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Review

Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives

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Abstract: With every passing second, we witness the effect of the global environmental impact of fossil fuels and carbon emissions, to which nations across the globe respond by coming up with ambitious goals to become carbon-free and energy-efficient. At the same time, electric vehicles (EVs) are developed as a possible solution to reach this ambitious goal of making a cleaner environment and facilitating smarter transportation modes. This excellent idea of shifting towards an entirely EV-based mobility industry and economy results in a range of issues that need to be addressed. The issues range from ramping up the electricity generation for the projected increase in consumption to developing an infrastructure that is large enough to support the higher demand for electricity that arises due to the market penetration of EVs. Vehicle to grid (V2G) is a concept that is largely in a testing phase in the current scenario. However, it appears to offer a solution to the issues created by a mobility sector that the constantly growing EV fleet will dominate. Furthermore, the integration of EVs with the grid seems to offer various cost-wise and environment-wise benefits while assisting the grid by tapping into the idle energy of parked EVs during peak hours. This review aims to present some of the possible ancillary service potentials of such a system while also discussing the potential challenges, impacts, and future market penetration capabilities of V2G technology.

Keywords: electric vehicle; vehicle-to-grid; ancillary service; aggregation

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1. Introduction

Electric vehicles (EVs) are believed to be feasible solutions for reducing greenhouse gases (GHGs) and, more broadly, global anthropogenic emissions that predominantly emanate from the transportation and energy sectors. In addition, they also contribute to the diversification of the energy market and present new economic opportunities. Since EVs primarily receive their electricity from the electric grid, synchronizing these grids with low-carbon electricity production by adopting renewable energy with high energy-conversion efficiency will undoubtedly create a cleaner landscape in both the energy and mobility sectors. In addition, electric vehicles also tend to have higher overall efficiency when compared with their conventional gasoline counterparts, the internal combustion engine (ICE)-based vehicles. This is due to the higher efficiency in grid electricity generation and regenerative braking [1].

According to the International Energy Agency (IEA), the global number of battery electric vehicles (BEVs) in 2019 reached 4.79 million, with more than half (2.58 million) of the BEVs population coming from China [2]. Moreover, the number keeps increasing at a significant rate, at about 36% annually, hinting at a possible projection of the global EVs stock growing as large as around 245 million EVs in 2030 (under IEA sustainable development scenario) [2]. Assuming that the average battery capacity installed in each EV is 50 kWh, the total battery capacity of all EVs in 2030 can reach up to 12.5 TWh [3].

The global share of EVs in the mobility market is rapidly increasing due to favorable policies, incentives, and subsidies from the government, reduction in the costs of manufacturing and battery, increasing social acceptance, and broader infrastructure to support EVs, such as charging stations [4].

Seventeen countries have committed to phasing out the ICE-based vehicles while making changes on multiple levels to consciously adopt more environmentally friendly vehicles and zero-emission vehicles by 2050 [2]. In 2019, the total GHG emitted due to the electricity generated for consumption by EVs was 51 Mt-CO_2-eq, which was about half of the total GHG emitted by the same number of ICE-based vehicles in that year (53 Mt-CO_2-eq) [2].

The need for EVs to be equipped with a battery pack that is good enough to meet the energy demands of their propulsion, air-conditioning, and other auxiliaries, while ensuring and maintaining high reliability, capacity, and energy density strongly influenced the expansion of the battery manufacturing industry. This expansion is expected to bring down the costs of battery units and ramp up the pace at which the technological developments took place in the realm of battery research. These factors then contributed to the gradual reduction in the total costs of EV manufacturing.

The average duration over which EVs are used as a transportation instrument is only about 5%, which is comprised mostly of commuting during the weekdays and traveling during the weekends [5]. Therefore, for the remaining 95% of their time (idling time), EVs can be utilized for other purposes by tapping into their batteries and communication capabilities, which forms the basis for the vehicle-to-grid (V2G) concept.

The IEA has predicted that the demand for EVs charging in 2030 under a sustainable development scenario can reach about 1000 TWh. This demand is primarily expected to spring from regions like China (263 TWh), the USA (153 TWh), Europe (187 TWh), India (83 TWh), and Japan (21 TWh). This charging demand makes up about 2% and 6% of the total electricity demand in Japan and Europe, respectively. In a conventional charging system, EV charging is performed in a uni-directional mode, in which the electricity only flows from the charger (grid) to the EV battery, but not in the reverse direction. This uni-directional charging could potentially lead to uncoordinated charging, resulting in an unpredicted, fluctuating, and concentrated electricity demand at some points of time.

Managing the charging patterns of EVs is considered a crucial step for the penetration of EVs in the global markets since it strongly affects the quality of transmission through the electrical grids. The IEA has also predicted that in 2030, there will be a significant rise in electricity demand, especially during the evening hours, while attributing this spike in demand to the unmanaged and concentrated EVs charging. This demand is estimated to be around 5.5% for the US, 6.5% for the EU, and 9.5% for China [2]. Furthermore, through appropriate management and control, it is possible to tap into the massive battery reserves of EVs for utilization in other secondary applications, especially when EVs are connected to the electrical grid.

The term vehicle-grid integration (VGI) is a broader term or a concept that hints at a possible synergistic utilization of both the grid-to-vehicle (G2V) and V2G systems. While the former refers to the flow of electricity from the grid to EVs (which would be the case during charging), while the latter facilitates the flow of electricity from EVs to the grid (discharging, electricity return). It is also helpful to note at this point that V2G as a term has been used synonymously with that of VGI to mean the flow of electricity in both directions (both from and to the grid). That being said, not only can a system like that of VGI bring down the load to the grid (that might arise due to a higher charging demand created by the EVs at a particular point of time), but it also positively supports the grid by effectively controlling both the charging and discharging behaviors [6].

Integration of EV charging systems and renewable energy has a huge impact on the quality of electricity that can be made available from the grid. In the event of a spike in power demand due to a large number of EVs charging simultaneously, the grid overload will negatively affect the power quality. This is proposed to be overcome by integrating renewable energy systems (RES) with charging stations, which will also improve grid stability. Such vehicles that are compatible with the grid and allow for bi-directional power flow are commonly referred to as gridable electric vehicles (GEVs). It is also important for the grid, RES, and EVs to be in constant communication with each other for efficient grid functioning, which could be reliably achieved using V2G telematics.

An illustration of the V2G, or in general as VGI, concept during different times of the day is presented in Figure 1. This paper presents an overview of the current scenario with the V2G technology while outlining some of the potential ancillary services, such as frequency regulation, voltage regulation, peak shaving, load leveling, spinning reserve, congestion mitigation, renewable energy storage, reduction of intermittence and curtailment that can be provided with an infrastructure that supports vehicle grid integration. The infrastructure and system architecture in terms of charging stations, communication protocols, security, networked grid, and control algorithms that are required to essentially support the sustainability of this technological development and the subsequent planning and optimization needed to promote sustainable development across all of the involved sectors are also discussed This review aims to provide a comprehensive picture of the present developments with EV and grid integration while also throwing light on the possible ancillary services that could be made available due to V2G while also showing the possible room for economic developments and business opportunities that arise with an increasing number of global electric vehicle fleets and the impact and challenges they pose in various aspects, such as the economic, environmental and technological fronts.

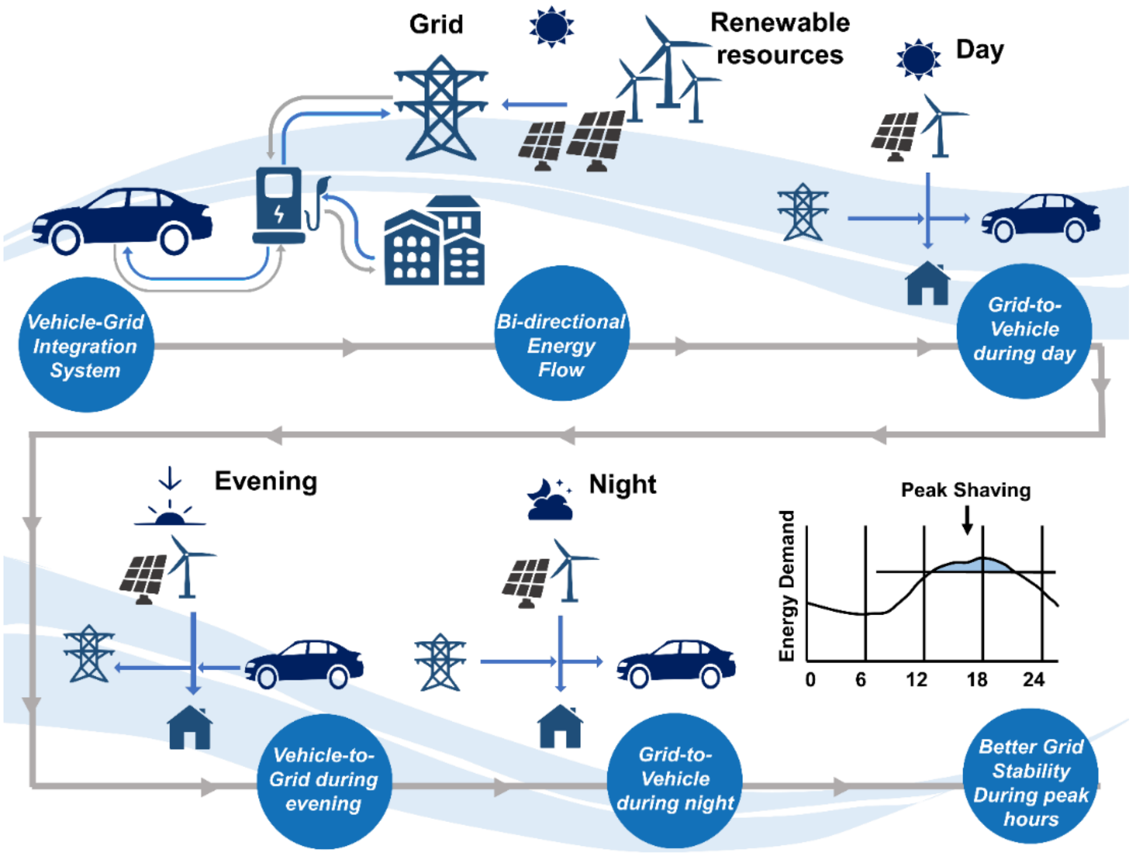

Figure 1. An illustration of the V2G concept during different times of the day. The graph shown in the figure is only for illustrative purposes (redrawn from [7]).

