Chapter 7
Experiences and Applications of Electric and Plug-In Hybrid Vehicles in Power System Networks

Cagil Ozansoy, Taha Selim Ustun, and Aladin Zayegh

Abstract Transportation electrification is inevitable driven by rising energy costs, climate and emission control requirements, and availability of petroleum supplies. Even a realistic 10 % electrification of transportation is expected to impact the electricity generation, transmission, and distribution capacities, and hence the world economy. In this chapter, the authors seek to enlighten the reader on electric vehicle usage around the world by discussing their applications, electric vehicle trials, and key learnings from these trials across three continents: America, Europe, and Australia. Special emphasis has been given to discussing the commuting trends across the three continents and how that effects the transition into the electrification of transportation. The chapter continues with an impact analysis of electric vehicles on car users, the power quality of grids, and finally carbon emissions. Finally, examples of charging infrastructure and worldwide vehicle-to-grid applications are reviewed. The chapter concludes with a discussion on the need for interoperable communication standards, as an enabling technology for the management of the transactions between the grid and electric vehicles.

C. Ozansoy (✉) • A. Zayegh
College of Engineering and Science, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia
e-mail: cagil.ozansoy@vu.edu.au; aladin.zayegh@vu.edu.au

T.S. Ustun
School of Electrical and Computer Engineering, Carnegie-Mellon University, Pittsburgh, PA, USA
e-mail: ustun@cmu.edu

O. Veneri (ed.), *Technologies and Applications for Smart Charging of Electric and Plug-in Hybrid Vehicles*, DOI 10.1007/978-3-319-43651-7_7

7.1 Electric Vehicles in Smart Grids Around the World: Experiences and Applications in the USA, Europe, and Australia

The use of EVs in smart grids in the world is increasing and more and better charging stations are being retrofitted around major cities to enable EV users to charge their cars. The following subsections review the use of EVs around the world with a major focus given on the analysis of EV usage in Australia, Europe, the USA, and Canada. Commuting trends of people in these parts of the world are discussed followed by a discussion on earlier findings from various EV trials conducted in these parts of the world. The share of EVs across the worldwide markets is relatively small but surely on the rise. However, EVs are expected to start having a sizeable share in 15–20 years. Therefore, it is vital to acquire a comprehensive understanding of challenges facing EV users, charging infrastructure operators, and distribution grid operators. The following subsections present a worldwide analysis that will provide fruitful examination of EV usage around the world.

7.1.1 EV Potential and Applications of EVs in Australia

Section 7.1.1 reviews the potential for EVs in Australia. First, the commuting trends of Australians are investigated followed by an analysis of the EV market in Australia. Then, a comprehensive analysis of the EV trials conducted in various Australian states is presented. The findings demonstrate that although EVs do not currently represent a significant portion of the Australian market, they are expected to play a more dominant role in the many years to come.

7.1.1.1 Commuting Trends of Australians

In a recent article [1], Australians' love affair with cars has been investigated, and high car ownership and usage in Australia was elaborated linking the discussion to the very large potential market that exists for electric vehicles (EVs) in Australia. Australia is a very large continent, where widespread communities with insufficient public transport services live resulting in a very large car ownership ratio. The Australian population is growing and new suburbs are continuously being developed at the outer fringes of large cities resulting in large commuting distances to work or study.

Public transport is considered to be poor in Australia due to insufficient reach of public transportation services, high ticket costs, and safety concerns [1]. Therefore, driving is considered a necessity for Australians, and Australia has one of the lowest rates of public transport use when compared to other countries and a very high

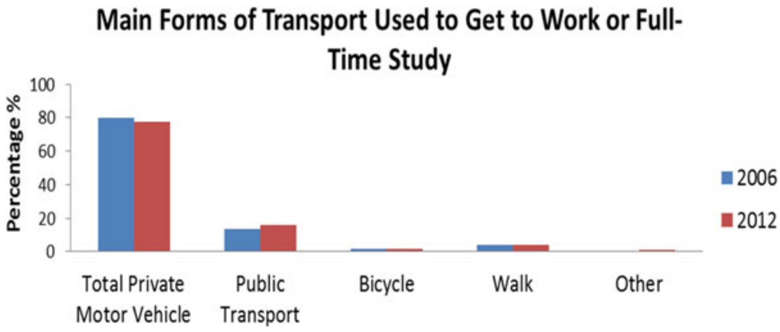


Fig. 7.1 Forms of transport used by Australians [4]

passenger vehicle ownership [1]. The total number of motor vehicles, including motor cycles, registered for the 2013 Motor Vehicle Census (MVC) was 17.2 million, which represents a 2.6 % increase from 2012 and a 12.3 % increase since 2008 [2].

In a recent article [3], the Australian Bureau of Statistics (ABS) has released new statistics to discuss the high vehicle ownership and use in Australia in comparison with the low public transport levels. Figure 7.1 demonstrates the main forms of transport used by Australians to get to work or full-time study. As shown in Fig. 7.1, only 16 % of Australians used public transport in 2012 to travel to work or full-time study [3]. The ABS article reports that the environmental impacts and exhaust emissions from passenger vehicles were amongst the least considered factors by Australians when purchasing a new passenger vehicle with 93 % of users not considering the issue despite the increased awareness on the adverse impacts of greenhouse gas emissions on the natural environment.

By fuel type, petrol (unleaded and leaded)-powered vehicles represent the biggest percentage (79.9 %) of the total vehicle fleet with 13.7 million petrol-powered registered vehicles in 2013. The proportion of hybrid and electric cars is not very well measured and reported since these fuel types are often not separately identified in the individual MVs of state and territories. As shown in Fig. 7.2, there is a clear increase in the number of other fuel vehicles between 2008 and 2013, which represent LPG, dual-fuel, and electric cars. However, the overall proportion of these fuel-powered cars within the market is very low compared to others.

7.1.1.2 Electric Vehicle Market in Australia

As discussed in the previous section, the share of the electric vehicles in the Australian market is almost nonexistent. A report produced by the Energy Supply Association of Australia (ESAA) reports that fewer than 500 EVs have been sold in Australia since 2011 when Mitsubishi i-MiEV was released [5]. Mitsubishi's i-MiEV, Nissan's LEAF, and Holden's Volt are the three leading EVs available in the Australian market, with Toyota's plug-in Prius and BMW's i3 in line for

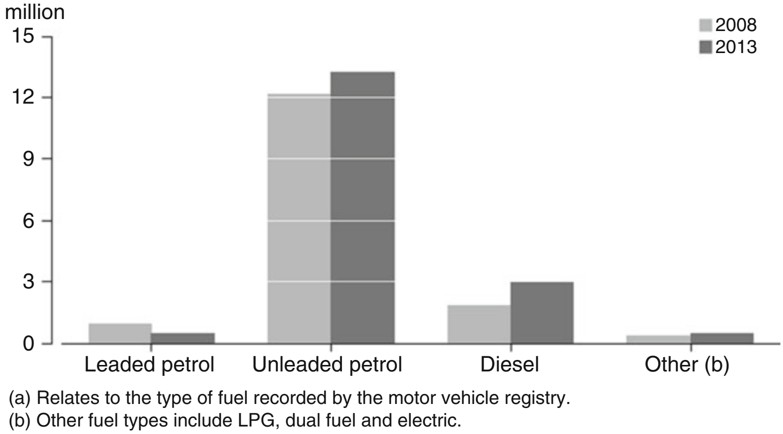


Fig. 7.2 Forms of transport used by Australians [2]

launch in Australia. An interesting statistics shows that the bulk of EV car purchases in Australia were made by corporate companies rather than private motorists [5]. The potential growth of the EV market in Australia has recently been forecasted by a number of government and nongovernment agencies.

In 2011 and 2012, the consultancy firm AECOM carried out a range of studies [6, 7], which predict a long-term transition from internal combustion vehicles (ICV) to plug-in hybrid electric vehicles (PHEV) and electric vehicles [5–7]. The AECOM report produced for the Australian Energy Market Commission [6] projects that around 20 % of the total new car sales will be EVs by 2020 and by 2030 that figure will rise to around 45 %. A Commonwealth Scientific and Industrial Research Organisation (CSIRO) study [8] carried out in 2012 suggests that, by 2033, the market share of EVs within the total Victorian fleet will account for 12 % on a base case and 48 % on a maximum uptake case scenarios. PHEVs on the other hand are expected to comprise 21 % in the base case, and 51 % of the total Victorian fleet in the maximum uptake case.

7.1.1.3 Trial of Electric and Plug-In Hybrid Vehicles in Australia

There have been many electric vehicle trials conducted throughout the world. A number of trials have been conducted or are under way in Australia. The following subsections present a review of the trials carried out in Western Australia, Victoria, and Queensland. An analysis of the trials is provided from a number of aspects including trial participants, organizations participating in the trail, EV cars used during the trials, and finally the charging infrastructure. Some of the key findings of the trials elaborated further in the following subsections include the following:

- When EVs are used as part of company fleets, then most charging is likely to occur during early morning hours, which would help to lessen the concerns of electricity distribution utilities in regard to time of charging. This early morning charging could easily be offset by local solar PV generation, which would correlate with this demand in terms of time of the generation capacity.
- The need for providing customers more charging options and the need for managing peak demand during the likelihood of mass uptake and a network upgrade: The travel distance and battery capacity are amongst the most important factors that help to determine the electricity tariff that a customer should be on when it comes to recharging an EV.
- The importance of having a fully interoperable charging infrastructure to support seamless user roaming across the providers similar to banking services and mobile phone use.
- Although the running cost of an EV is low, the initial take-up costs including the cost of charging infrastructure and the car itself are potential holdups.

Western Australian Electric Vehicle Trial

Australia's first EV trial was run in Perth, Western Australia, with 11 locally converted Ford Focus vehicles and 23 fast-AC charging bays (Level 2) and completed at the end of 2012 [9, 10]. Determining the optimal number and locations of EV charging stations in the area was the goal of the trial, which also formed "part of a road mapping exercise for business and government" and assisted in the development of relevant standards and regulations [9].

According to [10] when the trial started in early 2010, there were no EVs available in Australia, and hence locally converted Ford Focus cars were used in the trial. During the conversion, each car was "equipped with a 23 kWh battery pack, a 27 kW DC motor, and a 1000 A motor controller" [10]. During the trial, they were used as fleet vehicles by the project partners with an objective to demonstrate their potential use in everyday driving. A single-charge driving range of 131 km was achieved, which is claimed to exceed 112 km driving range of the Mitsubishi i-MiEV [10].

The charging stations, based on the international charging norm IEC 62196, were installed around the Perth Central Business District (CBD) and they were capable of charging an EV in about 3.5 h from empty to full. Figure 7.3 shows the location of the charging stations installed around Perth CBD. Besides charging stations installed around Perth CBD, trial participants were also able to charge their EVs at their residences and business places using charging infrastructure installed at those locations. Some charging stations had high power outlets (32 A) and others lower power outlets (10 A or 15 A). The average charging time for an electric vehicle over the 6-month period reported in [9] was 2:06 h. On the higher powered sockets, the cars were charged in 1:26 h on average, and 2:32 h on the lower powered sockets.

