Impact of Transportation Electrification on the Electricity Grid - A Review

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Abstract

Transportation electrification is a pivotal factor in accelerating the transition to sustainable energy. Electric vehicles (EVs) can operate either as loads or distributed power resources in vehicle-to-grid (V2G) or vehicle-to-vehicle (V2V) linkage. This paper reviews the status quo and the implications of transportation electrification in regards to environmental benefits, consumer side impacts, battery technologies, sustainability of batteries, technology trends, utility side impacts, self-driving technologies, and socio-economic benefits. These are crucial subject matters that have not received appropriate research focus in the relevant literature and this review paper aims to explore them. Our findings suggest that transitioning toward cleaner sources of electricity generation should be considered along with transportation electrification. In addition, the lower cost of EV ownership is correlated with higher EV adoption and increased social justice. It is also found that EVs suffer from a higher mile-per-hour charging rate than conventional vehicles, which is an open technological challenge. Literature indicates that electric vehicle penetration will not affect the power grid in short term but charging management is required for higher vehicle penetration in the long-term scenario. The bi-directional power flow in a V2G linkage enhances the efficiency, security, reliability, scalability, and sustainability of the electricity grid. Vehicle-to-Vehicle (V2V) charging/discharging has also been found to be effective to offload the distribution system in presence of high EV loads.

Index Terms

Transportation electrification, distribution system, electric vehicle (EV), energy storage, vehicle-to-grid (V2G), vehicle-to-vehicle (V2V), social justice, battery technologies.

I. INTRODUCTION

TRANSPORTATION is a necessary vehicle for economic growth and social development. The consumption of fossil fuels emits carbon dioxide that leads to greenhouse gas (GHG) emissions which are not environment friendly [1]. Electricity generation and transportation sectors contribute to greater than one-half of the total carbon footprint [1], [2]. A sustainable transportation system has higher efficiency, lower fuel consumption, and helps to mitigate adverse environmental impacts. Nevertheless, the current transportation system is not sustainable due to the high reliance on fossil fuels. U.S. government announced new fuel standards in 2012. They direct that the average fuel economy of cars and light-duty trucks has to increase to 54.5 MPG (4.3 L/100 km) by 2025 [3]. Such bold targets can not be accomplished by improving the Internal Combustion Engine (ICE) technology because an ICE has an average efficiency of less than 30% and most vehicles achieve an overall efficiency of about 10-20%.

Transportation electrification is the most promising solution to achieve such targets because energy storage systems, power electronic converters, and electric machines provide higher efficiency, and sustainability, and are environment friendly. Transportation electrification is a paradigm shift from ungreen ICE-based vehicles to more efficient and green electrified vehicles. Electricity has become a substitute for fossil fuels in passenger vehicles because fossil fuels have harmful emissions and low-efficiency [4]. An efficient way to decrease carbon emissions and guarantee carbon security is EV deployment [5]. The efficiency of a vehicle's powertrain increases from 30% to 60-70% when ICE is replaced with electric drives [6]. Lithium-ion battery costs were reduced by 60% as hybrid vehicle manufacturing increased from 20,000 per year to 3 million per year [7]. The first EV is introduced globally in 2000 [8]. Hybrid EVs (HEVs) are considered a substitute for internal combustion engine-powered transportation [9], [10]. Electrified transportation uses energy to provide power to traction and non-traction loads. The efficiency of the electric path, energy density, and power density are key factors to maintain less GHG emissions and energy consumption. An efficient and reliable operation of the powertrain is possible due to sustainable architecture, design, software development, and smart control of powertrain components [4]. The affordability, reliability, high performance, and high efficiency are maintained in an EV by coupling the architecture of the powertrain, controls, and software development.

Renewed efforts in coupling electric power and transportation systems are emerging due to GHG emissions, short supply of fossil fuels, and more often power outages. It is recognized that decentralization of the electricity grid and transportation electrification are persuasive ways to mitigate the energy scarcity problem [11]. The development and integration of microgrid and EV technologies support the adoption of distributed renewable energy resources and thereby renewable energy integration reduces the carbon footprint, enabling the establishment of zero-carbon grids [12].

An efficient operation of the electricity grid is viable by penetrating EVs and utilizing the batteries as an energy storage resource because the total mechanical power of all light vehicles in the U.S. is 24 times higher than total electric power generation from utility companies [13]. A study is designed in [14] to evaluate the vehicle electrification challenges and identify the implications of transportation technology choices. An overview of transportation electrification in the industrial environment by considering EV batteries, charging infrastructure, and smart energy management systems is presented in [15].

In [16], the authors investigated the benefits and disadvantages of the implementation of electric vehicles for road freight transport based on the model of trolleybuses. The current status, present deployment, and challenges in implementing the charging stations and EVs infrastructure are studied in [17]. It also studies the potential for EVs and their impacts on society. Recent studies focused on optimizing the energy efficiency in terrestrial and aerial EVs because their adoption is rising [18]–[20]. The capacity of the battery pack or electrical energy principally depends on state-of-charge, driving style, temperature, charge, and discharge current profiles [21], [22]. The bi-directional power flow in EVs uses the energy storage capacity of batteries to provide ancillary services to the electricity grid. It can reduce the dependence on fossil fuels in a microgrid during peak load generation, spin reserve, and regulation.

The preparedness of the electricity grid in response to the rise in EV demand are concerning [23]–[31]. Numerous attempts are taken to systematize the charging/discharging of EVs to mitigate the potential detrimental impacts [32]–[39], propose pricing schemes [40]–[47], and coordination with the transportation network [23], [48]–[51]. There are numerous studies on the benefit of EVs for grid services to provide ancillary services [52]–[56], peak shaving [57]–[61], power quality improvement [62]–[66], and frequency regulation [67]–[74]. Moreover, various transactive energy methods are presented to accelerate the interaction of EVs with the grid [75]–[80]. Nevertheless, adoption of EVs by consumers as depicted in [81]–[86] confronts numerous challenges studied in the literature including cost of ownership [87]–[91], battery degradation [92]–[99] regardless of advancements in battery technologies [7], [100]–[109], travel demand uncertainty [110]–[114], along with range anxiety [115]–[126], access to fast-charging electric vehicle supply equipment [127]–[130], and social justice [131]–[133].An overview of the topics covered in this review paper is shown in Fig. 1.
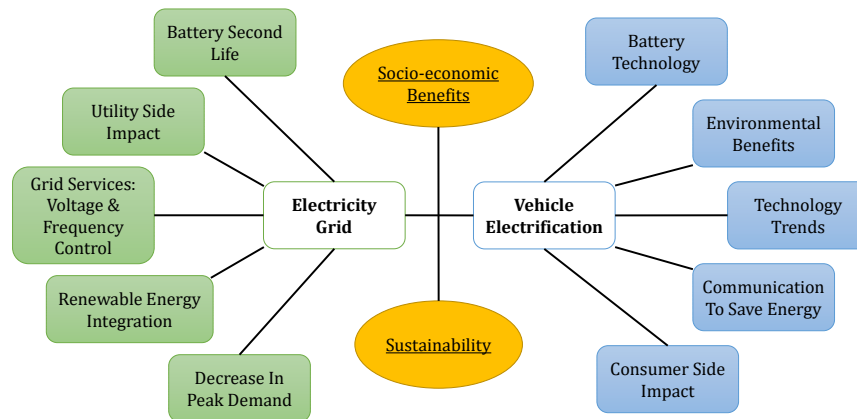

Fig. 1. Services/Impacts/Concerns of Vehicle Integration in the Electricity Grid

The rest of this paper is organized as follows. The environmental benefits of transportation electrification and its effects on consumer side are discussed in sections II and III respectively. The battery technologies and battery second life are reviewed in sections IV and V respectively. The technology trends of vehicle electrification are elaborated in section VI. The impacts on the utility side are assessed in section VII. The application of communication technologies to save energy is discussed in section VIII and section IX reviews the socio-economic benefits. Key takeaways of this research are presented in section X, whereas recommendations for policies are displayed in section XI. Finally, section XII is designated to discussing limitations and future research recommendations.

II. ENVIRONMENTAL BENEFITS

In this section, different environmental benefits of vehicle electrification are assessed. EVs make the environment sustainable by reducing fossil fuel consumption and GHG emissions. By electrifying transportation and integrating renewable energy resources into the electricity grid, China is aiming to reverse the rising trajectory of CO_2 emissions by 2030 [134]. GHG emissions objective is used as a benchmark to find the EV expansion and renewable energy integration to achieve this goal in [135]. Here, an electricity supply and emission model is presented to forecast the intensity factors of GHG under different renewable energy generation scenarios. It shows that the high efficiency of EVs reduces GHG emissions and energy demand. More EVs and electricity generation from renewable are needed to nullify the rising trajectory of CO_2 emissions. In [136], the electric vehicle operation from the viewpoint of the environmental impact of electric power generation from different primary power production sources is studied. It is shown that differences in the effectiveness of the conversion of mixed forms of energy into electricity and their share in this process directly affect the final level of GHG production and the ecological footprint of electric vehicle operations. As a result, in [137], a model is implemented that charges the EVs using PV farm generation to obtain zero-emission transportation.

