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Project Template

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Project title

**Integration of Electric Vehicles for Grid Support in Urban
Environments: A Case Study of Amman**

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1. Chapter 1: Introduction

1.1. Research Background

The increase in GHG emissions is a significant global concern. Excessive costs and substantial energy waste from voltage regulation, daily load demand fluctuations, and frequency adjustments are the main reasons why the operational efficiency of power grids is still unsatisfactory. In times when the amount of energy required surpasses that which can be supplied by baseload power plants, peak load plants come into operation. Conversely, on days with minimal electricity needs, unwanted energy from baseload generators ends up as waste. Also, Voltage/frequency control of this nature has high operating costs.

This issue can be solved through Vehicle to Grid (V2G) technology that uses electric vehicles (EVs) extensive energy storage capacity as a buffer for both power grid and renewable sources of electricity. EVs can be attached to the smart grid in V2G or G2V modes. The vehicle-to-grid involves the flow of energy from EV to the grid, while grid-to-vehicle mode involves movement of electric charges from the grid to the EVs.

Smart grids and V2G systems are interconnected and have a symbiotic relationship between them. An important function is played by AC to DC (and vice versa) conversions during energy exchange processes. Energy storage systems in electric vehicles become very useful when exchanging electrical power with a grid system. As an example, when grid demand goes down sharply, the cars can take on extra energy overloads which in turn help to reduce power plants strains.

Electric vehicles can store excess electricity during low network load demand periods to avoid wastage. When prices drop, purchasers of EVs may prefer to import power from the distribution companies only to sell them back during peak periods at high costs, thus providing a chance for gains.

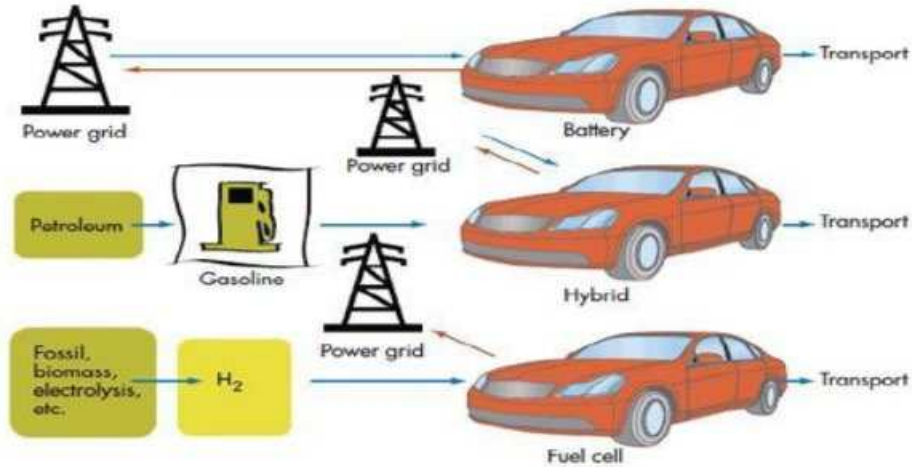


Fig. 1: The schematic diagram of V2G (Harighi et al., 2018).

1.2. Research Problem

The main research issue that this project focuses on is about the integration of Electric Vehicles (EVs) into Amman's urban power grid while considering theoretical and practical challenges:

1.2.1. Theoretical Gaps

- Existing literature primarily focuses on technical aspects of EV integration for grid support, such as:
 - Modeling EV charging behavior.
 - Optimizing charging schedules
 - Analyzing impact on grid stability and power quality?

However, there are major gaps in understanding the business and management implications associated with integrating EVs, especially within urban areas like those in Amman.

- Lack of research addressing business and management implications of EV integration, including:
 - Development of viable business models
 - Assessment of economic feasibility
 - Analysis of policy and regulatory frameworks needed to incentivize EV adoption and V2G participation.

- Existing theories and frameworks fail to consider unique challenges and opportunities presented by urban environments, such as:
 - High population density
 - Presence of diverse stakeholders
 - Need for coordinated planning and decision-making.

1.2.2. Practical Gaps

- Rapid growth of EV adoption in urban areas can strain existing power grid infrastructure, leading to challenges in:
 - Grid stability
 - Peak demand management
 - Energy distribution

For instance, uncontrolled EV charging may cause voltage deviations, overloading of distribution transformers, and increased energy losses.