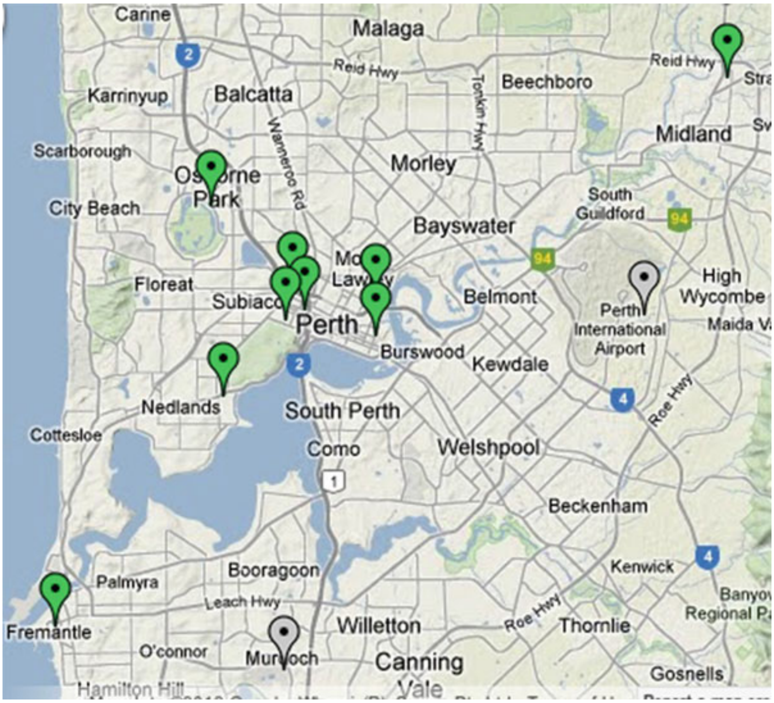


Fig. 7.3 Perth EV charging station network [9]

Another noteworthy statistics observed was the fact that after the vehicles were charged, they remained plugged in an extra 17:06 h, which signifies that only 12.9 % of the total parking time was spent on charging. The Conversation article [10] suggests that this was a direct outcome of charging stations being misused as free parking spots since both energy and parking were free for the duration of the trial. Applying standard fees for parking and power is suggested as a solution to change this behavior, which would otherwise block charging stations for other EV owners, who may have wanted to use them. The report written on the "Analysis of Western Australian Electric Vehicle and Charging Station Trials" also points out that, on average, EVs were not being driven for 97.84 % of the time or 23:29 h per day.

The charging infrastructure was capable of providing three-phase power, which charges three times faster and achieves a better grid balance [10]. The data recorded from the vehicles as well as the charging stations enabled researchers with a multitude of information on vehicle usage and charging patterns. When the EV was being charged at a charging location, then all charging stations would log customer IDs, start time, end time, and exact amount of electricity used for charging. If the EVs were charged at a user's residence or business place, then the system would factor in amount of electricity used during that non-charging station event in the statistics data. This was done by approximating the amount of electricity used during those non-charging station (non-CBD charging) events from the battery level of the vehicles, distance traveled before charging, and recharging time at the station and the level of supplied power [9]. Hence, the integrity of data was maintained by taking into account the non-charging station events.

The total number of charging events over the 6-month period reported in [9] was 1203 with 186 home charges, 392 station charges, 548 business charges, and 77 in unknown locations. Therefore, only 32.58 % of the chargers were conducted at the CBD charging stations, which further highlight the need for and significance of correcting system data by taking into account non-CBD charging station charging. A very useful smartphone application was also developed that enabled the users with the ability to check the charge status of their EVs during the charging process [10].

Over a 6-month period, the cars were driven 17.56 km per day per car on average, less than the daily distance average (32 km) of a passenger vehicle in Western Australia. The usage corresponds to an estimated annual energy usage of 1.13 MWh. The maximum average daily kilometer was 48.53 km and the maximum EV distance in a single journey was 71 km, both of which are less than the maximum driving range of 131 km [9]. A concern with EVs is the short range they can travel without recharging. Yet, usage patterns in this trial show that cars were indeed underutilized and not used to their maximum range. This is indeed an important piece of knowledge demonstrating that, at least for city drivers, such a long full-charge driving range is not necessary. This is of course not taking into account the continuous recharging process that the user needs to go through similar to nuisance that would have been experienced if one had to fill up the petrol tank of his/her car every day or so.

Figure 7.4 shows the power drawn from the grid for car charging at various charging stations including home, business, and CBD station charging. As demonstrated, the business and CBD station charging peaks around 8 am until 10 am when EVs are driven from homes and parked to charge before being further driven.

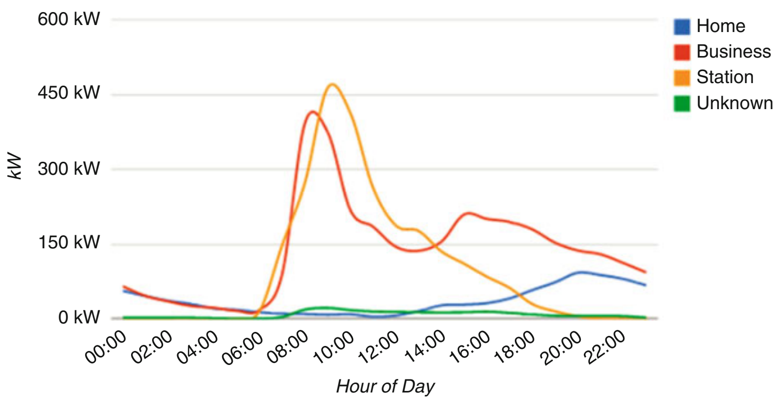


Fig. 7.4 Energy usage for charging over daytime [9]

Home charging peaks around 8 pm when cars are driven home and parked for slow charge. Home charging is a small component of the overall charging influenced by the restrictions of some participating organizations on their fleet vehicles such as not taking the vehicle home, and most EV drivers not being reimbursed for electricity usage in their homes.

The demand profile shown in Fig. 7.4 and the fact that most of the fleet charging was during the early morning hours would help to lessen the concerns of electricity distribution utilities in regard to EV charging magnifying the peak demand in the early evening hours. The research carried out suggests that this early morning charging could easily be offset by local solar PV generation, which would correlate with this demand in terms of time of the generation capacity. The results of this study are important, as according to [9], the initial EV market will be heavily biased towards the business fleet over the next half decade. The trial report does not report on any social investigations and the trial had purely focused on technical matters.

Ergon Energy's Queensland EV Trial

Ergon Energy's 18-month EV trial, which involved a fleet of five Mitsubishi i-MiEVs being driven by Townsville customers at Mt Low and Mysterton during separate 8-month periods, was completed in mid-2013. The objective of the trial was to determine the differences in location upon customer driving, charging behavior, and tariff preferences. The results of the trial will be used to shape Ergon Energy's strategy for managing the impact of large-scale uptake of EVs, which according to [11] "are expected to become cheaper in the next few years and reach a price point where sales will increase considerably" [11].

Figure 7.5 shows the locations where the trial was carried out. As expected, the EVs were driven a lot less by 138 km on average per week by the residents, who live in Mysterton, a predominantly residential suburb of Townsville. On the contrary, EVs were highly utilized by the Mt Low customers, who drove the cars 330 km on average per week [11]. As reported in [12], the driving range of the EV cars was about 90 km and it took about 7 h to fully charge the car [12]. The trial outcomes signify the need for providing customers more charging options and the need for managing peak demand during the likelihood of mass uptake and a network upgrade.

The trial has discovered that the travel distance and battery capacity are amongst the most important factors that help to determine the electricity tariff that a customer should be on when it comes to recharging an EV [11]. Metering.com [11] reports that "because of their location involving less driving, the Mysterton drivers were more likely to charge their EVs with the cheaper tariff, while the Mt Low drivers appeared less likely to because of its availability times and the distances to be driven." The trial has also shown that the further from the CBD, the greater will be the impact on the network due to the presence of customers, who will need to drive a lot further to access work, study, shops, and schools. The average cost of driving an EV per 100 km was determined to be AU $4.81, which is

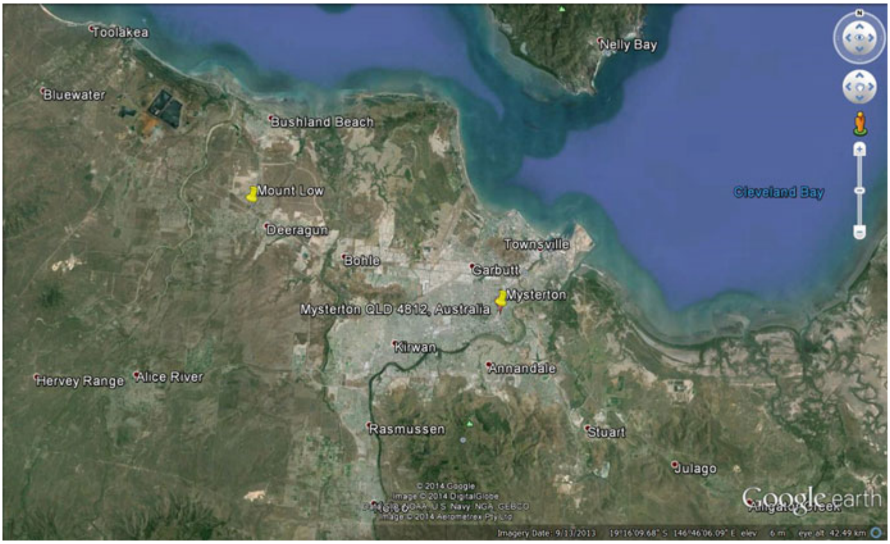


Fig. 7.5 Ergon energy trial location in Queensland

quite economical when compared to the cost (AU$5.77) of driving a hybrid vehicle, and the cost (AU$7.69) of a small diesel car, and that (AU$11.54) of a small petrol car for an equivalent distance [11].

According to ABC [13], the observed peak charge time during the trial was around 10 pm, but recharging was observed to impact the Ergon network between 6 and 8 pm. An interesting assignment during the study simulated the recharging demand of 30 EVs using a battery system, which was connected to the Mt Low transformer. Another first was also achieved with the installation of a solar-powered EV charge station at Townsville Airport [12]. The cutting-edge technology, which used renewable energy generated from a 4 kW PV shade-membrane shelter covering six car parks, was an exciting new addition to Townsville's residential EV trial [12].

Victorian Department of Transport (DoT) Trial

The Victorian Government's Electric Vehicle Trial [14] is a $5 million project, which was first launched in October 2012 and will run until mid-2014, investigating the process, timelines, and barriers for transitioning to electric vehicle technologies. The Department of Transport, Planning and Local Infrastructure [14] is reporting EVs as a natural fit for Victorians, who mostly do short trips and drive on average 40 km per day. Low running costs of EVs and their innovative, less polluting nature are highlighted and the state of Victoria's strong presence in the EV sector, with businesses manufacturing hybrid and fully electric vehicles, is emphasized.