The benefits of V2G cover various aspects and subjects and can be summarized as follows:

- For the EVs owner: V2G can reduce the total ownership cost of EVs, and V2G also can be extended for local utilization as a home energy storage and emergency backup storage.
- For the grid operator: V2G serves as a new resource for both up- and down-regulation and power storage. It provides and facilitates a solution to the fluctuation due to the high share of renewable energy, as well as the solution to the grid congestion and circumvents the need to upgrade the grid infrastructure.
- For the government: V2G creates a new circular economy in society, provides higher energy security (supply and quality), facilitates a greener environment, and reduces the noise due to vehicle engines. EVs and V2G will restructure the lifestyle and infrastructure in the city, leading to huge movement in economic activities.
- For the aggregator/EV operator: V2G presents a new business opportunity in the electricity sector, including grid balancing services (in correlation with utilities, grid operators, and consumers) and renewable energy storage services (e.g., storage and minimization of curtailment and fluctuation).
- For the office and real estate owners and business entities (e.g., office, factory): V2G can facilitate local peak shaving, load leveling, and balance out the electricity demand. Therefore, the total cost of electricity might be reduced.

2. V2G Potential

2.1. Possible Ancillary Services

The ancillary services provided by GEVs are popularly referred to as V2G services, which can be uni-directional or bidirectional in nature [8]. Uni-directional V2G (uni-V2G) services involve the flow of controllable uni-directional power to the EVs and are offered by actively charging EVs. Bi-directional V2G (bi-V2G) services involve active power flow in both directions while utilizing the power stored by the standby EVs. There are certain advantages that are posed by the uni-V2G over the bi-V2G, such as lower battery degradation, reduced cost and initial investments, relatively simpler control, minimal social barriers, and also not having to need a bi-directional charger and all the associated communication that comes with it [9]. The potential of parked EVs in a charging station studied by Raveendran et al. [10] found them to offer an improvement in power quality. Unveiling the V2G potential of EVs requires smarter charging techniques to attain different objectives at different levels of the grid (shown in Figure 2). The potential services include virtual power plant (VPP), frequency and voltage regulations, spinning reserve, peak shaving, load leveling, reduction of intermittence and renewable energy curtailment, renewable energy storage, congestion mitigation [11], and economy-based services, such as reduction of the charging cost [12]. Some of these objectives/ancillary services are explained in the following sections.

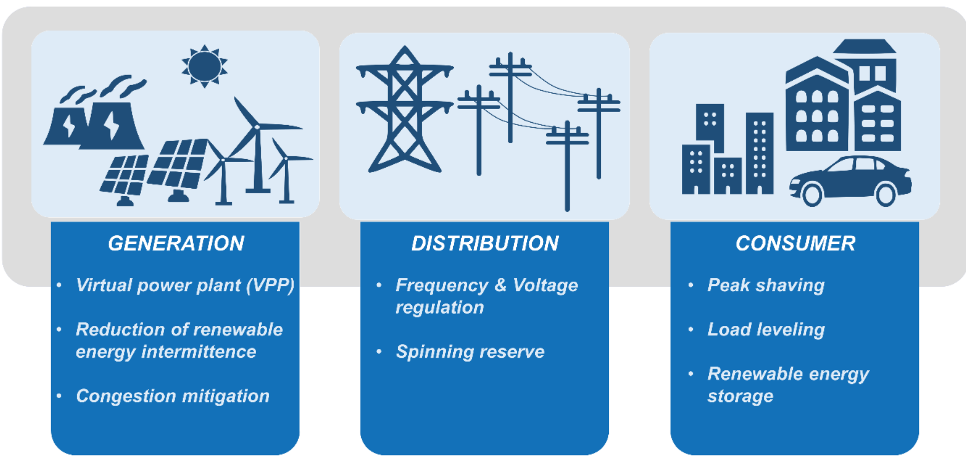

Figure 2. Potential services of V2G for different levels of the grid.

2.1.1. Virtual Power Plant (VPP)

Like the other objectives/services mentioned before, VPP is not a direct objective per se, but a means to achieve some objectives, such as better grid stability and frequency and voltage regulations. Depending on the given market environment and needs, VPPs can achieve different objectives. In a more general sense, the objective here is to network the distributed energy resources (which is the standby EVs in our case) by monitoring, forecasting, optimizing, and trading their power to balance the fluctuations in the generated electricity by renewables, which is summarized in Figure 3. That aside, VPPs can also serve by integrating renewable energies into the markets. Since individual smaller plants cannot provide balancing services, by aggregating the power of these individual units, a VPP can work just like a large central power plant by delivering essentially the same service and redundancy.

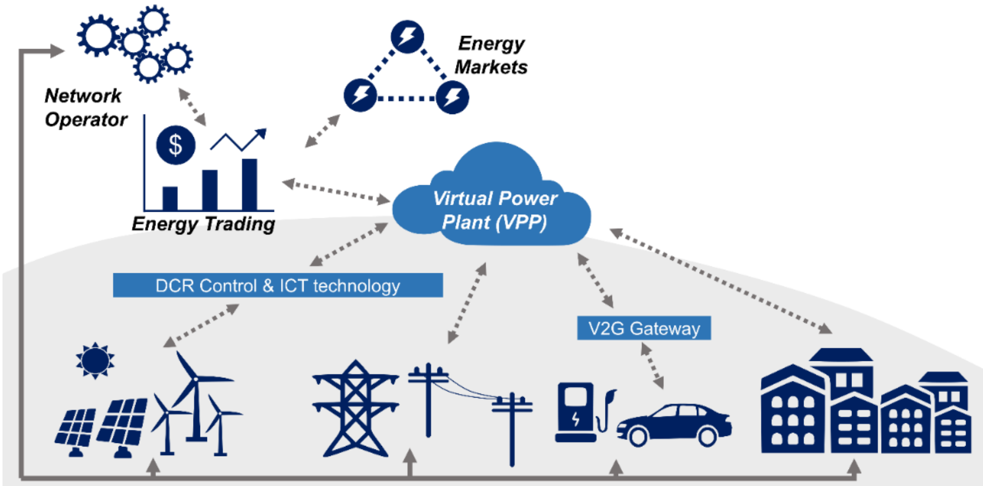

Figure 3. An illustration of V2G units trading energy using VPPs (redrawn from [13]).

2.1.2. Frequency Regulation

Some of the critical aspects that need some considerations regarding frequency regulation with V2G are the issues that revolve around the grid stability and economy. Maintaining the stability of the grid frequency by managing the EVs integrated into the grid is conducted together with efforts to increase and encourage the number of EVs integrated into the system and break the social barriers to participate in the frequency regulation service. The criterion for stability is that the grid frequency must match the frequency of the load consumption. The feasibility of EV integration to the grid and its role in frequency regulation in the Great Britain power grid was analyzed in [14]. The simulation shows that the EVs integration to the grid can stabilize the grid by significantly reducing frequency deviations. A quasi-Monte Carlo (QMC) based probabilistic small signal stability analysis (PSSSA) method is suggested to assess the stability of the grid that arises from the frequency regulation ancillary service [15]. Figure 4 shows the two simulation scenarios where the input frequency signal with negative and positive frequency deviation is considered. In scenarios where users want to maintain their battery state of charge (SOC) level, the simulation time was 80 s in order to study the response of charging power of the EVs, before and after the frequency deviation. Moreover, in the case where the users demand a higher SOC level, the simulation time became 3 h. It was proven that EVs can participate in both a positive and negative frequency control market.

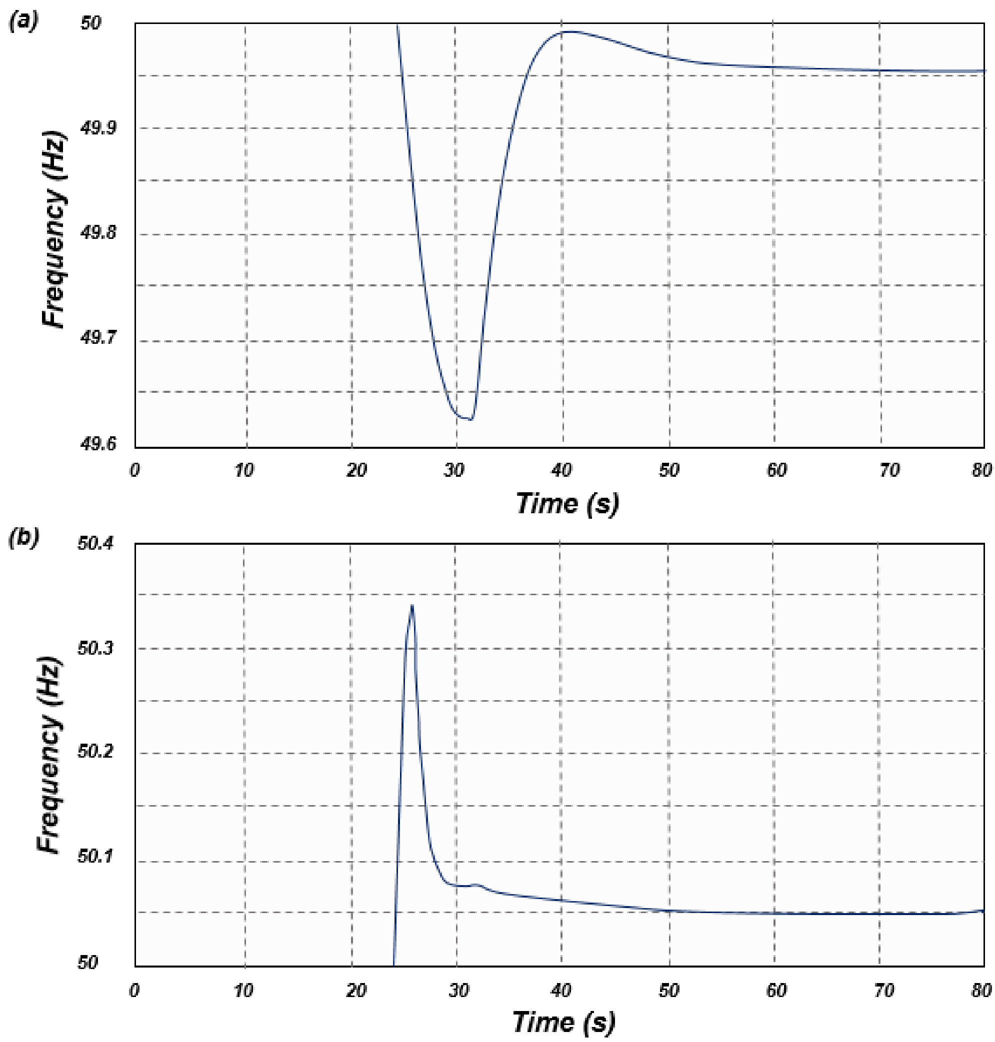

Figure 4. Frequency response signals: (**a**) with negative deviation, (**b**) with positive deviation (redrawn from [16]).

