Chapter 10

Electric Vehicles Integrated with Renewable Energy Sources for Sustainable Mobility

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Additional information is available at the end of the chapter

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Abstract

Across the globe, governments have been tackling the concerning problem of air-polluting emissions by committing significant resources to improving air quality. Achieving the goal of air purification will require that both the private and public sectors invest in clean energy technology. It will also need a transition from conventional houses to smart houses and from conventional vehicles to electric vehicles (EVs). It will be necessary to integrate renewable energy sources (RESs) such as solar photovoltaics, wind energy systems and diverse varieties of bioenergies. In addition, there are opportunities for decarbonisation within the transportation sector itself. Paradoxically, it appears that the same transportation sector might also present an opportunity for a speedy decarbonisation. Statistics indicate that transportation is responsible for 14% of global greenhouse gas (GHG) emissions. However, there are numerous options for viable clean technology, including the plug-in electric vehicles (PEVs). There are indeed many technologies and strategies, which reduce transportation emissions such as public transportation, vehicle light weighing, start-stop trains, improved engine technology, fuel substitution and production improvement, hydrogen, power-to-gas, and natural gas heavy fleets. This work concentrates on EV adoption integrated with RES. Specifically, this chapter examines the feasibility of significantly reducing GHG emissions by integrating EVs with RESs for sustainable mobility.

Keywords: electric vehicles (EVs), renewable energy sources (RESs), solar photovoltaic energy, wind energy, vehicle fleet, smart grid, pollutant emissions

1. Introduction

The transport sector is the main responsible of the air pollution in European cities, as it produces almost a quarter of all the greenhouse gas (GHG) emissions. There has been a decrease in the emissions since 2007, but they are still remaining higher than in 1990. Road transport, in particular, was considered responsible for more than 70% of GHG emissions from the transport sector in 2014 as it can be observed in **Figure 1** [4].

In December 2015, 195 countries including Canada acceded to the Paris Agreement, an additional international measure to more increase efforts to address climate change through a reduction of global GHG emissions, and restriction of the global average temperatures to below 2°C. According to the Intergovernmental Panel on Climate Change, this is based on understanding that 2°C is the maximum allowable emissions threshold, after which irreversible climate harm would have occurred. All efforts must consequently be on deck to resolutely instigate to lower GHG emissions in order to avoid unsustainable climate conditions from occurring [1–3]. Considering that nations have different sectors contributing to their respective GHG emission profiles, each is anticipated to accomplish its obligation by engaging diverse procedures. For example, Canada, which signed its official commitment in April 2016, must somehow reduce GHGs by 30% below 2005 levels by 2030, and this turns to reducing emissions between 200 and 300 megatonnes from projected levels.

The European Commission has adopted a low-emission mobility strategy, a global shift towards a low-carbon, and circular economy since 2016. The European strategy for the transport sector consists in an irreversible shift to low-emission mobility, as it is mandatory to reduce air pollutants critical for our health. GHG from transport will have to be at least 60% lower than in 1990 and be firmly on the path towards zero. The strategy integrates a broader set of measures to support Europe's transition to a low-carbon economy and supports jobs, growth,

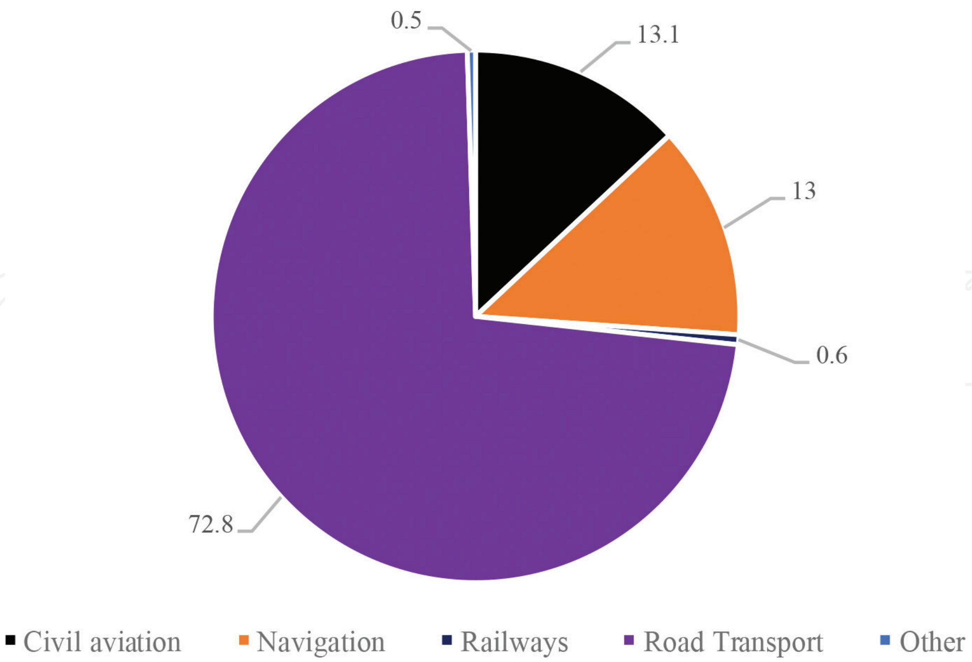

Figure 1. GHG emissions from transport by mode in 2014 [4].

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investment and innovation. The strategy will benefit European citizens and consumers—by improving the quality of the air, reducing the levels of noise, lowering the levels of congestion and ameliorating the safety [4].

