
Australia	• No stamp duty for full EVs • 20% discount on annual registration of EVs
Canada	• CAD 5000 for EV price with a limit of up to CAD 45,000 (for a six-seater or smaller)
China	• USD 3500 for BEVs
Denmark	• No tax on BEVs until 2015
France	• Applicable for vehicles that emit less than 20 g of CO_2 per kilometre • Up to EUR 6000 for private individuals for a list price of EUR 45,000 • EUR 900 for a two- or three-wheeler
Germany	• EUR 6000 (about USD 6700) for electric car price EUR 40,000 (USD 44,500)
Ireland	• EUR 5000 for BEVs and PHEVs
Israel	
Japan	• USD 7770 for EVs

Table 3. *Cont.*

Country	Subsidy
New Zealand	• NZD 8000 (USD 4880) for EVs
Spain	• EUR 5500 for list price EUR 48,400
Sweden	• EUR 5700 for BEVs
South Korea	• USD 6600 for BEVs • USD 18,600 for FCEVs
UK	• GBP 3500 for BEVs
USA	• USD 2500 for BEVs • USD 1500 for PHEVs

Currently, vehicles which are electrified are mostly light-commercial vehicles which include medium truck and two- or three-wheelers. Electric bicycles or 'e-bikes' are power-assisted/self-powered bicycles. They have physical pedals, with optional assistance from an electric motor, which can typically support speeds of up to 25 km/h and 45 km/h. Light-weight and efficient lithium-ion batteries are now common for e-bikes, replacing their cheaper, heavy-weight lead–acid counterparts. In the EU, e- bikes have shown a steady growth between 2006 and 2014. In 2014, around 1,325,000 e-bikes were sold in the EU which was 14 times higher than in 2006. E-bikes are mostly imported from China (80%). Germany has the largest e-bike consumption, followed by Austria, Belgium and Switzerland in the EU. Consumers who like to do manual work and who enjoy steep hills and long distances use e- bikes often. By the end of 2018, electric two- and three-wheelers exceeded 300 million, and China is the biggest consumer of them.

Electric buses have potential but need high capacity batteries. In 2018, globally 460,000 electric buses occupied the roads, and Austria has the highest number of EV buses, followed by Belgium and the Netherlands [166]. Recently, Hyundai created an all-electric bus which has a 290 km range and a 256 kWh Li-ion battery pack. In 2018, EVs consumed a total of 58 terawatt-hours (TWh) of electricity globally [166].

8. Conclusions

Decarbonization of the transport sector could be possible by using EVs as a sustainable and efficient alternative to traditional diesel- and petrol-based vehicles. In this review work, brief details of different EVs, storage facilities, charging EVs through PVs, different socio-technical challenges for EV uptake and global status of EVs have been highlighted. Battery electric vehicle (BEV) is considered to be a true zero-emissions vehicle because of the lack of tailpipe emissions when compared to other types of EV. However, the saving of particulate matter generation from EVs is not significant because of the enhanced weight of BEVs due to the presence of battery storage. Fundamental challenges with EVs are the lack of a suitable energy storage system and an efficient battery management system that could support the competitive mileage when compared to traditional fuel-based vehicles, as well as the lack of a high-performance fast charging facility. An increase in EV uptake depends on government policies that provide lucrative incentives and benefits. Consumer intentions to adopt EVs include, willingness to pay and socio-economic background. To escalate the sale of EV, EV manufactures must pay attention to diversity and creating an appealing model which will attract a large number of consumers.

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