2.1.3. Voltage Regulation

The large-scale integration of EVs into the grid will significantly affect the grid voltage [17]. The influence of the integration of EVs to the UK's grid was analyzed under different EV aggregation levels and penetration scenarios [18]. Integrating 24 users at the low voltage segment, a power systems computer-aided design (PSCAD/EMDTC) model was used whose simulation results show that the low-voltage limit was exceeded for the minimum load and 50–100% for the penetration extreme conditions. Another study by Muhammad et al. gives an overview of the energy management system to manage and control the transient voltage stability through V2G [19]. It is shown that EVs can provide the baseload for a short period of time to improve the grid stability. Since the charging voltage of EVs is typically the lowest in the system and EV charging loads will account for a large part of electric loads in the future, it is essential for EVs to participate in under-voltage load shedding, especially in the AC electric vehicle charging stations, to avoid a voltage collapse [20].

2.1.4. Peak Shaving and Load Leveling

Peak shaving, apart from the apparent economic advantage, also benefits the grid operator and end-user and helps in the reduction of carbon emissions. When the demand (load) increases, the stress on the overall grid system increases. This could lead to a blackout in worse scenarios. Peak shaving techniques generate an efficient load demand profile, ultimately improving the power quality while reducing costs [21]. Since the generated load demand profile is sustainable, the overall load on the transmission and distribution system also decreases, which helps to increase the system's efficiency. For the end-user participating in the V2G, incentives and financial compensation, in terms of electricity cost reduction, are considered crucial to encourage their participation. A comparison of both peak shaving and load leveling is shown in Figure 5. While peak shaving (shown in Figure 5a) is a strategic way of load shedding, load shifting/leveling (shown in Figure 5b) refers to a short-term reduction in consumption followed by an increase in the demand load when power prices or grid demand is lower.

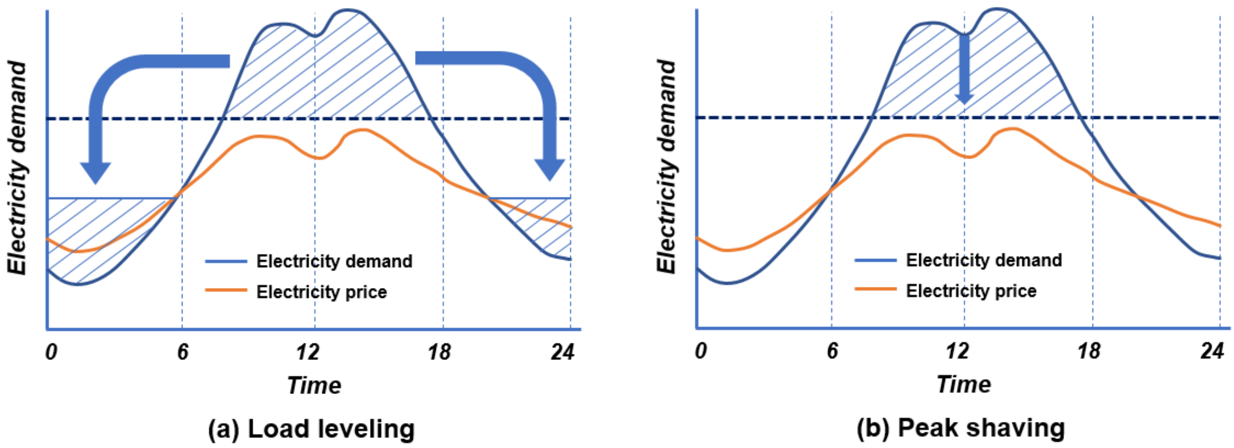

Figure 5. Load leveling and peak shaving: (**a**) load leveling: overall consumption remains the same during load leveling, (**b**) peak shaving: overall consumption is reduced during peak shaving.

However, the number of EVs participating in the grid integration process becomes a crucial factor for the effective performance of peak shaving and load leveling algorithms. In addition, synchronizing the charging and discharging of a large number of EVs can also be a problem that will influence the efficient management and optimization of the systems [22].

2.1.5. Spinning Reserve

Another ancillary service that can be offered by V2G is a spinning reserve. Spinning reserves have a current market value of about 10 USD/MWh [23]. A spinning reserve is typically provided by online generators which can immediately adapt their output power in response to major transmission outages. These units are equipped with automatic gain control (AGC) telecommunication systems. They can attain their full potential in 10 min while being able to sustain this response for up to 2 h to comply with North American Electric Reliability Corporation (NERC) guidelines. To put it simply, a spinning reserve requires lower total energy compared to active power generating units, but has a quicker response time, which is well suited for batteries. Another criterion is that the active power supplied must be electrically synchronized with the grid, which is the case for an EV connected to a charger with a phase lock loop. Once again, the challenge here is that a sufficient number of EVs need to be available and connected to the grid with enough electricity stored in the battery to serve as a spinning reserve [24]. Another study that took into account three scenarios—with V2G, without V2G, and with V2G and a wind farm—has summarized that the reserve potential of the grid increases significantly with the integration of V2G and a wind farm, as shown in Figure 6 [25].

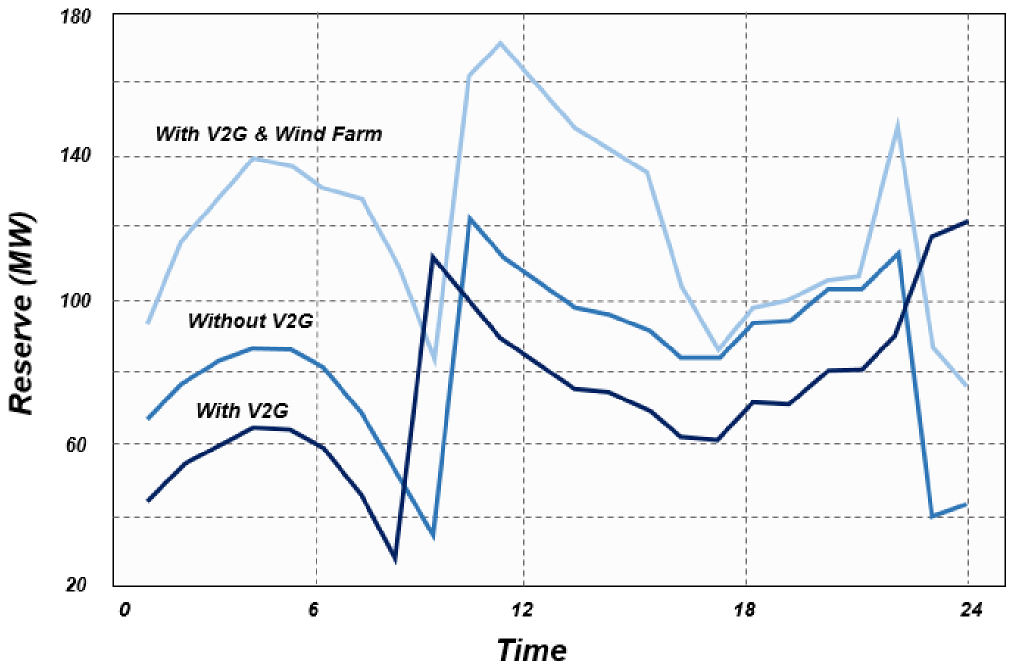

Figure 6. Spinning reserve of generation system for each hour during different scenarios (redrawn from [25]).

2.1.6. Congestion Mitigation

When the power consumption/load increases, it can overload the grid and subsequently increase power consumption bills due to peak grid prices. Looking at this issue, even without the utilization of communication strategies and a VPP, it should be noted that a building's ability to balance its electricity demand with V2G charging stations on a small scale also helps out the power grid on a larger scale. This also improves with an increase in electricity production from solar and wind power, which are intermittent by nature.

These circumstances can give rise to what is popularly termed as "grid congestion" [26,27] or bottlenecks that impede electricity from reaching its destination. V2G can offer a solution by utilizing the energy from standby EVs. This does not only serve as a solution to grid congestion but also circumvents the need for expensive grid infrastructure upgrades. In the absence of V2G, the additional demand for energy would need to be supplied from the reserve power plant, leading to increased costs and even more demand during peak hours, making it an economically unviable option [28].

2.1.7. Renewable Energy Storage and Reduction of Intermittence and Curtailment

When the electricity generated from renewable energy is higher, especially when surplus electricity is obtained, this electricity could be used to charge electric vehicles—otherwise, the surplus electricity results in grid imbalance. Since renewable energy is volatile and intermittent by nature, and it is hard to incorporate such an energy source into the conventional electric grids that typically involve controllable fixed power generation units. However, if this intermittent energy source is tapped to charge the EVs, which are integrated with the power grids, this would form a very efficient way of renewable energy storage while also tackling the problem of energy intermittency.