The "Victorian Electric Vehicle Trial Mid-Term" report reviews progress up to the halfway point in the trial with a discussion on experiences, results, and interpretations from the early stages of the EV market development in Australia. According to [15], the Victorian Electric Vehicle Trial has seen the collaboration of over 80 organizations including government bodies, electricity firms, charging infrastructure providers, vehicle manufacturers, and environmental groups, all wishing to contribute and have inputs in providing the foundations of an EV market "worth having." The objectives of the trial cover investigating technology as well as the social and environmental aspects, and the key goal is to ensure the safe and efficient rollout of EVs in Victoria considering the needs of Victorians and the impacts of EVs on the Victorian society and resources. The activities that have constituted the trail are [15]:

- *Household Vehicle and Fleet Vehicle Rollouts*

The interest in the trial was great. According to a Victorian state government report [16], total number of 2200 applicants completed the expression of interest to participate in the Victorian Electric Vehicle Trial. Figure 7.6 shows the distribution of applications in the Greater Melbourne area. Around 120 households were eventually given the opportunity to trial an EV for 3 months each. On the other

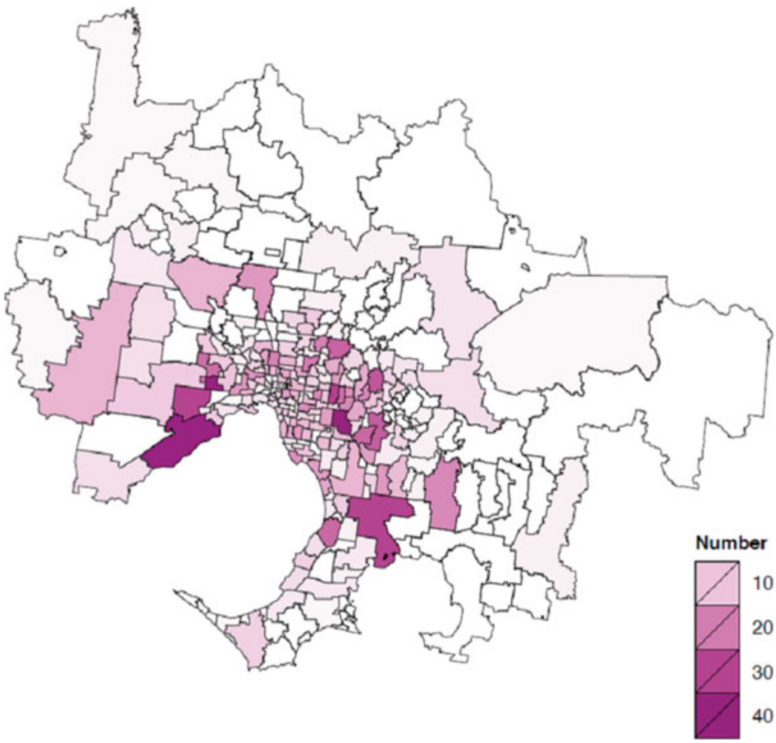


Fig. 7.6 Distribution of trial applicants in the greater Melbourne area

hand, around 40 fleet have been provided the opportunity to trial a range of EVs for up to 6 months at a time. A range of vehicles with diverse manufacturers and makes have taken part in the trial and significant differences were observed in the utilization rates of various vehicle makes. There were also EV make-based behavioral and attitudinal differences amongst the participants. Melbournians displayed liking towards the technology especially in terms of quiet, environmentally friendly, and low-cost operation with purchase price, size, and limited operating range being the criticized aspects.

The results of study indicate that the average running cost on renewable energy was $7–10 a week, far less than the cost of running an equivalent petrol vehicle. Results show that EVs are a viable transport option albeit the high purchase price, which stands as a major obstacle to take up the technology [15].

- *Charging Infrastructure Rollout*

This has so far included the installation of around 140 [15] charging outlets for household, fleet, and public use to establish the foundations of Victoria's EV charging network. A range of EV charging and infrastructure providers participated in the trial where "Level 2"-compliant charging outlets were primarily used. "Level 2" standard-compliant charging infrastructure is suitable for home/public use [1] and involves 240-V, 15 A charging, and charging system-EV interaction in accordance with the SAE J1772 technical specification. The charging infrastructure was specified and designed capable of providing up to 32 A in locations with sufficient electrical supply taking into account the fact that next-generation EVs are expected to draw up to 32 A.

The user feedback and network support provided by the trial charging infrastructure providers were quite diverse. For example, one network provider supplied users with the capability of remotely accessing the real-time information on charging status and charge management capability while others provided much reduced levels of support. Information on the location of charging stations was provided to users primarily through the trail website [14] that provided a Google Maps-based geographical information system.

There was full agreement amongst the charging infrastructure providers on the importance of achieving interoperability across different EV charging networks; however, this was not included as an objective in the trial time frame due to a large number of higher priority issues that had to be dealt with during that period. The importance of having a fully interoperable network is stressed throughout the report [15] to support seamless user roaming across the providers similar to banking services and mobile phone use. Collaboration between the charging service providers is recommended in [15] to progress towards a fully interoperable network that will provide a better customer experience. The need for a unique data key for individual users was identified by all parties as a low-cost option with potential future benefits. The department's "lookup" table and user identification codes, where charging infrastructure provider's own user identification details have been mapped to, are proposed as a suitable future framework for business-to-business or industry-wide interoperability.

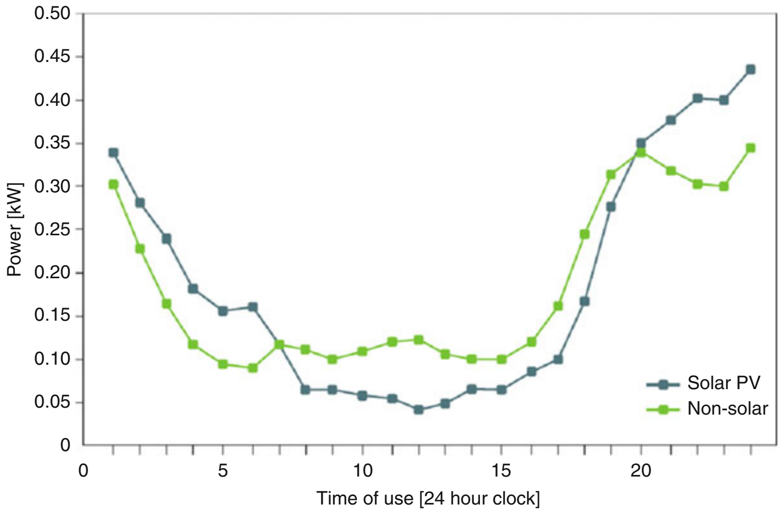


Fig. 7.7 EV charging demand profiles for solar and nonsolar trial participants [15]

The challenge of standardizing the charging requirements and specifications for different vehicle types including electric bikes, motorcycles, and passenger vehicles is identified as another obstacle in achieving a fully harmonized electric vehicle space. A standards development process for electric vehicles through Standards Australia is proposed as a means of addressing many of the standardization issues. The potential revenue impact of EV charging is also outlined as another concern in the EV space due to electricity not being subject to fuel excise. Increased use of EVs is expected to impact government revenues by contributing to a reduction in the fuel excise, which is the largest contributor to revenue raising in Australia [15].

The EV charging demand is reported to align with the general electricity household demand as shown in Fig. 7.7 [15]. As shown in Fig. 7.7, the charging demand starts to increase after 3 pm for both solar and nonsolar households implying that most trial participants started to charge their cars immediately after arriving at home.

An important observation made was in relation to the variation in the charging habits of trial participants with solar PV installations. This is clearly demonstrated in Fig. 7.7, which shows a continued rise beyond 8 pm in the power demand at houses where PV systems were installed. The likely cause of this is reported to be the time-of-use electricity tariff of PV households, which encourages PV household trial participants to defer their charging to off-peak periods in response to the financial incentives of doing so.

An electricity demand response and load control demonstration project was also undertaken as part of the overall trial by the participation of a small group of participants. These participants had their charging outlets bound to their residential smart meters upon installation and the project aimed to demonstrate the role Victoria's Advanced Metering Infrastructure could play in managing the EV charging demand. A total number of 64 charge management events were issued to the charging outlets through the distribution network provider's infrastructure (Zigbee) as part of the project known as "grid-friendly" charging. These charge management events basically helped the electricity distributor to control the EV charging loads and were termed "peak charging" and "emergency charge management" events [15]. Such electricity distributor charging is considered as a tool that would assist the electricity distributor to preserve the reliability of the network and avoid network infrastructure investments that would lead to increases in electricity costs. A widespread acceptance of this charge management method was observed and participants overwhelmingly agreed to have their car charging managed in this way even in the absence of any financial benefits.

Majority of households who participated in the Victorian trial were satisfied that home charging alone was easy to use and understand, and met their needs, but more information about costs and energy use would have been desirable [15]. Participants also suggested that further information relating to the charge management of EVs such as time until complete charging would have been ideal. Victorian trial identified a number of issues and potential opportunities for home charging such as the expensive cost of the home-charging infrastructure, which is considered as a potential obstacle second to the start-up cost of purchasing an EV. Some of the other challenges are [15]:

- The likely increase in the cost of charging infrastructure with electricity supply upgrades, and shared parking arrangements
- The likely loss of the capital after house moves
- The wide varying specifications of charging outlets in response to specific needs of the user and his/her vehicle
- The potential voltage drop beyond the regulated voltage levels on distribution feeders with clustered EV take-up

Some of the potential suggested opportunities include [15]:

- Charging circuits to be designed and constructed as part of new construction and refurbishments
- Benefits of informing the public about the property value benefits of including charging circuits during the design and construction of new buildings
- The importance of proving guidance on the allocation, placement, and design of EV charging infrastructure
- Communicating the benefits of off-peak charging practices during the time-of-use electricity tariff periods
- The opportunity to use EVs as energy storage devices

7.1.2 EV Potential and Applications of EVs in Europe

The electric vehicles (EV) on the road have increased significantly in most European countries in the last 5 years [17]. Despite the good and reliable public transport in most West European countries, the move towards EV is mostly justified by economic, political, and environmental reasons. In Europe, the major incentive for the increase of EVs and the strong support and investment by the government are based on the following reasons:

- Reduce dependency on oil with cheaper fuel
- More silent operation through smart grid
- Reduce direct carbon emission CO2 (global warming)

The global warming is a major issue that has been widely discussed for many years. Faced with serious consequences, governments worldwide are enforcing plans for reducing carbon emission [17]. For example, by 2020 some network operators in the UK are planning to reduce carbon emissions by 45 % [18], while European Union (EU) countries are obliged to cut their emissions by 20 % [19]. The European Commission has put electric vehicles at the heart of its commitment to the long-term goal of reducing carbon emissions by 60 % within the transport sector by 2050.

Electric and alternative fuel vehicles have emerged as one of the key players in the quest to diversify road transport energy sources and thus potentially help the European Union achieve its CO_2 emission reduction targets. Accounting for more than 12 m jobs in the EU, the automotive industry is vital to the economy and, as such, developing innovative and alternative fuels will not only maintain competitiveness and create high-skilled employment opportunities, but also make the European economy more resource efficient [20].

7.1.2.1 Electric Vehicle Market in Europe

European EV market has increased due to government's strong support to resolve the upmentioned reasons. Figure 7.8 shows the sales of electrified vehicles in most of the European countries in 2013. Several governments have subsidized the high cost of EV compared to ICV. For example, France, responding to public concern about rising fuel prices and climate change, already backs the segment, offering drivers a rebate of 7000 Euros on the purchase of a battery-powered vehicle and 4000 Euros for a hybrid electric-gasoline model. The global market for electric cars in France is dominated by Renault SA, based in the Paris suburb of Boulogne-Billancourt, and Japanese partner Nissan Motor Co.

