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# Overview of Opportunities and Challenges to Vehicle-to-Grid Integration and Bahrain Perspective

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**Abstract:** Transportation sector is among the largest consumers of fossil fuels, which also makes it a significant contributor to the greenhouse gas emissions. A great deal of effort has been made to reduce this reliance of transportation on fossil fuel for its operation. These efforts have resulted in innovations in vehicle technology which include vehicles operating on electric and hybrid energy. The advent of these technologies has showed the way toward new possibilities to further increase the efficiency of energy systems and their utilization. One such system utilizes the integration of electric vehicles with the national grid system, and it is referred to as vehicle-to-grid (V2G) technology. This technology provides a cost-effective and efficient solution to address the problems associated with the high demand and variable supply of renewable energy systems. This study provides a brief overview of the research conducted in this area, consequently identifying the opportunities and challenges related to this technology. Research shows that V2G integration has environmental benefits in the form of reducing $CO_2$ emissions and reducing reliance on traditional energy sources. In spite of this, the economic feasibility of this technology requires efforts for standardization, infrastructure expansion, and smart charging strategies. This paper is expected to provide future direction of work for all stakeholders, including academia, industry, and governmental bodies. There are collaborative efforts required to standardize the vehicle and grid technology and infrastructure expansion, while the research needs to focus on optimization strategies. In the end, discussion on the implementation of this technology in Bahrain is also presented. In this context, it was found that the major challenges are due to the current reliance on fossil fuel and the trend of increase in car ownership which must be addressed before taking steps towards V2G systems.

**Keywords:** vehicle-to-grid, grid systems, electric vehicles, Bahrain, optimization

The contribution of transportation sector in the energy consumption and the emissions has been on the rise in the past decades. It consumes more than double the energy consumed by the residential or commercial sector. Consequently, the $CO_2$ emissions from this sector are the highest than any other sector with more than 1800 million metric tons per year [1]. Furthermore, the emissions of other elements such as unburned hydrocarbons, carbon monoxide, nitrogen oxides, and various compounds of lead are also associated with the operation of vehicles. Most of the above-mentioned issues can be linked with the use of internal combustion engines (ICE) and fossil fuels [2]. The advent of electric vehicles is perceived to be useful in catering to these issues.

## 1. Introduction

Electric vehicles (EV), referred to as the term, are vehicles that consume electrical power for their engine operation. Three types of technologies are available in EVs, namely Plug-in Hybrid Vehicle (PHEV), Battery Electric Vehicle (BEV), and Hybrid Electric Vehicle (HEV) [3]. HEVs are provided with both electric motor system and another power system including an ICE or hydrogen cell for their operation [4].

Vehicles remain idle for as much as 90% of the day, during which time they could be utilized as power storage or power generation source for the system by linking the grid system with these vehicles. This was the basic idea coined by Kempton and Letendre [5] for vehicle-to-grid (V2G) technology. They proposed the battery-operated vehicles can serve as a power storage, whereas hybrid or fuel-operated vehicles can serve as power generation source for the national grid system. This technology comprises a two-way mechanism that charges and discharges through a converter module, circuits, and batteries using three-phase AC power supply [6]. This technology enables the vehicles to be part of the grid system and become Gridable [7].

The objectives of this study include providing an overview of V2G technology and identifying the opportunities and challenges associated with it. The current literature scarce presents a comprehensive study of this nature. Moreover, the context of Bahrain is also exclusively presented with regard to the implementation of V2G technology. The study is expected to be beneficial for governmental bodies in developing effective and efficient strategies to pursue full V2G implementation. Moreover, it can also be used to set directions of future research and development by the academic community and entrepreneurs.