The measures to be taken to accomplish air purification will include:

- leveraging digital technologies, implementing affordable pricing and promoting the move to decrease emissions from transportation, in order to enhance the efficiency of the transport system;
- encouraging and accelerating a revolutionary shift to internal combustion engines, and alternative sources of energy for transportation having lower emission levels and which use alternative fuels such as hydrogen, innovative biofuels and renewable synthetic fuels, and electricity;
- accelerating the conversion in the direction of low- and zero-emission vehicles.

A critical determinant of the success of these strategies is the consistent support of local authorities. These authorities may offer incentives to people to use vehicles with low-emission based on their employing alternative energy sources. They may also encourage the use of other methods of conveyance, including biking and walking, public transport and car-sharing/pooling arrangements, which effectually decrease polluting emissions. In addition to the European Fund for Strategic Investment, EUR 70 billion is offered for transport under the European Structural and Investment Fund, comprising EUR 39 billion for funding the change to low-emission mobility, of which EUR 12 billion for low-carbon and sustainable city mobility only. A fund of EUR 6.4 billion is offered for low-carbon mobility projects in the research programme Horizon 2020.

In the last decade, EVs have become in some way widespread, principally because of their negligible flue gas emissions and lesser reliance on oil. It is estimated that by 2022, EVs will be over 35 million in the World. However, a critical problem associated with EVs is that their high penetration raises branch and transformer congestion and heavy electricity demand to the power grid. One efficient approach to relieve the effect is to integrate local power generation such as RESs into the EV charging infrastructure [5–8].

There is a lack of systematic studies considering the interaction and integration of EVs with renewable RESs, the power grid, the charging infrastructure and the strategies to decrease air pollution, all together. This chapter seeks to investigate the integration of EVs with RESs for sustainable mobility in greatly reducing GHG emissions.

The structure of this chapter is as follows: in Section 2, a description of solutions for reducing CO_2 emissions in road transportation is provided. Section 3 discusses in detail the EV interaction and integration with RESs including wind energy, solar energy, the electrical network integration with the management of distribution grid, and electric vehicle coordination; while the conclusion is presented in Section 4.

2. Road transportation and the menace of harmful emissions

Road transportation generates about one-fifth of the EU's overall emissions of CO_2, the principal GHG. Although these emissions reduced by 3.3% in 2012, they are nevertheless 20.5% greater than that generated in 1990. Transport is the main sector in the EU where GHG emissions are still increasing. Europe can achieve its long-term transition to a low-carbon economy if it transforms its road transport sector. EVs powered with electricity from RESs can diminish future air pollutant emissions, including GHGs from road transport. It is found that 15% of the EU CO_2 emissions are generated by light-duty vehicles and falling each year as the automotive industry works to achieving EU emission targets. Member states are required to disseminate relevant information to drivers. The car and van targets for 2015 and 2017, respectively, were attained in 2013.

EU legislation obliges member states to certify that appropriate figures are delivered to users in order to guide drivers' choices of vehicles with low fuel consumption and that vehicles must display labels indicating a vehicle's fuel efficiency and CO_2 emissions.

Trucks and buses are accountable for 25% of CO_2 emissions from road transport in the EU and for approximately 6% of total EU emissions. In spite of some amelioration in fuel consumption efficiency in recent years, these emissions are continually growing, essentially owing to increasing movement of road cargo. To mitigate these issues, the European Commission is currently developing an elaborate plan to decrease CO_2 emissions from heavy-duty vehicles.

It is noteworthy that fuel quality is an essential factor in decreasing GHG emissions that emanate from transportation. EU regulation imposes that the GHG concentration of vehicle fuels to be reduced by up to 10% by 2020.

Electricity instead of oil for vehicle propulsion will contribute to achieve the European Union targets on CO_2 emissions reduction. The electricity needed could be produced by various renewable and carbon-free energy sources. In fact, the EVs have a three times higher efficiency than internal combustion engine vehicles. Moreover, they emit no tailpipe CO_2 and other pollutants like nitrogen oxides (NO_x), non-methane hydrocarbons (NMHC) and particulate matter (PM). Furthermore, they are really silent and do not produce any vibration. The future optimisation of EVs is focused on technological optimization and market development. On the technology side, the main efforts are on the reliability and durability of batteries and supercapacitors, on the reduction of battery weight and volume, on improving their safety and on reducing their cost. Other technological challenges regard improving hybrid electric powertrains, charging infrastructure and plug-in solutions.

The European Commission promoted a Europe-wide electromobility initiative known as Green eMotion. In this plan, EUR 41.8 million invested by 42 partners both public and private within the energy sector and supported with 24.2 from the European Commission with the goal of exchanging and developing knowledge and experience, and enabling the deployment of EVs in the market. However, currently, there are other ongoing and challenging projects with focus on mobility, in particular eMobilita (electromobility in urban transport: a multi-dimensional

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innovation (socio-economic and environmental effects)) [9], NEMO (hyper-network for electromobility) [10] and OSEM-EV (optimised and systematic energy management in electric vehicles) [11].