Germany is investing heavily to establish itself as the world leader in EV technology and steal a march on the likes of Japan, the USA, Korea, and China. The German Government announced that it would double its existing investment in the rollout of electric cars to two billion euros ($2.7 billion). Chancellor Angela

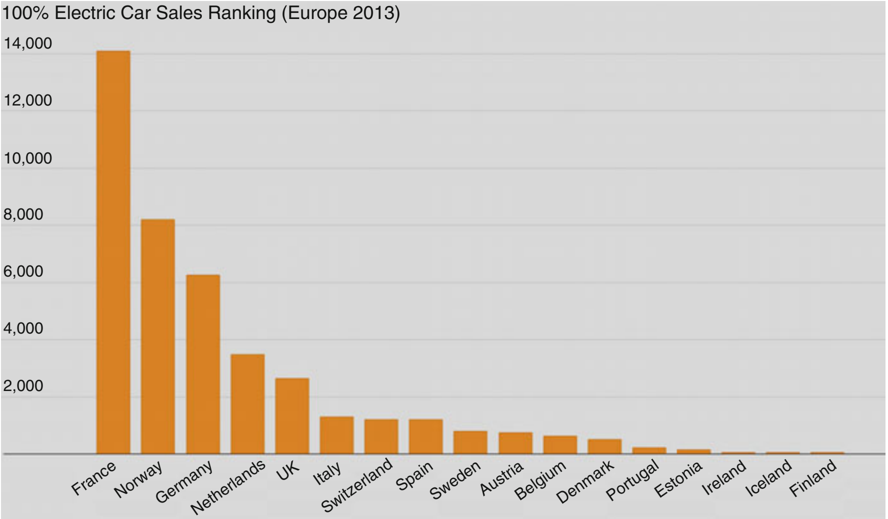


Fig. 7.8 Sale of EVs in Europe [21]

Merkel wants to have one million electric cars on German roads by 2020, and six million by 2030, with the likes of Mercedes-Benz, BMW, Audi, Porsche, and Volkswagen at the vanguard. A commission established by the German Government to spearhead the push to electric cars, the National Electric Mobility Platform, warns that the government instead needs to quadruple its investment if it wants to achieve its ambitious targets.

In Europe, specifically the impact of EV market is not limited to the transport sector, but more on the electricity sector. That has large effect on the electricity generation and on the grid load and stability. Also, it requires charging infrastructure and smart charging. Electricity grid, both transmission and distribution grids, varies considerably in terms of resilience to external pressure. Therefore the expected future electricity market of the EU has to consider the effect of the high increase in the EV on the road [21].

Across Europe, a greater variety of hybrid (HEV), plug-in hybrid (PHEV), and battery electric vehicle (BEV) models are being offered by manufacturers each month. Although government support is waning, the increasing availability of vehicle charging infrastructure that enables vehicles to charge at home, at the workplace, and in public places is facilitating market growth.

The top six European countries for BEVs on the road in 2020 will be Germany, France, Norway, the UK, the Netherlands, and Sweden, with this group representing more than 67 % of the total market, and each having a volume in excess of six figures. The situation is different for PHEVs, where only four countries are expected to exceed a volume of greater than 100,000 vehicles—Germany, France, Italy, and the UK—and these four represent 52 % of the total. By 2020, Pike Research forecasts that more than 1.8 million BEVs will be on Europe's roadways, along with 1.2 million PHEVs and 1.7 million HEVs [21].

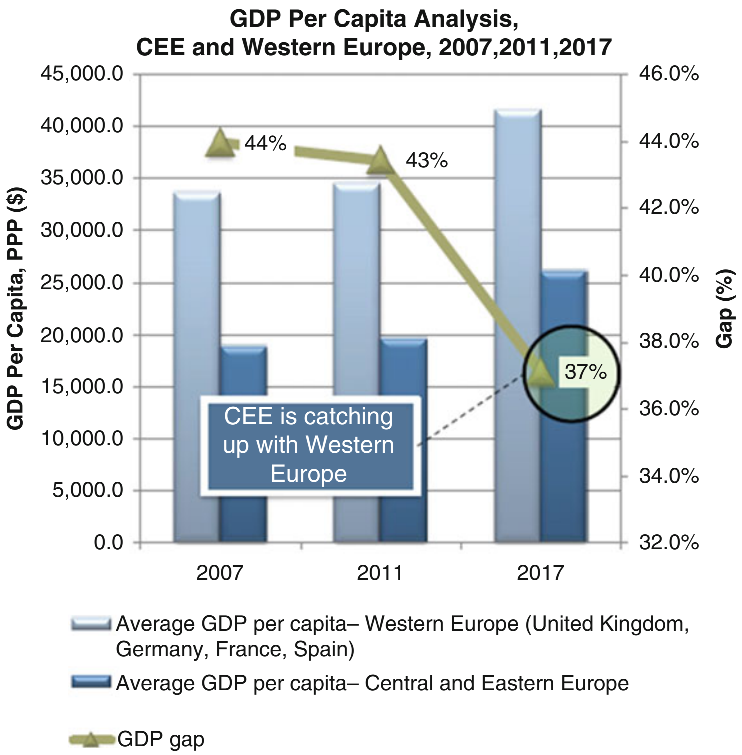


Fig. 7.9 GDP per capita analysis in Europe [22]

A special study done by FROST & SULLIVAN on the forecast of EVs and charging infrastructure industries in Central and Eastern European countries [22] shows very interesting scenario as depicted in Fig. 7.9. The study shows that Central and Eastern Europe (CEE) as a region is expected to generate roughly 23 % of GDP of top four countries investing in the EV industry (the UK, Germany, France, Spain) by 2016. The development of the EV industry in CEE region is expected to grow by approximately 5.2 % annually in terms of GDP per capita during 2011–2017. EVs are not a priority at this time for CEE Government due to economic situation and the low purchasing power for the EV market.

7.1.3 EV Potential Applications of EVs in the USA and Canada

Similar to Australia, cities in the USA and Canada are widespread where people like having large houses with their own gardens. In addition to that, due to lack or inefficiency of public transport, people opt to use their own vehicles. In fact, results

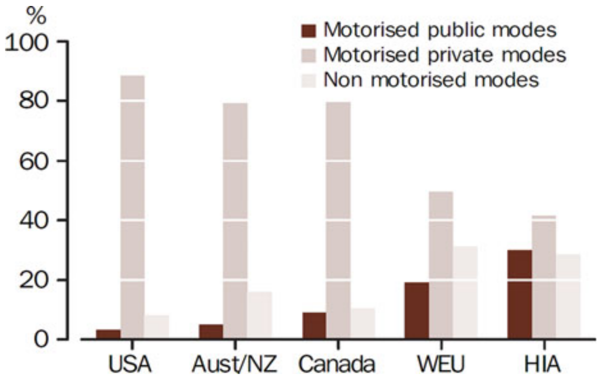


Fig. 7.10 Comparison for levels of public transport [23]

of a recent study demonstrate, as shown in Fig. 7.10, that the vehicle ownership/ usage behavior can be summed up in three categories:

1. Vast countries such as the USA, Australia, and Canada where private mode of motorized transport is very common
2. Western European Union (WEU) where a more decent share of public and non-motorized transportation can be seen
3. High-income Asian (HIA) cities, where private motorized transport is actually a less preferred mode of transportation

Daily work commute is significant in the US daily population change where some counties experience 94.7 % and 111.4 % change increase (such as New York County) while some lose 41.4 % of its population [24]. Although commuting happens all around the country at significant levels, the share of public transportation is very small. The statistics in the USA indicate that Americans prefer private vehicles for their daily commutes [25]. For instance, daily work commute means distribution given in Fig. 7.11 which shows that 86.2 % of the US population uses private automobile for this purpose [26].

It is notable to mention that share of public transportation and other means does not show real change. It is observed that the mobility of the population is met by private automobiles. The survey also documented the share of public transport in 50 largest metropolitan statistical areas. New York, New Jersey, and Long Island regions lead the pack with a little more than 30 % public transportation use. However, the figures drop dramatically after this. The next two regions only have around 15 % while eight regions have 6 % public transport usage [27]. This low use of public transport affects the quality and frequency of public transport vehicles such as buses or trains. With less frequency, people tend to use their own vehicle more and this loop results in poor service and low preference of public transportation. US-wide figures indicate that 79.9 % of the workers commuting drove alone while only 10.1 % chose to car-pool [28]. This results in the highest motor vehicle ownership per capita in the world: 828 motor vehicles per 1000 people [29].

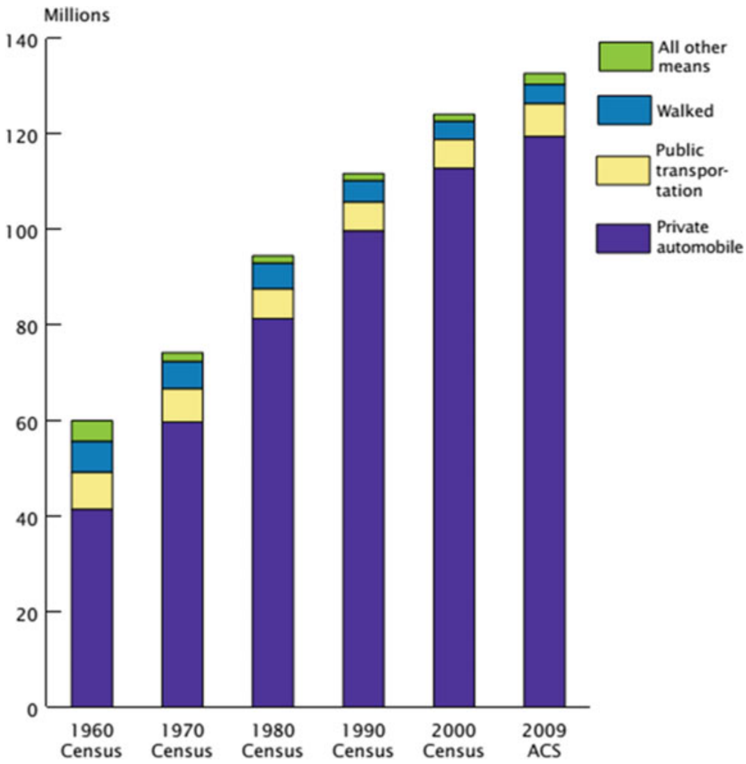


Fig. 7.11 Means of daily work commute in the USA [26]

As shown in Fig. 7.12, in 2011, only 9 % of American households did not have access to a vehicle while 34 % had one vehicle, 37 % had two, and 20 % had three or more vehicles. It is not a surprise that 70.2 % of total petroleum consumption in the USA is due to transportation and this corresponds to more than 1.7 billion annual metric tons of CO2 [29].

Motor vehicle registrations from 1990 to 2009 show that the number of motor vehicles in the USA is increasing. Table 7.1 shows that overwhelming majority of them are privately owned and almost half of them are comprised of privately owned vehicles [30]. These figures do not include 7,883,000 motorcycle registrations in 2009.

Relevant to the discussion of electric vehicles and their adoption is the part of daily commute in the above given facts. On average, daily commutes account for approximately a quarter of the total daily travel in miles. Federal Highway Administration's (FHWA) National Household Travel Survey in 2009 shows that daily travel per person is 3.8 trips and 36.12 miles [31]. Figure 7.13 shows average annual trips and miles per household based on their purposes.