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## 2. Previous Studies

### 2.1. Advent of technology

As mentioned above, the concept of V2G was introduced by Kempton and Letendre [5]. The main focus of their study was on justifying the use of EVs as storage for utilities' power. In return, the vehicle owners may be given subsidies on the consumption of utilities. They also mentioned that the use of V2G approach will reduce the system costs for utilities by providing extra storage and generation capacities. They also presented that passenger cars can be the most efficient vehicle type in this regard which can give the greatest number of discharges (2–3 times higher than trucks or sports cars) at lower costs with the storage capacity of 30 kWH. Hence, the potential for this technology is also higher because most of the traffic stream is composed of passenger cars [8].

Further building on this concept, Kempton and Tomić [9] also presented that light vehicle fleets provide the power generation capabilities at 1/10th of the capital cost of utility generators. On the other hand, these generators have lower operating costs and longer operating life. Thus, using these strengths in conjunction will be the harmonious solution to the power generation and storage issues. In another study by Kempton et al. [10], they have enumerated the benefits of using EV and V2G technology including reducing air pollution, providing domestic energy resources, and consequently increasing energy security and independence. However, they have mentioned issues related to the use of this technology such as the natural monopoly of electric supply systems and power overload problems. They have also mentioned high capital cost to be another issue for the adaptation of this technology at the mass level. The implementation of integrated government interventions has been advocated by them to cater these issues. These include subsidies, removing market barriers, standardization of EVs, and development of regulations pertaining to grids.

### 2.2. Progress in technology

Considering the contribution of electrically powered engines in reducing air pollution and consumption of fossil fuels, it has been suggested to convert all vehicles to this technology [11]. They also mentioned that fact that renewable energy sources like wind, solar, and hydro suffer from fluctuations. In this case, the integration of V2G technology can provide a more stable system without developing excess production capacities. The integration of these technologies would also result in reducing $CO_2$ emissions by at least 10 million tons [12].

Sovacool et al. [13] suggested a business model to be adopted before adopting the V2G approach for the countries/regions where this technology is sought to be adopted. Their business model included developing and laying out an intelligent rechargeable grid network which is connected via the internet. Other components of their model included coordination with vehicle manufacturers and other industry stakeholders and encouraging users through subsidies, leasing, and other facilitations to buy EVs. They advocated the fact that direct carbon emissions control cannot be effective with the current scenario of having 95% vehicle fleet operating on oil contributing to 50% of emissions. This business model will be a useful tool to cater this issue as well.

Saber and Venayagamoorthy [14, 15] proposed a cyber-physical energy system (CPES) which works on the concept of smart grid systems. The concept is to optimize the use of V2G power, using particle swarm optimization, with other conventional and renewable resources to minimize the cost and emissions. They have identified the need for such a system since higher emission control incurs higher costs. The system is designed to distribute the load due to random connecting of EVs to the system from peak to off-peak hours. Their system can reduce the emissions by 2000 tons and reduce the capital cost by $4 million through smart load leveling. However, the system will be at its full potential with the utilization of renewable energy resources of wind and solar power which would require significant capital costs.

Yin et al. [16] proposed an optimization algorithm based upon scheduling of EVs and incentivizing the use of electricity. They proposed that the EVs can calculate the charging schedule based upon the peak hour requirements. On the other hand, electricity prices will be varied to encourage use of electricity when the renewable generation is high. Their system reduced the negative residual load by approximately 22% by increasing consumption of residual load to more than 30%.

Richardson [17] presented an overview of the research carried out in this field. They found that literature pertaining to the integration of V2G with wind is more prominent than solar energy systems. V2G technology is found to be a useful measure to control the supply in fluctuation of renewable energy resources and avoid developing excess supply systems. Hasan et al. [18] focused on the development in EV technology and argued that the present hybrid EV should be converted to EV to realize the full potential of this technology. They presented that the maximum efficiency can be obtained with low-level component control and high-level control algorithm. The innovations in vehicle technology have increased the performance of these vehicles, and they are becoming more popular in countries like the USA, especially in urban areas due to their small size options.