- Practical implementation of EV integration for grid support in urban environments is hindered by:
 - Lack of coordination among stakeholders (utility companies, EV manufacturers, policymakers, end-users)
 - Need for investment in infrastructure upgrades (smart charging infrastructure, V2G-enabled vehicles)
- Practical application of EV integration for grid support is limited by lack of clear policy and regulatory frameworks that incentivize EV adoption and V2G participation.

1.3. Research Significance

The findings of this study will contribute to the following:

1.3.1. At the theoretical level

At the theoretical level, this research project contributes to the existing body of knowledge on electric vehicle (EV) integration for grid support in urban environments by addressing the gaps in the current literature. The study provides a comprehensive analysis of EV integration's business and management implications, including developing viable business models, assessing economic feasibility, and analyzing policy and regulatory frameworks needed to incentivize EV adoption and V2G participation.

Moreover, the research extends the existing theories and frameworks used to analyze the integration of EVs for grid support by considering the unique challenges and opportunities presented by urban environments, such as the high population density, the Presence of diverse stakeholders, and the Need for coordinated planning and decision-making. By incorporating these factors into the analysis, the study offers a more nuanced and context-specific understanding of EV integration's potential benefits and challenges for grid support in urban settings.

1.3.2. At the practical level

- **Grid Optimization:** The study will provide empirical insights into the impact of EV integration on grid stability, peak demand, and energy distribution in Amman, enabling utility companies to develop effective strategies for optimizing grid performance and supporting renewable energy integration.
- **Economic Benefits:** The research will analyze the feasibility and benefits of V2G technology for grid support, energy trading, and peak shaving in Amman, potentially leading to cost savings for EV owners and utility companies.
- **Sustainability:** By proposing empirically grounded strategies for transitioning to a Smart Grid model in Amman, the study will enhance energy efficiency, grid resilience, and sustainability in urban settings, promoting a greener and more sustainable future.

- **Policy Implications:** The research findings will inform policymakers and regulatory authorities in Amman about the necessary policy and regulatory changes needed to incentivize EV adoption and V2G participation, thereby facilitating the large-scale integration of EVs for grid support.

This section addresses the study's theoretical and empirical significance, highlighting the research project's importance in advancing academic knowledge and informing practical decision-making in EV integration for grid support in Amman.

1.4. Research Questions

1. How can the urban power grid of Amman be updated to integrate Electric Vehicles (EVs) effectively to improve the stability and efficiency of the grid?
2. What are the managerial and business implications for using EVs as sources of power in cities like Amman?
3. What does the economic viability of Vehicle-to-Grid (V2G) technology mean for EV integration economics on support grids?
4. Which policy and regulatory frameworks should be established to encourage EV uptake and V2G participation in Amman?

1.5. Research Objectives

- Evaluate how the integration of EVs affects grid stability, peak demand, and energy distribution within Amman.
- Develop viable business models for integrating EVs into urban settings that focus on sustainability and economic viability.
- Assessing the financial viability of V2G technology in smart grids, electricity trading, and load leveling.
- Suggest policies and regulations supportive of electric car adoption and participation in Vehicle-to-grid services by JEA.
- To identify and address the unique challenges and opportunities related to integrating EVs into urban environments.

1.6. Research Hypotheses

- **H1:** Integrating EVs can significantly improve grid stability and efficiency in urban environments like Amman.
- **H2:** Develop viable business models for maintaining the grid's stability and economic feasibility in consideration of EV integration.
- **H3:** The utility companies' adoption of EVs and V2G technology in Amman would have significant economic benefits.
- **H4:** A substantial increase in EV adoption and V2G participation will result from effective policy and regulatory frameworks in Amman.
- **H5:** Urban environments demand a customized way to integrate electric vehicles successfully.

1.7. Research Model

The research model will investigate how dependent variables (grid stability, economic viability, EV adoption, urban challenges) are related to independent ones (integration of EVs, business models, V2G technology, policies).

1.8. Research Methodology

The power utility sector in Amman is recommended as the industry for empirical research on integrating electric vehicles into the grid to provide support. The study will include stakeholders such as Amman utility companies, end-users, policy makers as well as manufacturers of electrical cars.