It is important to note that when miles and trips for a vehicle are investigated (red line with squares) it is observed that on average a trip for a car is slightly more than

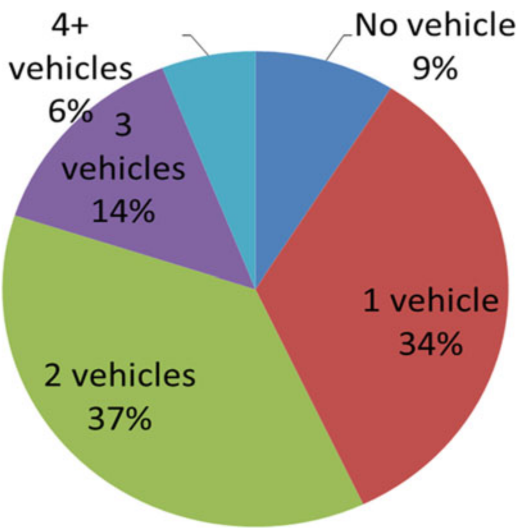


Fig. 7.12 Motor vehicle ownership per household in the USA [29]

Table 7.1 State motor vehicle registration: 1990–2009

Type	1990	2009
All motor vehicles	**188,798,000**	**246,283,000**
Private and commercial	**185,541,000**	**242,058,000**
Public	**3,257,000**	**4,225,000**
Automobiles	133,700,000	134,880,000
Private and commercial	132,164,000	133,438,000
Public	1,536,000	1,442,000
Trucks	54,470,000	110,561,000
Private and commercial	53,101,000	108,269,000
Public	1,369,000	2,292,000

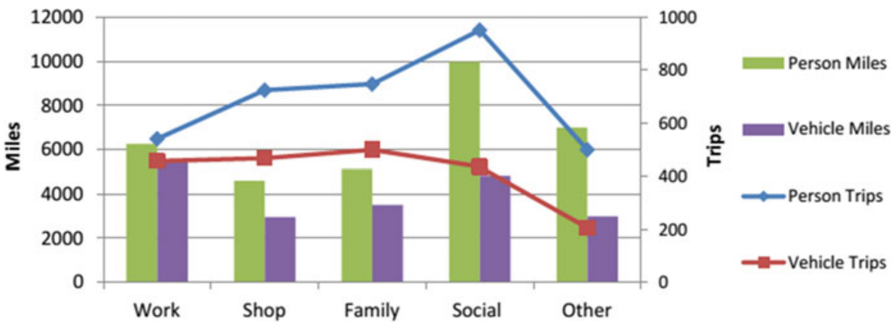


Fig. 7.13 Annual average trips and miles for a household [31]

Table 7.2 Urban/rural vehicle travel [31]

	Trip length (miles)		Trip time (mins)	
Type	Urban	Rural	Urban	Rural
Work	11.11	15.36	22.36	24.34
Work related	15.53	20.99	26.66	29.41
Shopping	5.49	9.50	13.47	17.14
Family/personal	6.07	9.17	14.27	16.33
Other	10.98	16.06	20.16	25.13
Social	10.72	12.85	19.69	20.90
All	8.79	12.59	17.96	20.67

10 miles. Given the battery capacity and performance of current electric vehicles, it is safe to say that electric vehicles can meet the daily commute requirements in the USA. Table 7.2 shows the length of the trips with different purposes in urban and rural areas. Although rural areas have longer trips, especially for work-related trips, ranges of current electric vehicle are sufficiently long. This is crucial in capitalizing on vehicle usage and using it for electric vehicle migration.

In summary, motor vehicle ownership in the USA and the length of the trips show that there are a large number of vehicles in the USA. This high value of vehicle ownership can be utilized for electric vehicle migration, especially, due to the short range of trips in daily commutes. The car owners can cover the same distance with an electric car and help cut down on carbon emissions.

7.2 Impact Analysis of Electric Vehicles

This section presents the impacts of EVs on car users, grids and power quality, and finally carbon emissions. Considering the potential of EVs and increasing rate of migration to electrical networks, EVs are bound to make a strong impact at different levels. The relatively small driving range of EVs, small number of charging stations, and long charging times are some of the bottlenecks for users. As more and better charging stations are developed and put into operation, this is expected to become less worrying. Section 7.2.2 discusses the impacts of EVs on grids and power quality in electrical grids. A large uptake of EVs is expected to impact electrical networks at the distribution level. The increasing use of EVs is expected to make a positive impact on the environment when the charging power comes from renewables. Section 7.2.3 discusses the impacts of EVs on carbon emissions throughout the world.

7.2.1 Impacts on Car Users

It is true that EV uptake is estimated to be slow. Therefore, the impact would not be experienced abruptly. However, given the current trend towards EVs and the willingness to cut down dependence on petrol cars, it is safe to say that numbers

Table 7.3 Ranges of various electric vehicles

Manufacturer	Model	EV type	Electric range (km)	Battery size (kWh)
Toyota	Prius	PHEV	8	4
Buick		PHEV	16	8
Chevrolet	Volt	PHEV	64	16
Fisker	Karma	PHEV	80	22
Nissan	LEAF	EV	160	24
Toyota	RAV4 EV	EV	190	27
Cooper (BMW)	Mini E	EV	251	28
Tesla	Roadster	EV	354	53

and impacts of EVs will surge in the future. Today, the major difference between EVs and cars, which run on internal combustion engine, is the driving range. Due to constraints in battery technology, despite being more efficient, EVs have less range than regular cars. Table 7.3 shows ranges of different electric vehicles that are available in the market today.

PHEVs have ranges that are significantly small while pure EVs have ranges that are comparable or equivalent to ranges of conventional cars that run on petrol. Depending on the electric vehicle that is used, the car users might need to plan their routes and car usage more wisely. Especially, during the first years of migration to EVs, PHEVs would be more prevalent. They can run on both petrol and electricity and can go for long ranges. However, pure EVs with low ranges are likely to force users to be more aware of their usage. Statistics show that majority of daily car use is less than the range of electric vehicles. Therefore, this only becomes an issue when the owner decides to go for a long drive.

Another reason for this is the small number of charging stations during the first years of migration. Car owners have to make sure that they reach a charging station before their limited range expires. As the EV market grows and more charging stations appear, this challenge is expected to vanish on its own. Another aspect is the long charging hours and demand-side management applied by the grid operator. Car owners would be encouraged to, or at times obliged by the network operator, accept charging that is regulated by the grid. This may result in EV charging taking long periods. For a regular user this would have infinitesimal impact as the charging takes place at night and the owner would be fast asleep during that time. However, should there be an unexpected need for travel (an emergency case requiring long-range drive at night) the EV may not have sufficient charge. Again, this is a challenge that relates to the first years of migration as more and more EVs are deployed, better charging facilities and options will emerge, such as super-fast charging. Eventually, it is expected that even with a demand-side management program, EVs will have sufficient charge or can be super-charged in short periods. This would minimize the impact on the car users.

7.2.2 Impacts on Grids and Power Quality

The most trivial impact of EVs on grids is the increase in load. This is not as much as feared, though. Due to small number of EVs and the expected low pickup rate, impacts on grids are manageable and sometimes solved with regular upgrade and maintenance works. The power company "Southern California Edison" stated in its recent report that of almost 400 upgrades only 1 % was specifically required for EV power demand [32]. These upgrades are only required at distribution level, since the impact of EVs does not reach transmission and generation level yet [33]. Although grid operators are looking into ways of using batteries of EVs, V2G technology is not implemented commercially yet. There have been some pilot projects in by PG&E and Xcel Energy, both in the USA. These are projects of very small scales and their impact on the larger grid has not been investigated. The main idea was to verify the applicability of V2G technology. These pilot systems were successfully implemented and the applicability of the technology has been verified.

The impact on power quality is not a concern of EV charging since chargers have power electronics interfaces and the power quality is tightly controlled. In addition to regular battery charging, which has very high power factor, EVs may contribute to increasing power quality at the point of common coupling, if power electronics interface is utilized accordingly [34]. Figure 7.14 shows a sample neighborhood developed to investigate the impact of the electric vehicle charging and power injection to the grid. The results listed in [1] show that the impact of electric vehicles in the grid is only at the distribution level and no change is required at transmission and generation level. In addition, the upgrades that are required at distribution level can be made gradually as the electric vehicle migration progresses.

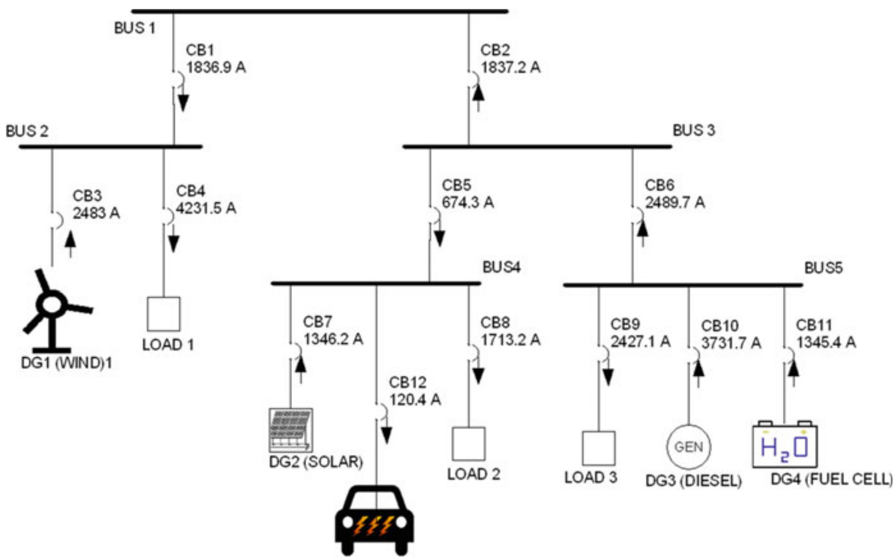


Fig. 7.14 Simulation model for EV impact studies

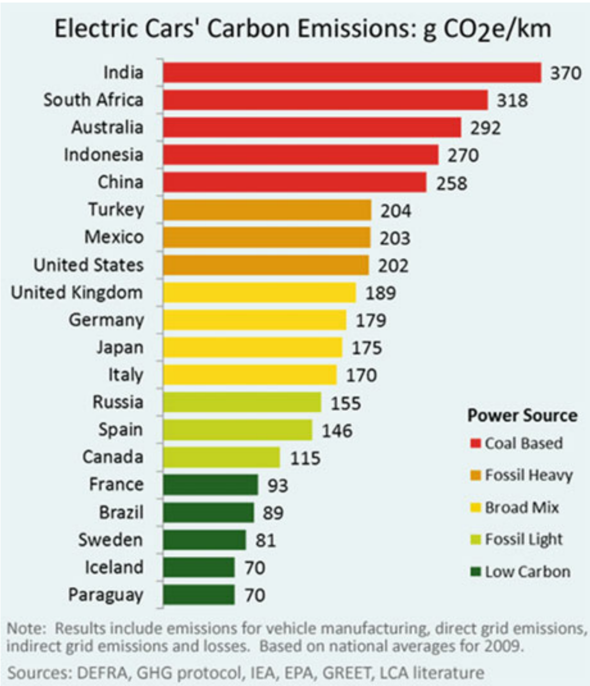
7.2.3 Impacts on Carbon Emissions

One of the most significant benefits of EVs to the broader community is certainly their positive impact on the environment and their potential to reduce the greenhouse gas emissions in the transport sector as well as the amount of imported fuels. Australia, for example, imports petroleum products from abroad and the transportation of these products is costing Australians and weakening the continent's economic performance and energy security. An increase in the share of EVs in the Australian transport market will not only lead to reduced fuel imports but also decrease the contribution of the emissions from the transport sector to the national emissions.

It is well known that when compared to petrol- or diesel-powered vehicles, the emissions from EVs are much lower and can further be offset if charging power is sourced from renewable energy sources such as solar, wind, tidal, or geothermal. Hence, the type of electricity (fossil, renewable, nuclear) used in the charging process dictates the overall environmental benefits of EVs [35].

Figure 7.15 presents a comparison of EV-related emissions in 20 of the world's leading countries after considering emissions associated with those related to electricity generation and vehicle manufacturing [36]. As demonstrated in Fig. 7.15, the carbon emissions associated with EVs in countries (such as India, South Africa, and even Australia) with coal-based generation are no different to

Fig. 7.15 Comparison of worldwide emission factors [36]



average petrol vehicles [36]. The rate of exhaust emissions from pure EVs propelled by electric motors is considered to be 0 g CO_2/km even though there are indirect emissions associated with EVs when they are plugged into the electricity grid [37]. The exhaust emission rate of plug-in hybrid vehicles is below 50 g CO_2/km [37]. According to a European Parliament study [35], the vehicle-to-grid and load management solutions could further make EVs part of an overall energy strategy allowing for the more efficient use of the fluctuating energy. In the European Union (EU), the number of new registrations of pure EVs has increased mostly driven by Germany and France.