A case study that models electric power systems to assess the variation in generation emissions by integrating EVs into the Texas grid is presented in [138]. The results indicate that the generator efficiency increases significantly when there is flexibility in vehicle charging. During the ozone period, the change in generator dispatch results in a decrease in generator NO_x emissions. V2G services including energy storage and spinning reserves lead to a sufficient reduction in SO_2, NO_x, and CO_2 emissions. The trend of decrease in CO_2 emissions due to EVs and vehicle miles traveled from 1990 to 2020 is shown in Fig. 2. EVs are incorporated into the transportation network starting in 2010 and their quantity increases sharply. The increase in the number of EVs leads to a decrease in CO_2 emissions. From 2010 to 2015, the number of EVs increases by 400 million and it results in decreasing the CO_2 emissions by 425 metric tons.
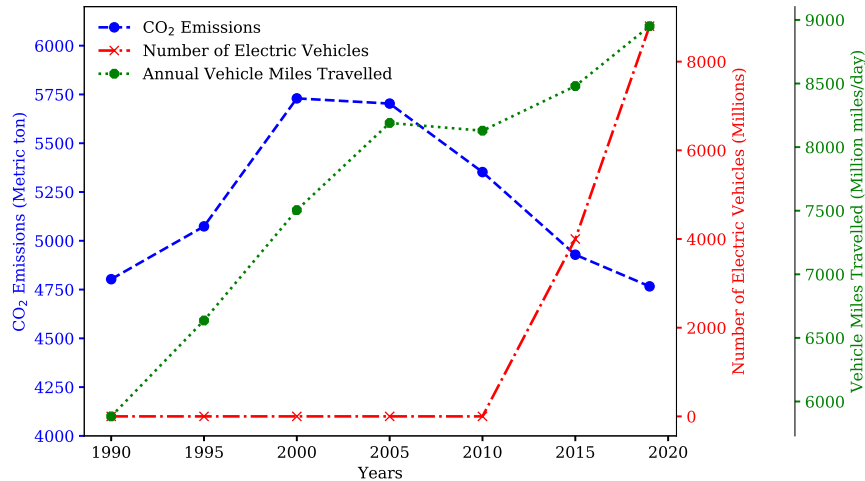

Fig. 2. Impact of EVs and vehicle miles traveled on CO_2 emissions for 30-year period

A life cycle evaluation of EVs, internal combustion EVs (ICEVs), HEVs, and their impact on the environment based on energy consumption is presented in [139]. A comparison between HEVs and EVs shows that EVs have a large environmental impact for 60% of the time and a comparison between ACEVs and EVs shows that EVs have a large environmental impact on 7 out of 15 environmental factors. It is necessary that the supply of national electricity must be cleaner earlier to electrify the urban transportation system. Vehicle electrification could consume a significant portion of the energy in an electricity grid. Series of electric vehicle loads are analyzed in terms of electrical energy usage and battery storage in an environment where more road transportation is electrified [140]. This configuration is used to determine the impact of the increase in private vehicle electrification on the local roads and the possibility of residential load and vehicle integration.

III. IMPACT ON THE CONSUMER SIDE

This section discusses the impacts of vehicle electrification on the consumer. The impacts including cost, adoption rate, range anxiety, and social justice are considered.

A. Cost of Ownership

In this section, the cost of owning an EV is assessed. The cost comparison between EVs and ICEVs is greatly impacted by the vehicle usage level. However, EVs are currently cost-competitive with ICEVs under certain cost conditions. A model for estimating the probabilistic cost of EV ownership is presented in [87]. It involves deterministic and stochastic variables. It suggests that EVs are not more cost-effective than conventional cars. However, if annual travel distance is high enough and incentives are offered, EVs become economically advantageous as compared with hybrid EVs and even some diesel cars. Finally, it is expected that by the rise in fuel cost and advancements in battery technology, the ownership cost of EVs will become more competitive.

The initial purchase price of EVs is the most important factor that negatively affects EV adoption. Potential car buyers are usually deferred from buying EVs due to their high initial cost. However, in the long run, EVs can end up costing less. A model to compare the cost of ownership of EVs and ICEVs during 10 year period is presented in [88]. The modeling includes the forecast of electricity and fuel costs, the behavior of EV owners, battery replacement costs, and incentives for EV buyers. It suggests that for a 10-year period, EVs are already competitive in terms of costs with ICEVs. It is also deduced that stimulations offered by governments and battery technology are two areas that can highly improve the EV cost of ownership. An online survey that provides potential customers with information on 5-year fuel saving costs or total cost of ownership is presented in [89]. The information on 5-year fuel costs does not affect the customer inclination towards hybrid, plug-in hybrid, and battery EVs. However, the information on total cost of ownership affects the probability of adopting EVs in the small/middle-sized car consumer group.

Financial incentives are offered to facilitate the adoption of various types of EVs. However, they are not in accordance with the life cycle effects of different vehicles in the transportation sector. A method for life cycle cost estimation that can be applied for different types of vehicle technologies and fuels is presented in [90]. Indirect costs such as emissions (local/global pollution) and time losses are augmented to the direct total cost of ownership. The results indicate that HEVs have the lowest total cost of ownership, due to their low emission, high fuel efficiency, and low capital cost. Although EVs have the lowest life cycle costs, their expensive initial costs still do not allow them to have lower total costs than HEVs. It is expected that with advancements in EV technology, they are rendered more economically viable.

Although EVs are more environmentally friendly, their high initial purchase cost deters customer adoption. One measure to overcome this issue is to calculate the total cost of ownership (TCO) of a vehicle over a period. This will allow for a better understanding of EV costs, and potentially more EV adoption, as the TCO of EVs is competitive with ICEVs in certain cases. A probabilistic model that uses Monte Carlo method for predicting TCO of various vehicle types is presented in [91]. TCO of EVs becomes more financially competitive with more vehicle usage, especially for smaller cars. Although the TCO of EVs is expected to become lower than ICEVs, it is observed that simply lower TCO will not result in more EV adoption by consumers. Policy measures and education can improve EV adoption. Charging infrastructure and battery technologies are also important subjects of research for improving TCO.

A real-time price demand response based power utilizing strategy for EV charging stations based on photovoltaic (PV) is presented in [35]. Its purpose is to meet charging demands, and minimize charging costs and charging impacts minimization. The feasible charging region mode is utilized to figure out the demand mode of an EV instead of demand estimation. The wavelet neural network is applied to forecast the real-time price. The particle swarm optimization (PSO) algorithm is utilized to optimally allocate the charging power and minimize the charging cost based on PV output and real-time price.

A comparison of the forecasted residential electricity and gasoline costs from 2019 to 2034 is shown in Fig. 3 [141]. The deviation in residential electricity cost from the reference value is within $\pm 10\%$ while the deviation for gasoline is approximately $\pm 26\%$. The deviation in cost increases from the reference value as we move from the year 2019 to 2034. Therefore, it is anticipated that the EVs industry will make more economic sense in the near future.
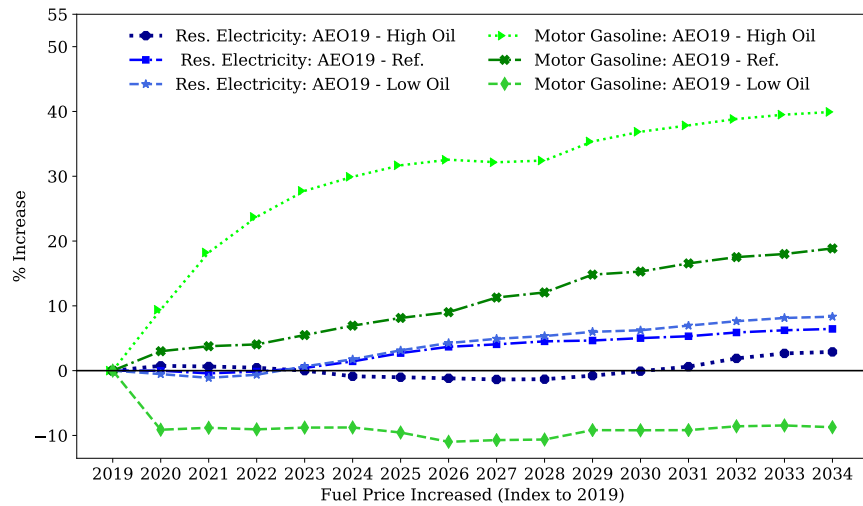

Fig. 3. Projected residential electricity and gasoline costs for 15-year period

B. EV Adoption Rate

In this section, consumer interest in adopting EVs is assessed. The adoption of EVs provides environment-friendly inventions to society in the long run. The public EV adoption rate is dependent upon the perception of customers in regard to EVs [142] and it is essential to understand it. EV penetration level of 1.39% in 2011 and 2.45% in 2012 is considered very low [143]. Multiple factors that affect consumer inclination towards EV adoption are investigated in [81]. It considers the customer knowledge of EVs, perceived risk, perceived usefulness, and financial incentive policies. It suggests that more EV knowledge is correlated with increased perceived usefulness and decreased perceived risk, hence it leads to more adoption. Also, higher perceived risk leads to less intention for EV adoption. Interestingly, the results indicate those incentive policies have no meaningful effect on EV adoption. Fiscal incentives and tax rebates are suggested as measures to increase the EV adoption rate [144].

The impact of financial incentive policies on increased EV adoption is considered in [84]. Based on the data from 22 countries, it is inferred that financial incentives, charging infrastructure, and regional manufacturing sites are significantly correlated with EV market share. Although charging structures are correlated more strongly than other factors, it is mentioned that neither incentives nor charging station availability ensure higher adoption. The role of policies for EV adoption promotion

namely financial, information provision, and convenience policy measures are analyzed in [85]. The results indicate that all of these policy directions are related to more EV adoption, while the convenience policy group is the major one for EV promotion.

The presence of charging stations at the workplace increase the potential for EV adoption. The value of transportation electrification focusing on the involvement of utilities in establishing public charging stations is estimated in [86]. The cost/benefit comparison for utility programs is favorable with lower battery costs while gasoline prices are highly variable and impactful. A coordination strategy for battery swapping and EV charging to satisfy the minimum driving time requirement of EV owners is presented in [145]. The economical switching of low state-of-charge batteries with high state-of-charge batteries occurs at charging stations and it leads to the promotion of renewable energy resources. Adding more charging stations rather than increasing battery size is also effective in promoting EV adoption.

A comparison of the per-mile repair and maintenance costs of battery EVs (BEVs), plug-in HEVs (PHEVs), and ICEs based on different distances traveled are shown in Fig. 4. In the range of 0-50 k miles, ICE has the highest repair and maintenance
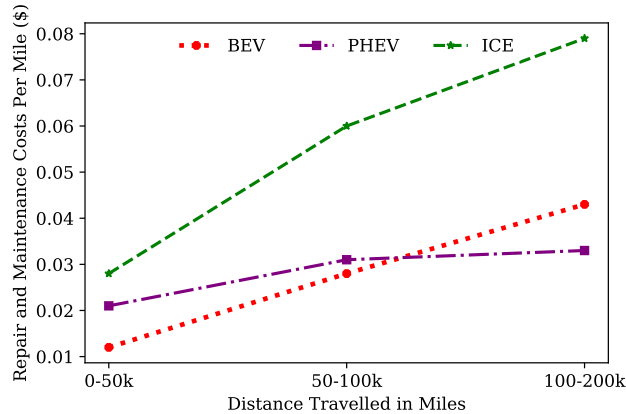

Fig. 4. Per mile repair and maintenance costs of BEVs, PHEVs, and ICEs with different traveled distances

costs of $0.028 and BEVs have the lowest costs of $0.013. For 100-200 k miles, repair and maintenance costs for ICEs increase to $0.08 and PHEVs have the lowest costs of $0.03 at this range. Therefore, EVs have lower repair and maintenance costs as compared to ICEs. The lifetime savings comparison for BEVs, PHEVs, and ICEs is shown in Table I. It can be observed that lifetime savings of $4600 occur when ICEs are replaced with either BEVs or PHEVs.

