BABEŞ-BOLYAI UNIVERSITY
FACULTY OF BUSINESS
SPECIALIZATION
BUSINESS ADMINISTRATION IN HOSPITALITY SERVICES

Bachelor Thesis

Electric Vehicle Battery Usage for Grid Stabilization - Web Application to Monitor and Analyze Real-Time Energy Production and Consumption

Scientific coordinator,
Conf. Dr. Mihaela-Filofteia Tutunea

Student,
Demeter I. Zsolt

Cluj-Napoca
2024

Contents

List of Acronyms and Abbreviations

V2G – Vehicle to Grid

EV – Electric Vehicle

AWS – Amazon Web Services

API – Application Programming Interface

NoSQL – Not Only Structured Query Language

UI – User Interface

kWh – Kilowatt-hour

EC2 – Elastic Compute

VM – Virtual Machine

HTTPS – Hypertext Transfer Protocol Secure

SSL – Secure Socket Layer

SSH – Secure Socket Shell

URL – Uniform Resource Locator

This study examines the relationship between electric vehicle (EV) batteries and grid stabilization and addresses the urgent need for sustainable energy solutions. It centers around the development of a web application aimed at real-time monitoring of energy consumption and production. Focused on the Romanian energy landscape, the research utilizes AWS Lambda, Python, Selenium, and MongoDB to integrate Transelectrica's real-time data into an intuitive user-interface. Objectives include gaining insights into electric vehicle batteries, V2G technology, and conducting environmental impact comparisons. The paper presents successful case studies and proposes future directions, highlighting advancements in battery technology, grid integration, and potential policy implications. The conclusion provides perspectives on potential beneficiaries and outlines future work, envisioning a roadmap towards a more environmentally friendly and resilient energy future.

Introduction

In an era characterized by global awareness of environmental issues and increasing demand for sustainable energy solutions, the intersection of electric vehicle (EV) technology and grid stabilization represents a promising frontier. As the world transitions to cleaner and more renewable energy sources, the contribution of electric vehicle batteries to grid stability is becoming a fascinating topic of research. This thesis addresses the complex relationship between electric vehicle batteries and grid stabilization, presenting a comprehensive examination of the opportunities, challenges, and implementation of V2G technology.

The increasing challenges caused by climate change and the exhaustion of conventional energy sources highlight the urgency of applying innovative and sustainable practices. Electric vehicles relying on advanced battery technologies have become a powerful force in creating a greener and more flexible energy environment. This study aims to investigate the feasibility of employing electric vehicle batteries for enhancing grid stability. By utilizing data from Transelectrica, the Romanian electricity transmission system operator, this projects goal is to provide a better insight into energy consumption and production trends, which in theory would help to stabilize the grid when the vehicle to grid concept will be feasibly.

The motivation behind this research comes from the need to strengthen the incorporation of renewable energy sources into the existing electricity infrastructure. As the world witnesses the adoption of electric vehicles, understanding the potential synergies between electric vehicle batteries and grid stabilization becomes crucial. In addition, the exploration of novel technologies such as V2G systems further motivates our efforts, as they represent a bridge between the transport and energy sectors, promising a more efficient and sustainable energy ecosystem.

The primary objectives of this current work are to:

- Provide a comprehensive understanding of electric vehicles and battery technology.
- Analyze the challenges faced by electric grids and establish the need for grid stabilization.
- Explore how electric vehicle batteries can be leveraged for grid stabilization.
- Examine the types of grid stabilization services that EV batteries can provide.
- Highlight the benefits of using EV batteries for grid stabilization.
- Investigate the application of V2G technology.
- Conduct a detailed methodology for the development of a web application to monitor and analyze real-time energy production and consumption data.

To achieve the outlined objectives, a systematic methodology has been employed. The focus is on the development of a web application, with a back-end script that uses AWS Lambda and Python to retrieve real-time data from Transelectrica. Selenium is used for web scraping and MongoDB is used as a database to store and access the collected data. The Express Node API facilitates communication between the backend and the frontend, and Angular is used to create an intuitive user interface.

