Benefits, Barriers, and Human Factors of V2X Implementation – A Brief Review

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Abstract. To achieve the decarbonisation of the transport sector, a mass roll-out of electric vehicles (EVs) is crucial. Transport decarbonisation, however, poses significant pressure on the existing electrical grid to meet the peak demand of charging these electric vehicles. The concept of vehicle-to-everything (V2X) will aid the entire power grid through various applications, including vehicle-to-home (V2H), vehicle-to-building (V2B), vehicle-to-load (V2L), vehicle-to-grid (V2G), and vehicle-to-vehicle (V2V). V2X technology allows electric vehicles to interact with the power grid and other devices, providing flexibility and support to the energy infrastructure. This paper presents a brief review of the benefits and barriers of V2X deployment, as well as the challenges and potential solutions related to human factors in its implementation. In addition, the benefits of V2G to the UK electricity market are discussed. By examining these aspects, this paper aims to provide insights into how V2X can be effectively integrated into the energy and transport sectors to support sustainable development and reduce carbon emissions.

Keywords: Electric Vehicle (EV), Vehicle to Everything (V2X), Benefits, and Human Factors.

1 Introduction

Electric vehicles (EVs) are becoming increasingly popular since the last decade because of climate change problems and environmental regulations, hike in energy costs and the supply challenge with fossil fuels. In response to increasing demands on EVs, automobile manufacturers have added more models to their lineups. During the 2020 outbreak, the world vehicle sales declined by 16%, but the registration of EVs raised by 41% [1]. Across Europe in 2020, the EVs registered had an increment of 141% against the previous year [2].

EVs are conventionally viewed as electrical loads connected to electrical network. This implies the charging of these vehicles from the grid is the predominant part of the power flow. It was illustrated in [3] that EV charging through a grid powered home will substantially increase homeowner energy tariffs. EVs' large batteries and their high charging power, on the other hand, have made it more difficult for the electric grid to adequately meet their energy demand. An EV power flow in both directions is a key method for not only mitigating the impact of charging EVs, but also supporting the grid.

An EV can be charged or discharged at home or at a charging station through bidirectional power flow control. Vehicle to everything (V2X) is an approach to electrifying residential and commercial buildings, other electrified cars, and the grid by using the energy from EV batteries.

V2X technology can help EVs reduce electricity costs, regulate frequency, shift loads, control voltage, and arbitrage energy. The International Energy Agency (IEA) regularly share information about the latest progress in V2X [4]. Stakeholders should engage in market, social, and technological activities, according to the report. The approaches, processes, and technologies of V2X were reviewed in [5]. [6] examined the performance of V2X energy services and found that deferred payments and fee administration are more beneficial than spinning reserves. Authors in [7-8] discussed some difficulties associated with the deployment of V2X. An implementation of V2X was proposed in [9], examined the driving distance anxiety, electric market data, and charging station site to EV drivers. A study was conducted in [10] to determine the financial impact of battery degradation for EVs with lithium-ion batteries participating in V2X. The paper also investigated how several battery energy management strategies for various V2X applications. It was not discussed in the literature what measures might be taken to overcome the barriers to integrating V2X.

The emphasis of this paper is to review the potential benefits and barriers of V2X, and the potential measures to address the human factors affecting the deployment of EVs for V2X. The contributions of this paper include a brief review of the following:

1. Benefits of V2X, with a focus on the UK markets.
2. Barriers posed by the human factors and strategies for overcoming these barriers.

The advantages of deploying EVs for V2X as well as V2G in the UK markets are presented in sections 2 and 3. Section 4 discusses the challenges and remedies of human factors in the use of EVs for V2X, followed by the conclusion in section 5.

2 Services and Benefits of V2X

The concept of V2X helps to harness extra benefits of electric vehicle batteries during their non-use periods. By providing benefits to the electricity network, reducing the energy consumption of residential and commercial buildings, or providing energy support to loads, V2X services produces income from the battery facility by engaging bidirectional power flow. To offer System Operators and key stakeholders with much needed flexibility for the practical functionality of the electric network, energy services are defined as providing dynamic charge control as accumulated flexible size in the bulk and secondary Services outlets.

2.1 Spinning reserves

In case of an unforeseen event owing to the loss of power supply, to meet load demand, an additional available power generating unit is required. This additional generating unit to keep demand and supply balanced is known as spinning reserves [10]. This service is not a regular but rather occur seldomly. This results in the providers remunerated for having supply capacity in hand and as well as responding to issued demand signal. According to the record of the PJM system in the US, they occur at intervals of 20 to 50 [11-12] times annually. The spinning reserve is a service that EVs could participate in conditions when battery degradation is a major issue for EVs [13].