Intermittent renewable energy production sources are particularly challenging because they disrupt the conventional methods for planning the daily operation of the electric grid. Moreover, their power fluctuates over multiple time horizons, forcing the grid operator to adapt its operating procedures.

V2G policies that bring down RE curtailment are looked upon favorably because the curtailment—although it serves to balance grid stability—raises the operating cost and is an ineffective way of utilizing renewable energy resources [29]. Curtailment is often used because of grid congestion and unmatched supply and demand [30], and lowering curtailment can improve confidence amidst investors in developing future renewable energy projects [31]. Assuming that 0.95 to 5 million plug-in electric vehicles [32] (PEVs) are placed in a smart charging environment instead of unmanaged vehicle charging, smart charging brings down the annual renewable energy curtailment by 9–40%, more than the original value, which is around 120–410 GWh, respectively. It is to be noted that PEVs are not to be confused with plug-in hybrid electric vehicles (PHEVs), which can charge their battery through external power sources and using their on-board ICE. Even though annual curtailment with unmanaged charging is only 1.1–1.4% of renewable energy generation, more study is needed in this matter to understand renewable energy curtailment with future renewable energy levels [33]. The EV drivers/owners require sufficient stored electricity in the battery before departure for their travel. On the other hand, the grid operator and aggregator demand accurate availability and power capacity during the service.

2.2. Grid Ancillary Potential

The potential of V2G is influenced by EVs availability, which depends on the owner acceptance, driving behavior, willingness to participate, system readiness (e.g., charger availability), technical constraints (e.g., battery degradation), market readiness, and regulations. This availability of EVs has been simulated using multiple probabilistic algorithms. The available V2G power modeling (AVPM) was designed to calculate the available power for EVs that commute to the office in the mornings and back home in the evening. The model used fundamental parameters that were estimated using the fundamental parameters estimation (FPE) block, which contains SOC on arrival, V2G and G2V energy, and plug-in interval. These indirect parameters were calculated by utilizing the output parameters from the multivariate modeling of stochastic variables (MMSV) block and averaged PEV characteristic parameters, such as driving, charging, and discharging efficiencies. Alternatively, probabilistic availability uncertainty modeling (PAUM) block can also be utilized to calculate the V2G power, which uses data of daily commuting in order to associate a probability density function to the availability uncertainty phenomena [34].

In order to reduce the load stress due to the fast charging of EVs, especially in charging stations, Aziz et al. [35] have developed a charging system equipped with a battery. Their system consists of AC-to-DC inverter, DC-to-DC converter, stationary battery, and charger. The developed system has the potential to provide fast charging while keeping the contracted power capacity. Furthermore, Huda et al. [36] have conducted a techno-economic analysis of V2G in the Indonesian grid. They found that by adopting V2G, the electricity supply by both coal and natural gas during peak hours can be reduced by about 2.8% and 8.8%, respectively. In addition, the adoption of V2G by consumers can reduce the power generation cost and increase the power company's revenue by approximately 3.65% as the peaking power generator can be reduced. Table 1 lists selected V2G projects in different countries and services [37].

Table 1. Representative V2G projects for different services and locations.

Project Name	Country	From	To	No. EVs/Chargers	Tested Services
M-tech Labo	Japan	2010	2013	5	Peak shaving, load shifting
Grid on wheels	US	2012	2014	15	Freq. regulation
Smart MAUI	Hawaii	2012	2015	80	Load shifting
INEES Volkswagen	Germany	2012	2015	20	Freq. regulation
Zem2All	Spain	2012	2016	6	Freq. regulation, load shifting, emergency backup, arbitrage, reserve, distribution
US Air Force	US	2012	ongoing	13	Freq. regulation, load shifting, backup, reserve
Cenex EFES	UK	2013	2013	1	Freq. regulation, reserve, load shifting
US DoD, Smith Trucks	US	2013	2014	5	Load shifting, backup

Table 1. *Cont.*

Project Name	Country	From	To	No. EVs/Chargers	Tested Services
Amsterdam Vehicle2Grid	Netherlands	2014	2017	2	Load shifting
Torrance V2G School Bus	US	2014	2017	2	Freq. regulation, load shifting
City-Zen Smart City	Netherlands	2014	2019	4	Arbitrage, distribution
Clinton Global Initiative School Bus Demo	US	2014	ongoing	6	Freq. regulation, load shifting, backup
ITHECA	UK	2015	2017	1	Freq. regulation, load shifting
Solar-powered bidirectional EV charging station	Netherlands	2015	2017	1	Load shifting
Distribution System V2G for Improved Grid Stability for Reliability	US	2015	2018	2	Load shifting, distribution
Vehicle-to-coffee—The Mobility House	Germany	2015	ongoing	1	Load shifting
Smart Solar Charging	Netherlands	2015	ongoing	22	Distribution, load shifting
NewMotion V2G	Netherlands	2016	2018	10	Freq. regulation
Parker	Denmark	2016	2018	50	Freq. regulation, arbitrage, distribution
Parker Denmark	Denmark	2016	2019	15	Freq. regulation, distribution service
SEEV4City	UK	2016	2020	6	Freq. regulation, arbitrage, load shifting
Denmark V2G	Denmark	2016	ongoing	10	Freq. regulation
UK Vehicle-2-Grid (V2G)	UK	2016	ongoing	100	
KIA Motors, Hyundai Technical Center Inc., UCI	US	2016	unknown	6	Load shifting
Grid Motion	France	2017	2019	15	Freq. regulation, arbitrage, load shifting
INVENT—UCSD/Nissan/Nuvve	US	2017	2020	50	Freq. regulation, distribution, load shifting
BlueBird School Bus V2G	US	2017	2020	8	Freq. regulation, load shifting, backup
Static and Mobile Distributed Energy Storage (SaMDES)	UK	2017	2021	2	Load shifting, back up
Elia V2G	Belgium	2018	2019	40	Freq. regulation
V2Street	GB	2018	2020	2	Arbitrage, distribution, load shifting
E-REGIO with Power2U and ÖBO	Sweden	2018	2020	2	Freq. regulation, arbitrage, distribution, load shifting
SOLARCAMP	France	2018	2020	1	Freq. regulation, arbitrage, distribution, load shifting, backup
OVO Energy V2G (Project Sciurus)	UK	2018	2021	320	Arbitrage
e4Future	UK	2018	2022	unknown	Freq. Response, Arbitrage, Dist. Services, Time shifting
FlexGrid	Netherlands	2018	2022	1	Freq. regulation, load shifting, backup
EV-elocity	UK	2018	2022	35	Arbitrage, load shifting
uYilo eMobility Programme—Smart Grid EcoSystem for EV-Grid Interoperability	South Africa	2018	2023	1	Freq. regulation, distribution, load shifting
Powerloop: Domestic V2G Demonstrator Project	UK	2018	ongoing	135	Arbitrage, distribution, load shifting, backup
Utrecht V2G charge hubs (We Drive Solar)	Netherlands	2018	ongoing	80	Arbitrage
Bus2Grid	UK	2018	ongoing	unknown	Freq. regulation, arbitrage, load shifting
E-FLEX -Real-world Energy Flexibility through Electric Vehicle Energy Trading	UK	2018	ongoing	unknown	Freq. regulation, distribution, load shifting
V2GO	UK	2018	ongoing	unknown	Freq.regulation, arbitrage, load shifting
Share the Sun/Deeldezon Project	Netherlands	2019	2021	80	Freq. regulation, distribution, load shifting
BloRin	Italy	2019	2022	1	Freq. regulation, load shifting
Peak Drive	Canada	2019	2025	21	Distribution, load shifting
Piha vehicle-to-home (V2H) trial	New Zealand	2019	ongoing	2	Load shifting
Smart micro grid EMS	China	2019	ongoing	5	Freq. regulation, load shifting, backup
UNDP Windhoek (Namibia) V2G	Namibia	2019	ongoing	2	Load shifting
V2G EVSE Living Lab	UK	2019	ongoing	2	Load shifting, back up

Table 1. *Cont.*

Project Name	Country	From	To	No. EVs/Chargers	Tested Services
Realising Electric Vehicle to Grid Services	Australia	2020	2022	51	Freq. regulation, reserve
Electric Nation Vehicle to Grid	UK	2020	2022	100	Reserve, distribution, load shifting
Optimized HF isolated DC/DC converter	Spain	2020	2022	2	Reserve, load shifting, back up
Milton Keynes Council—Domestic Energy Balancing EV Charging Trial	UK	2020	2022	4	Load shifting
Direct Solar DC V2G Hub @Lelystad	Netherlands	2020	2023	14	Freq. regulation, distribution, load shifting, backup
V2G Zelzate	Belgium	2020	2023	22	Freq. regulation, reserve, load shifting
VIGIL (VehIcle to Grid Intelligent controL)	UK	2020	ongoing	4	Reserve, distribution, load shifting
V2G @ home	Netherlands	2021	2022	1	Load shifting, back up
Bidirektionales Lademanagement—BDL	Germany	2021	2022	50	Freq. regulation, arbitrage, load shifting

3. V2G System and Infrastructure

3.1. System Architecture

The system architecture associated with V2Gs can be classified into centralized and decentralized architectures. In a centralized architecture, the aggregator is the primary component for handling all the charging and discharging phenomena of EVs. In addition, the aggregator can also perform optimization for smart charging of the EVs: hence, it may have access to the system data whenever necessary. These features serve to organize the distribution, increase the system capacity, and provide ancillary services. However, this also means that the system has a huge quantum of data to process and optimize, such as the preferred level of SOC, available battery size, charging time, and many more to arrive at the most optimum solution [38]. Frequency control also becomes complicated with a centralized control architecture, since controlling is difficult when different vehicles are at different states of charge, and this could often be coupled with the uncertainty of EVs at the charging stations. Most literature, for this reason, dives deeper into the prospects of a decentralized or a local control architecture [39].