The potential of RESs to power EVs can help reduce pollution, with a considerable decarbonisation effect and improve resource efficiency. Surely, it varies a lot by country, based on the level of the infrastructures and on the demand for additional electricity. It is likely that additional electricity generation will be needed in the European Union to cater for the extra demand arising from approximately 80% share of EVs in 2050. According to the recent report, it is estimated that the European electricity consumption from electric cars will shoot from roughly 0.03 in 2014 to 4.5% by 2030 and approximately 9.5% by 2050. It is highly argued that additional power production is the ultimate way of meeting the other electricity demand resulting from the high rates of EVs ownership. Moreover, the extra electrical energy needs to be incorporated in the infrastructural system of Europe. Currently, it is quite impossible to tell, how much electricity is required and what type of production can be sufficient to cover the current electricity demand. However, once certainty has been attained, the increasing demand for electricity generation is likely to have an enormous impact on the overall power system in Europe. It is estimated that the electricity consumption needed by an 80% share of EVs in 2050 will differ between 3 and 25% of total electricity demand across the member state of EU. According to the department of dynamic management, an additional electrical capacity of about 150 GW will be required to charge the traditional electric car. In general, the increased number of EVs will automatically need an additional generation of electricity. As for the nations with a similar share of renewable energy, the management strategies may differ in the attempt of accommodating the charging of the increased number of electric cars. Importantly, the core principles of management strategies depend on the nation's types of renewable energy as well as conventional power generation systems. For instance, states characterised by high solar energy production capacity for which the preferred charging peak will be during the day will have to adopt different power management strategies from countries which only depend on wind, combined solar or wind electricity production. In addition, it will be necessary for regions with weak network infrastructure to add grid reinforcement or rather implement specific smart charging approaches to ensure efficiency as well as flexible electricity production and distribution infrastructure. The main benefit related to increasing the number of EVs is that it significantly minimises direct emissions of CO_2 as well as air pollutants from road transport. Nonetheless, these positive impacts could be partially offset due to additional emissions caused by increased amount of electricity needed as well as continued use of fossil fuel in the power industry. That is to say, lower emissions of CO_2 and air pollutants determined by a substantial increase of EVs could cause higher emissions by the electricity generation when it is based on fossil fuel combustion and when the reduction in electricity demand is not made in other sectors.

Overall, the avoided CO_2 emissions in the road transport sector should outweigh the higher emissions from electricity generation. In countries with high shares of fossil fuel power plants, electric vehicle demand could, however, lead to higher CO_2 emissions. Ecologically, the significance of electrically driven automobiles in cases of EV aggregator may not wholly be accomplished. As a case example, 80% portion of electrically operated vehicles in about 2050 can help reduce the unswerving exhaust emissions released by each contaminant by roughly a figure higher than 80% as compared to the levels in 2010. Nevertheless, concerning carbon dioxide gas, the total reduction of nitrogen oxides, as well as PM, may to some extent offset the further releases of the toxic pollutants resulting in the electric power production sectors. The reduction depends on the type of contaminant, for instance, 1% for NO_x while 3% for PM_{10} (PM_{10} refers to the particulate nature of matter). Unfortunately, the situation is different for sulphur compounds. Furthermore, sulphur oxides are released into the environment in various ways, for example, through the exhaust fumes from the fuel driven automobiles and the use of coal as a source of energy. These emission entries will additionally result in further pollution whose results will exceed by 5% the mitigation capacity designed by the road transport department. Notably, the extra abatement strategies of the highly concentrated SO_2 emissions are a need that cannot be negotiated.

The main disparity regarding air contaminants resulting from road transport segment and the power production is directly incomparable based on their corresponding effects on humanity. Systematically, these impacts rely on a more prominent extent on locality, the intensity as well as types of emission sources. Pollution from automobiles happens at the ground level and usually, in such areas as residential, workplaces, offices among others. In comparison, contamination is significant within the cities, municipalities as well as towns. A considerable portion of the population is exposed to pollution. Contrastingly, power plants are built outside the cities/towns where there is sparse population. Since there is low-exposure, there is a change in the release of contaminants, for instance, from roads to power generation sector, which is a very significant environmental concern for public health.

A considerable portion of chargeable cars primarily on the European highways in the future is anticipated to have consequences on electricity production as well as distribution infrastructures. In the process of incorporating extra electricity need, it is worth considering that road and energy sectors should be firmly joined. Besides, the decisions regarding policies as well as investments across these two sectors should be integrated. Chargeable automobiles are just another way through which not only the European continent but also the entire world can make positive steps forwards towards the achievement of a more sustainable as well as resource-efficient economy as well as carbon-free transportation structure. The replacement of the conventional cars with electricity-driven ones is a significant means of reducing emissions, but this relies on which source of electricity to rejuvenate the vehicles. Causes may include; renewable sources, fossil fuels and also nuclear. Therefore, blindly substituting the conventional cars is not a perfect solution to the transport-related issues, for instance, rapid congestions as well as demand for road transportation. It is evident that proper systems of the transport are urgently required, and this may encompass additional expansion of renewable energy like biofuels. In a nutshell, a deviation in the public means of transportation as well as the underlying structures. Undoubtedly, this approach will help accomplish the EU obligation to ensure an eco-friendly economy [12].

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3. Electric vehicle integration with renewable energy sources (RESs)

The growing wind power and solar photovoltaic (PV) installed capacity has initiated high-requirements on power balance control and power quality in several regions in Europe [13–15].

Large offshore wind farms tend to direct a high-power capacity at a single location. Notably, the magnitude of the power fluctuation can reach extremely high values due to wind speed variations. For instance, the 10-min average wind power profile from the 160 MW wind farm Horus Rev. is depicted. Within 11 days, the normalised wind power generation differs from zero to approximately 100% production. Wind power fluctuations are visible at different time scale such as short (intra hour) and long (several hours) [6, 16–28]. Furthermore, wind power and PV are known as non-dispatchable energy sources since the active power production is variable over time [6, 17–29]. The transmission system operator (TSO) plays a significant role in ensuring the balance between consumption and production at all times including at intra-hour time scale.