1.9. Scope of The Study

Geographical Focus:

- Analyzing the urban power grid and investigating the potential of electric vehicle integration in Amman, Jordan.

Technological Integration:

- Exploring EV and V2G technology for supporting grid.

Marketability Assessment:

- Appraising feasibility of integrating EVs, and creation of an enabling business framework.

Policy and Regulatory Framework:

- Current policy review with recommendations on new guidelines to encourage the adoption, participation, and use of EVs.

Stakeholder Engagement:

- Data will be collected through surveys, interviews, and case studies from utility companies, electric vehicle manufacturers, and suppliers to such industries.

Environmental Impact:

- Evaluation Of Environmental Impacts and Challenges Associated with The Integration of Electric Vehicles on The Urban Grid.

Implementation Roadmap:

- Develop a roadmap that outlines how to incorporate EVs into the power grid, indicating key milestones and resource needs.

This research aims to offer a comprehensive analysis that will guide stakeholders in promoting sustainable urban development through integrating electric vehicles, thereby improving stability within the grid.

1.10. The Suggested Project Structure

Chapter 1: Introduction includes sections on Research Background, Research Problem, Research Significance, Research Questions, Research Objectives, Research Hypotheses, Research Model, Research Methodology, Scope of the Study, and Project Structure.

Chapter 2: Literature Review covers an Introduction, details on the Independent Variable (EV integration), the Dependent Variable (Grid stability, economic feasibility), the Relationship between Independent and Dependent Variables, and a Conclusion.

Chapter 3: Research Methodology discusses Research Design, Data Collection Methods, Sampling Techniques, Data Analysis Methods, and Ethical Considerations.

Chapter 4: Data Analysis and Results presents Descriptive Statistics, Hypothesis Testing, and Case Study Analysis.

Chapter 5: Discussion interprets the Results and explores Implications for Theory and Practice.

Chapter 6: Conclusion and Recommendations summarizes the Findings, offers Recommendations for Stakeholders, and suggests Future Research Directions.

2.Chapter 2: Literature Review

2.1. Introduction

The chapter extensively surveys Vehicle-to-Grid (V2G) technology and emphasizes its role in improving grid stability, economic sustainability, EV adoption, and mitigation of urbanization-related problems. V2G technology allows electric vehicles (EVs) to consume and supply electricity, enabling two-way energy flow between cars and the power system. This becomes more significant as the world integrates higher levels of renewable energy sources and gravitates towards sustainable energy solutions. It also shows how the independent variables can impact V2G technology, affecting its dependent variables.

2.2. The independent variable

2.2.1 Overview of Vehicle-to-Grid Technology

It is based on the concept that electric vehicles can both use and provide electricity. When prices are lower, EVs connected to V2G-enabled chargers can store energy and feed it back into the grid during high-demand times when rates are higher. Technology is vital for balancing supply and demand, given the penetration of renewable energy resources like solar and wind, which inherently vary (Virta, 2023).

The system incorporates advanced communication systems that allow real-time interactions between electric cars, charging points, and the grid. Smart chargers with complex software manage energy according to grid state, price signals, and each vehicle's specific needs. This enables secure data transfer and user authentication in the V2G process through ISO 15118 standards (Clou Global, 2023).

2.2.2 Electrical Vehicle Technology

Electric vehicles (EVs) have lately experienced enormous technological advancements that make them strong rivals for traditional internal combustion engine vehicles (ICEVs). Nations are encouraging EV adoption globally as a measure of reducing greenhouse gas emissions. For instance, Electric Vehicle Market in Jordan is expected to grow at a CAGR of 34.0% from 2019 to 2025. In Jordan, government initiatives like installing 3,000 charging stations and fiscal reliefs are stimulating the demand for electrical cars.