In 2012, 700 new pure EVs were registered in EU whereas that number rose to 14,000 in 2012 [37]. In EU, GHG emissions in the road transportation sector are growing despite steady or even decreasing emissions in the other sectors [38]. Clearly, the focus of the EU should be on reducing the CO_2 emissions in the road transportation sector. A number of initiatives, such as the Green eMotion project [39], have already been initiated to achieve abatement in the road transport-related emissions. The "Green eMotion" project was launched as part of the European Green Cars Initiative (EGCI), and supports the target of reducing emissions by 60 % by 2050. One of the project initiatives focuses on the research and development of road transport solutions towards a more sustainable future.

In Australia, a significant portion of the overall emissions is because of GHG emissions from the transport sector. According to a recent report by CSIRO [40], the transport sector contributes to 16 % of the national GHG emissions and emissions from the road transport sector accounts for 87 % of these emissions. In Tasmania, the transport sector contributes to 24 % of the state's total emissions [41]. The same CSIRO [40] study identified EVs as one of the top three options in the abatement of GHG emissions. During the Western Australian EV trail [42], a survey conducted had shown that "zero tail-pipe emissions was considered the most desirable feature of EVs" by the trial participants [42]. Over the 20-year average Victorian lifetime, a renewable-energy-operated EV is expected to provide a reduction of over 50 % in terms of lifecycle carbon emissions [15].

Figure 7.16 shows the comparison of lifetime emissions from an EV when operated on renewable energy and on Victorian grid energy, which has a minor renewables component. Despite all these, the Victorian trial midterm report [15] argues that the projections indicate the break-even point in terms of zero net carbon emissions from EV operation to be some years away due to the small share of renewables in the overall generation mix. GHG emissions associated with the Victorian trial were equivalent to 79 tCO_{2e} at the midpoint mark but was accounted for and reconciled with renewable energy purchases. Few interesting arguments put forward in [15] include the following:

- In Victoria, the smart charging during off-peak periods is likely to be of higher intensity than demand charging during peak periods due to the characteristics of the Victorian electricity mix.
- Publicly accessible EV charging facilities are associated with electricity metering and billing complications demonstrating the need for renewable energy charging strategies.

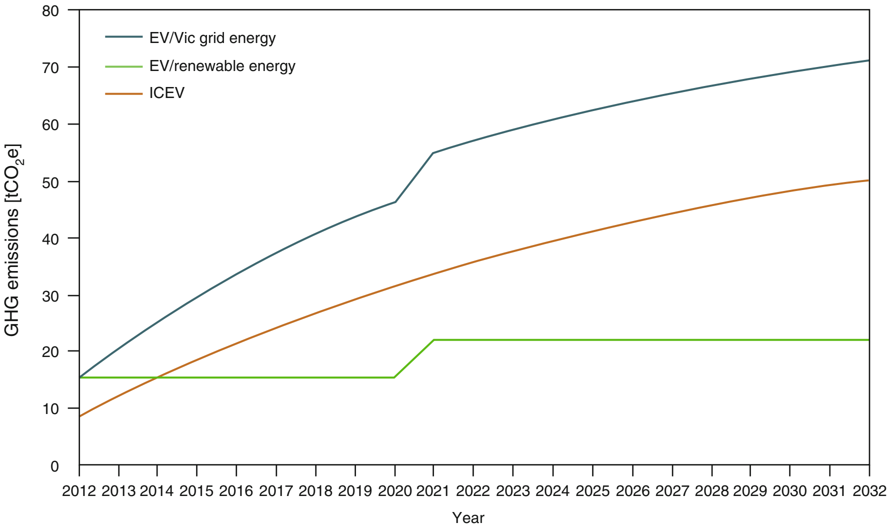


Fig. 7.16 Comparison of GHG emissions for EVs operated on renewable and nonrenewable energy types [15]

The USA is also taking ambitious targets for reducing its dependence on oil and GHG emissions by putting more EVs on the road [43]. This has been well supported by a number of federal and state policy initiatives to encourage the introduction and sales of EVs [43]. Throughout 45 % of America, electricity is generated with a larger share of cleaner energy sources implying that the global warming emissions of EVs in these regions are less than emissions from even the most efficient hybrids. In the remaining 55 %, where coal is still the main source of electricity, hybrids are considered less GHG emitters than EVs [44].

An important notion outlined in [44] suggests that an EV is likely to become less emission intensive over its lifetime as the share of renewables in the overall mix of electricity increases as older power plants are retired and cleaner electricity is generated. According to [44], "By 2020, global warming emissions intensity of electricity generation is expected to have improved in some regions of America by as much as 30 % over 2010."

7.3 Applications of Electric Vehicle Recharging/ Discharging

Widespread use of EVs requires expertise in different fields such as mechanics, power electronics, control, and battery technology and power systems. The latter two constitute the direct link between EVs and the electrical network that is present. The link under discussion is mainly one-way power flow from the network towards the vehicle, i.e., recharge. Therefore, most of the charging apparatus/station applications focus on grid-to-vehicle power flow and try to enhance its performance.

Vehicle-to-grid (V2G) concept is the opposite of this idea where the charge present in batteries of electric vehicles is used to supply power to the electric grid, preferably for power support at peak times. This feature is still in development phase since it requires extensive data collection, e.g., state of charge (SOC) in batteries, pattern recognition, e.g., driving patterns of drivers, communication, coordination, and management, e.g., billing and payment. Accordingly, V2G technology is implemented in either pilot projects for further development or special applications (e.g., military).

In addition to vehicle-grid coordination, there are microscale applications such as electric vehicle discharge control, which focuses on the discharge amount of electric vehicle's battery. These applications aspire to enhance the discharge performance of the batteries and increase their time of use. These objectives hold key importance for electric vehicles as when they are achieved; longer battery life and longer travel ranges will facilitate mass migration to electric vehicles. In this section, several examples are given for electric vehicle chargers, vehicle-to-grid applications, as well as vehicle-battery implementations for enhanced performance. Furthermore, standard communication and interoperability aspects are discussed for coordination and management of infrastructure.

7.3.1 Electric Vehicle Chargers and Vehicle-to-Grid Technology

There are different EV charger applications in the market. Although these chargers have different topologies and vendors, the main classification used for them is the charging level used. As shown in Table 7.4, there are roughly three different charging levels.

Level 1 and Level 2a are directed towards residential use. The charge powers corresponding to these levels are not very high and can be provided with existing electrical infrastructure. However, the downside of having a small charge power is the long charging times since only "trickle charging" can be realized. Level 2b and, definitely, Level 3 require special arrangements in electrical infrastructure due to high power flow they require. While Level 2b, after required upgrade, can be realized for home use, Level 3 is specifically designed for "super charge" purposes.

Table 7.4 Electric vehicle charging levels

Charging set	Utility service	Usage	Charge power (kW)
Level 1	110 V, 15 A	Opportunity	1.4
Level 2a	220 V, 15 A	Home	3.3
Level 2b	220 V, 30 A	Home/public	6.6
Level 3	480 V, 167 A	Public/private	50–70

Fig. 7.17 Clipper Creek HCS-40 and Bosch Power Max Chargers [45, 46]

Fig. 7.18 ChargeIQ, smart charging solution [47]

Super charge is beneficial for fully charging the battery of an electric vehicle in a short period of time and for long-distance use, e.g., during a road trip. Therefore, Level 3 is expected to be used in large charging stations installed in intercity/ interstate highways. There are different chargers in the market such as Clipper Creek HCS-40 [45] and Bosch Power Max [46]. They can support Level 1 and Level 2 charging for residential purposes and vary in terms of quality, durability, and warranty (Fig. 7.18).

However, the real groundbreaking developments are being made in "smart charging" technology. Smart charge is the term coined for collaborative charging operation where different features of the electric vehicle and preferences of the owner and grid operator are taken into account. An optimal solution is reached after meeting the demands of the owner and following the constraints of the grid operator. For instance, the vehicle owner may opt to choose "grid-friendly charging" where the charging will be managed by the grid and moved to off-peak hours. In return, the grid operator offers some incentives such as deductions in overall electricity bill. Needless to say, in order to realize "smart charging" a comprehensive communication and coordination system is required. Considering the entities involved in the process, it is required to synchronize smart meter, the electric vehicle (and charger), vehicle owner, and the grid operator. Accordingly, the charging operation is not a mere power transfer from grid to vehicle anymore; rather it is a large power management and optimization problem with several parameters.

This problem is solved with IT-based electric vehicle charging infrastructure that are connected to the electric grid. The owners, grid operator, as well as smart meter of the house have access to said charging infrastructure. The applications are based on available IT technology and the information exchange is performed over convenient communication lines (e.g., wired or wireless) in accordance with predetermined communication standards (see Sect. 7.3.4 for more discussion on standardization and interoperability). ChargeIQ, developed by an Australian company named DiUS, is a grid-friendly smart charging solution that comprises a charger and uses Zigbee standard for communication [47]. Figure 7.19 shows the

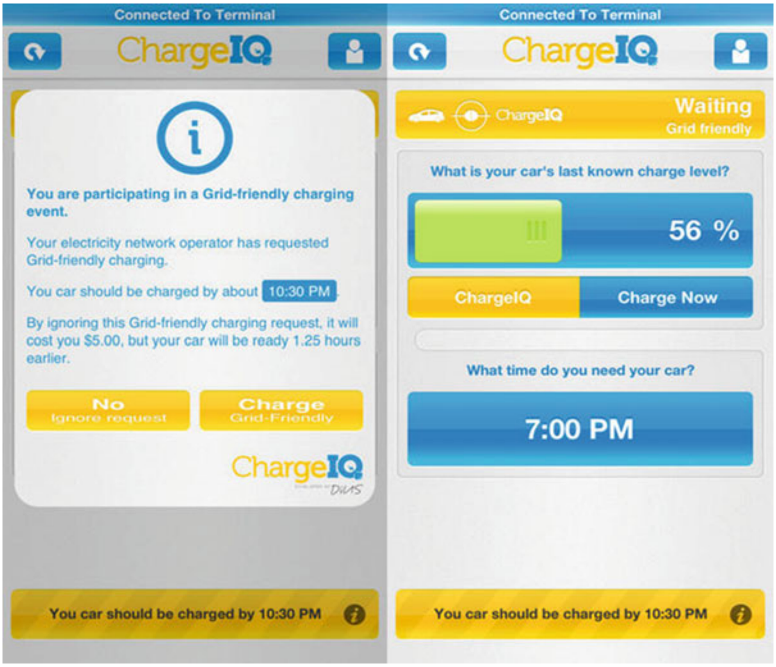


Fig. 7.19 Smart charging (demand-side management) in ChargeIQ [47]

working principle of ChargeIQ. Based on the figure, it is clear that the user (i.e., owner of the electric vehicle and the house) communicates with smart charger over Internet with the help of a smartphone. Smart charger is linked to smart meter over house area network (HAN), and reports any parameter change in the system as well as updates sent by the user. Smart meter is the interface between the charger and the network operator (i.e., grid operator). The coordination with the grid is performed over wide area network (WAN) for power dispatch and demand-side management.

As shown in Fig. 7.19, ChargeIQ smartphone application is very beneficial in following the SOC of the battery, the time required for full charge (3.75 h), and when the vehicle would be available (9:30 pm). This helps the owner manage his/her vehicle use and the charging times. It is observed that the system is operated in "Charge Now" option and vehicle is connected to the grid. Grid-friendly charging is the charging type when the owner agrees to give permission to the operator for managing charging times. In an effort to cut down the peak hour load, the grid operator would like to shift some load to off-peak hours. Considering that most people need their cars to/from the office, it is a fact that most cars sit idle at home in the evening. Therefore, some owners may not need their cars charged immediately. As long as the car is fully charged in the morning, the actual charging time is of no concern to them.