TABLE I
LIFETIME MAINTENANCE AND REPAIR COST

Powertrain Type	Lifetime Maintenance and Repair Costs	Lifetime Savings versus ICE
ICE	$9,200	-
BEV	$4,600	$4,600
PHEV	$4,600	$4,600

Many European vehicle manufacturers have shifted focus on the EV side due to environmental and energy security concerns. However, several factors contribute towards less adoption of EVs including technical (performance, range, charging time, availability of charging station and service), financial (high initial cost, resale anxiety), and consumer awareness/attitudinal barriers. It is recommended that policy-makers should get involved to promote EV adoption [82]. The investigation on the consumer perception towards DC fast charging (DCFC) technology and the effects of different pricing on customer charging habits are considered in [83]. The results indicate that flat rate pricing negatively affects the utilization level of DCFC stations.

C. Range Anxiety

In this section, range anxiety is discussed which is one of the challenges that need to be addressed in order to increase EV adoption by customers. Range anxiety can be defined as the EV owner's concern about the EV running out of power during a trip. The main hurdle for the adoption of EVs is limited range as compared to vehicles with ICE [118]. This issue discourages more EV penetration and has been a subject of interest for researchers. The range anxiety definition is categorized into three concepts: technical (range demand is higher than EV's range), psychological (driver is unreasonably worried about range), and rhetoric (consumers do not have a good understanding of range anxiety and only use it as an excuse) [119]. Based on surveys and interviews, it is concluded that range anxiety is neither solely technical nor psychological. Policy measures designed to overcome range anxiety by focusing on technical or psychological aspects will not be successful. Programs such as investment in public charging stations might return outcomes that are much less beneficial than believed. That is why policy-makers are urged to come up with programs that deal with rhetoric components of range anxiety. One of the ways for overcoming the range anxiety challenge is to come up with better range estimates. A big data based scheme for estimating the range of driving

for an EV is presented in [120]. The utilized battery model considers the state of health and internal battery resistance which is suitable for prolonged usage periods. The resulting machine learning model is capable of handling battery degradation, and different driving patterns, and is proven to improve range estimation.

A mobility-aware coordination approach for EVs inside a smart grid with advanced communication infrastructure is presented in [121]. It decreases the power system overload and also reduces the average travel costs of EVs, which is a contributing factor to range anxiety. The travel cost of EVs is composed of the distance traveled to reach the charging station and the amount of time spent before charging is allowed. This work collects real-time vehicle information, which is used for predicting the mobility of EVs. Simulations show that this framework leads to an increase in charged energy, and a decrease in the overall waiting time and distance traveled before charging while taking overloading constraints into consideration.

Range anxiety is one of the reasons that prevent more EV sales. The analysis of parking configurations and etiquette, legislations, and regulations regarding EVs is presented in [122]. To improve range anxiety, it proposes changes in charger placement in parking lots, the number of charger plugs, reduced charging fees, and legislation for unplugging and fining charged vehicles. An investigation to find the impact of the precision of displayed data (range and state of charge (SOC) of EV) on drivers' driving experience and attitude is presented in [146]. Here, 73 participants are asked to ride the same EVs on the same route. The displayed information on EV was chosen to be with high and low ambiguity. The results suggest that the drivers who are presented with more ambiguous data exhibited less range anxiety, enhanced driving experience, and more appropriate driving performance.

A path rejection capability of EVs to deal with range anxiety is proposed in [126]. By doing so, the driver is assured that the battery of the EV is able to provide the required energy for an upcoming trip. An algorithm is designed that always makes sure the EV battery has enough energy to reach a charging station. During the trip, EV software constantly calculates the minimum energy required to reach the nearest charging station. The driver is notified by a warning signal if the remaining energy drops below twice the required energy. Simulations show that the introduced solution is effective in reducing the range anxiety concerns of potential EV adopters. A method to reduce range anxiety by modeling it in proportional to SOC of EV is presented in [147].

Range anxiety and distance deviations to reach charging stations are introduced as two major hindrances for more EV adoption in [123]. In this work, the battery charging station placement is studied to mitigate these issues. The objective considers the principal cost of the charging station and the potential deviation. A bi-level integer programming problem is solved with a heuristic approach. The results suggest that distance deviation tolerance and range anxiety threshold of the drivers substantially affect the decision of where charging stations should be located. It also demonstrates that the costs of the charging station establishment decrease with the extended range of driving. A V2V charging system that enables EVs with extra energy to charge EVs that are at risk of running out of energy is presented in [124]. A social network is considered along with a communication platform and it allows EVs to communicate with other nearby EVs. The presented structure can mitigate range anxiety among drivers. The proposed model needs no capital cost and is argued to be helpful for both drivers and manufacturers.

An enhanced range estimation model to mitigate range anxiety is introduced in [125]. An extensive database that reports second-by-second data for 3 year driving period of 44 EVs is implemented. Energy consumption models are estimated based on this database, which is able to model the impact of different speeds and topographical road conditions. Then a graph search method is applied to improve the route selection algorithms based on less energy consumption. It helps EV owners with efficient range estimation and navigation. Many range estimation methods use simplified models, which is not an appropriate approach to mitigate range anxiety. To reach a better estimate of EV driving range, dynamics and environmental conditions should also be considered. The location, environmental conditions, and time-dependent losses of the drive system are modeled in [116]. It results in improved SOC and range estimation. The Extreme Fast Charging (XFC) technology is investigated as a means of dealing with range anxiety in [127]. XFC enforces remarkably large and intermittent load demands on the network which induce operational challenges. The impacts of XFC stations on power distribution networks are studied and a coordinated planning model is proposed. The location and number of XFC stations are optimized and on-site storage is considered. It can help enhance EV utilization.

The short driving range, long charging time, charging station accessibility with a depleted battery, and battery health concerns during depletion are counted among the risks that discourage prospective customers from buying EVs. To come up with a better range estimation model, multiple information such as mapping, environmental conditions, vehicle constants, driver's behavior, battery information, and sensor data are considered in [115]. The experimental results for actual EV driving validate the proposed model by demonstrating its accuracy against existing ones. Range anxiety can be reduced by off-board charging stations but off-board charging stations are designed only for public and commercial charging stations. The analysis of actual EV trip data is presented in [110]. The range estimation provided by EV proved to be overestimated on more than half of the occasions. It is deduced that if the driving pattern of a driver is more aggressive, the range estimation will be more incorrect. The traveled distance and the type of road (freeway or smaller road) are also proven to be correlated with the range estimation error. The impact of range and resale anxieties on EV adoption are studied in [117]. It is argued that these issues are detrimental to manufacturers' profit, but they increase consumer surplus. For higher levels of range anxiety, battery leasing is suggested instead of purchasing.

D. Social Justice Concerns

Social justice concern arises as a transition from ICEs to EVs occurs. Transportation infrastructure and technological developments frequently benefit middle and upper-class people because these advancements cater to their needs [148], [149]. A survey showed that high-income people are more likely to have a Plug-in Electric Vehicle (PEV) as a second vehicle [150]. PEVs are considered a luxury and elite customer technology in China [151]. The key factors for societal costs of electric vehicles and how they vary based on different parameters based on 5 scenarios of electric transportation are studied in [131]. The results show that large batteries and static charging stations result in increased costs of the system. The key electric vehicle deployment barriers in Denmark are vehicle capital cost differences, people are not ready to pay for EVs, and consumer discount rates. The potential impacts of connected and autonomous vehicles (CAVs) due to travel demand, environmental emissions, and safety on human health are studied in [133]. It estimates that CAVs reduce 70%-90% crashes, over 30% reduction in CO_2, and better engine performance. A socially optimal path for V2G and electric vehicle deployment is presented in [132]. It considers 4 different scenarios with different renewable penetration levels and bi-directional charging. It is estimated that the projected annual savings of $1200 per vehicle in 2030 exist. Therefore, technological improvements can make EV economical and accessible to the lower middle class.

IV. Battery Technologies

Batteries to store and use electrical power are the most expensive component of an EV. It is necessary to reduce the battery costs per kWh to reduce the overall cost of an EV. Battery technologies are usually classified based on energy density, charging and discharging characteristics, costs, and system integration. The appropriate performance parameters are cycle lifetime, calendar lifetime, safety, and low and high temperature performance [86], [101], [152]. Massive adoption of the electric powertrain has become possible due to the technological advancements in power electronics, electrical energy storage systems, and electric motors [153]. The principles and design requirements of thermal management for vehicle powertrain are introduced in [154], [155]. The electric power components in the powertrain have low heat generation, and high efficiency, and operate in particular temperature range [156], [157].

The battery storage system is the critical component of an EV. Various issues need to be addressed for EVs to become commercially viable. EV battery charging time is significantly large [158]. The charging rate of the Chevrolet Bolt is 4 miles/h with an input AC voltage of 110 V resulting in a range of 240 miles [159]. Another challenge is the limited space because the batteries tend to be heavy and bulky. The transportation needs require high energy density and high power batteries. The maximum output power of the Chevrolet Bolt battery pack is 160 kW, the maximum energy stored is 60 kWh, and it weighs about 437 kg which is 27% of the total weight of the vehicle [159], [160]. A powertrain based on transmotor to address such challenges is presented in [161]. It leads to significant improvement in acceleration and deacceleration of the powertrain.

The system performance of the battery including life span, fast charging, fault tolerance, and energy utilization increases when dynamic reconfiguration of different battery levels such as cell, module, and pack levels is feasible [108]. Battery dynamic configuration leads to improved energy storage and conversion in both electricity grids and EVs. Due to the various benefits of re-configurable battery systems (RBS), various algorithms for performance optimization and principles for managing RBS are presented. The state-of-health (SoH) and SOC of EV batteries using Kalman and extended Kalman filters are presented in [109]. It considers state constraints, integration of nominal models, bias estimation of the current sensor, and asymmetric circuit model behavior. The aging, cell changes over time and parameter deviation are managed using delta parameters. The presented method is validated on drive-cycle data obtained from experimental EV and hybrid EV applications.

A method to analyze the demand for electrification by considering the battery load profile and chemistry is presented in [162]. A trade-off between vehicle design parameters and battery metrics for the full life-cycle of light commercial vehicles (LCVs) is analyzed. It is concluded that for a driving range of over 400 miles, cell-level specific energy of greater than 400 Wh/kg and pack-level specific energy of 200 Wh/kg is required. An algorithm to capture the individual features of battery cells and forecast models to effectively manage the battery is presented in [163]. Battery cells have different characteristics and these change with operating conditions and time because of numerous factors including operational conditions, changes in chemical properties, and aging.