Importantly, the research has majorly focused on the potential contribution of EVs to facilitate the integration of RESs in the power system. The research topic has been developed within the paradigm of the smart grid, and it is centred on the EVs potential of establishing mutual benefits to both the electric power system with RES and future EV users. The term "smart grid" refers to the operation of the power system using communication, control technology, power electronics technologies as well as storage technologies to balance production and consumption at all levels [18]. Regarding this vision, an EV is in a position to act as a controllable load or as storage, charging or discharging part of its battery capacity back to the grid, conferring to the vehicle to grid (V2G) notion, as stated by Kempton and Letendre [19].

If the charging of EVs is uncoordinated, their impact on the grid is equivalent to a large electric load resulting in higher power systems peak-load and to distribution grid congestion issues [20]. To avoid such scenarios, the study has researched on what impacts EV coordinated charging can have in correlation with RES production. To be precise, the research has focused on the solutions using EVs for the provision of ancillary services for wind integration as well as energy storage for PV integration.

3.1. Electric vehicle integration with wind energy

Using EVs in power systems together with wind power has been reported to be ideally suited for the provision of ancillary services [18]. According to Kempton et al. [21, 22], EVs should be coordinated for high-value services including ancillary services that often reduces the operating cost to EV owner in the short-term period. The EV owners are likely to experience lower price despite a higher initial value compared to the ICE cars. Pillai and Bak-Jensen [23] examined the benefits of ancillary services provisions by EVs in the western Danish power system. They mainly checked at the disposition of secondary reserves, load frequency; control (LFC), which is assessed through simulation models. The authors explain how EVs can efficiently control power mismatch resulting from the variability of wind power, therefore eliminating the use of conventional power plants. Galus et al. [24] developed a similar idea where large amounts of clustered EVs, as well as household apparatus, can be used to offer secondary reserves, LFC in the power system. Regarding the simulation results, it is observable that vehicles batteries are subject to extensive energy excursion, which tends to pass from empty to full state of charge. The report by Hay et al. [25] analyses the opportunity of using EVs for regulating power: it is believed that in order to reduce the excessive use of automatic reserves [26] and in order to re-establish the availability of these, it is necessarily essential to increase the purpose of regulating power in Denmark. The authors affirm that using EVs to offer monitoring power in Denmark is one of the most effective solutions for substituting the reduced reserve power generated from conventional power plants in the future. The research also looked at micro-grid applications. In [27, 28], Lopes et al. discuss how EV load coordination can be used in stabilising the system frequency in micro-grid with wind power by using a droop control strategy. It was discovered that the penetration level of wind power could be increased even more by using a coordinated EV load. In a different study, EVs and power systems are believed to be perfect as controllable loads in simulation environment; however, the research failed to address the possible hindrances like EV control requirements as well as EV elements response during moments of coordination.

3.2. Electric vehicle integration with solar energy

The research on the usage of solar power through EVs is significantly diversified as compared to various studies focusing on wind power and EVs. Substantially, it is possible to generate electricity PV at both medium and low voltage levels within the power systems. Besides, this alternative additionally motivates the concept of incorporating the PV generation with EVs [6]. As evident from the analysis conducted by Bessa and Matos [29], utilising EVs in the process of distributing grids using PV is considered an alternative to storing energy instead of controllable loads vis-à-vis the suggestions made by various scholars. Additionally, research reveals that during the daytime when the solar radiation is at the peak, solar power can be easily stored in the car batteries for future usage. In this field, several contributions, for instance, the idea of "green" charge [29] has enabled people to understand the significance of maximising the cost of EVs throughout the irradiation period. On the contrary, Birnie [30] also recognised another application. The scholar introduced a concept in which EVs can be charged during the day at the parking areas situated, for instance, within the workplaces. In addition, EVs can be re-energised entirely during the working periods to realise the solar-to-vehicle (SV2) approach. Furthermore, the research also illustrates that energy generated in each parking area is essential in the extra generation of adequate electricity for transportation requirements for the EVs operator.

Although grids may have high penetration capacity of PV, they may too have lower voltages. In such situations, the primary constraint is linked to variations of voltage magnitudes along the feeders. Moreover, such discrepancies can be noticed particularly within the periods of high production as well as the conditions of low load [31–34]. Unsurprisingly, these events are likely to occur regularly, but on areas majorly the places of residence that have highly concentrated roof-top PVs. Conversely, many studies have examined various alternatives in the mitigation of voltage capacity, for instance, the grid reinforcement [32], approaches to reactive power control [34–38], harmonised active power curtailment [33], as well as permanent storage of energy [39].

Research exposes that the application coordinated EV load within the feeders using high PV penetration has not been satisfactorily analysed.

3.3. The electrical network integration with the management of distribution grid

The need for a transition to a more sustainable energy system leads to a deep change in the energy, building and transports sector. Power installation from RESs is becoming more and more relevant, new mobility schemes, namely car sharing, are growing more popular and particular attention is paid to energy efficiency in buildings. Moreover, each of these aspects is related to another important concept that is energy storage. The greatest change in the energy sector has occurred due to the development of distributed (or diffused) generation (DG). According to DG consists of the totality of power plants having a nominal power lower than 10 MW and connected to the distribution network. DG plants exploit primary energy sources—in the majority of cases renewable—which are distributed on the territory (thus the name distributed generation) and that could not otherwise be exploited in a traditional centralised plant; they supply local loads and they can be operated in a co-generative mode. In an urban district, examples of DG are PV panels and solar collectors mounted on top of buildings.