Figure 7.20 shows the implementation of this concept in ChargeIQ. A query screen is shown to the owner, asking whether he/she is willing to participate in grid-friendly charging. When agreed, ChargeIQ manages charging and power transfer is stopped during peak hours (Fig. 7.21).

This process increases the charge time, and awards the owner $5, but ensures that EV is fully charged at the specified time (i.e., 7:00 pm). Coordination of

Fig. 7.20 Charging locations in North America [48]

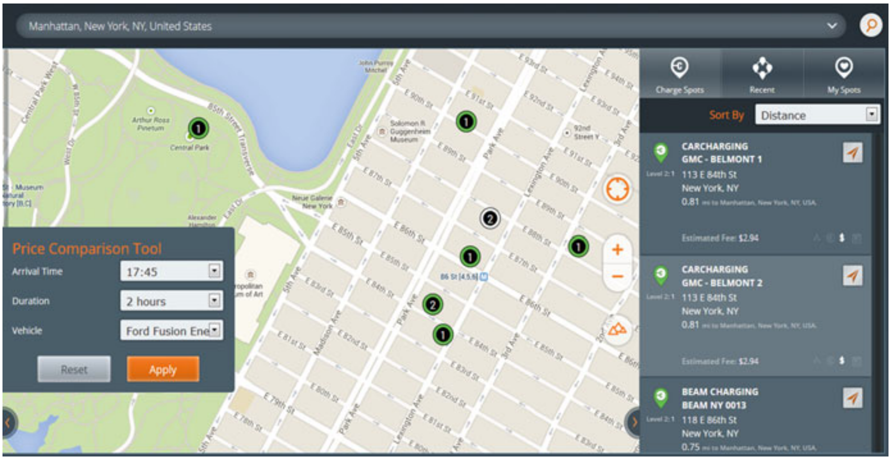


Fig. 7.21 Charging location details and price comparison [48]

Fig. 7.22 Charging stations on Paris roads [50]

charging stations is important that helps EV owners find available spots and charge their cars conveniently. Chargepoint [48] is an EV charging solution that lists nearby charging spots, their availabilities, costs, etc. This solution is Internet based and has a smartphone application. When a specific location is selected, say Manhattan, NY, as in Fig. 7.22, the application can be used to compare prices and get directions to a selected charging station. Furthermore, Chargepoint allows users to create their own account, save their preferences, and keep records of their recent charging stations. These applications are fast and enable for easy detection of available charging stations even in places that are unknown to the driver.

7.3.2 Vehicle-to-Grid Technology

Vehicle-to-grid (V2G) technology has been proposed to utilize batteries of electric vehicles as distributed storage devices and, thus, provide grid support. Considering the amount of the automobiles present in a neighborhood and assuming mass acceptance of electric vehicles, the amount of potential storage becomes significant [1]. Introduction of distributed generators and division of traditional large electric grid into several smaller sections, i.e., microgrids, changed the paradigm of power systems. Rather than large operation tolerances and bulk scheduling/dispatch, the new-age power systems require smaller windows and dynamic planning/dispatch is more preferred. V2G technology is a result of this urge to look for alternatives. Notwithstanding above, there are serious challenges that need to be addressed before V2G technology can be implemented commercially.

Continuous charge/discharge operation reduces the lifetime of the battery and it is not clear whether the owner or the grid operator shall bear the cost related with this technology. Although battery technology is always progressing, the prices are still very high and this makes V2G technology not profitable or worthwhile. Another challenge is the mobility and dynamic nature of electric vehicles. Unlike distributed storage devices that are deployed in power systems, electric vehicles come with many uncertainties. The availability of the vehicle, SOC, time period for which the vehicle will support V2G, and challenge to meet owner's charge requests (when the vehicle is required fully charged) can be counted as some of these uncertainties. It is true that the overall storage provided by the bulk amount of automobiles is very high. However, it is very difficult to know the exact number of vehicles, their exact places, and exact SOC. Accordingly, grid operators would abstain from highly relying on the storage provided by electric vehicles.

There are real-life implementations in military bases for improved power supply and there are good reasons for this. Due to their disciplined nature, military applications seem to be more suitable for V2G technology than other applications. Assessing the opportunity to use vehicles for better grid performance, the Air Force base in Los Angles [49] has replaced its entire vehicle fleet with electric vehicles. This has solid advantages for V2G technology:

- The vehicles will stay in the boundaries of the base most, if not all, of the time. The mobility of the vehicles is limited and this simplifies the problem.
- The range of travel has an expected upper bound. The vehicles used in the base will have an average distance traveled and will not fluctuate highly (as it would be in an ordinary neighborhood with people from all walks of life).
- These vehicles are entirely owned by the military and there is no ownership and V2G participation issues. As long as the base administration opts to implement V2G, every vehicle would participate in it.
- Unlike commercial applications, military applications tend to care more about reliability and durability more than the costs. Therefore, in a military application, high cost of vehicle batteries can be justified with independent and reliable power supply.

Table 7.5 Comparison between different implementation fields

	Commitment	Number of EVs	Baseline EV availability	Continuity
Military base	High	Less	Very High	Continuous
Stadium	Low	Moderate	High	Only during game hours
School/university	Low	Moderate	Moderate	Seasonal
Hospital	Low	Moderate	Moderate	Continuous
Neighborhood	Low	High	High	Continuous

The experience in military applications is valuable and sheds light to commercial applications. Network operators are looking into reducing uncertainties and increasing EV support in the grid. Some grids have introduced grid-support program for EV owners. Unlike grid-friendly charging, grid-support program not only moves charging to off-peak hours but also uses the charge stored in the batteries to perform peak shaving during peak hours. This is considered as a win-win situation as the grid operator decreases its peak load while the owner receives payment for V2G participation. In order to guarantee minimum participation, grid operators need to perform extensive surveying and estimate the base vehicle support for any given time.

Implementation in a residential neighborhood is easy since people mostly drive to/from school and work. Most stay home in the evening and their cars stay parked. There are other implementation opportunities as well. Large public places and their parking lots such as stadiums, hospitals, and universities can be utilized to reach minimum amount of support and reduce uncertainty. As shown in Table 7.5, a stadium or a hospital can be utilized as a V2G support hub. Supporters who came to watch a game give a hint about the amount of time they will spend in the premises. The grid operator will have more known parameters to perform scheduling.

Building on experiences acquired with these special implementations (military applications, pilot projects in selected neighborhoods, public places such as stadiums and hospitals) V2G technology can be implemented widely. Serious challenges such as battery lifetime costs should be addressed as well.

7.3.3 EV Charging Technology

EV charging can be divided into three categories: household connections, fast charging, and battery swap systems. A major obstacle in Europe especially in large cities is that most car owners do not own a garage but park their cars at the curb. This requires a multitude of capital-intensive public charging stations. Current charging stations are either free or at least highly subsidized by either electricity provider, car manufacturers, or local government [21]. There are three standards for EV power plugs. These are the American SAE, European International Electro-Technical Commission (IEC), and Japanese CHAdeMO standards. An international standard is still needed and is expected in 2017. There are strong hopes that induction charging might become safe and user friendly by 2020. The development of plug-in vehicles in France is seen as a symbolic step towards more environmentally friendly transport to achieve national goals. The government has also announced an investment plan to support public infrastructure. An estimated one million public and private battery-charging stations will be built by 2015 under the plan. France is planning to deploy this infrastructure in all sectors of daily life, in particular for the following groups:

- Enterprises: Charging infrastructure will be installed for captive fleet of plug-in vehicles, such as corporate fleets.
- Public domain: Plug-in vehicles and charging infrastructure will also be deployed in public areas, such as roadways and public parking garages.
- Residential sector: Plug-in vehicles and charging infrastructure will be made available to individual users, with or without vehicle ownership [50].

France now counts about 6000 charging stations for electric vehicles and plans to increase that to 8000 points by the end of the year, as Montebourg said. Figure 7.23 shows a charging station in Paris. In the UK, there are already about 5725 public charging points and that number is growing fast, with both public and private investment. Figure 7.23 is the map of UK charging points and their types [51].

The government's Plugged-in Places scheme was launched to help kick-start this process. £30 million has been allocated to eight pilot regions that will see 8500 charging points installed over the coming years. The UK Government is setting official National Charge point Register to resolve the problem of multiple schemes of government and private companies installing charging points and different maps all competing to present charging point locations [51]. Three types of charging point are currently used in the UK [51]:

- "Slow" points use a standard 3 kW (13 A) supply (6–8 h for full charge).
- "Fast" points use single- or three-phase 7–22 kW (16–32 A) supply (3–4 h).
- "Rapid" points provide 40 kW+ AC or 50 kW+ DC supply (80 % charge in 30 min).

For most personal electric cars, it is expected that most charging will be performed at home, during (off-peak) nighttime hours when electricity is cheapest. Although a standard single-phase 13 A three-pin domestic socket is adequate to charge a car in 6–8 h, fleet cars can be charged in company special fast point or rapid point provided with special station arrangement [51].

7.3.4 Addressing the Interoperability Challenge

The Victorian trial discussed in Sect. 7.1.1.3.3 identified the need for having a fully interoperable charging infrastructure to support seamless user roaming across the providers similar to banking services and mobile phone use. Standardization and interoperability is one of the key challenges to be resolved to open the path to

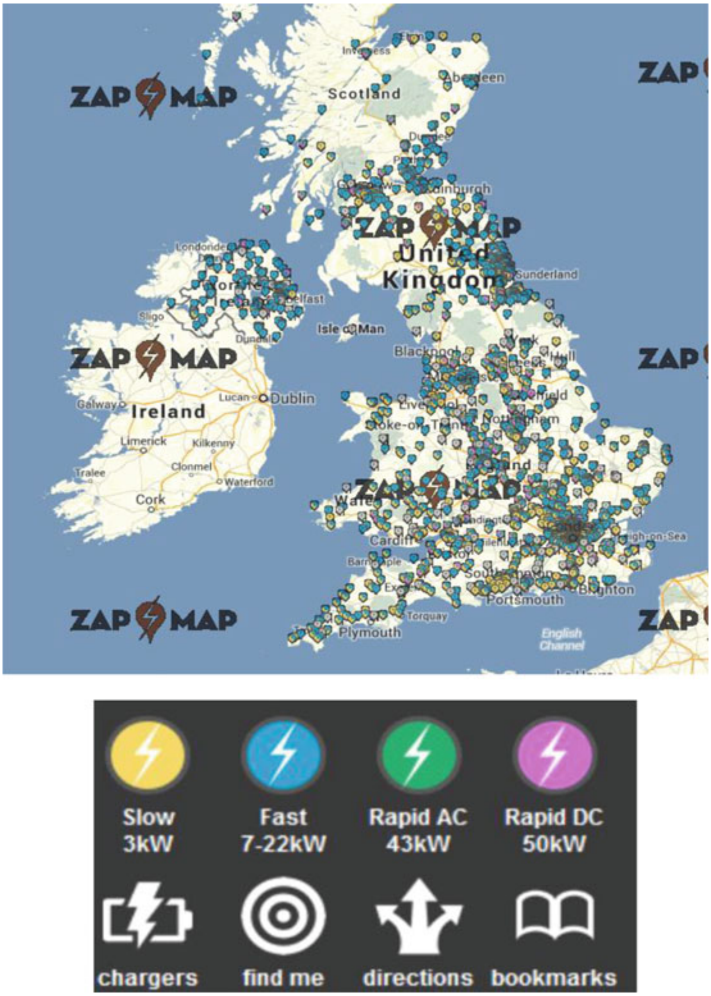


Fig. 7.23 Charging stations in the UK [51]

universal charging making it easier for customers to adopt EVs. The challenge is creating a platform where EVs could charge at any changing station and communicate with the utility grid operator enabling various functions such as billing, load management, and utility grid-managed charge management.