The methodology includes data collection and storage, back-end development, front-end design, integration, functionality and data analysis. The development process includes deploying serverless features on AWS Lambda, seamless data flow, and creating an interactive user interface for powerful data visualization.

This paper aims to offer an in-depth examination of the connection between EV batteries and grid stabilization. The following chapters outline the background of electric vehicles and battery technology, the challenges facing electric grids, the potential of electric vehicle batteries to stabilize the grid, and the types of services they offer. The implementation of V2G technology is checked considering technical, economic, and environmental aspects. Case studies provide examples of successful applications, while future directions and innovations in battery use for electric vehicles are contemplated. The methodology outlines the development of a web application for real-time data monitoring, and the paper concludes with suggestions for future work and potential beneficiaries of the results.

The final beneficiaries of the research results are diverse. First, power grid operators can gain valuable insight into real-time power dynamics, enabling them to optimize grid performance and ensure stability. In addition, EV owners benefit from an incentive-driven approach that promotes responsible energy consumption habits and contributes to the overall resilience of the grid. Policy makers and environmentalists can use the results to inform energy policies, contributing to the transition towards a more sustainable and cleaner energy future.

As a glimpse into the future, the possible avenues for further research are plentiful. The development of a mobile application for electric vehicle owners, which focuses on the introduction of dynamic incentive systems, is a logical step forward. The integration of emerging technologies, advancements in battery technology and the investigation of smart grid solutions present exciting opportunities for ongoing research and innovation in the field.

In conclusion, the integration of electric vehicle batteries into grid stabilization is a promising way to achieve a more sustainable and flexible energy infrastructure. By taking advantage of advanced technologies such as V2G systems, we can not only address the challenges facing electrical networks, but also contribute to reducing carbon dioxide emissions and promoting the spread of renewable energy.

Chapter 1. Electric Vehicle Batteries and Grid Stabilization

1.1 Background on Electric Vehicles (EVs) and Battery Technology

The automotive sector is experiencing a significant shift, marked by the increasing significance of electric vehicles (EVs) as a sustainable substitute for conventional internal combustion engine cars. Electric vehicles, relying on electricity as their primary source of energy, symbolize a noteworthy progression in transportation. They bring forth a multitude of ecological advantages and technological advancements. This transformation in the transport sector is highlighted in the studies by Faizal et al. (M. Faizal, 2019), which underscore the potential of EVs in redefining the future of mobility. The electric car market is experiencing remarkable expansion, with sales exceeding 10 million in 2022. According to data from the International Energy Agency, illustrated in Figure 2.1, the percentage of electric cars in total sales has more than tripled in three years, rising from around 4% in 2020 to 14% in 2022. (International Energy Agency, n.d.)