Guo et al. [19] emphasized the fact that the power distribution system planners need to conduct studies and develop models to predict the impact of V2G on the system. It is necessary for safe and reliable operation of the distribution system. They showed that V2G technology can relieve the system due to the times of line congestion and transformer overload. However, the extent of this relief depends upon the degree of penetration of V2G into the system. They estimated that penetration levels of 50% or more will be effective in saving large investments on system upgrades which are done to meet the increase in energy demand.

Manousakis et al. [20] proposed the idea of a smart parking lot located optimally through genetic algorithm to minimize the distribution losses. They also performed time-dependent charging optimization to counter the unpredictability of the arrival and departures from the parking lot. The parking lot is connected with a hybrid renewable energy system and the overall supply is controlled through the optimization algorithm using the available sources (EVs) in the lot.

Eid et al. [21] focused on the fact that the charging demand for the EVs is varying and may require to be fulfilled through non-renewable energy in cases when renewable sources are not sufficient. They developed Lyapunov optimization-based model to minimize the delay of EV charging and the cost of non-renewable energy systems. They used the fact that EV charging rate is variable and can be controlled for optimal utilization of renewable energy resources.

Mwasilu et al. [22] have identified the following gaps for the full adaptation of V2G technologies. Firstly, smart control, communication, and metering mechanisms are important for the integration of V2G in the power system. The feasibility of V2G over the other energy storage systems should also be established through concrete research. There still exists a challenge to improve the capacity of batteries in terms of sustaining frequent cycles of charging and recharging which is expected to increase under the V2G system. Another challenge is the low penetration of EVs in the vehicle market and traffic systems. It was found to be persist in the current scenario as well, which will be later shown while discussing the case study of Bahrain. Additionally, the dynamic nature of energy demand can also create issues if the system is totally reliant upon renewable energy sources.

Su et al. [23] applied stochastic and deterministic optimization of energy generation using renewable and non-renewable energy resources with the integration of V2G. They used algorithms on micro-grid stations to cater the issue of variability of renewable energy resources. They found that the stochastic model is more efficient in minimizing the losses. The charging of EVs was scheduled optimally along with other alternatives to reduce the system losses.

Zhou et al. [24] proposed the use of pulse-width modulation (PWM) to the battery charging and discharging. This approach was aimed at reducing harmonic interference and consequently improving operational quality and energy savings. Kim et al. [25] compared the economic benefits of using EV with and without V2G with the traditional ICE engines. They found that the use of V2G can increase the profit to the drivers by $4500 over the operational lifetime of the vehicle ($210 per year). This reduces the cost of ownership by more than 6% in comparison with non-V2G scenario. However, the cost was still found to be higher than traditional ICE engines by approximately 10%.

Mathiesen et al. [26] extended the concept of integration of power systems with V2G and also included the heating and thermal, gas and fuel grid systems into the system. They referred to such systems as the coherent smart grid systems. They argued that solutions focusing on single sector of energy are sub-optimal and integration between all areas of energy sector is important for sustainable long-term solutions. However, the design and operation of this requires caution and considerable effort. On the other hand, care has to be taken to avoid the issue of induced demand in such a system.

Nworgu et al. [27] stated that the current electric grid system has shifted from a centralized model to a decentralized model with V2G integration. They studied the economic benefits of using V2G in different operational scenarios. The scenarios included the use of V2G for ancillary service power supply, releasing energy source into the system and the impact of their location and capacity. They emphasized the need for such study for the whole system to realize the potential impacts of such technology. V2G technology was found to be economically feasible in their study; however, they mentioned that economic costs and benefits may change based on system configuration and operational practice. They also pointed out the need to extend this study to include the effects of improved voltage profiles on inducing energy demand and consequently increasing energy sales.

## 2.3. Economic issues

The economic issues, associated with the traditional liquid fuel, have been evident with the fluctuation (largely inflation) of its prices with the increase in demand. Srivastava et al. [28] rightly pointed out that the use of EV, coupled with the V2G technology, can help to stabilize the fuel economy. In spite of this positive impact on fuel price stability, there are concerns over the economic issues associated with this technology within the industry [29].