One of the drawbacks of DG is the high specific investment cost mainly due to the fact that, being medium or small plants, scale economy cannot be applied. Nevertheless, this can be faced thanks to a suitable incentive strategy. The real problem is the difficulty in predicting and controlling the power produced and put on the distribution network. So the distributed generation, together with other distributed energy resources such as EVs and energy storage, is the main driver for the shift to a new paradigm in the management of the grid: the passage to a smart grid.

Smart grid is defined as a modern electric power grid infrastructure that guarantees the reliability of the system and the security of supply, allowing to face problems related to the distributed power generation from RESs and to control the load, promoting energy efficiency and involving the passive final users. In order to do so, integration of the electrical grid with information and communication technology (ICT) is needed.

The availability of electricity is of crucial importance for all human activities. Therefore, continuity and security of the supply service are necessary. Since nowadays electrical energy cannot be stored at low-cost and in large quantities, electrical systems must guarantee a constant equilibrium between production and consumption. This means that the power generated has to correspond exactly to the one requested at any time interval. The electrical network is ruled in a way to ensure that this balance is respected despite any possible disturbance, from load fluctuations to faults determining the unavailability of some grid elements. The structure of the electrical grid is investigated in the paragraph below.

In a traditional network configuration, power generation occurs mainly in big, centralised power plants. The energy produced is put on the transmission network at high voltage (HV network, 132–220–400 kV), then it is transformed into medium voltage (MV network, 15–20–23 kV) through primary substations and eventually it is converted in secondary substations into Low Voltage (LV network, 230–400 V) and distributed to the final users. Domestic and commercial users are generally connected to the LV network while the majority of industrial users are connected to the MV network.

HV grid is designed to transfer bulk power from major generators to areas of demand; it has a network structure to ensure different alternative paths for the power flow in case some of its elements are unavailable owing to a fault. In Italy, for example, the transmission network has reached a high automation level, leading to a good reliability and security of supply. The transmission grid is ruled by the transmission system operator (TSO) which in Italy is Terna.

On the other hand, MV and LV grids have a radial structure. To be more precise, even if in MV grids different possible paths are available for the power flow, these grids are operated in a radial way. Distribution networks (MV and LV grids) are managed by the distribution system operator (DSO). Distribution networks have originally been conceived to transfer power just in one direction: from the substations to the final customer. This model is appropriate as long as only loads, with the exception of a very few generators, are connected to distribution networks so that they can be regarded as passive. Due to recent large spreading of distributed generation, mainly from renewables, this model needs to be re-visited.

At present, generators are connected to the distribution network according to the fit and forget approach. In the fit phase, the DSO checks that technical rules for connection to the grid are respected and that the generator’s functioning does not create any problem in any credible operational scenario. The capability of the distribution grid to accept a certain amount of diffused generation is called hosting capacity. The nodal hosting capacity (NHC) methodology is utilised to determine how much DG can be connected to a given network respecting performance limits. Typically, the operating limits are as follows: rapid voltage changes, short circuit currents, reverse power flow and line thermal limits. The DSO deals with the generator as a negative load, since; it puts power on the network instead of withdrawing it. So, the DSO is forgetting it because it cannot control the generator during its operation: The generator can introduce power into the grid at any moment depending on the will of the producer or on the availability of the energy resources. Therefore, it is possible to identify three main issues related to the actual distribution network. First of all, the DSO is obliged to limit DG connection in order to keep the control of the grid, reducing the power that could be installed through DG. A way to overcome this issue would be allowing the generators to collaborate to the management of the grid. The second drawback is related to the behaviour of DG in case of faults or contingencies. If there is an anomaly in the measured values of frequency and voltage at the connection point, DG is disconnected even if the problem is not related to the distribution network but to the transmission one. This results in the sudden unavailability of the power produced by DG which could have dangerous consequences for the safety of the overall electrical power system.

Last but not least, reverse power flow can occur if the installed DG grows. It means that the power does not flow anymore only from the substations to the users but vice-versa. Thus, the updating of protection and regulation systems is necessary. Provided all this, a transition to a new management of the electrical network and of the entire power system is needed; we refer to this new model as smart grid. The aim is to move from a system in which power production is centralised and controllable while consumption is completely random, so the responsibility for the balance between generation and consumption is entirely on the production side, to a system in which part of the generation is non-programmable, but this can be counterbalanced by a controllable portion of consumption. The idea is to move from a passive grid to an active one in which there is a bi-directional exchange between producers and users as it shown in **Figure 2**.

So, besides all the technical aspects regarding protections and regulations, in order to face the changes brought in by DG, the involvement of the final user has a fundamental role because he/she has to become responsible for part of the load control.

While EVs expend power, they can likewise send out energy to the grid as 'mobile energy' units of storage. An expansion in electric vehicle reception may mean greater adaptability for the framework to react to supply as well as demand. The vitality providers will offer the "vehicle-to-grid" administration to purchasers of the EVs. For this situation, reserve funds from vehicle-to-grid administrations could take care of the yearly expense of charging an electric auto. The proprietor of the auto should introduce a unique charger at home and the provider will deal with the auto's battery. The energy providers will naturally exchange power from the auto's battery to the grid amid peak times when costs are most noteworthy, possibly giving money related come back to the proprietor. The auto's battery will be charged amid off-peak times when costs are least. This improvement shows that vehicle-to-grid administrations could be utilised as a part of different nations amid peak hours to discharge stored