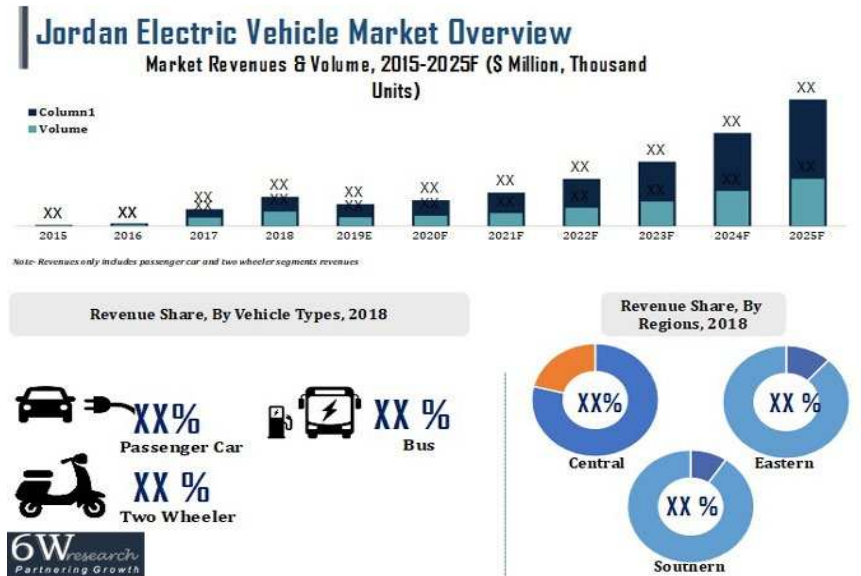


Fig. 2: Jordan Electric Vehicle Market Overview (Harighi et al., 2018)

The expansion of the electric vehicle (EV) market necessitates continuing research and development for wide EV adoption in days to come (Sarlioglu et al., 2017). Several types of EVs are available, including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), plug-in electric vehicles (PEVs), and battery electric vehicles (BEVs). This study concentrates on BEVs, which runs exclusively on battery power. The larger capacity batteries allow for more excellent range besides enabling compatibility with grid integration to use them as vehicle-to-grid (V2G) systems. Powertrain, energy storage systems (ESS), and charging infrastructure will be critical areas of EV development supporting future V2G scenarios (Yong et al., 2015).

2.2.2.1 Power Train

In an automotive system, the power train transfers drive from the engine to the axle. A battery electric vehicle (BEV) operates simply by using a battery as its power source, which is used for locomotion by an electric motor. The BEV power train consists of three main components: a battery, an electric motor, and a transmission. Figure 3 shows a basic power train diagram for a BEV (Sarlioglu et al., 2017).

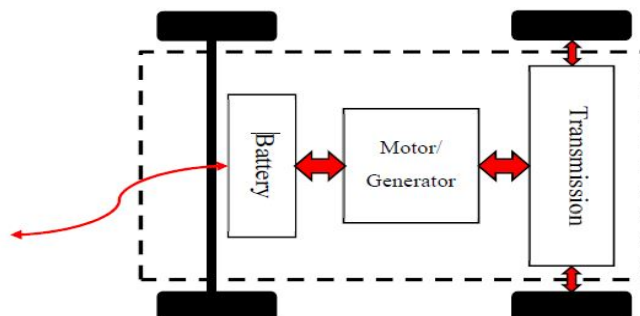


Fig. 3: Schematic diagram of BEV power train (Sarlioglu et al., 2017).

BEVs can be charged from external sources such as the electrical grid or regenerative braking (Ergon Energy,2017). This study's focus is limited provisionally to external charging techniques only and eliminates any reference to recharging batteries through regenerating braking in model construction.

2.2.2.2 Energy Storage System

As a car battery, the energy storage system (ESS) is integral to Battery Electric Vehicles (BEVs). At present, batteries are one of the costliest components of BEV technology. However, there are limitations to battery technology that have hindered widespread EV adoption in the transport sector. Battery technologies are the best suited to attracting global attention to electric vehicles concerning range, acceleration, and costs (Yong et al., 2015).

Ongoing research and experimentation have resulted in two main types of batteries for EVs: Nickel-Metal Hydride (NiMH) and Lithium-ion (Li-ion). NiMH batteries were used earlier, but this changed with the advent of Li-ion batteries, which revolutionized EV technology, enabling long-distance models and more powerful ones that can compete with traditional internal combustion engine vehicles (ICEVs) (Yong et al., 2015).

In today's market, major EV manufacturers utilize Li-ion batteries due to their being the primary Li-ion batteries user by leading manufacturers of electric cars today, including having longer ranges, higher energy densities, affordability, and being nontoxic, among other advantages. Moreover, Li-ion also enables fast charging, removing concerns about lengthy charge times (Yong et al., 2015). Such major brands as Nissan Leaf, Mitsubishi i-MiEV, Tesla Model S, and Chevrolet Bolt all feature Li-ion-battery-based ESS. Table I compares NiMH and Li-ion cell types used in BEVs.