2.2 Energy Arbitrage and Related Services

In energy arbitrage, energy is purchased at an affordable price and sold at an expensive price. Price variation can be utilized to offset power losses and running costs inherent in energy storage, and it is possible to profit from energy storage. Using a retail 'time-of-day' or real-time energy price model, this can be employed at the retail point. Residential customers have access to real-time retail pricing in some jurisdictions, while large industries could access more frequently. While it is one of the most straightforward operational schemes to execute, it also has the tendency to be very complex in terms of results [14].

2.3 Renewable Energy Integration

Electrification of the transportation sector presents one of the most compelling opportunities, as well as the highest means of actualizing carbon emission reduction in the global energy systems. Due to the networked nature of electricity, it is difficult to determine which load receives green electricity, but several investigations have highlighted the tendency of intelligently coordinating electric vehicles to maximize the usage of intermittent renewable energy sources (RES) [15].

2.4 Load Management

An array of several goals can be accomplished by a load management system, which is a very broad term. Several studies, including [16], examine the feasibility of integrating photovoltaic plant with V2H energy storage and V2H with a hybrid EV. Essentially, they want a house to operate without grid power for the longest amount of time possible. By using a variable operational horizon of up to 10 years, [17] attempts to reduce electricity tariffs in a more holistic manner.

2.5 Frequency Control

Whenever there is a power imbalance between power generated and demand, particularly for ac power systems, the frequency component of the system deviates from its rated value resulting in the market demanding a swift supplier response to restore the frequency to its nominal value. This phenomenon of quickly restoring the system frequency is known as ‘frequency control’. Battery energy storage system can participate in providing this service, since their response time is within the response requirement of this service [18-19], which is usually issued in two- to five-second time steps, with response times generally not exceeding a few minutes. In addition, frequency regulation markets are increasingly focusing on quicker response, that respond to schedules and with commitment to control signals not viable with synchronous generators. In light of the highly competitive transaction prices for the Frequency Regulation (FR), early V2X work assumed the preferred service for vehicle batteries would be Frequency Regulation [20].

2.6 Voltage Regulation and Power Factor Improvement

Certain types of equipment can be affected by deviations from a perfect sinusoidal voltage and current profile over a certain period. There are a variety of types of grid-connected loads that can affect Power Quality, including those that introduce harmonics. Therefore, power quality throughout the grid can vary based on distribution systems' spatial scales. A power enhancement service is one that monitors the voltage and current quantities locally and corrects alterations by accurately timing power inflows or outflows within a fraction of the time it takes for voltage to cycle. The authors in [21] developed a sensitivity matrix to examine the possibility of EVs supporting voltage levels. In addition to examining cases where users consider only local impacts, as well as cases where users consider all impacts.

2.7 Summary of Potential Services

In Table 1, all the services that V2X can participate in are listed. It is important to note, however, that these benefits are only available if aggregators can meet the requirements for market participation in terms of power rating, response time, and service duration.

3 Benefits of V2G from UK Markets

EVs can participate in a variation of balancing services in the existing UK market, including demand flexibility services, frequency response services, and balancing reserve services. Aside from this, electric vehicles can also help the power sector reduce wind curtailment expenses through their participation in the wind curtailment market. The following content will elaborate on detailed market information and potential benefits.

3.1 Demand Flexibility Service Market

The ESO introduced the Demand Flexibility Service (DFS) for the winter period in 2022. With the emergence of the Demand Flexibility Service (DFS), the ESO will be able to utilize extra flexibility when national consumption is peak particularly during winter – a period that is not presently available to it in real time [22]. In this novel service, users will be rewarded for actively altering the period of electricity usage. During the winter of 2023/24, the ESO will conduct 12 tests between November and March 2024.

Table 1. Potential benefits from V2X.