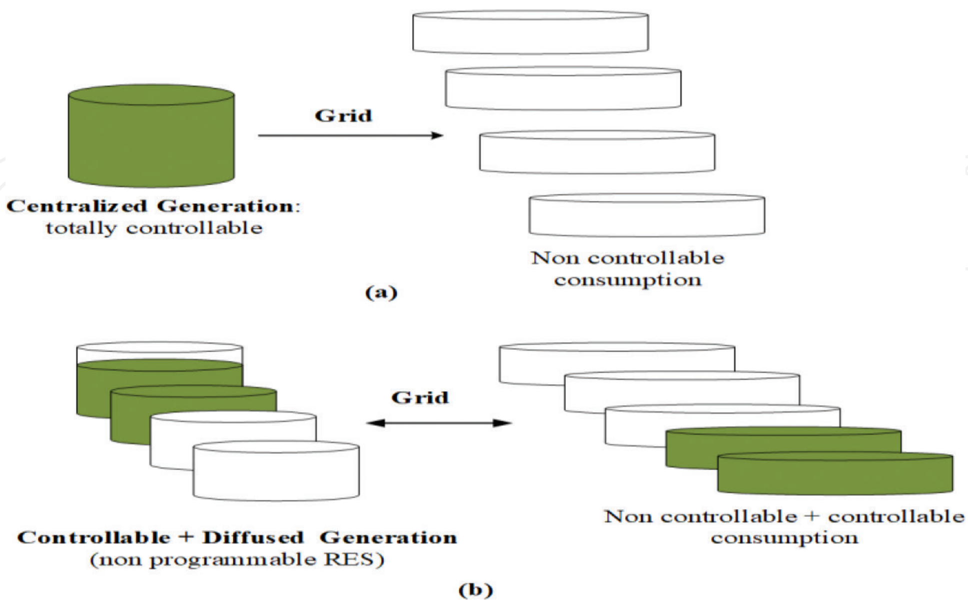

Figure 2. Comparison between the (a) actual and the (b) future electric system.

power onto the grid and reduce charging costs. Adjusting the supply as well as demand of power with electric autos additionally could bring about maintaining a strategic distance from exorbitant moves up to the grid, for example, putting resources into new power plants. In this way, transportation expenses and power bills could reduce with vehicle-to-grid administrations. As more clients embrace EVs, vehicle-to-grid administrations ought to be considered to help level out power supply as well as demand. This alternative might be particularly helpful in urban communities that have embraced electric transports for public transportation. These electric transports could give power to the grid when not being used, diminishing expenses for the city as well as clients. Some alert ought to be taken as more EVs are associated with the grid. Huge spikes popular for power could cause anxiety that could influence soundness, productivity, and working expenses of the grid. Subsequently, the effect of charging an electric vehicle is subject to where it is situated on the grid and the season of day it is charged.

Utilities plan to utilise disseminated assets, for example, sustainable power source generation, storage and demand reaction, to incompletely control charging effects of EVs. Keen grid innovations, for example, progressed metering foundation could demonstrate accommodating in dealing with the charging of EVs. Such gadgets permit charging stations to be incorporated with time-based rates that support off-peak charging. They likewise enable utilities to examine charging station utilisation and charging practices to illuminate speculation choices. Moreover, calculations that successfully plan the charging and releasing of EVs are vital for the grid to work proficiently. Be that as it may, growing such calculations is troublesome because of the irregularity and vulnerability of future occasions. More electric vehicle charging stations in advantageous areas are important to adjust request on the grid and increment accommodation. On the off chance that an electric vehicle needs to charge amid a lengthy, difficult experience trip, it would need to stop at the closest charging station. The nearest charging zone may not be along the driver's way, conceivably expanding power utilisation and diminishing convenience. Microgrids could likewise support unwavering quality while charging EVs in an area or work zone. Small community areas with disseminated assets, for example, solar-power oriented, wind as well as storage would decrease the strain on our power grid. Maybe circling capacity into nearby microgrids would additionally improve power versatility. As clients receive EVs, it is vital to consider all the potential advantages these autos could give to the grid. The grid could turn out to be more adaptable amid peak times for less cost and costly foundation updates could be kept away from with vehicle-to-grid administrations.

3.4. Electric vehicle coordination

Providing supplementary services from EVs is a very plausible option in case the process involves large fleet vehicles [40]. As revealed by Kempton et al. [40] in the year 2001, only one EV can neither unswervingly make it electricity market nor establish transactional engagements with electrical institutions because of the power constraints. The authors, therefore, suggested an aggregator technology, which may serve the purpose of intermediation between the automobiles, the utility organisations as well as the energy market. **Figure 3** vividly demonstrates the aggregator frameworks alongside other forms of the framework [41, 42].

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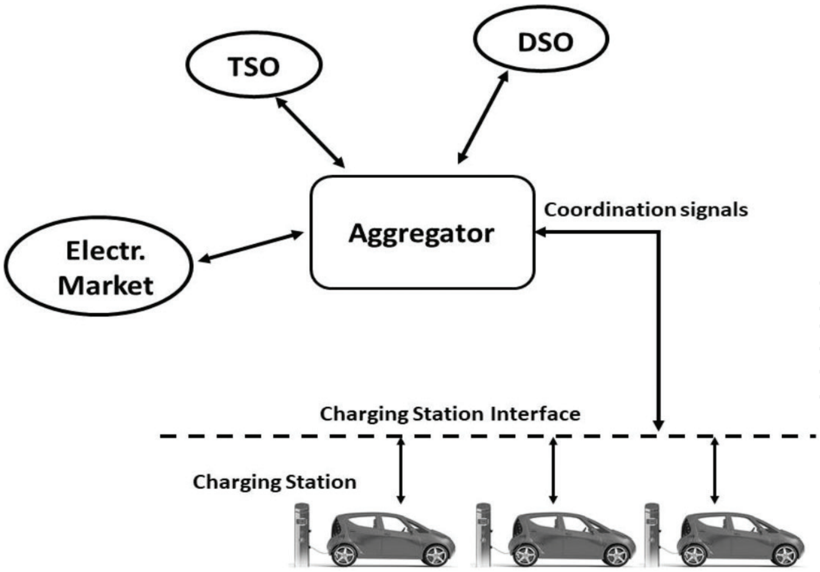

Figure 3. Simplified EV coordination framework: transmission system operator (TSO), distribution system operator (DSO), electric market and charging stations for EVs.