TABLE I
COMPARISON OF NiMH AND Li-ION CELL TYPES IN EVs (SARLIOGLU ET AL., 2017).

	NiMH BEV	Li-ion Plug-in Hybrid EVs - BEVs
Nominal cell voltage [V]	1.2	3.3-3.8
Energy density [Wh/l]	250	200-400
Specific Energy [Wh/kg]	100	120-200
Power density [W/l]	500-800	800-2200
Specific power [W/kg]	200-400	500-1200

There are some disadvantages associated with Li-ion batteries, such as the potential for fire or explosion if they malfunction (Battery University, 2022). Although this technology is still

developing, it looks to be an ideal battery solution for future EVs (Yong et al., 2015).

2.2.2.3 Charging infrastructure

Rectifiers are commonly included in electric vehicle (EV) chargers, i.e., AC-DC converters. Furthermore, the DC-DC converter is also available in fast charging stations for better power conversion efficiency. The chargers can either be onboard or off-board depending on their configuration and the capacity of the charging (Yong et al., 2015)

The design of onboard chargers must be compact and lightweight to enable the effective movement of an EV. However, one problem is that they are low-powered, making them ideal only for slow charging. In contrast, off-board chargers usually occupy specific locations, thus being more significant due to the Presence of charger units incorporated with a rapid charger DC-DC converter (Yong et al., 2015).

Further still, there are global guidelines governing electric vehicles' recharging process. International Electromechanical Commission (IEC), Society of Automotive Engineers (SAE), and CHAdeMO EV standards, among others, are some of the bodies that influence these regulations. Table II refers to SAE charging levels per the SAE electric vehicle conductive charge coupler standard (Insideevs,2017).

TABLE II
SAE CHARGING STANDARDS (INSIDEEVS,2017).

Charging level	Charge rating	Charge time	Remark
AC level 1	120 V, 1.4 kW (12 A) 120 V, 1.9 kW (16 A)	PHEV: 7 h (SOC-0% to full) BEV: 17 h (SOC-20% to full)	On-board charger
AC level 2	240 V, up to 19.2 kW (80 A)	For 3.3 kW charger: PHEV: 3 h (SOC-0% to full) BEV: 7 h (SOC-20% to full) For 7 kW charger: PHEV: 1.5 h (SOC-0% to full) BEV: 3.5 h (SOC-20% to full) For 20 kW charger: PHEV: 22 min (SOC-0% to full) BEV: 1.2 h (SOC-20% to full)	On-board charger
AC level 3	> 20 kW, single phase and three-phase	To be determined	To be determined
DC level 1	200-450 V _{DC} , up to 36 kW (80 A)	For 20 kW charger: PHEV: 22 min (SOC-0% to 80%) BEV: 1.2 h (SOC-20% to full)	Off-board charger
DC level 2	200-450 V _{DC} , up to 90 kW (200 A)	For 45 kW charger: PHEV: 10 min (SOC-0 to 80%) BEV: 20 min (SOC-20 to 80%)	Off-board charger
DC level 3	200-600 V _{DC} , up to 240 kW (400 A)	For 45 kW charger: BEV (only): <10 min (SOC-0 to 80%)	Off-board charger

Table II and Figure 4 show that DC fast charging systems can allow electric vehicle (EV) users to charge their vehicles in less than an hour, with some systems taking as low as 10 minutes to charge. Presently, DC fast charging systems are available in two power flow configurations: from the grid to the EVs and vice versa (Wang et al., 2012).

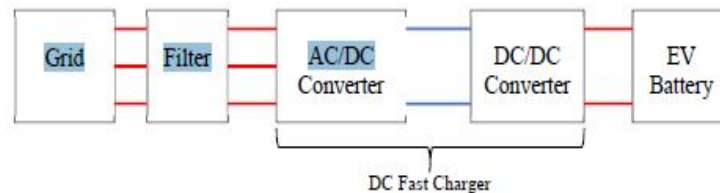


Fig. 4: Block diagram of DC fast charging station Wang et al. (2012).