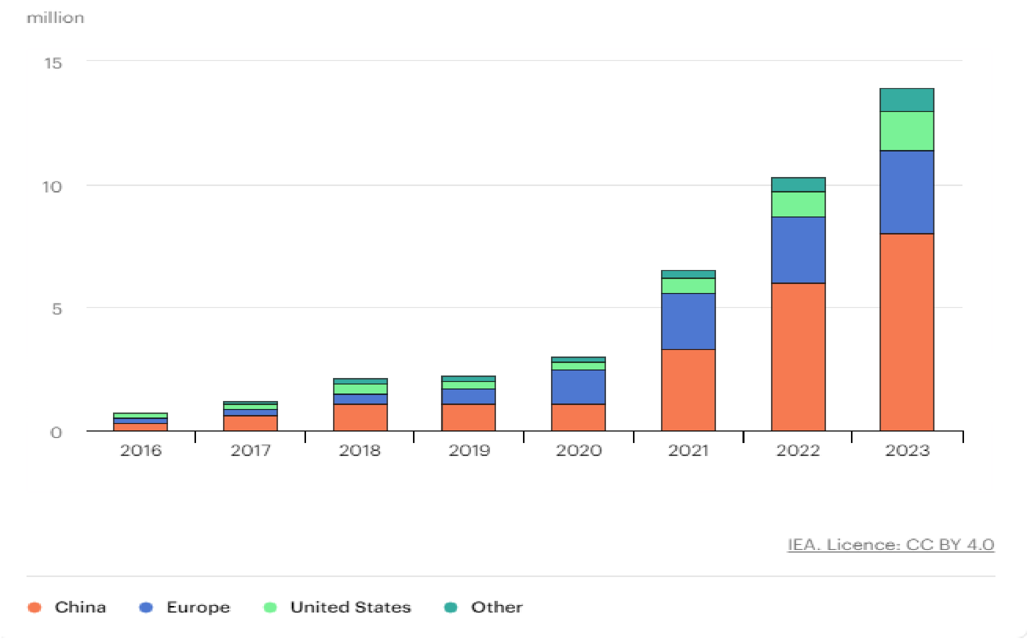

Figure 1.1. Electric car sales 2016-2023

Source: IEA (https://www.iea.org/energy-system/transport/electric-vehicles, accessed on January 20, 2024)

Electric Vehicles, present a multitude of advantages in emission reduction and are set to revolutionize the future of the automotive industry. These vehicles leverage advancements in battery technology and hold immense potential in steering transportation towards sustainability while significantly mitigating environmental impact. (Karduri, 2018)

1.2 Challenges Facing Electric Grids and the Need for Grid Stabilization

The modern world relies heavily on electrical grids for almost every aspect of our lives. From lighting our homes to powering industries and facilitating communication, the demand for electricity is constantly increasing. However, the rising incorporation of renewable energy sources, increasing energy demands and the emergence of complex technologies pose substantial challenges to the stability and reliability of electrical networks. To guarantee a sustainable and robust energy future, it has become essential to address these challenges by stabilizing the grid. (Karduri, 2018)

Power grids are complex networks that include power generation, transmission, and distribution systems. Traditionally, these systems have predominantly depended on centralized power plants fueled by non-renewable resources like coal, oil, and natural gas. Nevertheless, the global push toward decarbonization and sustainability has accelerated the integration of renewable energy sources such as solar, wind, and hydro. (Notter, 2010)

While the shift to renewable energy sources holds promise for reducing carbon emissions, it presents new challenges for grid operators. Renewable energy sources are sporadic, relying on weather conditions, and often geographically dispersed. The variability of their generation can lead to fluctuations in the power supply, which can cause instability in the network. For example, a sudden change in wind speed or cloud cover can cause a sudden drop or spike in power, challenging the grid's steady state. (Alam, 2020)

In addition, the aging infrastructure of many power grids further complicates the situation. Outdated transmission and distribution systems are not designed to handle the bidirectional energy flow required from sources such as rooftop solar, distributed generation. This discrepancy increases vulnerability to failures and power outages.

Another critical challenge arises from the increasing electrification of sectors such as transport and heating. The increased demand for electric vehicles and electric heating systems will further strain the grid and require major upgrades to meet these load increases without compromising stability.

Grid stabilization is paramount to address these challenges and ensure a reliable energy supply. There are several key strategies and technologies crucial for achieving grid stability:

Energy Storage Systems (ESS)

Deploying energy storage systems, including batteries, pumped water tanks, or flywheels, is crucial in addressing the intermittent issues associated with renewable energy sources. These systems have the capability to store surplus energy during periods of high production and discharge it during spikes in demand or when there is a decrease in renewable supply, thereby mitigating fluctuations and ensuring a more stable energy supply. (Alotaibi, 2020)

Grid modernization and smart grids

The modernization of infrastructure and the implementation of smart grid technologies facilitate ongoing real-time monitoring, control, and automation. This, in turn, supports the effective management of distributed energy resources (DERs), enhances grid resilience, and allows for predictive maintenance, ultimately reducing the frequency of outages. (Alotaibi, 2020)

Advanced Grid Control and Management Systems

Utilizing advanced control systems incorporating machine learning and AI algorithms can optimize grid operations by predicting demand patterns, managing supply fluctuations, and dynamically balancing the grid in real-time. (Murat Yilmaz, 2013)