On the other hand, in the local/decentralized control architecture [40], the local systems, such as office, factory, and apartment, autonomously pursue their own way to optimize the charging cost and other parameters associated with V2G. The local systems are equipped with a server that has real-time communication with the EVs that belong to the local systems (such as employees and residents). However, this would tilt the scale in favor of probabilistic individual-made decisions [41]. This unpredictability factor can also snowball into increasing or decreasing the electricity cost when a large fleet of individual vehicles chooses to vary their charging rate. This problem is expected to be less of a concern if the sample space of vehicles participating in the decentralized/local control architecture is high enough. The advantages and disadvantages of these control architectures are shown in Table 2 below [39].

3.2. Charging System

V2G involves two main types of charging systems: AC and DC charging systems. While the AC charger charges the battery via the vehicle's on-board charger, the DC charger directly charges the vehicle's battery using an AC-DC converter on the charger side, as shown in Figure 7a. Before diving into the details of how the AC and DC charging works and why it is used, it is important to understand what an on-board and off-board charger are all about. An on-board charger is primarily responsible for charging the battery pack during its final stage. It utilizes the AC power source from the electric vehicle supply equipment and converts this power into the required battery-charging profile (typically in high-voltage DC). While the on-board charger's primary role is to transform power from the off-board charger before supplying to the battery management system (which often is abbreviated as BMS—an electronic system that manages/protects the battery by operating it within a safe operating region and controlling its environment), the off-board charger has the ability to work without an on-board charger and is interfaced directly with the battery management system [43].

Table 2. Advantages and disadvantages of centralized and decentralized control architecture [39,42].

Control Type	Advantages	Disadvantages
Centralized control	• Larger scale, number of EV, and coverage • Various possible ancillary services • Possible different connections to transmission, distribution, and renewable energy • Smart manipulation of network capacity • Possible real-time implementation • Flexible and wider geographical accessibility • Possible wider and larger-scale electricity market and higher possible revenue	• Extensive and expensive central control system, as well as the backup and storage sources • Complex and expensive communication architecture and infrastructure • Big data to process • Demand for higher connection security (risk for privacy defilements) • Possible full control of EV (the anxiety of the user that EV charging process can be interrupted at any time)
Decentralized control	• Smaller and simple communication infrastructure • Higher control flexibility/autonomy (charging control in the hand of the local system, resulting in faster and convenient service) • High data security as the data are stored locally • Higher consumer trust and acceptance (especially during initial adoption) • Scalable and adaptable to EVs fleet and energy management system • Better fault tolerance	• Limited types of ancillary services, electricity market, and connections • Smaller revenue due to limited services • Uncertainty in the end-result • Accurate forecast and prediction of the user behavior of users are necessary • Possibility for avalanche effects or concurrent reactions

With AC charging stations, the Society of Automotive Engineers (SAE) has characterized these charging stations into two standard levels: Level 1 and Level 2. A Level 1 electric vehicle supply equipment (EVSE) usually used in a residential charger utilizes the commonly available 220 V AC power from the grid in the current range of 12–16 A. Usually, a Level 1 charger requires about 11–20 h to completely charge an EV with a 16 kWh battery. On the other hand, a Level 2 EVSE, which is primarily used in commercial spaces, such as malls and offices, uses three-phase 440 V AC power off the grid to power up to an electric current of 32 A and would require 3–8 h to fully charge an EV with a 16 kWh battery [38,43].

At the same time, DC charging stations (also known as Level 3 fast-charging stations) take AC power from the grid and utilize a power converter to supply high-voltage DC power at a voltage of 300–750 V and a current of up to 400 A to charge the battery directly. This type of equipment circumvents the need for an on-board charger (OBC). Because high voltage power is directly used to charge the vehicle, the time needed to charge is much lower (less than 30 min) to completely charge an EV with a 16 kWh battery [38].

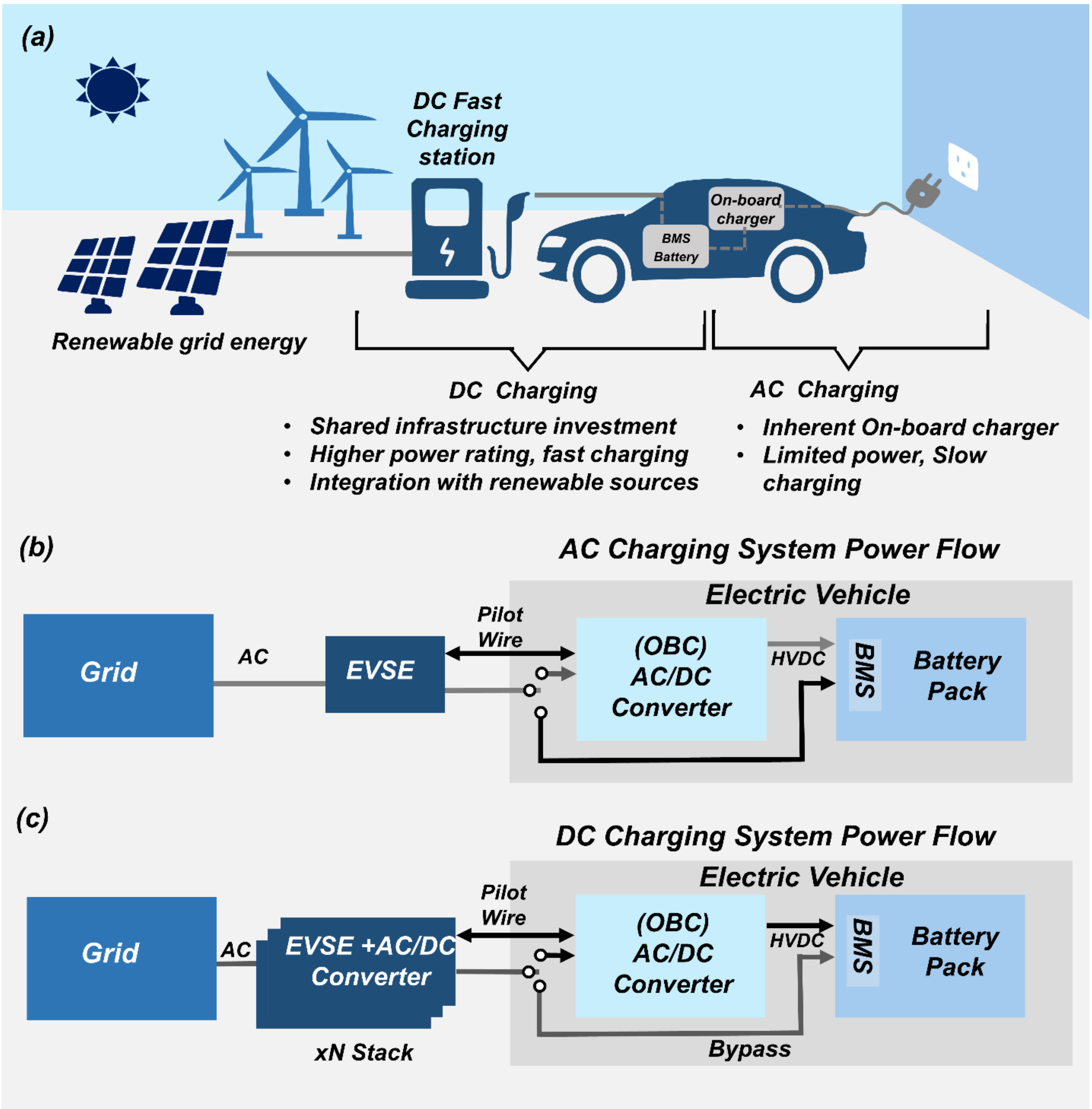

Figure 7. Conceptual diagram of V2G enabled charging system: (**a**) Differences between AC, DC charging and on-board charger (**b**) Level 1 and Level 2 AC charging stations and (**c**) Level 3 DC charging station (fast charging) (redrawn from [44]).

3.2.1. Uni-Directional Charger

When EVs are integrated with a grid, they serve as either a load or a distributed storage device to power and support the grid. Uni-directional chargers can only charge the EVs from the grid but cannot redirect the power to the grid when needed. Various studies are currently in progress on optimizing uni-directional charging to yield the most benefits for EV owners, aggregators, and grid operators [45,46]. Most of the utility objectives that arise with EVs can be addressed with uni-directional charging, even if there is a higher level of EV penetrations in the market while avoiding many major issues, such as equipment cost, system performance, and safety associated with bi-directional chargers [47,48]. This way of charging adds to no additional cost for implementation while also preventing the degradation of the battery life due to high charging and discharging cycles [49]. Countries with higher EV penetration require no additional investment for uni-directional charging. For example, the power grid in Ontario, Canada, can charge up to 500,000 EVs at no extra infrastructure cost [48,50]. In addition, time-sensitive energy pricing can be adopted to manage uni-directional charging. Integration with the grid and other complexities that arise due to uni-directional charging are detailed in standard IEEE −1547.8 [45]. Thus, uni-directional charging offers financial incentives for early adopters of EVs in the market [49,51].

3.2.2. Bi-Directional Charger

V2G requires a bi-directional system to deliver electricity from the grid to EVs' batteries, and vice versa. This bi-directional system can be facilitated using double uni-directional or single bi-directional converters [52,53]. However, utilization of double uni-directional converters (chargers) means a higher total cost, heavier weight, and larger dimensions. Therefore, bi-directional converters (chargers) and the advanced development of solid-state technology lead to optimum techno-economic benefits.

A bi-directional AC-DC converter facilitates both AC-DC power conversion and power factor correction. EVs with bi-directional chargers can achieve various features due to the nature of the power flow both off and to the grid, which is popularly termed V2G. When the batteries of EVs are idle but still connected to the grid, they can provide energy to the grid when the demand is high, enhancing the grid efficiency [54–56]. Also, bi-directional charging plays a key part in integrating RES with the grid [57,58]. While bi-directional charging aids in voltage regulation, recurrent charging and discharging (cycling) of the battery causes battery degradation, which finally affects the battery life. Another issue with bi-directional charging is the additional cost involved with its infrastructure. Additionally, customer acceptance and secure two-way communication networks impede the market penetration of bidirectional chargers [51,59–61].