There were concerns over the degradation in the life of battery of vehicles and grid infrastructure. However, it has been argued that the long-run economic benefits outperform this degradation in operational life [30]. These benefits can be maximized by the standardization in infrastructure decision-making and battery manufacturing technologies [31]. The electrification of the current vehicle fleet could be a challenge in this standardization of policies. For most countries, the complete electrification of vehicle fleet is still a very far-fetched idea [4].

In the context of expanding the EV fleet, the economic subsidies to encourage, and subsequently higher investment in the infrastructure development to support the expansion are some of the vital steps required from the governments and their partners [32]. Other important factors, which influence the realization of the full economic potential of V2G technology and require government intervention, are the charging/discharging strategies and vehicle aggregation [33]. Intelligent scheduling and coordinated charging are recommended for efficient operation of this technology [34]. Other economic strategies include off-peak charging, and delayed charging [35].

There have also been case studies in which the capital investment on the implementation of technology could be very high for areas which are geographically isolated, such as Western Australia. The findings are true for most of the variants of the V2G technology [36].

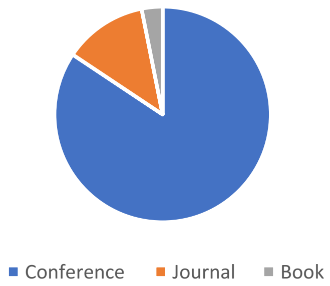
## 3. Bibliometric Analysis

In this section, the articles reviewed for this study summarized according to their sources and topics. It should be considered as a comprehensive picture of the research published in this field because the scope of this article focused on the determination of challenges and opportunities rather than providing an exhaustive literature review. Hence, the research which showed the progress in this V2G technology has been filtered to select that which pertains to the existing opportunities and challenges.

The literature search was mainly done using Google Scholar as it contains results from all the major research platforms (such as ScienceDirect, Scopus, etc.,). Some other renowned sources were also considered to track and review the articles, which were linked to Google Scholar, to access the full text of the article. These sources included sciencedirect.com, researchgate.net, and academia.edu. The keywords used for research included "autonomous vehicles, vehicle to grid, renewable energy, electric vehicles, challenges, opportunities, Bahrain, car ownership, fuel consumption, energy consumption, implementation". The search was done using these phrases uniquely as well as in combination. The search was conducted in two phases, firstly, without any time restrictions and then by restricting the time to last five years (2018 onwards). The papers were filtered according to their date of publication by discarding any paper published before the introduction of V2G. References related to books were not preferred to be included in the review. It was due to the fact that research articles provide much-advanced version of the information in a more summarized manner, compared to books.

There are 44 references which have been selected according to their relevance for this research. Out of these 44, 40 are from refereed journals, 4 are published in conference proceedings while there is only one reference from a book, as shown in Figure 1. Another important aspect to note is that the journal articles are published in journals which are dedicated to research related to certain aspects of energy. The keywords "clean" and "renewable" often appear, associated with energy, in the title of these articles. This clearly shows the clear emphasis on the topic of energy conservation and consumption among researchers at the highest level.

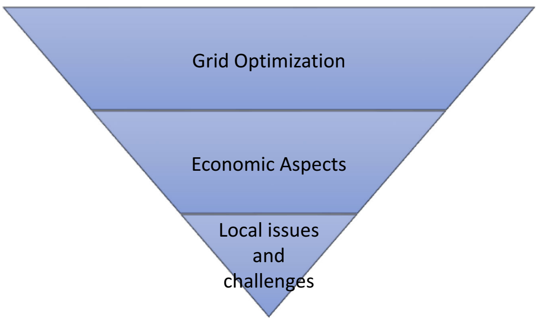
**Figure 1**
**Distribution of references with respect to sources**




The conference articles were found to be published in conference proceedings which were related to simulation or technology, in general, and not dedicated to the energy conservation sector. Hence, this shows the need for better organization of platforms to share new ideas related to this field. The absence of book references could be indicative of the lack of efforts to combine the body of research and state-of-the-art available in this field. It could also be related to the need for standardization of different aspects of this field which has been presented in the proceeding section as a challenge.