The temperature effect is very critical for the battery because the charging speed and driving range drop significantly in low temperatures. The appropriate temperature for efficient operation of Lithium-ion (Li-ion) batteries ranges between 25-40°C and it protects the battery from aging [95]. Li-ion battery life degradation occurs due to high temperature while cold temperature decreases the energy and power capacities and thereby reduces the EV driving range [93], [94], [164]. The desired temperature range for battery operation is maintained using the battery thermal management systems. It uses different cooling mechanisms such as liquid cooling [104] and phase change materials [105], [106]. As compared to diesel engines, much less waste heat is produced by the powertrain. When the ambient temperature is low, a substantial portion of battery energy is used to heat the cabin [165], [166]. Li-ion batteries possess high energy density but issues during high temperature exists [7], [100]. The benefits of Li-ion batteries as energy storage devices have been evaluated in [167]. The fuel economy is dropped due to the high weight of hybrid electric vehicles [168]. Nickel-metal hydride (NiMH) batteries perform better in hybrid and electric vehicles and have trustworthy automotive applications [107]. The low temperature issues are addressed by All-Climate Battery (ACB)

[169]. The ACB cells can work in cold temperatures and still provide optimal performance. It results in an EV independent of weather environment and regions.

Li-ion batteries are most widely used as a storage system in electric vehicles due to their high energy density and mass production [102]–[104]. The specific energy of Li-ion batteries ranges 100-250 Wh/kg and power ranges 800-2,000 W/kg and these ranges are higher than NiMH and lead-acid batteries [170]. Li-ion battery has the characteristics of fast charging and a long lifetime. Nevertheless, Li-ion battery has flammable electrolyte and it may enter into a thermal runaway. Thus, it may release toxic and flammable gases and caught fire [171]–[177]. The battery of the Tesla Model S caused 3 car fires in 2013. The number of automobile fires in Tesla Model S is substantially lower and is 1/10,000 automobiles [178]. The average number of automobile fires in the USA is 1/1000 automobiles [179]. Li-ion batteries also caught fire in airplanes. Li-ion battery in Boeing 787 Dreamliner created fire incidents in 2013-2014 [180]. Such critical accidents increased safety awareness regarding Li-ion batteries [181]. In 2016, Federal Aviation Administration alerted the loss of an aircraft if a Li-ion battery fire occurs in the cargo hold because it is not possible to control such fire with fire extinguishers [182]. Thus, the International Civil Aviation Organization (ICAO) Air Navigation Commission (ANC) published rigorous guidelines for carrying Li-ion batteries as cargo in passenger aircraft [183]. Li-ion battery experimental abuse tests are performed in [184] to identify the potential aspects of fire. A review of different features of Li-ion batteries associated with energy management, safety, performance, and durability for transportation applications is presented in [185]. The potential of Li-ion batteries for stationary applications in second life is presented. The relatively higher energy density of Li-ion batteries makes them preferable in transportation electrification applications. The advantages of Li-ion batteries over other energy storage technologies and other types of batteries are investigated in [186]. The international standards in EV charging infrastructure, best practices, and guidelines are presented in [187]. These standards are necessary to meet the requirements for the substantial operation of EVs. An enhanced structure and optimized inductive power transfer (IPT) magnetic pad which is suitable for dynamic charging EV applications is presented in [188]. The experimental results show that the power transfer fluctuation with load independent voltage gain is within $\pm 6\%$, and the efficiency is approximately 93% with an air gap of 140 mm.

The improvements in battery materials and the potential for large-scale manufacturing are the key factors to decrease the battery costs [189]. The rate of acceleration, current status, and issues of EVs are reviewed in [190]. It mentions that the coordination operation of EVs and PHEVs leads to the least energy resource utilization. A centralized charging station built near a substation has a small impact on local distribution power grids [191]. The power rating of charging station power plugs increases with the high capability of DC-link voltages. Thus, it decreases the charging time of the battery and the drive train current rating reduces by two [192]. A techno-economic assessment of Li-ion batteries and pack designs for applications in transportation electrification is presented in [193]. The modeling of manufacturing operations and power capability is developed to determine the minimum cost of cell and pack designs. The manufacturing of batteries becomes economical when annual production reaches approximately 200-300 MWh. An increase in volume does reduce the unit cost but transportation with large energy requirements reduces the cost significantly. The durability and manufacturing concerns do not allow to use the of electrodes thicker than 100 or 125 microns but relaxing this constraint could reduce the cost of electrified transportation with large energy requirements. An ex-ante forecast for the price of BEVs up to 2040 is presented in [194]. It is predicted that no breakeven between prices of BEVs and ICEVs occurs before 2040. To ensure the competitiveness of BEVs and ICEVs, long-term support is needed from policy-makers. Li-ion battery technology is dominating the EV industry and its costs are coming down significantly. The costs of Li-ion batteries based on 80 estimates starting from 2007-2014 are studied in [195]. The industry-wide cost has declined from above \$1,000/kWh to about \$410/kWh which is about a 14% decrease annually. An analysis of the electrification of the public transportation system is studied in [196]. It discusses the operating scenario, demand analysis, charging routines, cell selection, cost estimation, and thermal management.

An analysis of different batteries and hydrogen fuel cells for potential commercial applications is presented in [197]. Most EVs are powered by Li-ion batteries and the three transportation markets that are not served by Li-ion batteries are low-cost, high-utilization, and long-range transport. Numerous technologies such as cost, compatibility of power grid, specific energy, and safety must be improved in such markets with Li-ion batteries. Battery sizes vary based on the vehicle types such as cars, sports cars, sport utility vehicles (SUVs), etc. The projected battery size of different vehicle types till 2030 are shown in Fig. 5. It is expected that the battery size of large cars is expected to decrease from 79 kWh to 75 kWh. The decrease in battery size is due to the potential advancements in battery technology. But for sports cars, it is anticipated that the battery size increases from 94 kWh to 135 kWh. The increase in battery size of sports cars is due to the need for high speed.

The need for a more efficient battery management system (BMS) is increased due to the necessity of particular characteristics of smart grid and EV including precise SOC, SoH, and charging/discharging protection. BMS algorithms should be accurate to measure the status of the battery and should protect the battery from harmful and unfit operating conditions [198]. A trade-off between improvements in charging infrastructure and battery capacity to reduce public spending costs is quantified in [199]. The impact of battery capacity, charging power, and charging infrastructure on electric mobility is evaluated here. With data input from 909 vehicles that traveled over 28.9 million miles, the charging behavior, energy consumption behavior, destinations' electric rechargeability, electric mileage share, and grid impact are analyzed. Improvements in realistic battery capacity eliminate the solid charging infrastructure need. It is observed that fast charging benefits are small and limited to only a limited segment of drivers.
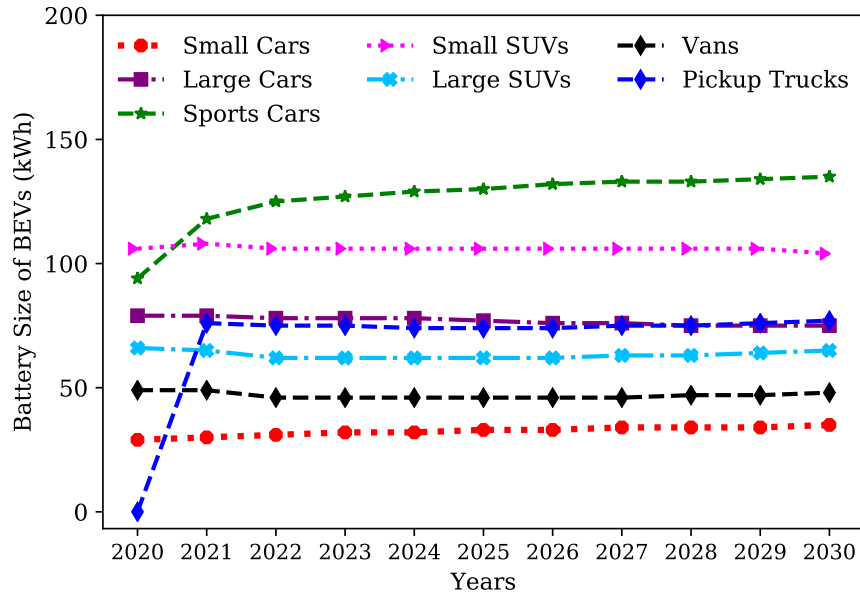
Fig. 5. Forecast battery sizes of BEVs for different vehicle types

V. SUSTAINABILITY, AFTER SALVAGE, AND BATTERY SECOND LIFE

In literature, one of the solutions to reduce the upfront costs of EVs is the second-life use of EV batteries. This concept consists of reusing EV batteries in less demanding grid-connected energy storage applications after they do not meet the requirements of automotive applications. An overview of the second-life battery (SLB) technology and various aspects including applications, manufacturing process, challenges, and solutions can be found in [200]. An economical review of SLBs along with the obstacles and solutions from the perspective of stakeholders is presented in [201]. Another analysis of EV batteries including economical, environmental, technological, safety, and policy assessments of their utilization and recycling process is presented in [202]. The authors proceed to present a 4H strategy with the aim of promoting efficiency, safety, environmental benefit, and economical return pf battery recycling. Besides, authors in [203] presented a framework for EV charging stations to strategically compete in a retail electricity market. Numerous EV architectures including practical ranges, power costs, battery replacement cost, the significance of grid operations, and technological trends are discussed in [204]. It is observed that the regions such as the U.S. where fuel cost is low, enjoy the discounted net value of EVs supposing that the original battery is in a healthy condition and needs no replacement.

Li-ion battery cost is anticipated to decrease from \$1,000/kWh to \$500/kWh [205]–[208]. The calendar life of a Li-ion battery is 15-20 years based on the ambient temperature [209]. The decrease in battery cost is due to the enhancement in manufacturing technology and volume of cell production. Batteries used in EVs have adequate energy and power to provide ancillary services. EV batteries cycle from an upper SOC limit of 80-90% and lower SOC limit of 20-30% [210]. A mechanism to maximize the utilization of battery over its first life (EV) and second life (ancillary services) is presented in [211]. By 2030, it is estimated that the energy available from the second life of EV batteries will be between 3.6 GWh and 17.6 GWh in a best-case scenario [212]. The ancillary services include frequency regulation, voltage regulation, and load following services. Load following ancillary service is energy-intensive and its payoff is merely \$0.04/kWh and it is not considered in [213]. For spinning reserves, the revenue ranges \$0.2-0.6/MWh provided the battery is accessible for the grid during the whole year [214]. The voltage and frequency regulation ancillary services have the highest revenue rates ranging \$3.4-170/MWh [13], [215]–[218] and these are selected for the second use in [211]. There are two types of regulation services: up-regulation and down-regulation. Up-regulation occurs when the battery is delivering power to the grid and down-regulation occurs when the grid delivers power to the battery. Numerous regulation rates are reported such as \$40/MWh [13] and \$40-100/MWh [217].