3.3. Communication System

Communication between the grid and the EVs to transfer the data (e.g., travel, battery, EVs conditions) and decide the charging mode results in a complex communication structure [62]. Seamless communication is a prerequisite to designing a charging station network [63]. Various communication schemes and strategies have been proposed to avoid compatibility issues within the charging station network. [64–67]. Also, to avoid this scenario, specific standards have been established that must be complied with by the manufacturing companies. Standards have been set for EVs in four levels of the V2G technology, which are the plug, communication network scheme, charging topology, and safety standards.

In V2G technology, both the data and the energy flow are bi-directional amidst the vehicles, charging stations, and power networks. As summarized in Table 3, ISO/IEC 15110 standard establishes the standard for EV charging station communication, while the IEC 61850 standard establishes the standard charging station-grid communication as a result of which tariffs and charging are carried out effectively [68–71].

Table 3. Communication/safety standards associated with V2G technology [71].

Communication/Safety Standards	Operation Procedures
IEC 62196-1	Plugs, socket-outlets, vehicle couplers, and vehicle inlets—conductive charging of electric vehicles, charging of electric vehicles up to 250 A AC and 400 A DC.
IEC 62196-2	Plugs, socket-outlets, vehicle connectors, vehicle inlets—conductive charging of EVs, dimensional compatibility, and interchangeability requirements for AC pin and contact-tube accessories.
IEC 62196-3	Plugs, socket-outlets, and vehicle couplers—conductive charging of EVs, dimensional interchangeability requirements for pin, and contact-tube coupler with rated operating voltage up to 1000 V DC and rated current up to 400 A for dedicated DC charging.
IEC 61850-x	Communication networks and systems in substations.

Table 3. *Cont.*

Communication/Safety Standards	Operation Procedures
ISO/IEC 15118	V2G communication interface.
IEC 61439-5	Low-voltage switchgear and control gear assemblies, and assemblies for power distribution in public networks.
IEC 61851-1	EV conductive charging system—general requirements.
IEC 61851-21	EV conductive charging system—EV requirements for conductive connection to an AC/DC supply.
IEC 61851-22	EV conductive charging system—AC EV charging station.
IEC 61851-23	EV conductive charging system—DC EV charging station.
IEC 61851-24	EV conductive charging system—control communication protocol between off-board DC charger and EVs.
IEC 61140	Protection against electric shock—common aspects for installation and equipment.
IEC 62040	Uninterruptible power systems (UPS).
IEC 60529	Degrees of protection provided by enclosures (IP code).
IEC 60364-7-722	Low voltage electrical installations, requirements for special installations, or locations—supply of EVs.
ISO 6469-3	Electrically propelled road vehicles, safety specification, and protection of persons against electric shock.

3.4. Aggregator

An aggregator must be able to participate in the electricity market through different ancillary services of the grid by organizing and optimizing the EVs charging and managing the load profile [72]. A simplified architecture of the V2G system highlighting the role of an aggregator is shown in Figure 8. A little consideration will show that the aggregator plays as an interface between EV fleets and grid operators. In the first step of the process, the aggregator will establish a connection to each vehicle in the EV fleet, which has a service contract with the aggregator to utilize its battery, based on its current SOC to participate in ancillary services to the grid. Data from the EV will pass on the parameters required by the aggregator, with the condition for participation in this V2G system being that the EV sufficiently charges during the plug-out time. However, it should be noted that if the EV driver does not abide by the contract and drives away before the pre-notified departure time, the battery may not be sufficiently charged at time of the plug-out. Since the aggregator deals with thousands of vehicles at a time, the fraction of vehicles departing before the pre-notified time will remain constant and is negligible when considering the regulation process [72].

As a final step, the aggregator makes another contract, this time with the grid operator, and communicates to decide the type of the service and regulation capacity to be provided to the grid or the power required by the aggregator to charge the EVs in hand, thus simplifying the task of the grid operator significantly [73].

3.5. System Operation and Optimization

Power grid optimization has multiple objectives that must be achieved, but these objectives are riddled with many uncertainties and non-linearities while being limited by multiple constraints [74]. Furthermore, the dynamic and unpredictable nature of EVs could also increase the system complexity. This further complexity demands an optimization algorithm to utilize EV mobility to achieve V2G services. Since the integration of EVs and the grid will create a complex system that will increase a large number of non-linear variables, unit commitment becomes necessary to determine the optimal dispatch schedule, and various optimization approaches are usually applied to such unit commitment problems. Optimization approaches, such as genetic algorithm (GA) and particle swarm optimization (PSA), were applied to this unit commitment problem. This has been analyzed by Tan et al. [69]. In addition, many of the V2G objectives or ancillary services can be optimized to maximize benefits for the consumers. Figure 9 presents the summary of various types of V2G, services offered, and the associated optimization objectives and constraints.

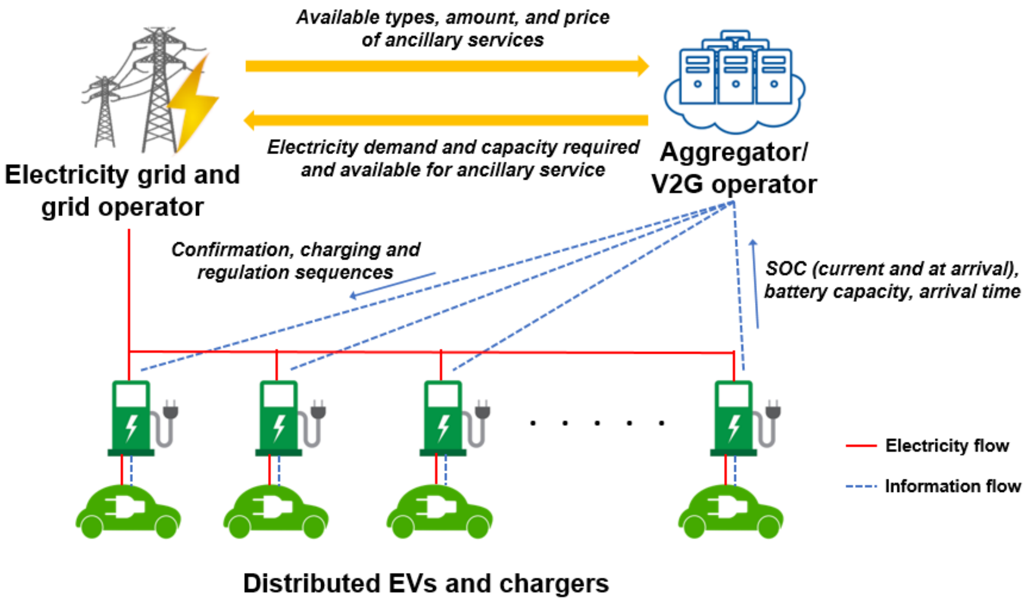

Figure 8. A simplified data flow and architecture of the V2G system highlighting the role of an aggregator.

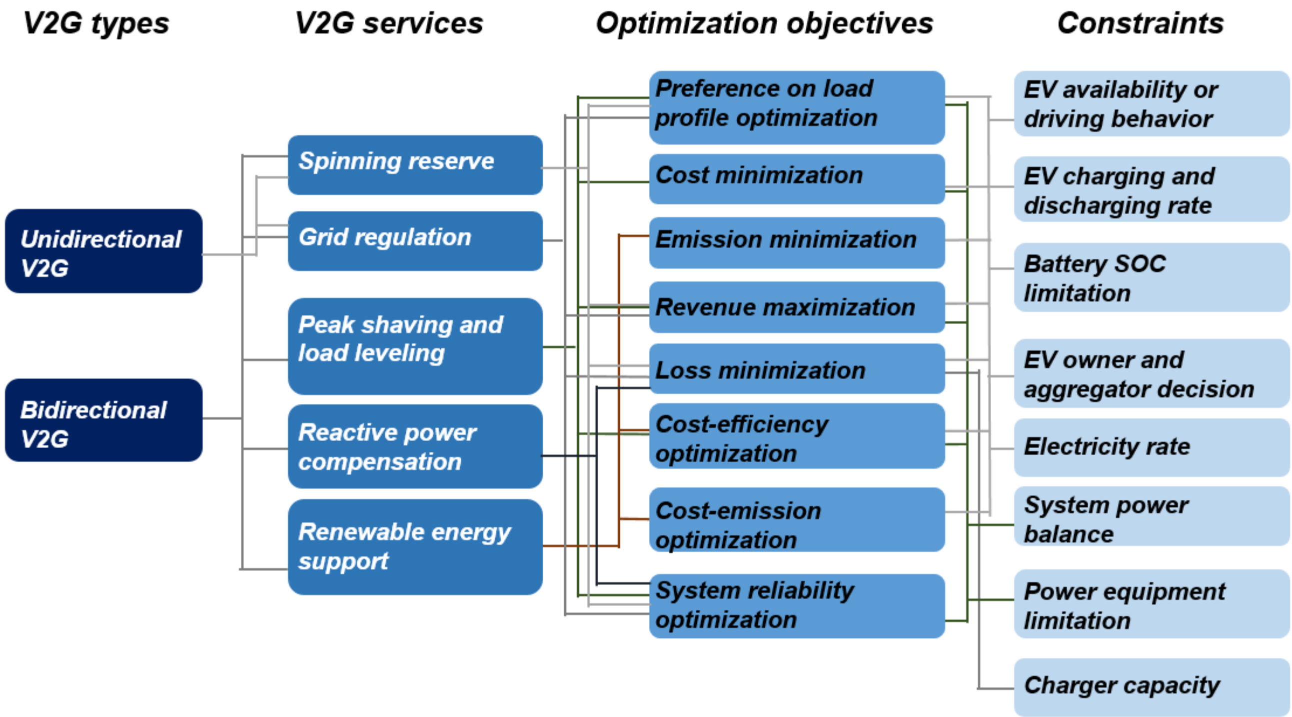

Figure 9. Relation diagram for V2G types, V2G services, optimization objectives, and constraints (redrawn from [9]).