With regard to the topics or the focus of the research, most of the articles were found to be dealing with the optimization algorithms for creating the smart grid system. Then, there was a body of research dealing with the economic aspects of V2G technology. There is a clear lack of emphasis on studies which focus on certain regions and their specific issues with regard to the implementation of this technology. This distribution is shown in Figure 2. Such a lacking justifies the need for the present research of this article.

**Figure 2**
**Distribution of research with regard to the scope**




## 4. Opportunities and Challenges

The review of literature in this field has resulted in the identification of the following opportunities and challenges for V2G technology.

### 4.1. Opportunities

1) Reduction in $CO_2$ and other harmful emissions associated with ICE technology.
2) Energy independence in the form of less reliance on fossil fuels.
3) Adding in the renewable energy sources, especially to cover the fluctuations due to insufficient power of these sources.
4) Low capital cost compared to generation systems.
5) Avoiding the cost on developing excess power generation system for renewable energy sources and system upgradations.
6) Providing extra benefits to EV users through utility subsidies.
7) Passenger cars which have the highest proportion in the traffic stream have the lowest operating costs and provide the highest charging/discharging capabilities.
8) Variable charging rates which can be adjusted according to system capacities and loading.
9) Stabilization in liquid fuel prices.
10) Long-run economic benefits for vehicle owners and infrastructure operators through smart charging strategies and vehicle aggregation.

It could be observed that the beneficial opportunities with this system are mainly due to the fact that V2G technology can be implemented without high cost to infrastructure. Another important aspect is the mutual benefit to the authorities as well as individual users.

### 4.2. Challenges

1) Higher capital costs for car users as compared to the traditional vehicles which hinders its utilization for mass-scale use.
2) Potential overloading of the system.
3) Optimization of charging location and capacities.
4) Integration with the existing system(s) and energy resources including renewable and non-renewable sources.
5) Optimization of charging schedule.
6) Increasing the efficiency of vehicles and the battery charging/discharging capabilities.
7) The implementation of operational configurations for the system with V2G integration.
8) Understanding the dynamic behavior of electric system with the integration of V2G.
9) Minimizing the use of non-renewable energy resources and its cost through the design of smart grid system.
10) Development of smart control, communication, and metering system.
11) Avoiding over-utilization of energy resources due to voltage profile improvement with V2G technology.
12) Supporting V2G integration through policies, subsidies, and infrastructure development.
13) Standardization of and electrification of vehicle fleet.
14) Research on examining and addressing the issues related to different regions for the implementation of V2G technology.

The challenges for the implementation of V2G technology are mainly related to the ongoing development in this area. This hinders the process of standardization and increases the risks associated with the use of any new technology which is in the developmental phase.

### 4.3. Important questions for future

In light of the review done in this study, the following questions have been identified that should be focused on for future academic and industrial efforts in the field of V2G technology.

1) What could be the effective measures to encourage users and entrepreneurs to be part of implementation of V2G technology?
2) How would the governments collaborate with the private sector to standardize vehicle technology in this fast-paced era of development?
3) How could countries like Bahrain, who are far behind in the adoption of EV and V2G technologies, can benefit from practical examples and technology development to speed the pace of their growth towards sustainable energy generation and management?