The utilization of SLBs for peak load management and their cost-effectiveness in a commercial building application is studied in [219]. The goal is to use a second-life battery system of the appropriate size to meet a percentage of peak load. In [211], an optimal strategy to replace batteries in the transportation sector to provide gird services is discussed. Here, the first-life value of a battery and its grid services in the SLB form are maximized according to parameters such as the depth of discharge, the battery's SoH at the end of its first life, and the rate of ancillary services. An analysis of the modules of Nissan Leaf that have been used for the first life is presented in [220]. A feasible substitute for recycling is to use the battery for second life because it allows using the rest of the energy and prolongs its lifetime. The potential applications are the support of an isolated system and its use in stationary systems.

An analysis of the first life period of automotive batteries and how healthy they are at the end of first life is presented

in [221]. The initial capacity of the battery decreases from 100% to 70% over 15 years. After 15 years, the battery is made available for a second life. The re-purposing facility makes the battery available for use in second life and it reduces the re-purposing cost of a variety of batteries. The battery having second life is applied for peak-shaving services and it is expected the lifetime is around 10 years. It is estimated that the second life of 10 kWh Li-ion EV batteries can provide profits up to 35% during 15 years of service [222]. About 50% of the cost of EVs is due to batteries. The re-use of batteries during second life enables them to apply approximately 70%-80% of their energy capacities for profits. The second-life reuse of EV batteries decreases the EV cost. The dynamic properties of the battery over its lifetime when present in the EV are analyzed in [223]. The control system of EV can be applied for the active management of the degradation of the EV battery and it enhances the performance of the EV. The replacement of EV battery at the right time have good techno-economic consequences.

The evolution of the battery second use market from a macro-environmental perspective to comprehend key opportunities and threats in the future is studied in [224]. EV manufacturers can charge less for their vehicles if their batteries prove to have value in second life. Thus, secondary markets for discarded EV batteries are emerging whereby the current preferred method of recycling discarded batteries may be diminished and new innovative business models will arise that have yet to be quantified. The environmental re-use feasibility of EV batteries after first life in a life cycle model is analyzed in [225]. CO_2 emissions are reduced by 56% when natural gas fuel is replaced with second-life EV batteries to serve the peak demand in an electric power system. The utilization of second-life EV batteries gives double benefits: EV storage and peak demand reduction in an electricity grid. The repurposing of second-life batteries as immobile storage systems for integration with wind power to replace fossil fuels with renewable energy is considered in [226]. The model considers the future market of electric vehicle penetration, availability of second-life batteries, and energy storage capacity to meet the base load. A model to determine the cost of renewable while serving the base load is also presented. It suggests the independence of an integrated system to address the impact of EV electrical charging with renewable energy.

In [227], some of the challenges and issues that need to be taken into account when managing SLB operations are discussed. Here, several aspects of reusing EV batteries including SoH evaluation, technologies, communication systems, and BMS are addressed. This report also examines several solutions that deal with battery variability, while paying particular focus to the key factors that should be considered before launching remanufacturing companies. Giving batteries a second life was an innovative idea that was developed to partially recover the price of batteries. However, before being reused, these batteries must go through a transformation process that is not straightforward. They should be gathered, examined, and, if necessary, modified to meet the needs of the new application. These days, every automaker has a battery partner that uses a specific cell shape and chemistry. Each battery also has a unique set of electronic control parameters, equipment, and module combinations. Additionally, each battery model has a unique cooling system. These factors place the reusability of electric vehicle batteries on a precarious path where a wrong move could prove disastrous for the industry.

VI. Technological Trends

In this section, the trends in technological advancements for vehicle electrification are reviewed. The major technological developments in transportation electrification are studied in [228]. EV concept development mainly focuses on powertrain architectures, vehicle segments, and vehicle development stages. The state-of-the-art technologies in the development phase are electric machines and batteries. Due to the advancement in technology, the electric range is increasing with the passage of time. A projected trend for the increase in the range of different EVs till 2030 is presented in Fig. 6. For sports cars, the electric range increases from 224 miles to 353 miles in 2030. Here, we review the technological trends in fast charging availability and different charging levels.

A. Fast Charging Availability

The accessibility of fast charging stations (FCS) supplying high quality of service facilitates the high penetrations of EVs. Two major EV charging types are destination and emergency charging. Destination charging occurs when the EV reaches the final destination while emergency charging occurs on the way to the destination when state-of-charge drops below a certain threshold. The emergency charging needs are satisfied by FCS [128]. The operation of a fast charging station by employing a queuing model is investigated in [129]. Besides, a charging strategy is proposed in which the drivers are motivated to limit their energy demands and allows charging stations to serve more customers without an increase in the queue waiting time. In [130], an optimal planning strategy for PEV fast-charging stations by taking the interaction of the electrical and transportation networks into account is presented. In order to explicitly model the demand of PEV charging on the transportation network considering driving patterns, the capacitated-flow refueling location model (CFRLM) is examined in this work. Additionally, a mixed-integer linear programming model is developed for planning PEV fast-charging stations, by taking high voltage distribution networks and transportation networks as well as electrical network constraints into account. In [229], the efficiency of wireless charging is increased from 84.9% to 95.7% by augmenting an active power source into the receiver. The main drawback of this method is its inferior efficiency compared to conductive methods. In addition, it is noticed that when the active power source acts as a load, the efficiency will drop.
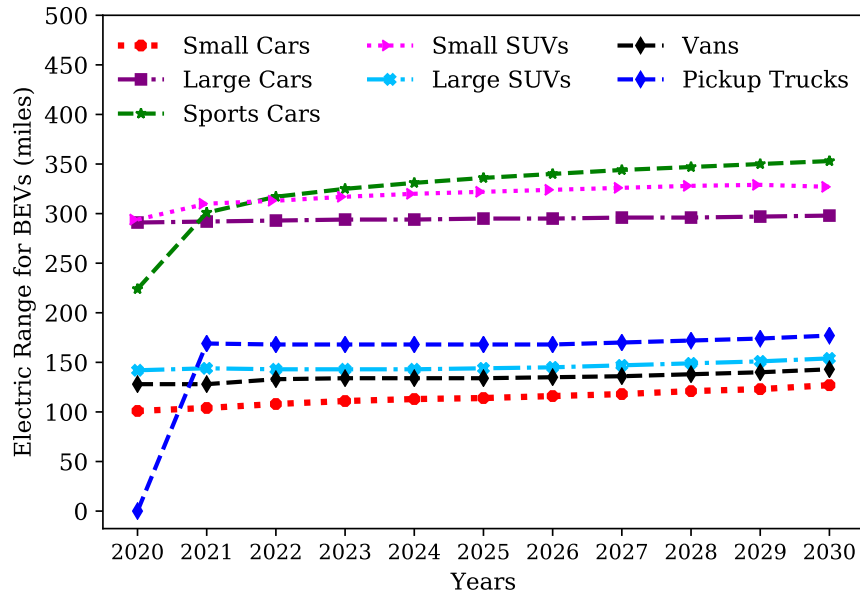
Fig. 6. Electric range for different types of vehicles

B. Charging Levels and Current State of the Art Charging Units

In this section, different charging levels and their charging duration are reviewed. Long charging duration is a concern for EV drivers [230]. The role of FCS for EVs is similar to that of gasoline stations for ICE vehicles. The duration for charging an EV is considered long as compared to refilling an ICE vehicle (1-3 min). There are three charging levels available in the market as given in Table II. Level 1 charging equipment takes 11-36 hours, level 2 charger takes 2-3 hours, and level 3 charger takes between 0.2 and 1 hour to charge an EV battery up to 80% of its rated capacity [231]. During peak traffic hours, charging an EV may lead to the formation of queues and long waiting duration. Long waiting times and queues may lead to dissatisfaction and discomfort for EV drivers. It is crucial for FCS operators to develop methods for queuing time estimation based on the random arrival and charging time of EVs.

TABLE II
CHARGING POWER LEVELS

Power Level	Voltage Level (V)	Charging Speed (mph)	Location
Level 1	120	3 to 5	Home/Workplace/Public
Level 2	208-240	12 to 80	Home/Workplace/Public
Level 3	400-900	180 to 1200	Public

An on-road dynamic wireless charging technology for EVs is introduced in [232] and its comparison with the stationary conductive charging for EVs is presented. The two most significant factors for the customers are charging time and convenience [233]. Desired characteristics from onboard level 1 and level 2 EV chargers are small size, better power quality, and greater conversion efficiency. Small size is possible with zero voltage switching, high-frequency switching, and state-of-the-art packaging. The good power quality of the conversion stage is obtained by reducing the total harmonics distortion and power factor correction. Greater conversion efficiency can be obtained using advanced power electronics, power semiconductors, and magnetic materials. Level 3 charging is an alternative for level 1 and level 2 onboard charging because it has a higher power level. Large level 3 charger installation is crucial to increase public acceptance of EVs.

VII. IMPACTS ON THE UTILITY SIDE

In this section, V2G, V2V, and the advantages and disadvantages of vehicle electrification from the perspective of utility are discussed.

A. Potential for V2G and V2V

In this section, the potential for V2G and V2V due to the integration of EVs into the electricity grid is discussed. V2G and V2V reduce emissions and operation costs by decreasing the dependency on small distribution generation units. For balancing power and demand during charging and discharging of EVs, overloading of power distribution transformers may occur which can cause disturbance in power system network operation. This problem is addressed using direct V2V charging. This V2V

charging/discharging mechanism offloads the power distribution system. A charging schedule of V2V charging to meet the needs of owners is presented in [234]. A hierarchical bipartite graph matching mechanism for EV's V2V plug-in and plug-out operations is presented in [235].