In almost every circumstance, the EV aggregator produces essential signals for coordinating the EV fleet based on the data shared between the supply the energy market, TSO as well as the DSO.

There are multiple reasons behind the deployment of EV aggregators. Firstly, under current market conditions small loads individual participation is prohibited. Also, it permits easiest interaction with the DSO for troubleshooting. With an appropriate strategy, it can lead to a reduction of the risk of forecast errors of the EV load.

As PV penetration increases in LV grid, controlling the EV load can lead to an improvement in the feeder operation and a decrease in the need to invest in infrastructure upgrades of the grid. In grids with such high penetration, there are constraints to keep in mind. Customers will evaluate improvements with respect to dependability, quality, and price. We expect a major change in the near future in the voltage quality improvement, which will aim to reduce long-term variations in voltage magnitude that arise in a decentralised RES generation context. We know from theory, that EV load coordination can facilitate keeping a local balance between production and consumption, which can reduce under and over-voltages.

Planning rules are currently being revised so as to allow for greater RES penetration by European energy suppliers. The options include [43]: (a) redirecting the power route to decrease circuit distance; (b) improvement of the upstream transformer volume; (c) improvement with MV/LV transformer with automatic voltage control; (d) improvement of the grid circuit thermal capacity, (e) improvement of the grid's rated voltage level; (f) setting up of additional reactive power compensation; (g) erection of new substations; and (h) modifications to the grid architecture.

Above are the grid reinforcement options. Recently, automatic power curtailment is being looked at within DSOs, if RES induced voltage variations were to exceed the allowable bounds. To do so, requires linking all units in a communication infrastructure network, which may not be convenient to owners and might imply compensating them for the inconvenience. Extensive research has been made into reactive power methods for LV grids, showing some limitations in the effectiveness of reducing voltage rise [46, 48–50]. In view of the case of PV, most PV units previously connected in LV grids work with unit power factor. Furthermore, the high R/X ratio (imaginary part of impedance divided by the real part of impedance) of LV cables creates challenging the efficiency of these techniques. By providing reactive power contribution by all PV units, there can be visible voltage rise reduction in a feeder [50]. Besides, active power solutions can be utilised as an alternative one.

For the interest of knowledge, Fell et al. [43] explained that an EV aggregator is vital requirement in the coordination of the grid-connected operations of several EVs to achieve the regulation needs or standards by the TSO. It is noteworthy that, the meaning of EV aggregator is also recognised by Brooks and Cage [44]; in this regard, the priority of EV aggregator is to check the driving needs of the operators. Some authors have suggested a strategy that allows the user to communicate their operation needs to the aggregator. Consequently, the aggregator works by processing the information about the driving data. Considering the convenience of all the operation profiles of the user, the aggregator produces a “virtual power plant” in which the number of the automobiles anticipatedly plugged plus the accumulated power as well as the levels of energy. Moreover, the estimation can be done per hour. Equally, Bessa et al. [45] also invented a procedure that can as well be used to optimise and support aggregator in enhancing the engagement of the day-ahead (also known as spot market) as well as subordinate reserves sessions. Further analysis was conducted a 2-year simulation on the Iberian market and concluded that; the agent of aggregation with augmented bidding is likely to reduce the costs of charging more than the coordinated system of billing. Secondly, in case the payment regarding the reserve capacity is convenient, then it is financially expedient to regulate EV participation. Lastly, if there is no reserve capacity compensation, the idea of optimised bidding can as well pay off. Prediction of the EV loads as well as approximating the qualms is essential in problem-solving. Lopes et al. [46] applied the concept y describing the architecture through which EVs are accumulated on a micro-grid as well as multi-grid ideas. Again, the aggregator in this context functions as interplay between the users of EVs and the energy market. In this case, these concepts are like to offer frequency regulation. Researchers Galus and Anderson [47]; introduced a different idea on an aggregator. They asserted that an aggregator is not a corporation but an intangible computational unit that monitors and evaluates a control are: Adequately, it is a smart interface amid the electrical utilities and the EV. Harmonisation of EV is easy to detect if there is the likelihood of responding to the propagated indications. Therefore, the need of EV to react to the secondary services as well as technological shortcomings arising from EV coordination process is addressed by Galus and Anderson [47].

3.4.1. Synergies between EV needs and PV distributed generation

In this subsection, the concept of synergies between undispatchable generation sources and controllable loads, utilising in particular PV distributed generation and EV batteries, is presented. In the smart grid environment, increasing further PV generation, would involve storage systems to modulate power injections. In this situation, EVs (V2G) are more advantageous that conventional energy storage (batteries) within smart grids.

The potential of using RESs as alternative to conventional fuels such as fossil fuels, to power EVs can help reduce pollution with a considerable decarbonisation effect and enhance resource efficiency. Alternatively, sustainability targets are however in advance: more RES volume is expected such as share of renewable energy of 45% in the electricity sector by 2030, which is just currently 21%, and further sustainable transport has to be realised. Consequently, there is a requirement to integrate both elements in the best cost and effective manner.