Service	Definition	V2G	V2B	V2H	V2L
Frequency Regulation	Maintaining the grid frequency within the designated range through charging and discharging.	√			
Energy Arbitrage	At cheap tariff periods, EV battery is charged, while at high tariff it is discharged.	√			
Spinning Reserves	Maintain electricity balance by discharging or charging in response to grid contingencies.	√			
Peak Shaving	Discharge at peak hours to reduce demand.	√			
Renewable Generation Integration	Charge to absorb excess renewable generations.	√	√		
Reactive Power Support	Adjusting reactive power output to assist the grid in maintaining voltage balance.	√	√		
Network Deferral	Reduce consumption or increase generation at peak to meet projected load growth in capacity-constrained areas.	√	√		
Backup Power	Supply emergency power in event of outage.		√	√	

According to [23], the National Grid has offered up to £5/kWh or £5000/MWh as incentives for decreasing demand. Although the pricing for the actual implementation phase of this service is uncertain, we have considered a price range of £1/kWh to £5/kWh. Based on the data released by the ESO [24], demand flexibility service (DFS) primarily occurs between 9:00am and 10:00pm and 17:00pm to 19:00pm. Therefore, EV users have significant potential to arbitrage this market by flexibly adjusting charging and discharging times.

3.2 Wind Curtailment Market

Wind farms supported by government green subsidies might be paid more for switching off their turbines than generating power. Current constraints in the transmission system and a lack of long-duration grid storage often mean that the UK is producing more electricity from wind power sources than it can use. The only way to manage the grid imbalance, which happens when renewable power generation outstrips demand, is to curtail wind power [25]. The report by financial think tank Carbon Tracker [26] warns that grid enhancements are being surpassed by wind projects in the pipeline. The problem might cause the cost of inaction more than triple by 2030, amounting to £3.5bn annually and losing higher than 20% of wind generation in Scotland resulting in an extra £200 per household. Due to the flexible charging demand of EVs, they have the ability to have a substantial impact in reducing wind curtailment. UK Wind Curtailment Monitor [27] provides daily wind power curtailment information in the UK, along with the associated curtailment costs. In this regard, the f statistics on wind power curtailment during the period from September 2022 to September 2023 is illustrated in Fig. 1.

3.3 Environment Benefits

The environmental benefits brought by electric vehicles mainly manifest in their utilization of renewable energy sources to reduce carbon emissions originating from the electricity grid. According to [28], the current average carbon emissions from the UK's electricity grid are 157.33 grams of CO_2 per kilowatt-hour consumed. If electric vehicle users can adjust their charging times to coincide with periods of ample renewable energy availability, it will be beneficial in reducing carbon emissions originating from the power sector. The carbon factor and carbon price from 2024 to 2050 can be shown in the Fig. 2.

3.4 Frequency Response Service Market

According to recent Dynamic Response Services Provider Guide of the ESO, the provision of dynamic frequency response services for the power grid needs to meet the following requirements [29]:

- For each response unit, a minimum of 1 MW is required.
- Automated triggering is necessary from supply or demand, or energy limited re source like the battery.
- Energy restricted resources must meet with the “level of energy” governance rules.
- Service execution is conducted within four-hour EFA Blocks.
- Purchase requests may only be made in MWs.
- Submitted quotations need to have a minimum period of validity of 4 hours in accordance with EFA blocks.
- Tenders must therefore only commence, and finish, at the given periods: 23:00, 03:00, 07:00, 11:00, 15:00 and 19:00.

Considering the flexibility of scheduling charging and discharging during idle times of electric vehicles, EVs have the capability to participate in services such as Dynamic Containment High (DCH), Dynamic Moderation High (DMH), Dynamic Regulation High (DRH), Dynamic Containment Low (DCL), Dynamic Moderation Low (DML) and Dynamic Regulation Low (DRL) frequency response services to the grid.

According to the dynamic containment, regulation, and moderation auction results of the ESO [30], from Sep 2022 until now, the average prices for DCH, DMH, and DRH are £3.68, £4.3, and £2.41, respectively. The average prices for DCL, DML, and DRL are £2.82, £2.01, and £8.79, respectively. The price information and cost benefits on frequency response services are highlighted in Table 2.

The summary of the environmental, social, and economic benefits of V2G to the different stakeholders is presented in Table 3.

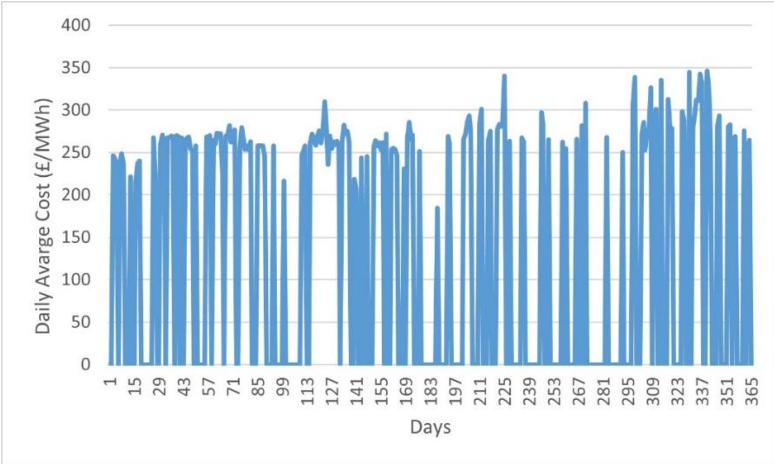

Fig. 1. Wind curtailment price from September 2022 to September 2023.