The optimization of cost and emissions for V2G under efficient unit commitment is presented using PSO in [236]. The results demonstrate a significant amount of reduction in cost and emissions. A framework to integrate EVs into the power distribution network considering the grid operation and electricity market is presented in [26]. Various pros/cons arising from integrating EVs into the electricity network during dynamic and steady states are studied. The spatial and temporal diversities of EV integration into the electricity network are analyzed in [237]. The wind renewable energy and 0-100% V2G penetration are integrated into the power distribution network to reduce CO_2 emissions at the national level in [238]. A framework of Markov decision process for optimal energy cost problem of EV owners using cyber insurance is presented in [239]. Based on the presented method, an EV owner is guaranteed the optimal price for charging and discharging of EVs. It is demonstrated that cyber insurance is an effective way to mitigate cyber risks and increase revenue for EV owners. A method to apply V2G for valley filling and electricity grid power peak shaving is presented in [57]. It studies the impact of interconnected EVs and the average of the target curve. The degree of equivalency between the two curves is calculated by standard deviation and RMS values. It is demonstrated that the presented control algorithm is practical and V2G can be applied to control peak shaving. V2G capability can support the electricity grid with respect to congestion management and voltage control. Distributed renewable energy resources in combination with EVs can provide storage systems and the stored power can be used either for EV charging or releasing it into the electricity grid.

The potential ancillary services provided by EVs are shown in Fig. 7. A V2G scheduling algorithm for ancillary services and energy optimization is presented in [52]. It considers spinning reserves and load regulation as ancillary services. This algorithm optimizes the profits for aggregators, low-cost EV charging to customers, and peak load shaving to the utility. It considers accidental departures of EVs as well. A unidirectional V2G regulation algorithm having applications for aggregators is presented in [63]. The results demonstrate that the presented algorithm enhances the profits of the aggregator and reduces customer costs and system load impacts. A method that plans the charging of EVs by considering the power and voltage constraints of the power distribution network is presented in [64]. It satisfies the needs of EV owners by planning the charging of each EV and prevents the congestion of the distribution system. A game theoretic model to recognize the interactions among aggregators and EVs is presented in [240]. In this model, EVs take part in frequency regulation services and an optimal frequency regulation mechanism is developed. The proposed model ensures the benefit of EVs in terms of additional income and power distribution grid in terms of frequency regulation services. The frequency regulation service using the energy storage capacity of aggregators is presented in [68]. To maximize the profit of aggregators, various techniques including the water filling algorithm and state-dependent allocation are proposed to reach the final EV SOC that fulfills the fairness standards between grid regulation service and EV charging.
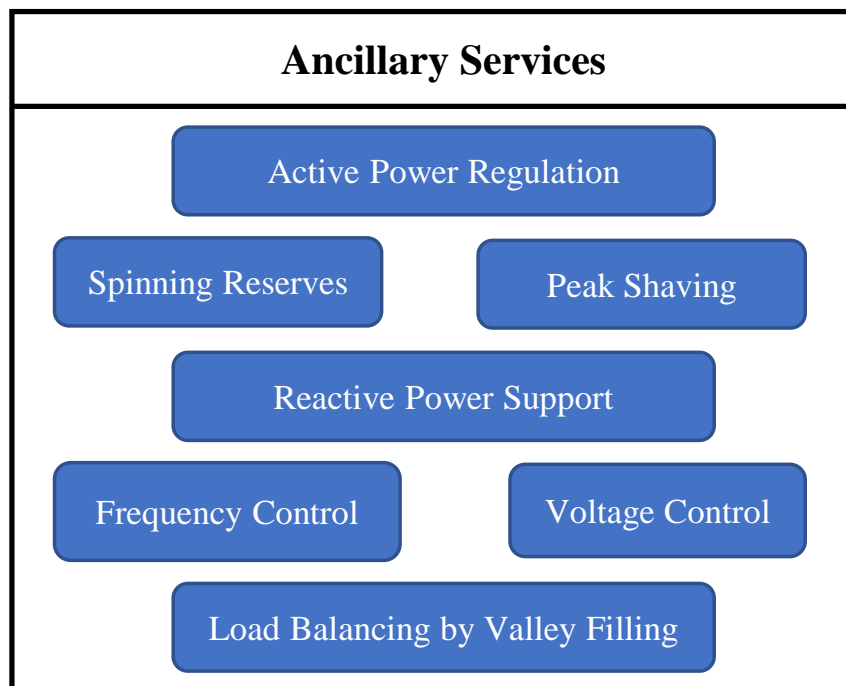

Fig. 7. Potential ancillary services of EVs

Promises and pitfalls of EVs and V2G are examined in [241]. A method to investigate the impacts of V2G regulation services on the economy due to uncertain EV mobility is presented in [111]. It considers V2G feasibility using dynamic and static approaches for ancillary services. It is observed that a 40% reduction in power availability occurs for the dynamic approach as compared to the static approach using Monte Carlo simulations. It concludes that vehicles are mainly used for mobility services and are not possible to get equal power during each hour of the week.

B. Advantages to Utility

In this section, the advantages to the utility due to vehicle electrification are reviewed. EVs are crucial for the future of transportation because of zero emissions and low maintenance and operation costs [242]. Integration of energy-efficient and smart equipment into the smart grid substantially speeds up the conservation of energy [243], [244]. The current electricity grid has no energy storage capacity so the batteries in EVs are a valuable asset. During a power outage from the main grid, an EV battery can provide power to small local loads for hours [245]–[247]. A utility generator is online about 96% of the time and it is estimated that the energy storage from EVs will be available to the grid at about the same time [248]. In this way, a substantial number of EVs can provide ancillary services to the power grid [249]. Due to the increase in electric power demand, V2G may contribute during peak hours based on the appropriately designed control system and deep solar penetration. With regard to utilities, V2G can reduce peak loads, assist load balancing, and supply backup power [250], [251]. V2G allows greater use of power distribution infrastructure [62]. The control schemes for primary frequency control and supplementary frequency regulation are presented in [67], [69]–[73], [252].

The balance of demand and supply using the optimal control strategies in a transactive energy system for EVs is introduced in [77], [78]. A mechanism for transactive energy coordination between EV batteries and community microgrids is presented in [79] while community microgrids are delivering power to multi-dwelling residential apartments. A multi-microgrid energy transaction framework using bi-level programming considering the power distribution system operation is presented in [80]. System-level interactions between power distribution and urban transportation networks are considered in the previous studies. An optimal traffic-based power flow problem is formulated as a mixed-integer second-order programming problem in an urban transportation network in [253], [254].

The charging management of EVs based on price in a power distribution network has been investigated in several studies. An optimal EV charging mechanism based on arrival time uncertainties of EVs and real-time electricity prices is presented in [255]. Integration of renewable energy resources and dynamic price management of EV charging stations having energy storage batteries is presented in [41]. An optimal charging schedule for EVs in an electricity grid congestion is presented in [256]. It applies the Lagrangian relaxation method for partial decomposition. Considering random arrival and departure times of EVs, a dynamic real-time pricing model of charging stations with renewable energy integration is presented in [257]. Stackelberg game is used to analyze the pricing competition of EV charging stations in [42].

A framework to improve the coordination between urban transportation and power distribution networks using services of EV charging is presented in [49]. It considers minimizing the social costs by determining the optimal charging fees of EV stations. The presented model is validated in Xi'an city in China, it demonstrates that improved coordination between urban transportation and power distribution networks occurs, and it decreases traffic congestion and improves renewable energy integration.

It makes energy management more challenging if the potential peak load of EVs overlaps with the peak load of residential customers. A smart method for charging EVs that provides facilities for battery swapping and various options for charging including DC fast charging and level 2 charging is presented in [37]. A multi-objective optimization problem is formulated to fulfill the charging needs of EVs considering minimum travel time, charging cost, and charging time. The presented method decreases the charging cost and waiting time substantially. A smart method for EV charging to enhance their hosting ability in power distribution networks is presented in [258]. The hosting capability of EVs increases by coordinating charging at homes. This method is developed using the hourly extra available power of distribution networks and distribution functions of daily charging period, departure time, daily travel distance, and arrival time. OpenDSS is used to perform AC power flow and Monte Carlo simulations are applied for determining the hosting capability. The EVs hosting capability is 43.2% higher than uncontrolled charging stations in the 123-node system. The adverse effects of load fluctuations and variable renewable energy generation in a power distribution system are reduced due to the contribution of EVs in auxiliary markets [259]–[261]. A tri-layer multi-agent distributed framework is presented to optimize the charging schedule of EVs based on charging demands in [36].

An analysis of the economics of EV battery packs for electricity grid storage is presented in [92]. It considers power storage from the grid during off-peak hours and supplies back to the grid during peak hours. For a 16 kWh EV battery pack, the vehicle owner receives an annual incentive of approximately $10-120 by including the battery degradation cost.

Probabilistic power flow (PPF) can be used to study the impact of EV charging on the electricity grid. A method to model the charging demand of EVs for PPF calculations is presented in [262]. Modeling of the charging demand of EVs in both residential areas and at a charging station is evaluated. A comparison of PPF calculations and Monte Carlo simulations on a modified IEEE 30-bus system is performed. A coordinated model for the probabilistic security-constrained unit commitment-traffic assignment problem (SCUC-TAP) is presented in [50]. TAP is implemented to model the traffic network in a constrained

environment and SCUC models the electricity grid with extensive integration of renewable energy resources. Based on the case studies, it is demonstrated that electric power generation and distribution costs can be decreased where EV owners benefit from the optimization of charging/discharging, electric power distribution schedules, and transportation.

C. Disadvantages to Utility

In this section, the disadvantages to the utility due to vehicle electrification are considered. The integration of EVs into the electricity grid may stress the power distribution system leading to overloads and performance deterioration [35]. The impacts of EVs are found to be more serious on lower voltage parts of the network [263]. Increasing the penetration level of EVs in the power distribution network increases the electricity load burden on the distribution network and increases the voltage magnitude violations [264]. Besides, utilizing a high penetration level of EVs with fast charging stations exacerbates the power quality delivered by the distribution network [265]. The charging of EVs based on PV generation stations effectively mitigates the indirect emissions of EVs [266] and reduces the pressure on the power distribution network [267]. A load reliability model integrating demand response in a distribution system with renewable energy generation is presented in [268]. To enhance the penetration of renewable energy and regulation of primary frequency, a centralized demand response mechanism is presented in [269]. In [270] the authors analyzed how wind power and solar generation power can compensate for the additional electricity load as a result of utilizing EVs with high penetration levels. A distributed demand response mechanism with emphasis on charging control of EVs is presented in [271]. A hierarchical coordination plan to protect the power distribution system from adverse effects of EV charging based on different locations of charging stations is presented in [33].

The stability of load frequency control in a microgrid using EVs is analyzed in [74]. It considers time delay for controlling the stability of the microgrid. The stability criterion is determined using Lyapunov-Krasovskii functional using the linear matrix inequalities. The maximum time delay to ensure the stability of the microgrid is calculated using linear matrix inequalities. The parameters affecting the microgrid stability are EV gain, EV time constant, microgrid inertia, and PI controller gains. A novel method to minimize the negative economic and technical impacts of huge EV penetration into the power system is presented in [272]. It minimizes the charging cost of EVs and conforms to technical constraints mandated by transmission and distribution system operators. It facilitates the EV owners to meet their charging time needs by providing numerous customer choice products.