Figure 4 shows per unit (p.u.) based graphs of the load demand profile (maximum peak load demand) and PV generation (Watt-peak installed PV capacity) against vehicles mobility patterns profile (maximum shares of vehicles in motion. Under unrestricted charging, it is clear that no interdependence can be drawn between the penetration impact of both EV and PV. It can be seen that, that there is no interdependence between the penetration impact of both EV and PV, given that the EV vehicles are charged in unrestricted manner. Actually, it is anticipated that EV generated load peaks should happen during the evening commute home. Besides, the EV demand peak corresponds with periods of little to no energy generation from PV sources, or in best situation to a minimal level throughout the summer when the days are extended.

A greater penetration level of DER along with a mitigation of the intermittent effects of high penetration of PV generation could be facilitated with more flexibility in EV demand. Such synergy requires the transferring of the EV demand peak in order to prevent bottleneck and high electricity prices during peak demand as well to relieve the excess of PV power generation. It is essential to emphasise that the tracked objective is principally focused on risk mitigation instead of minimising operational expenditures. Note that lacking to alleviate risk

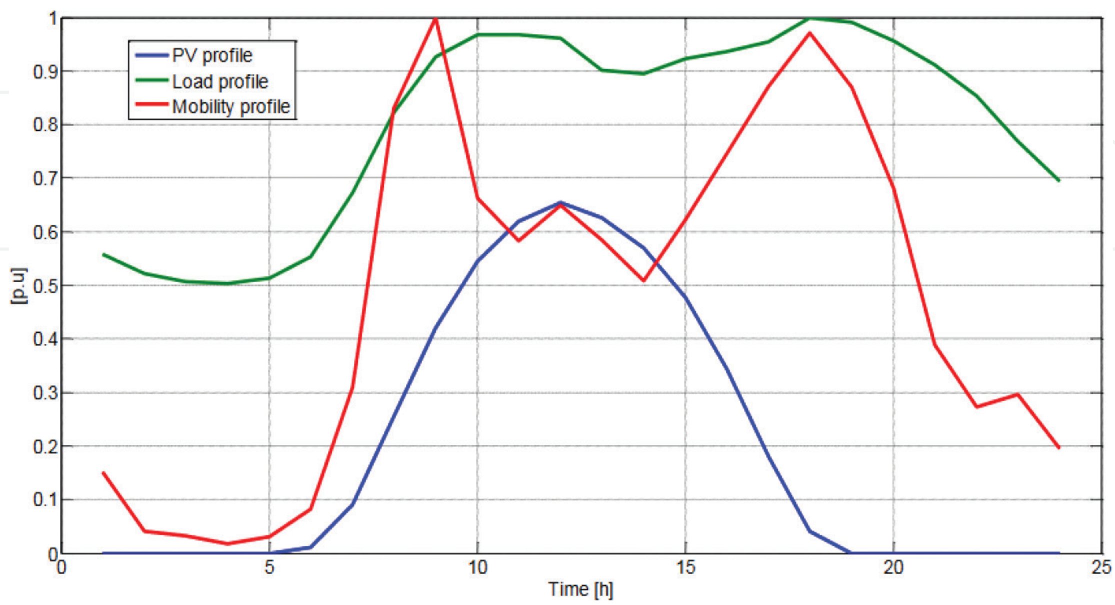

Figure 4. Load demand profile against typical EV load and PV generation profiles as a function of time of day.

could be costly (e.g. forfeit from regulator, energy not delivered or damaging, the standing of the utility company). Smart consumer and smart home comprises funds committed to create the required interfaces and utilities for prosumers interactions and communications with the appropriate objects (i.e. energy aggregators, utilities, DSOs, etc.). This essentially implicates direct funds in terms of white goods; smart meters in addition to the evaluation of prosumers commitment and sensitivity to diverse incentives. Virtual power plants amalgamation is probably the best attractive form regarding the synergies between EV and PV. Its operation is systematically reliant on other divisions.

Such funds concentrate on physical and market aggregation among distributed generation and controllable loads creating jointly a virtual power plan. A virtual power plant assessed to a conventional RES offers numerous benefits principally: greater inertia (aggregated sources), controllability (through storage or demand side management) permitting the option to interact and assist as a market participant whichever by delivering auxiliary amenities or bidding in energy market. The established design and the energy management approach are in agreement with the usual current and anticipated standards in terms of interoperability potential and functionalities. The evaluated EV charging comprises uncontrolled and synchronised charging approaches. The recommended plan intends to empower effective and harmonious communication among the diverse players within the DEMS (decentralised energy management system) domains. For the smart grid and the deregulated energy markets, it is anticipated to get a variety of players exploiting different equipment' suppliers. These performers require to be effectively interconnected and synchronised with interoperable solutions, directing to significant executions costs payable to the sheer number of procedures and involved equipment, functions or applications to be integrated.

4. Conclusion

EVs represent one of the best promising technologies for green and sustainable transportation systems. The high penetration of EVs will have positive effects and benefits such as lesser fossil fuel reliance, significant reduction of GHG and toxic pollutant emissions, as well as the capability to contribute in the integration of renewable energy into existing electric grids. This chapter reviewed the latest advances related to the interaction and integration of EVs with RESs such as wind energy, solar photovoltaics and EV coordination for sustainable mobility in significantly reducing air pollution. Some key concerns and possible solutions were also discussed in detail. The successful implementation of the coupling EV-RES technology includes and requires the full contribution of government, power utilities, EV and aggregators manufactures, policy-makers and owners. It is expected that this study can assist all involved parties to better understand the challenges and issues and contribute further to this field.

Conflict of interest

The authors declare no conflict of interest.

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