## 5. Bahrain Scenario

Bahrain still relies heavily on fossil fuel sources for its transportation as well utilities. This consumption has been on the rise with a rate 3 times higher than the global average [37]. This has resulted in an annual increase of 8% in $CO_2$ emissions [38]. Moreover, the road transport efficiency index is also lower than many other countries including neighboring Arab countries [37]. However, it has a lot of potential for renewable energy sources, especially solar energy. This is the reason that the public sector has been planning to invest heavily in this resource. On the other hand, the trend of car ownership is on a rise with more preference for newer vehicles. The feasibility of V2G technologies in Bahrain and their potential to complement the transition towards solar energy systems is supported by the aforementioned factors. There have been proposals and research done to design systems for the use of solar and wind energy, but these efforts have not resulted in any large-scale projects [39]. Furthermore, given the small size and population of Bahrain, the adoption of this technology can be accomplished relatively swiftly. It has been estimated that the use of such measures has the potential to reduce the emissions by as much as 22% in a short term [40].

Despite the above opportunities, the challenge is to create awareness among the general public and administration towards the potential benefits of this technology. This is also compounded by the fact that electricity and fuel are still available at a relatively low price in Bahrain. Moreover, a lot of planning and design is to be carried out even after the decision is taken to adopt this technology. Presently, the use of renewable energy resources as well as EVs is not visible in Bahrain so the whole system has to be built from scratch as well.

Recent research shows that the use of hybrid and renewable energy is still not common in Bahrain, even in other sectors including electricity consumption [41]. There is enough evidence available to suggest that a shift towards latest hybrid energy solutions (such as solar energy and V2G technology) will open new business opportunities and will be equally beneficial for consumers as well as economic sector in Bahrain [42]. Furthermore, the recent environmental issues such as greenhouse gas emissions and global warming have been reported to significantly influence Bahrain and other countries in the Gulf region [43]. This also adds to the urgency of implementing the latest technologies and systems for fulfilling the energy demand.

As a way forward towards the large-scale implementation of V2G technology, the first step has to be the promotion of EV in the country. It could be done by facilitating the import, manufacturing, and purchase of these vehicles with tax rebates and subsidies. Awareness campaigns could also be carried out for the general public to realize their environmental benefits. These factors have been highlighted by Shareeda et al. [44]. Furthermore, these actions should be complemented by the development of infrastructure with regard to charging of these vehicles. The success of V2G technology is only possible with a large number of EVs running in the country. In this regard, Bahrain has the advantage of learning of examples of other countries who have already made progress in the development and implementation of this technology. The current study has already highlighted such examples and the lessons learned from them, in the above sections.

## 6. Conclusions

The study was aimed at providing an overview of V2G technology and the opportunities and challenges offered by its implementation. Furthermore, its implementation for Bahrain is also discussed.

The literature suggests that the energy sector is the main focus of researchers. Nevertheless, there appears to be a deficiency in forums for introducing and debating novel ideas, as well as for establishing them as standard practices in the form of book publications. The opportunities, presented by the implementation of V2G technology, include the reduction in fossil fuel consumption, emissions, catering to the needs of the private cars which have the largest share of transportation modes, and benefitting from the variable charging demands. The challenges for this technology include reducing or managing the higher capital costs, optimization of grid loads, lack of research, and possible over-utilization of energy resources.

From Bahrain's perspective, V2G technology may help to curtail the fuel emissions due to excessive usage of car. Furthermore, the climatic conditions of Bahrain are suitable for the transition of national grid to solar energy and utilizing it for charging systems. However, there is a lack of research and awareness related to this technology among the researchers and practitioners.

The economically successful implementation of V2G integration requires support from the government through subsidies, policies, infrastructure expansion, and standardization of battery technology and infrastructure investments.

## Recommendations

The outcome of this research clearly identifies the need to invest more resources in the optimization of grid system, strategies to reduce the capital costs of V2G systems, and measuring and increasing awareness about these systems. The findings of this research are expected to provide valuable insights to policy makers and government bodies to devise effective policies and implement V2G technology. Furthermore, it can also be used to set directions for future research and development. The literature clearly shows a lack of tackling local issues for specific regions, which should be pursued for future research.

## Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

## Data Availability Statement

Data sharing not applicable – no new data generated.

## Author Contribution Statement

**Uneb Gazder:** Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization.

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