The uncoordinated charging and discharging of a large number of EVs in an electricity grid have detrimental effects on the power system operation [23], [273], [274]. Different coordination techniques are introduced to decrease peak load and power grid congestion for charging and discharging of EVs [275], [276]. The charging and discharging power of EVs is revised based on the initial SOC, expected SOC, and real-time SOC of a battery to smooth the power system operation [252], [277]. To balance the supply and demand in a power grid, a time-of-use approach is used in [278], [279] that enabled EV owners to charge the vehicle during low electricity purchasing prices and discharge during high electricity selling prices.

A probabilistic modeling method to analyze the impact of EV charging demand on the power distribution network is presented in [34]. Survey data and real measurements for EV charging time, battery SOC, and models of feeder daily load are used to study the impact. The results demonstrate that the proposed stochastic model is able to convey the system losses and security issues due to EV integration. A statistical clustering algorithm to analyze the impact of EV integration on the power distribution network is presented in [280]. It considers EV an electric load only. Different penetration levels of EVs from 0%-100% are considered and the impact on losses, loading, power quality, and voltages is observed. The results are analyzed and distribution system control and mitigation are considered.

A robust multi-stage expansion planning of allocating EV charging stations and power distribution systems using a mixed integer linear programming model is presented in [24]. Chance constraints are applied to address the uncertainties in load. The verification of the proposed algorithm is done through Monte Carlo simulations. The impact of EV integration on power quality, power demand, voltage sag, and transformer power losses are analyzed in [281]. An uncoordinated charging and discharging of EVs results in local power grid issues and it is studied in [282]. A transactive energy framework to address the cost optimization of residential buildings and overloading of the grid using multi-agent based system is presented in [283]. A smart EV charging method using the fuzzy logic controller to enhance the benefits of EV owner and utility is presented in [284]. This method lowers the EV charging cost for the owner and mitigates the impact of EVs on the power distribution network by shifting the Evs' load to off-peak hours. The results demonstrate that the presented method mitigates the impact of EV charging on the electric power distribution system as compared to uncontrolled EV charging.

Some papers have considered both electrical and transportation constraints for EV charging stations. A connected power distribution and transportation network is proposed in an equilibrium modeling context in [285]. It assumes that the nodal prices of the transmission network affect EV charging decisions and leads to the impact on traffic flow. To decrease voltage deviations and power losses in a distribution network, a multi-objective planning mechanism for EV charging is presented in [286]. A multi-objective evolutionary method for the interconnected planning of power distribution networks and EV charging stations is presented in [287]. The constraints for driving range are not considered. A genetic algorithm for optimum sizing and location of EV charging stations is presented in [288]. The EV charging demands are assumed to be uniformly distributed. The location of charging stations that is beneficial for the power grid operator, charging station, and EV owner is considered in [289].

A theoretical analysis backed by laboratory prototypes for the challenges that electricity grids are facing due to transportation electrification is presented in [290]. Transportation electrification imposes challenges on the electricity grid in terms of dynamic, synergistic, stable, and progressive integration of EVs. During plug-in, the onboard power electronics of EVs can be used in the occurrence of power failure irrespective of EV charging or not. From the perspective of electricity grids, off-board power electronics can be used to mitigate power quality problems. Power quality and losses for coordinated and uncoordinated charging methods in a Belgium test grid are given in Table III. The integration of PEVs into the electricity grid leads to an increase in power losses.

TABLE III
POWER LOSSES AND QUALITY FOR BELGIUM TEST GRID [291]

	Without PHEVs	Uncoordinated Charging	Coordinated Charging
Peak Load (kVA)	23	36	25
Line Current (A)	105	163	112
Node Voltage(V)	220	217	220
Power Losses (%)	1.4	2.4	2.1

VIII. SELF-DRIVING CAR AND POTENTIAL TO LEVERAGE COMMUNICATION TECHNOLOGIES TO "SAVE ENERGY"

In this section, communication among EVs, charging stations, powertrain, and customer needs are considered to save energy. An overview of different communication technologies to save energy in EVs is given in Fig. 8.
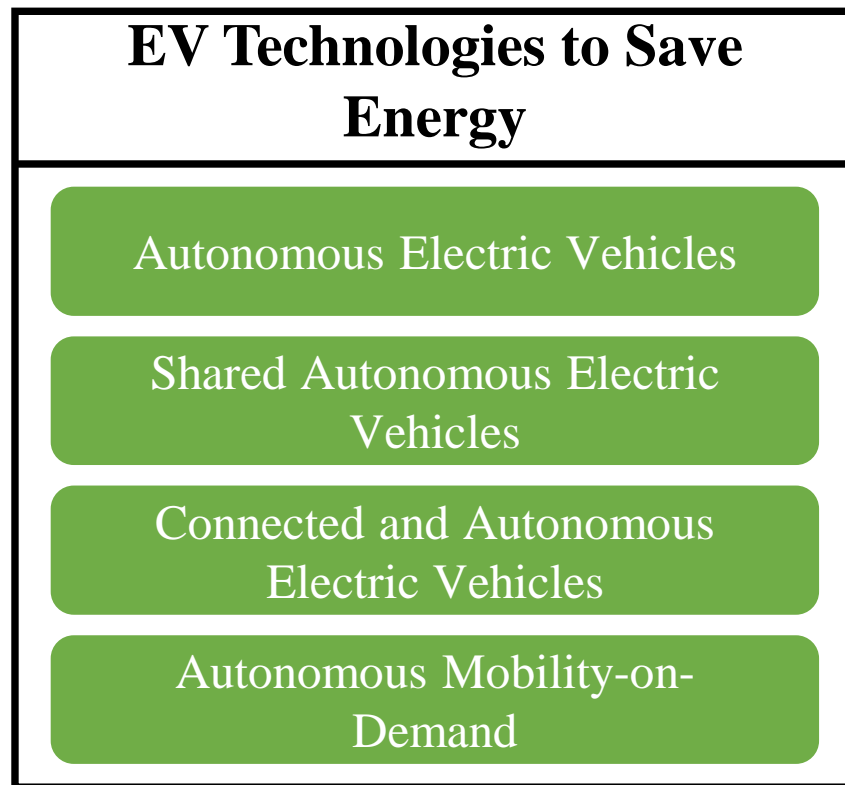

Fig. 8. Different EV technologies to save energy

EVs are a desirable choice for shared autonomous electric vehicles (SAEVs) fleets, due to their improved efficiency and potential to produce zero emissions, while their short range and charging times remain a challenge. A comparison of EV and HEV fleets is presented in [292]. It considers 6 counties across Texas, and the results indicate that HEV fleets perform better than EV fleets. HEVs reduce both cost and waiting time. The fare selection procedure in SAEVs is explored in [293]. The findings show that different strategies have different outcomes. If the goal is to provide demand and supply equilibrium, average waiting times will decrease. Also, faring policies that maximize profits require less sharing. Reduction in energy consumption and GHG emissions in the transportation sector are among the benefits of SAEVs. The driving range and charging station requirements of such a structure are obtained in [294]. The results demonstrate that the introduced model reduces 74% GHG pollution and 58% energy consumption. In the concept of SAEVs, an agent-based model is proposed for vehicle relocation

in [295]. In this framework, the EVs are supposed to visit charging stations in between relocations. This strategy allows for decreasing average waiting time and lost customers. An investigation of the aggregated storage capability of SAEVs in the presence of renewable energy is presented in [296]. The fleet is considered as a virtual power plant (VPP), with the ability to operate connected and isolated from the grid. The rooftop solar allows for isolated operation of such systems. The results show that overall costs can be reduced, and more renewable penetration can lead to higher savings. A design of wireless power transfer for SAEV applications to minimize the costs of wireless charging infrastructure is presented in [297]. The results show that in-route wireless charging stations can lead to a 52% reduction in the internal battery amount. The presented method is more efficient in terms of cost, performance, and convenience, compared with other methods such as stationary wireless power transfer and DC fast charging. A method for optimization of charging, V2G, routing, and relocation of SAEVs with a model predictive control algorithm is presented in [298]. The goal is to minimize waiting time and electricity costs to achieve optimal charging decisions and to minimize waiting times to reach optimized routing and relocation decisions. Results indicate that charging costs can be reduced substantially without affecting waiting times. A simulation of SAEVs for ride-sharing purposes is performed in [299]. According to the routing optimization results, allowing multiple occupancies will increase benefits by more than 13%. This also leads to a decrease in the number of required vehicles as well as charging stations.

An autonomous electric vehicle (AEV) fleet enjoys the advantages of both autonomous vehicles (AVs) and EVs. An optimization of fleet size and schedule, number and location of charging stations, powertrain constraints, and service fees is presented in [300]. Mobility, sensing, computing, traffic control, and energy management are among the applications of connected and autonomous electric vehicles (CAEVs). An appropriate service-management scheme, achieved by successful pricing and vehicle-selection methods, leads to substantial economic gains [301]. Among the shortcomings of CAEVs are costly relocation, charge time, and limited range. A model which successfully addresses customer demands while maintaining high vehicle utilization is presented in [302]. The results indicate more than a 30 percent reduction in energy consumption and a 42 percent reduction in carbon emissions occur.

Traffic congestion is rising and it results in both environmental and economic impacts. A loss of $124 billion occurred in the U.S. due to traffic congestion in 2013 [303]. A pricing strategy and service management scheme using energy management, traffic control, mobility, sensing, and computing is presented in [301]. A pricing mechanism to promote the application of autonomous mobility-on-demand (AMoD) is presented in [293]. The random arrival of customers and efficient control of AMoD using queuing-theoretical models is presented in [304]–[306]. However, these models have a complex structure and are difficult to interact with other transportation modes. The transportation systems with simulation-based models have good interactions and can incorporate complex models but they are not competently optimizable [307]–[309]. Multi-commodity network flow models are optimizable and can incorporate other complex models [310]–[312].

The development of the V2G concept and the services it can offer by modeling the communication and control infrastructure are assessed in [313]. The aggregated fleet can serve as a controllable load, with applications such as leveling off-peak load, storing and generating energy, peak shaving, and ramp up/down services.