Another factor for consideration/optimization when it comes to charging stations is the location of the substations. Planning the location of these charging stations, when approached from an electricity sector point of view, the only factors that need to be optimized include minimizing the investment and reducing the operations and maintenance costs. However, it is essential to understand that the planning of the location of a charging station is of particular interest to more sectors than one, thus making the problem of location planning, a problem of a multi-disciplinary nature. For instance, the considerations when planning the location of the charging stations from a traffic flow perspective and electric grid perspective is quite conflicting in general. Moving the location of a charging station away from an existing load center is beneficial from a grid perspective but is particularly undesirable from the consumer's perspective, making it a sub-optimal solution. Some of the primary considerations in location planning of charging stations are planning to locate the station optimally in such a way that the PEV drivers do not exceed their driving range in traveling from origin to destination and planning the station at a desirable location to facilitate the adoption of the technology with only minor changes to their driving habit [75,76]. Location planning is also done to reduce the burden to cost payers with regards to cost targets by reducing the investment and construction costs, operation and maintenance costs, and also the wastage cost to the user. Many algorithms, such as the cross-entropy (CE) algorithm and GA, have been utilized by defining specific objective functions based on these criteria mentioned above [77]. Table 4 summarizing the utilization of such algorithms across various literature has been shown below.

Table 4. A list of various optimization algorithms used for various objective functions across literature.

Journal with Year	Diligence	Controller/Optimization Techniques
IEEE Transactions on the smart grid, 2018.	Chance constraints-based rolling horizon controller used for minimizing cost and fulfilling end-user expected EV charge level during disconnection from the grid, though in the occurrence of uncertainty [78]	Mixed-integer linear program (MILP)
Energies, 2016	The charging station control schemes to control the grid side converter. The hybrid PI-Fuzzy controller reduced the settling period and peak over-shoot [79]	Hybrid PI-Fuzzy
IEEE Transactions on Industrial Informatics, 2018	A self-adaptive hybrid optimization algorithm, Hybrid of deterministic and rule-based approaches for reducing the running price of an EV facility integrated with solar and battery storage [80]	Deterministic-Rule based algorithm
Energies, 2014	Genetic Algorithm applied to harmonize the charging behavior of EVs. Also, to establish an optimum load pattern for vehicle charging reliability [81]	Genetic Algorithm (GA)
Energy, 2017	Stochastic optimization Bat algorithm is devised to control the power generators and charging pattern of PHEVs [82]	Bat algorithm (BA)
Energy and Buildings, 2015	The mixed-integer LP method is applied for the optimization of the model with appropriate home DSM to enhance microgrid stability with less grid domination [83]	Mixed integer linear programming (MILP)
Sustainable cities and society,2016	The genetic algorithm and PSO algorithm are used in the distribution system for loss minimization drive [84]	Genetic algorithm (GA) and particle swarm optimization (PSO)
International Journal of Electrical Power & Energy Systems, 2014	A smart Fuzzy logic controller is used which determines the optimal charging current based on grid voltage, battery state of health and user's trip requirement [85]	Fuzzy logic controller (FLC)
International Journal of Hydrogen Energy, 2017	A meta-heuristic algorithm HS-harmony search method is excelled for charge scheduling [86]	Harmony search algorithm (HSA)
Applied Energy, 2014	An improved PSO algorithm is proposed for the optimum energy flow, statistic features of EVs, owners' degree of satisfaction (DoS), and grid cost [87]	Improved particle swarm optimization (IPSO)
Energy, 2016	The Dijkstra's algorithm is selected to balancing load; the small node-voltage offset; and reduced power loss [88]	Dijkstra's algorithm

Table 4. *Cont.*

Journal with Year	Diligence	Controller/Optimization Techniques
International Journal of Energy Research, 2018	General algebraic modeling system (GAMS) for optimal strategy and firm decision to EVs supply chain demand has been employed [89]	Mixed integer linear programming (MILP)
IEEE Transactions on Power Systems, 2015	Charging load models and selection for EV charging stations [90]	Ant colony (AC) optimization
Mathematical Problems in Engineering, 2015	Smart power allocation plan for charging stations EVs [91]	Gravitational search algorithm (GSA)

4. Business Model and Power Market

From a power grid point of view, the charging of EVs can be considered an additional load to the grid. The increase and concentrated charging will need an additional generation of grid power, which is bound to increase the system cost and the cost of the power consumed. Furthermore, the current grid infrastructure will suffer losses through energy transmission with the increased EV penetration. Only through smart controlled charging can the cost of power consumed be reduced to about 60% [91,92].

When comparing the revenues generated by the V2G services with the investment costs, we find that the investment costs far outweigh the revenues generated from the V2G. Even if one tends to ignore the substantial investment costs, the opportunity costs that arise from not charging the vehicles at the parking facilities will outweigh possible revenues obtained by V2G ancillary services, especially frequency regulation.

A study conducted by Brandt et al. [93] discusses that even if a market environment appropriate for the V2G were present, the technology would not be feasible since high market prices for regulation are required to make up a viable model for business. The study goes on to suggest that just because V2G is a technically feasible concept does not make it an economically viable option. If this were the case, the increasing market penetration of EVs needs to be given more careful consideration with respect to the grid infrastructure that we currently have today. Be that as it may, it is also projected that the global V2G market size is projected to reach 28.12 billion USD by 2026, with a compounded annual growth rate of around 4.28% between 2021 to 2026 [94]. The V2G market size across various regions of the world has been summarized in Figure 10a. V2G could accommodate BEVs, plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) to support the grid infrastructure. The increasing adoption of electric vehicles across the world, which can be realized from Figure 10b, affects the demand for its associated infrastructures, including uni-directional and bi-directional charging infrastructures.

Furthermore, it is also crucial to note the effect policies and state fundings can have on improving technology growth. Figure 10c shows the investment trends on power grids in Europe. It is evident that there has been increased funding towards digital and smart grid technologies in the recent past, hinting at a favorable climate for V2G adoption in this region [95].

EVs are emerging as a promising alternative to conventional modes of mobility, both in terms of cost competitiveness and range. With the cost of the batteries taking up a major chunk of the EV cost, the recent trend of a fall in battery prices seems to suggest EV feasibility. However, this cannot be translated directly to the adoption of the V2G services on a larger scale. This possibly could be due to the uncertainties regarding battery degradation, efficiency, communication, and security associated with the V2G, which have developed only partially in the current scenario [97,98]. V2G is currently only implemented in test projects. Most EVs on the market today and the ones announced to be launched in the upcoming 3–5 years lack V2G capability, except for a few vehicles, such as the Nissan Leaf and eNV200 van [99].

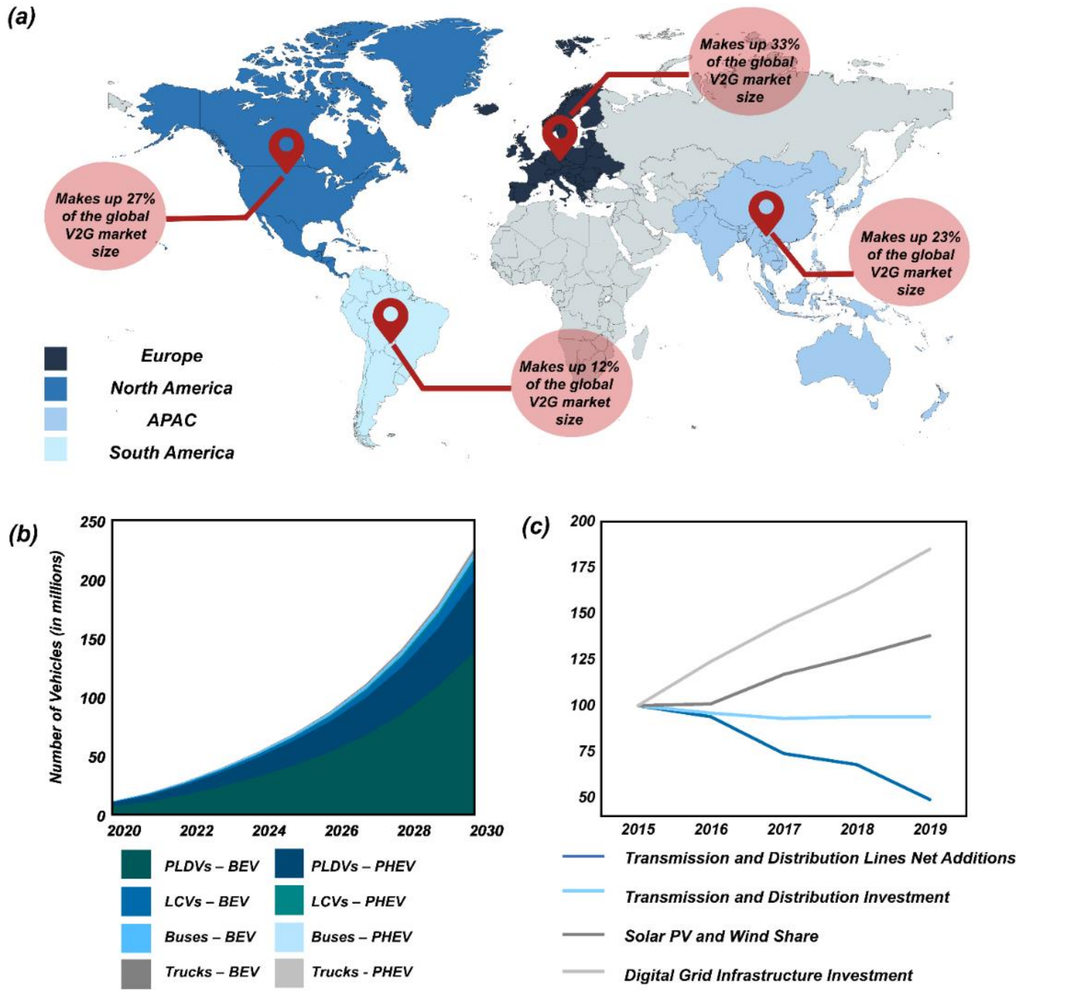

Figure 10. V2G market potential: (**a**) V2G market size across various countries globally (data from [94]), (**b**) projection of the number of EVs across different vehicle types till 2030 (data from [96]), and (**c**) power grid investments in Europe (redrawn from [95]).