Work has long started to achieve such a fully interoperable EV charging system, not just in using standardizing smart charging hardware (the physical plug to connect to the car) but also in the area of two-way communication between the grid and the EV charging infrastructure. The Electric Vehicle-Smart Grid Interoperability Center opened in July 2013 aims to develop common standards and systems worldwide to ensure that EVs and charging stations could work together seamlessly with the grid. It is a joint venture between the U.S. Department of Energy (DOE) and the European Commission's (EC) Joint Research Centre (JRC) [52, 53].

7.3.5 *Communicating Between EVs, Recharging Stations, and the Grid*

International Electrotechnical Commission (IEC) has long been developing smart grid standards specifically covering aspects that relate to how smart grid components can effectively communicate and interact. IEC 65850 is an international standard originally developed for substation automation systems, which described the communication between devices in a substation and the related system requirements. It is an Ethernet-based standard that suggest wired exchange of protection, control, and measurement data within a substation automation system. However, it has been continuously expanded to cover other elements of future smart grids such as hydroelectric power plants, wind farms, distributed energy resources, and recently EVs. IEC 61850 defines standardized communication interfaces with object models [54–57] describing the data and processes within a system as well as communication methods in order to control and monitor the data and processes within a system and its subcomponents.

IEC 61850 was recently expanded to cover the abstract object modeling for distributed energy resources. The new subcomponent of the standard, IEC 61850-7-420 [58, 59], mainly covered object modeling of distributed energy resources such as photovoltaic and combined heat and power systems. A number of papers published in the literature argued for the need to extend IEC 61850-7-420 to cover EVs as well as suggested possible extensions to IEC 61850-7-420 for covering information models [60, 61] that apply to electric vehicles. Such extensions were not added to IEC 61850-7-420 but IEC is currently in the process of developing the IEC TR 61850-90-8 [62] as an addition to the standard set of documents to specially cover object models for electric mobility. Once complete, this communication standard will define the data within an EV system through abstract object modeling and the processes to be monitored and controlled, which will assist in the grid integration of EVs.

7.4 Conclusion

Rising energy costs, climate and emission control requirements, and expected decreases in the availability of petroleum supplies are driving the transition towards electrification of transportation. This chapter has sought to enlighten the reader on electric vehicle usage around the world by discussing their applications, electric vehicle trials, and key learnings from these trials across three continents: America, Europe, and Australia. Commuting trends and their impacts on the transition into the electrification of transportation have first been analyzed across these three continents. An impact analysis of electric vehicles on grids has also been presented including impacts on peak demand and power quality of the network. Examples of charging infrastructure and worldwide V2G applications have been reviewed.

References

1. Ustun TS, Zayegh A, Ozansoy C (2013) Electric vehicle potential in Australia: its impact on smartgrids. IEEE Ind Electron Mag 7:15–25
2. Australian Bureau of Statistics. Motor vehicle census 2013. [cited 2014 10 March]. http://www.ausstats.abs.gov.au. Accessed 31 Jan 2013
3. Australian Bureau of Statistics. Australian social trends: car nation 2013 [cited 2014 10 March]. http://www.abs.gov.au/AUSSTATS/
4. Australian Bureau of Statistics (2012) Waste management, transport and motor vehicle usage use survey
5. Energy Supply Association of Australia (2013) Sparking an electric vehicle debate in Australia. ESSA, Melbourne
6. AECOM (2012) Impact of electric vehicles and natural gas vehicles on the energy markets
7. AECOM (2011) Forecast updake and economic evaluation of electric vehicles in Victoria
8. CSIRO (2012) Spatial modelling of electric vehicle charging demand and impacts on peak household electrical load in Victoria. CSIRO, Australia
9. Speidel S, Jabeen F, Olaru D, Harries D, Bräunl T (2012) Analysis of western Australian electric vehicle and charging station trials. Aust Transp Res Forum 1:1–12
10. Bräunl T (2013) Trial complete: electric vehicles can work in Australia: The conversation. [cited 2014 22 May]. http://theconversation.com/trial-complete-electric-vehicles-can-work-in-australia-18843
11. Metering.com (2013) Ergon energy trial finds mass uptake of electric vehicles could impact its network. [cited 2014 23 May]. http://www.metering.com/ergon-energy-trial-finds-mass-uptake-of-electric-vehicles-could-impact-its-network/
12. Royal Flying Doctor Service Magazine (2012) Townsville welcomes state's first green electric vehicle charging station. http://www.flyingdoctor.org.au/IgnitionSuite/uploads/docs/Flying%20Doctor%20Queensland%20May%202012%20edition.pdf
13. ABC (2012) New charge point pops up as electric car trial continues. [cited 2014 23 May]. http://www.abc.net.au/local/stories/2012/06/14/3525454.htm
14. Electric vehicle trial: Department of transport, planning and local infrastructure. [cited 2014 15 May]. http://www.transport.vic.gov.au/projects/ev-trial
15. Department of Transport Planning and Local Infrastructure (2013) Creating a market: victorian electric vehicle trial mid-term report
16. State Govenment of Victoria (2010) The Victorian electric vehicle trial: results of 2012 applications. Department of Transport, Melbourne
17. IAE (2013) International energy agency and electric vehicles initiative of the clean energy ministerial, Paris, France
18. Infield HSaD (2009) The potential of domestic electric vehicle to contribute to grid technology. p 6
19. European Commission Energy (2011) European Country Co_2 emission by 2020
20. Joint Research Centre-European Commission (2011) Plugging the sustainability gap: boosting the european electric vehicle market
21. Van Essen H, Kampman B (2011) Impact of electric vehicles—summary report
22. Frost, Sullivan (2012) 360 Degree perspective of the Central and Eastern Europe electric vehicle industry
23. Kenworthy J (2003) A study of 84 global cities. Transport energy use and greenhouse gases in urban passenger transport systems
24. McKenzie B, Koerber W, Fields A, Benetsky M, Rapino M. Commuter-adjusted population estimates: ACS 2006–10. Washington, DC: Journey to Work and Migration Statistics Branch, U.S. Census Bureau.
25. U.S. Census Bureau. American community survey. 2008–2012
26. McKenzie B, Rapino M (2011) Commuting in the United States: 2009. American Community Survey Reports

27. U.S. Census Bureau (2009) American community survey
28. McKenzie B (2013) Out-of-state and long commutes: 2011. American Community Survey Reports
29. Administration Bureau of Transportation Statistics (2012) Transportation statistics annual report U.S.A.: U.S. Department of Transportation, Research and Innovative Technology
30. U.S. Census Bureau (2012) Statistical abstract of the United States: 2012
31. Federal Highway Administration (2009) National Household Travel Survey (NHTS)
32. Technica C. Southern California edison offers insight into impact of electric vehicles on grid 2013. http://cleantechnica.com/2013/08/13/southern-california-edison-offers-insight-into-impact-of-electric-vehicles-on-grid/
33. Rahman S (ed) (2011) How can we minimize electric vehicle's impact on the electric power distribution network. ISGT ASIA, Perth
34. Kesler M, Kisacikoglu M, Tolbert L (2014) Vehicle-to-grid reactive power operation using plug-in electric vehicle bidirectional off-board charger. IEEE Trans Ind Electron 61:6778–6784
35. Reiner DR, Cartalos DO, Evrigenis MA, Viljamaa MK (2010) Challenges for a European market for electric vehicles. European Parliament, Directorate General for Internal Policies, Policy Department, Brussels
36. Shrink That Footprint. Shades of green: electric cars' carbon emissions around the globe. http://shrinkthatfootprint.com/electric-car-emissions#3oboXAxlpQ8H48UF.99
37. European Environment Agency (2013) Monitoring CO2 emissions from new passenger cars in the EU: summary of data for 2012
38. ALPIQ (2010) Electric vehicle market penetration in Switzerland by 2020
39. Green eMotion [cited 2014 30 May 2014]. http://www.greenemotion-project.eu/home/index.php
40. CSIRO (2012) Greenhouse gas abatement potential of the Australian transport sector: Australian Low Carbon Transport Forum
41. Logic J (2014) Tasmanian electric vehicle demonstration concept investigation report. Energy Advisors
42. Terrence Mader, Thomas Bräunl (2012) Western Australian electric vehicle trial: final report
43. Department of Energy (2011) One Million electric vehicles by 2015. USA
44. Union of Concerned Scientists (2012) State of charge: electric vehicles' global warming emission and fuel-cost savings across the United States
45. ClipperCreek. http://www.clippercreek.com/store/product/hcs-40-30a-240v-charging-25-cord-3/
46. Bosch. Electric vehicle solutions. http://www.pluginnow.com/power-max
47. Percepscion. ChargeIQ. http://percepscion.com/chargeiq/
48. ChargePoint. http://www.chargepoint.com/
49. U.S. Department of Energy. Electric avenue, federal fleet success stories
50. IA-HEV (2013) France-charging infrastructure
51. Greencar V (2014) Next green car, electric car specialist, UK charging point
52. Stewart J (2013) Electric cars: a universal plug for all models? BBC. http://www.bbc.com/future/story/20130903-universal-plug-for-electric-cars
53. Argonne National Laboratory (2012) Electric vehicle-smart grid interoperability center. US Department of Energy. http://web.anl.gov/eesa/pdfs/success_stories/43_Smart_grid_mou_v2.pdf
54. International Electrotechnical Commission (IEC) TC 57 (2003) Communication networks and systems in substations—Part 1: Introduction and overview. IEC Standard IEC/TR 61850-1, 1st edn. Geneva
55. Ozansoy CR, Zayegh A, Kalam A (2007) The real-time publisher/subscriber communication model for distributed substation systems. IEEE Trans Power Delivery 22:1411–1423
56. Ozansoy CR, Zayegh A, Kalam A (2009) Object modeling of data and DataSets in the international standard IEC 61850. IEEE Trans Power Delivery 24:1140–1147

57. Ozansoy CR, Zayegh A, Kalam A (2009) The application-view model of the international standard IEC 61850. IEEE Trans Power Delivery 24:1132–1139
58. Ustun TS, Ozansoy C, Zayegh A (eds) (2011) Distributed Energy Resources (DER) object modeling with IEC 61850-7-420. Universities Power Engineering Conference (AUPEC), 2011 21st Australasian, 25–28 Sept 2011
59. Ustun TS, Ozansoy C, Zayegh A (eds) (2011) Extending IEC 61850-7-420 for distributed generators with fault current limiters. Innovative Smart Grid Technologies Asia (ISGT), 2011 I.E. PES, 13–16 Nov 2011
60. Schmutzler J, Wietfeld C, Andersen CA (eds) (2012) Distributed energy resource management for electric vehicles using IEC 61850 and ISO/IEC 15118. Vehicle Power and Propulsion Conference (VPPC), 2012 IEEE, 9–12 Oct 2012
61. Ustun TS, Ozansoy CR, Zayegh A (2013) Implementing vehicle-to-grid (V2G) technology with IEC 61850-7-420. IEEE Trans Smart Grid 4:1180–1187
62. International Electrotechnical Commission (IEC). Power systems management and associated information exchange [cited 2014 31 May]. http://www.iec.ch/dyn/www/f?p=103:30:0::::FSP_ORG_ID,FSP_LANG_ID:1273,25