IX. Socio-Economic Benefits

In this section, the social and economic benefits of vehicle electrification as shown in Fig. 9 are discussed. BEVs have a crucial role in the reduction of GHG emissions [314]. It is mentioned that the presence of EVs is correlated with the reduction in premature mortality caused by air pollution [315]. United States has a national policy of reducing oil dependency and thereby GHG emissions by replacing ICEs with EVs. Therefore, economical benefits are provided to EV owners including the federal tax credit. An answer to the question from the fuel resources and emissions point of view, whether it is better to increase EV production or come up with measures to reduce fuel consumption and pollution of ICEVs is investigated in [316]. A Toyota Prius hybrid EV is compared with a Toyota Corolla ICEV to this end. The results show that Prius is not cost-effective in terms of fuel economy and emission reduction. The results indicate that for HEVs to be viable, gasoline prices should be three times more. Also, for policy-makers, the social value of pollutant emissions should be 14 times higher so HEVs are rendered attractive. EVs are considered as a means of reducing vehicle fuel consumption, pollution, and emissions. An economic and environmental analysis of different types of vehicles, including conventional, hybrid EVs, and EVs is presented in [317]. For the comparison, different levels of carbon emissions by electricity network are considered. With lower carbon emissions from the electricity network, the vehicles will have more impact on pollutant emissions. That's why it is shown that in a carbon-free electricity network, the environmental benefits of EVs are substantial. Thus, EVs will have a varying impact according to the emission level of the power system.

A comprehensive life cycle analysis for cost and GHG emissions of numerous vehicle-fuel combinations is performed in [318]. The results show that sizable reductions in GHG for light-duty vehicles are a challenging task and need life cycle considerations. Even though higher production volume leads to cost reduction, the current technology still is a hindrance to lower vehicle cost reduction which is the major component of cost of ownership. Also, low-carbon fuels can have higher costs than conventional fuels. Finally, it is mentioned that still, alternative fuels are not an option due to technical issues. The fuel economy of PHEV is highly related to the share of distance that EV has driven by the electric power supply. The impact of electric driving share and driver behavior on fuel economy is investigated in [319]. The real-world fuel economy of PHEVs is
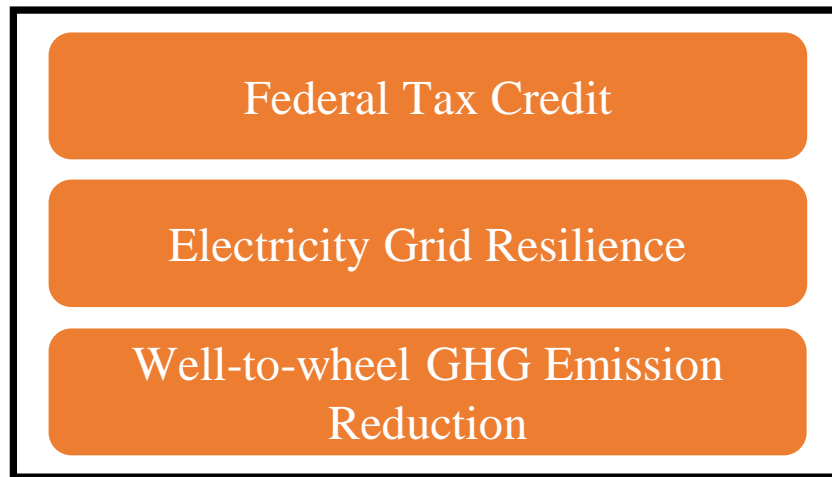
Fig. 9. Socio-economic benefits of vehicle electrification

affected by the range of driving, yearly mileage, driving habits, and probability of long-distance trips. Still, the fuel economy rating of EVs differs a lot from each other, a matter that should be taken into consideration by policy-makers and manufacturers to lift electric driving shares.

EV adoption can result in global effects regarding climate change. EVs might be similar in terms of production cost and technical matters worldwide, but each region has a different situation in terms of customer needs and economic context. Three different regions are compared in terms of customers and GHG benefits of EVs in [320]. The results indicate that although throughout these regions, fuel cost, driving patterns, financial incentives, and economical context is different, the overall advantages/disadvantages of EVs are the same among them. It is suggested that mass adoption of EVs can be achieved by lower battery cost and increased variety of EVs in the market. The interdisciplinary tradeoffs among EVs, policies, market conditions, consumer preferences, and technology improvements are investigated in [321]. A comprehensive model is presented that calculates and compares the cost and benefits of PHEVs, ICEVs, and HEVs.

An economic comparison of PHEVs, BEVs, and conventional vehicles (CVs) is presented in [322]. The proposed model considers dynamic pricing of electricity including time-of-use and real-time pricing, different vehicle types, fuel and electricity price trends, and well-to-wheel GHG emissions. Lower GHG emissions and fuel imports are two important factors leading to a shift towards PHEVs. These vehicles are battery dependent, with additional battery adding more range of driving while increasing the weight of the vehicle. PHEVs are modeled in terms of fuel consumption, cost and GHG emission for different battery sizes and travel distances in [323]. It suggests that PHEVs have lower fuel consumption compared to hybrid EVs. For scenarios with more frequent charging, PHEVs are also less expensive and generate lower levels of emissions. However, for scenarios with charging every 30-90 miles, hybrid EVs are cost-efficient.

Investors in the clean technology field with limited budgets usually opt for a combination of types rather than focusing on one group. The economical viability of a combination of clean energy technologies including solar photovoltaics and BEVs is studied in [324]. The model allows for comparing the payoff of single technologies with their combinations and provides a method for calculating the benefits of combined technologies, showing how combining technologies can profit the investor. In a case study with the combination of BEVs and PVs, it is shown that low electricity prices call for BEV investment whereas, with higher electricity prices, the PV-only investment is more profitable. For average prices, however, it is shown that a combination of these technologies is a better solution. Various aspects of EVs are not considered in cost-benefit analyses, such as human health, air quality, environmental benefits, economic growth, and grid resilience. A model to quantify societal benefits based on existing data is presented in [325]. The results can help policy-makers design incentives based on the true value of EVs in each region.

X. CONCLUSIONS AND KEY FINDINGS

The current status and the impact of transportation electrification on both the utility and customers were reviewed in this paper. Different aspects of vehicle electrification including benefits, impact on the customer, battery technologies, battery second life, technology trends, advantages/disadvantages to utility, socio-economic benefits, and how the communication technology saves energy were discussed. In the long-term scenario, it is necessary to effectively manage EV penetration into the electricity grid to avoid security issues due to high levels of EV penetration. EVs can serve as reserved energy resources against outages when integrated into the electricity grid. The benefits of EVs in the economy, emissions, and distribution systems depend on charging

and recharging frequency, vehicle aggregation, and control strategies. Coordinated and optimal charging and discharging of EVs are advantageous strategies for both the EV owner and the grid operator.

V2G helps to enhance efficiency, reliability, stability, and power generation dispatch. EVs offering V2G services can provide active power regulation, reactive power support, load balancing by valley filling, and peak shaving. Moreover, such vehicles can provide ancillary services including spinning reserves, frequency, and voltage controls. V2G services provide monetary support to owners depending upon the EV battery capacity, market value, and EV penetration level. The success of EV penetration depends upon optimal charging/discharging methods, energy storage using EV aggregations, standard requirements, and established rules for infrastructure decisions. EV batteries must be lower in cost and weight, more efficient, and have an extended life cycle to support optimal integration. The obstacles in V2G include battery degradation due to bidirectional applications, secure communication between EVs and the grid, and infrastructure changes. The impacts of communications, usage patterns, and controls should be assessed for both short and long terms on the power distribution systems and battery life cycle. Mutual cooperation between the EV owner/aggregator and grid operator is crucial to achieving the optimal net return from EV integration.

The key findings of this research can be summarized as follows:

- It should be noted that EVs consume electricity energy. That is why for the implementation of transportation electrification to be successful, transitioning toward cleaner sources of electricity generation such as renewable energy is essential.
- Currently, the cost of EV ownership is higher than conventional vehicles. However, it is expected that higher fuel costs and technological improvements will render EV ownership competitive with ICEs.
- It is concluded that EV price is a key factor in social justice and a lower cost of ownership promotes social justice.
- A major hurdle in the usage of second-life batteries is the complex transformation process of different batteries.
- Compared to combustion engine vehicles, EVs suffer from a higher charging speed in terms of miles per hour.
- Vehicle-to-Vehicle (V2V) charging/discharging has been found to be effective to offload the distribution system in presence of high EV loads.
- Even though there have been efforts to establish bulk energy storage systems in the electricity network, they are not comparable to the storage capacity offered by EVs.

XI. POLICY RECOMMENDATIONS

To meet CO2 emission targets and prevent the increasing trend of CO2, decision-makers are urged to come up with policies that promote the share of EVs in the transportation sector. It is suggested that policy-makers focus on improvements in EV technology, specifically batteries as they contribute to a large share of EV ownership costs. It is strongly recommended that policies should incentivize investors and research facilities in battery technology. policy-makers are also encouraged to address psychological and rhetorical elements in range anxiety of customers. Drivers are unreasonably worried about the range and do not have a good understanding of range anxiety and it is up to policy-makers to focus on these aspects. To promote social justice, it is recommended that incentive policies be designated for lower-income communities. In addition, facilities should be devoted to the improvement of battery technology research and development in different aspects such as charging rate, size, power rating, and life. The goal should be reaching large-scale manufacturing to lower the cost of batteries as much as possible. It also seems that there are no policies that encourage the usage of second-life batteries, which should be considered by policy-makers. Incentivizing policies for the promotion of communication-based fleets such as shared autonomous electric vehicle fleets and autonomous mobility-on-demand should also be considered. The fuel economy rating of EVs also remains an issue that needs to be addressed by policy-makers.

XII. LIMITATIONS AND FUTURE RESEARCH

Although EVs emit limited levels of pollutants, there is a lack of research on the GHG emission of processes in the making and fuel delivery (i.e., electricity generation) of EVs. Battery technology is a crucial aspect of EVs which is strongly correlated with EV range, costs, and adoption rate. Our findings suggest that a reasonable amount of research has been carried out in terms of EV range estimation and researchers in non-engineering fields are urged to focus on psychological and rhetorical aspects of EV ownership. Even though improvements in the battery technology have allowed for the currently increasing presence of EVs in the transportation sector, there are still limitations regarding charging time, charging rate, size, weight, power output, life, and efficiency of the batteries which can be further improved. Researchers in the fields of chemical engineering and material science are urged to further explore battery structures. The reusability of EV batteries remains a hot topic and requires more attention. There is also a huge potential in terms of advanced power electronics, power semiconductors, and magnetic material research to improve battery charging and discharging rates. Another path of future multi-disciplinary research is studying shared fleets in aspects such as communication, management, and road congestion.

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