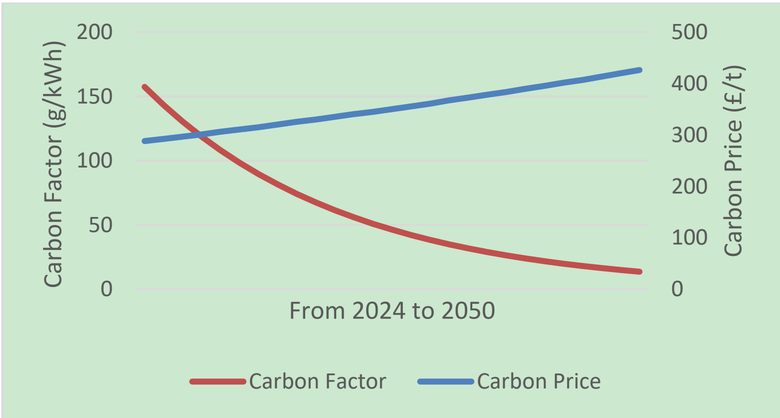

Fig. 2. UK carbon factor and price from 2024 to 2050.

Table 2. Frequency response services clearing price information.

Services	Maximum Price (£)	Minimum Price (£)
DCH	35	0.01
DMH	12.5	0
DRH	52.9	0
DCL	45.5	0.01
DML	7.04	0
DRL	55.99	0

Table 3. V2G benefits to the UK market.

Service	Beneficiaries	Environment Benefit	Social Benefit	Economic Benefit
Demand Flexibility Service	EV Users; Power sector		√	√
Frequency Response Service	EV Users; Power sector		√	√
Wind Curtailment Market	Power sector	√	√	√

4 Human Factors

There are many technical challenges that need to be overcome before wide-scale V2G applications can be used. However, many studies in this field concentrate only on the technical side. The field sampled by Sovacool et al. [31] only accounted for 2.1% of papers addressing user attitudes and activities, and 1.1% of papers addressed range anxiety. In spite of a general lack of interest, user behaviours and routines play a crucial part in how V2G will be successful in its implementation.V2G applications can face social and practical challenges (availability of vehicles for V2G events, predictability of users, behavioural incentives). Evidence for V2G applications can be gathered by examining user routines and vehicle use patterns. V2G services can significantly affect load management in different building types by vehicle usage patterns, battery state on arrival, and preferred charging status on leaving [31]. Usage patterns can also inform public charging infrastructure planning [32].

The "human factor" is a valuable component of V2X system of electric vehicles. Among these factors are the driver's preferences for vehicle charging, acceptance of new technologies, and concerns about data security and privacy. To ensure the effectiveness, acceptability, and safety of V2X technology when designing and implementing it, these factors must be taken into consideration when designing and implementing it.

4.1 Aspects of Human factors

In the context of V2X regulation, the various aspects of human factors with their challenges are discussed below.

Charging Behavior. V2X is affected by plug-in rate, or the percentage of time an EV is plugged into a charging point. EV users in [33] charge several times, whereas in [34], 30% charge when their batteries run low. This difference demonstrates that incentive initiatives encourage users to charge. Commercial fleets are better suited to V2X because they have established routines and are parked at one location, which minimizes infrastructural costs and supports smart charging solutions [35]. In contrast, domestic vehicles do not have a predefined schedule, resulting in variations in mobility needs.

Charging behavior has a significant impact on electric vehicle dispatch. Depending on user preferences, charging stations may be overloaded during certain periods and underutilized during others [36]. With the expectation for smart charging facilities, V2X applications can improve efficiency and user experience, optimize electricity resources through predictive scheduling, and V2G and V2H applications can be made more practical and attractive.