That aside, another market gap arises from an infrastructure standpoint since new charging stations can demand more electricity, creating capacity issues for local grids. It is also understood that fleet managers wanting to operate EVs faced two issues: a strict upper limit to the amount of power that can be drawn from the grid and the high infrastructural costs that might be needed to handle the additional capacity issues. An increase in problems such as this that are related to EV infrastructure could push for large-scale adoption of V2G since it promotes a more efficient way of utilizing resources and also taps into the energy that lays idle in the mobile vehicle batteries [100]. However, the charging infrastructure that we have today does not facilitate V2G. Since charging infrastructures are generally installed for a period of no less than five years, moving towards a V2G compatible infrastructure could inflict higher infrastructure costs or worse, leading to a situation where the entire infrastructure is made without V2G capabilities.

5. Impacts and Challenges

EVs have a very positive impact on the environment, with ground EVs being one of the cleanest transportation options available today. The well-to-wheel emissions of EVs (including both emissions from power plants and straight-line pollution) are concluded to be the least, according to [38,101]. However, if EVs are continued to be powered by electricity that is generated by burning fossil fuels, the resulting emissions might be higher than conventional ICE-powered vehicle. While that is true, it is also shown that deploying EVs and photovoltaics can reduce CO_2 emissions by around 80%. The impacts of V2G technology on power grid regulation, line losses, distribution components, and load profiles are also significant. Some of the biggest challenges that impede the growth potential of V2G, apart from the apparent economic challenges, are the social barrier, network security, and battery life degradation.

Consumers generally tend to resist new, unaccustomed methods, but this could be best overcome by appropriate policy decisions that encourage and incentivize citizens to opt for a technology change and nurture it in its initial stages. Since taking part in V2G means that the batteries of EVs will be used to support the grid, it creates anxiety and uneasiness among ground EV owners [38]. The lack of a fast-charging infrastructure does not make the situation any better. One possible solution that has been suggested to overcome this issue of reducing the downtime that comes with charging an EV's battery is battery swapping technology. A major issue when it comes to market penetration of EVs is their cost, of which 25–50% can be attributed to the battery packs in EVs. Battery swapping can also overcome this hurdle if an ideal scenario of a pay-as-you-go model is adopted, where a third party holds ownership of the batteries while managing their charging conditions. Battery swapping stations (BSSs) are needed in this case which adds to the infrastructural costs. A topology of BSS, along with a battery sharing network, is suggested to interact with each other using internet-of-things (IoT), thereby acting as an aggregator and providing services as a whole to the grid, such as enhancing grid stability and reliability in the process. Even if the infrastructural cost associated with this topology can be put aside for a moment, the idea of owning a car without the battery and having no guarantee for the state of health of the battery that is swapped can operate as a social barrier from the consumer's viewpoint. Standardization of battery packs, though unlikely, is also a necessary change that will need to be adopted globally for this technology to be widely accepted [102]. Hence, technological and policy developments are immensely important to overcome this social barrier.

Cybersecurity for V2G technology has garnered some attention from the research community [38]. V2G technology requires a certain level of cybersecurity for seamless operation and to ensure grid safety, since the grid going digital handles massive amounts of data, making V2G a perfect target for cyber-attacks. Thus, network security and integrity with data transmission in the grid becomes essential for the seamless and safe data transfer from EVs to the grid.

Finally, battery degradation might be an issue with V2G technology, as the recurrent charging and discharging cycles of the battery induced by the nature of the V2G infrastructure might degrade the battery life span. This will have a huge impact on the viability of the business models that pin on the V2G technology and affect the social acceptance of the technology [103]. Battery degradation is primarily dependent on two factors: calendar aging and cycling aging. While the former is dependent on temperature and SOC, the latter is dependent on the depth of discharge and power throughput [104]. Recent research shows that V2G, if used without proper management, may lead to significant battery life reduction, which will be the case when, for example, peak shaving services are used daily. However, the effects tend to be minor if the utilization for energy-intensive services, like peak shaving, is restricted to less than 20 times a year [105–107]. Furthermore, according to Krein [108], utilizing the battery at its middle range of SOC can reduce the rate of battery degradation because of a lower equivalent series resistance at this SOC range [109]. Therefore, Quinn et al. [110] have developed a control and optimization method for V2G conducted in this middle range of SOC. Both the optimization and smart control of charging time and energy flows have been proven to reduce the level of battery degradation [111].

Table 5 shows summarized potential challenges faced during V2G implementation and deployment. In order to measure the feasibility and improve the social acceptance of V2G, further massive demonstration projects are required, in which not only technological aspects are tested, but also other aspects (including regulation, social, and market creation).

Table 5. Summarized potential challenges toward V2G implementation in different dimensions.

Technical	Regulatory and Policies	Social	Market/Economy
Battery degradation (lifetime)	Taxation system (double tax system)	Distrust in V2G benefits, V2g technologies, and lack of motivations	Capital cost of charging system (needs for investment and subsidies)
Charging infrastructure	Integration policies and standards of chargers with distribution and transmission lines	Inconveniences (charging, maintenance, etc.)	Vehicle cost (user upfront investment)
Charging protocols	EVs purchase subsidies and incentives	Systematic confusions (hardware, software, and regulation/policies)	EV, especially battery, maintenance and replacement costs
Energy loss during charging and discharging	Infrastructure subsidies	Range anxiety (low interest for purchasing new EVs)	Interconnection cost
Risk of imbalances, overload, and limited energy buffer	Independent, open, and accessible aggregator	Remaining SOC anxiety	Communication cost
Grid connection, limited existing grid design	Lack of communication with all stakeholders	Conventional behavior (difficult-to-change behaviors)	Unclear revenues
Integration with renewable energy sources	Ownership issues (for chargers and other instruments)	Unclear environmental impacts	Market creation/reformation (emerging market)
Communication network	Data security and handling procedures and protection	Lack of early adopters, lack of public interest	High charging cost and limited distribution of chargers
Communication and data security	Policies for facilitative and accessible markets		Industry dependency (in the established conventional vehicle industries)
Battery self-discharging	Mutual communication among the stakeholders		Market decentralization

V2G-enabled EVs are more expensive than ordinary PEVs (except for a few V2G-enabled EVs, such as the Nissan Leaf), which are already considered expensive compared to their conventional counterparts. Another important aspect to note is the consumer mentality. Since most consumers seem not to consider the cost-saving in the longer run, the potential revenue of V2G is undervalued, which is the opposite of what a rational actor model would predict. A survey result shows that none of the surveyed Californian households had factored in the estimated fuel savings as a part of their decision-making process in purchasing a new vehicle [112]. While this does not necessarily tend to suggest a global pattern in the decision-making process when purchasing a new vehicle, this survey shows that it is possible for a community not to factor in pressing environmental concerns in their day-to-day decision-making process. In addition, it also suggests a global need for awareness regarding the environmental and economic advantages that this technology offers over conventionally available ones.

Another aspect of concern is the environmental impacts due to EVs and V2G. Even with the integration of EVs to the grid presenting many environmental advantages, this does not preclude the possibility of an environmental impact that is primarily suspected to arise in terms of water availability. Since a transition from conventional ICEs to electric power increases the overall electricity consumption, water is needed to cool the power plants that are primarily powered by fossil fuels and nuclear plants in today's energy landscape [113].

Another research gap that causes concern is the lack of modeling of the consumer/EV buyers who are typically always assumed to behave in an optimal way for the entire system or financially profitable for the self. However, consumer modeling could be more complicated, since perceptions and motivations behind a decision made by a consumer are more sophisticated than an optimizing agent. Such complex dynamics make a path for considering passenger vehicles as goods with private and public dimensions, and even more so for vehicles whose primary development motivation is reduced environmental impact [114].

6. Conclusions

Since EV technology is still developing, policies play a huge role in taking this technology forward to its next steps in terms of market and social acceptability. In countries where

EVs are still in the early stages of adoption, incentives, supporting infrastructure, and electricity, for both supply capacity and balancing capability, are considered fundamental problems to be solved initially. Fiscal incentives, including subsidy and tax reduction, and complementary treatments, e.g., free road parking, toll rebates, priority lanes, are considered some of the policy incentives that will ramp up the adoption of EVs by the public.

While that happens, equal care should be directed at the infrastructural developments to support the growing fleet of EVs, including the deployment of public and private charging stations and provisions in building and codes to support charger installation.

However, the government support in EV deployment is transitional, only in its early adoption period. These supports are arranged in order to shift the market transition from a predominantly oil-dependent mobility market to a renewable carbon-free market. As the benefits of EVs are experienced by the community and the total cost of EVs can be reduced, mass-market adoption is expected with government support wearing out step-by-step. Therefore, a mutual correlation among the government, EV industries, and community is required to facilitate a gradual shift towards emerging technologies, such as EVs and an associated V2G technology.

Currently, it is quite difficult to quantify the economic feasibility of V2G due to market and technical conditions, objectives, unestablished regulations, and the lack of a massive demonstration test [3]. Previous studies, which were predominantly simulation-based studies, tend to suggest technical feasibility; however, if the technology will serve to be an economically lucrative one when adopted is yet unclear. However, it will be fair enough to say that diversifying the mobility sector in terms of clean fuels, such as clean electricity, hydrogen, and carbon-neutral fuels (e.g., e-fuels), will help to combat the bigger issue of climate change and carbon emissions in more ways than a conventional one.

To summarize briefly,

- Huge steps towards infrastructural developments in terms of charging stations, charging and discharging protocols, security protocols, and standardization become quintessential. They need to be developed alongside EV technology to avoid overwhelming the current unprepared grid infrastructure.
- Government policies, incentives, and support that are provided initially to boost a transition towards EVs might not be sustainable. In addition, a collective increase in acceptance of the technology leading to mass production might make the technology more economically viable to the consumer.
- The social and market acceptability of a technology that is different from a conventional way is an issue that needs to be addressed.
- Since most vehicle grid integration-based studies are simulation-based and the lack of large-scale demonstration of the technology, it is quite uncertain to predict/forecast the economic feasibility of this technology at this point with the current market conditions and current technological developments.
- Small-scale demonstration and simulation-based studies suggest technical viability, which need not necessarily translate into economic viability.

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