The first kind is a unidirectional DC fast charger, which permits drawing power from the grid for recharging EV batteries. Its benefit is that it does not severely affect the battery life span due to lesser recharging cycles (Channegowda et al., 2015). However, these kinds of chargers cannot be involved in the V2G system when power from the car flows back into the grid. In contrast, bi-directional DC quick chargers work both ways by being able to both charge and discharge energy. Nonetheless, battery life is affected by bidirectional arrangement because more cycles are required (Channegowda et al., 2015)

2.2.3 Integrating Electric Vehicles

One of the core components of V2G technology is the integration of electric vehicles into the power grid. This integration enables EVs to offer support services, including load balancing and frequency regulation, necessary for sustaining power system stability (Bijan & Tekiner-Moğulkoç, 2021). By supplying energy during peak demands, EVs can ease pressure on conventional sources of electricity and the penetration of renewable energies (Sharma et al., 2020).

2.3.4 Business Models

The economics surrounding V2G technology determine its viability. Different pricing mechanisms, including time-of-use tariffs and dynamic pricing, can make participation in V2G more profitable for those who own EVs (Han et al., 2012). Innovative business models such as Product-Service Systems (PSS) can establish sustainable economic models that benefit all parties involved (IMET, 2020).

2.3.5 Policies

Government policies play a significant role in promoting EV adoption and enabling the implementation of V2G systems. Effective policy measures can provide fertile ground for the growth of V2G systems through financial incentives, subsidies, and regulatory support, among

other things (Maher & Collins, 2024). Clear legal frameworks are necessary to solve the operational and technical issues of V2G technology (Sovacool et al., 2009).

2.3. The dependent variable

2.3.1 Grid Stability

Grid stability is a significant dependent variable that is affected by how well electric vehicles (EVs) and V2G technology integrate. Electricity supply and demand fluctuation can be mitigated by EVs providing ancillary services that enhance grid reliability (Bijan & Tekiner-Moğulkoç, 2021). V2G, the vehicle-to-grid acronym, helps stabilize the grid by acting as a buffer that stores excess power when not needed during low-demand periods.

2.3.2 Economic Viability

Business models and policies affect the economics of V2G. Financial motivation for EV owners to sell off their extra energy back to the grid attracts them to participate in this kind of program instead of other programs (Han et al., 2012). Nevertheless, its overall economic possibility depends on market conditions and regulatory frameworks.

2.3.3 EV Adoption

Policies aimed at encouraging electric vehicles (EVs) and Vehicle-to-Grid (V2G) technology significantly impact EV adoption. Tax credits, rebates, etc., can encourage consumers to choose EVs instead of traditional cars, stimulating demand for V2G systems (Maher & Collins, 2024). For the successful rollout of decent V2G schemes, it is necessary to harmonize technological progress with policy steps.

2.3.4 Urban Challenges

Urban obstacles make integrating V2G technology into this area difficult. These include infrastructure limitations, varying energy demands, and the required efficient charging solutions (Gemassmer et al., 2021). Effective integration strategies and robust urban planning are needed to address these challenges.

2.4. The relationship between the independent and the dependent variables

The relationship between independent and dependent variables is more challenging but interdependent. Electric vehicles enhance grid stability when integrated into the network by offering vital services that control supply and demand imbalances. This ensures that V2G technology remains economically viable, as more EV owners will be attracted to participate in energy management programs if their grids are stable.

Business models based on V2G can offer financial incentives for EV owners, which can boost EV adoption. An increase in demand for V2G infrastructures and services follows a rise in consumer investments in electric cars, boosting these systems' economic feasibility.

Promoting EVs and V2G technology is one policy that can ease the integration of EVs into urban areas by dealing with infrastructure constraints and energy requirements. Effective policies can build a favorable context for the growth of V2G systems, which leads to grid stability and economic viability.

2.5. Conclusion

In summary, the interplay between the independent variables—integration of EVs, business models, V2G technology, and policies—and the dependent variables—grid stability, economic viability, EV adoption, and urban challenges—is crucial for implementing V2G technology. Understanding these relationships can inform strategies to enhance the effectiveness of V2G systems, contributing to a more sustainable energy future. Continued research and collaboration among stakeholders will be essential to unlock the full potential of V2G technology in addressing contemporary energy challenges.

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