Acceptance of New Technologies. Several factors influence user acceptance, including awareness and understanding, perceived benefits, ease of use, and privacy [37]. The user-friendliness of the technology, including the intuitive design and accessibility of V2X services, will result in improved user satisfaction and usage rates. Concerns regarding the collection and use of personal information, as well as whether the technology is secure, may cause hesitation and slow down the adoption of the technology if it is not adequately addressed.

Concern for Data Confidentiality and Security. The security of data is one of the major significant determinants that influence people's decisions. How their information is stored, protected, and used also influences how they participate in V2X [38]. A lack of clear privacy policies and practices for handling personal data may discourage user adoption in V2X. Hacking, unauthorized access to vehicle systems, and data breaches are possible risks to V2X adaptation. To maintain user trust and integrity of the system, V2X communication requires robust security measures. Data sharing, access control, and anonymity of vehicle and driver information are also important considerations to be addressed to avoid hindrance to the adoption of V2X.

4.2 Measures to Overcome Human Factor Barriers

To overcome the human factor barriers, several strategies are recommended as discussed below [38]-[40].

User Education and Engagement. Educate users about the importance of efficient charging behaviors and motivate them to engage in demand-response initiatives or use mobile apps that provide information on optimal charging times. Engage users through incentives such as discounts for off-peak charging or rewards for energy-efficient driving. In addition, effective communication and public relations are essential for fostering long-term acceptance of V2G. Accurate information about the benefits and risks associated with V2G needs to be communicated clearly to enhance general acceptance.

Data Analysis and Predictive Modeling. Utilize data analytics and predictive modelling to understand user behavior patterns, such as charging habits and driving preferences. This information can help optimize dispatch strategies and anticipate peak demand periods.

Dynamic Pricing and Incentives. Implement dynamic pricing schemes at charging stations to encourage users to charge during lower demand hours. Offer incentives such as discounts or loyalty rewards for users who comply with dispatch recommendations or exhibit energy-efficient driving behavior.

Driver Training and Feedback. Provide training programs for drivers on energy-efficient driving techniques and the effects of driving habits on vehicle range and battery life. Offer real-time feedback to drivers through in-vehicle displays or mobile apps, highlighting areas for improvement and incentivizing eco-friendly driving practices.

Optimization Algorithms and Decision Support Systems. Develop advanced optimization algorithms and decision support systems that consider human factors alongside technical constraints when dispatching electric vehicles. These systems can dynamically adjust dispatch plans based on user behavior, traffic conditions, and charging station availability.

User-Centric Design. Design user interfaces for electric vehicle dispatch systems that are intuitive and user-friendly, providing relevant information such as charging station locations, availability, and real-time energy prices. Solicit user feedback to continually improve the system's usability and effectiveness.

Strategy for Addressing Range Limitations. Because V2G applications primarily involve the discharging of electric vehicles, range anxiety may affect the acceptance of these technologies. To address the fear of losing control of their electric vehicle batteries' charging procedure, EV users are provided with control flexibility via a user interface when participating in V2G. In this user interface, users have multiple options to select their preferences rather than being confined to accepting V2G usage or opting out entirely. By selecting any desired charging mode along with certain targets such as state of charge (SoC), date and time, and charging/discharging rates based on electricity prices, the user can customize their charging preferences.

Communication System Interface. All EV preferences can be integrated into the user interface. It should be easy to operate and have touchscreen capabilities. This interface's home screen should provide the most relevant information and the different modes available. Additionally, the interface should provide a brief description of the various modes available. The interface should also be designed with the user in mind as well as the aggregator in mind. The SoC target will need to be converted into a range target that may be more useful to the user. Since the range target depends on the driving style and terrain covered by the driver, this estimate can be difficult to achieve. Depending on the mode selected, an additional window for SoC, date/time targets will appear. As soon as the user selects the appropriate option, it sends the desired information to the charging unit's microcontroller board.

5 Conclusion

This paper presents a brief review of the benefits of V2X and V2G in the world and UK markets respectively. Additionally, it discusses human factors related to V2X implementation, along with barriers and remedies. This review will be of benefit to manufacturers of electric vehicles, electric vehicle users, aggregators, and power system operators. V2X can benefit from several transmission and distribution network services like frequency regulation, spinning reserves, voltage support, energy arbitrage and renewable energy integration. V2G can enhance UK energy markets by providing demand flexibility services, frequency response services, and wind curtailment. These various services benefit the EV user and the power system operator. Human factors barriers have been discussed, along with measures recommended for addressing challenges associated with charging behaviour, acceptance of new technologies, and privacy and security concerns.

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