Demand-Side Management (DSM)

Encouraging consumers to participate in DSM programs by adjusting their energy usage during peak hours can alleviate stress on the grid. Time-of-use pricing and incentives for load-shifting help in balancing supply and demand. (Daiva Stanelyte, 2022) (M.A. López, 2014)

Microgrids and decentralization

The implementation of microgrids enables local energy production and consumption, increasing the resilience and reliability of the grid, especially in remote or critical areas. Decentralization aids in diminishing reliance on long-distance transmission, consequently lowering transmission losses and enhancing stability. (Chun-Hao Lo, 2013)

V2G technology

In the field of sustainable energy and transportation, V2G technology has surfaced as a groundbreaking innovation that connects electric vehicles with the electric grid, as emphasized by Kempton and Tomic (2005) in their work on vehicle-to-grid power implementation. V2G introduces a revolutionary concept of facilitating two-way energy flow, empowering electric vehicles to not only draw power from the grid but also to feed stored energy back into the grid as needed. (Kempton, 2005)

Barriers to Integration and Security Risks

Despite these solutions, many obstacles prevent the smooth integration of network stabilization measures. Financial constraints, regulatory complexity and resistance to change from traditional utility models pose significant challenges. In addition, lack of standardization and interoperability between different network technologies can hinder effective implementation.

Additionally, cyber security threats pose a critical risk to network stability. As networks become increasingly digitized and interconnected, they become vulnerable to cyber-attacks, which can cause widespread disruption and compromise the reliability of the entire system. Strengthening cyber security measures is essential to protect critical infrastructure.

Government policies and regulations are pivotal in addressing and overcoming these challenges. Encouraging investment in grid modernization, encouraging the use of renewable energy sources and storage technologies, and establishing clear standards for interoperability and cybersecurity are essential steps towards a resilient and stable grid. (Rudraksh S. Gupta, 2021) (Sarah LaMonaca, 2022)

In summary, the challenges facing electric grids require a concerted effort to stabilize the grid. The use of innovative technologies, the promotion of cooperation between stakeholders and the implementation of supportive policies are crucial to achieving a sustainable and stable energy future. The evolution of electrical networks from centralized, fossil fuel-dependent systems to decentralized, integrated networks with renewable energy sources is not only a technological feat, but also a fundamental condition for a greener and more flexible world.

1.3 How Electric Vehicle Batteries can be used for Grid Stabilization

Electric vehicle (EV) batteries, pivotal for powering vehicles, extend their role beyond transportation by serving as potential contributors to grid stabilization. The environmental benefits of EVs, underscore the imperative of leveraging EV technology for grid stability. Insights from Faizal underscore the multifaceted challenges and opportunities inherent in EVs, paving the way for their broader integration into grid stability initiatives. (M. Faizal, 2019)

Kempton and Tomic (2005) shed light on Vehicle-to-Grid (V2G) technology's transformative role, emphasizing its potential not only in stabilizing grids but also in supporting large-scale renewable energy endeavors. Building upon the environmental benefits of EVs, V2G technology emerges as a transformative solution. It allows EVs not only to consume power but also to supply stored energy back into the grid, playing a critical role in grid stabilization. (Kempton, 2005)

The technological development of electric vehicle batteries, as described by Sun et al. (2019) shed light on the evolutionary trajectory of electric vehicle technology. These developments, especially in battery efficiency and storage capacity, play a key role in strengthening grid stability by offering reliable energy storage solutions. Aligning with the concept of reduced carbon emissions and improved environmental sustainability, V2G systems effectively manage peak electricity demands (Xiaoli Sun, 2019)

The incorporation of renewable energy sources into the grid poses challenges due to their intermittent nature. V2G technology facilitates this integration by enabling EVs to store excess renewable energy and release it during low-generation periods, effectively balancing supply, and demand. Karduri et al. (2018) highlights the challenges and opportunities presented by the integration of renewable energy into existing power systems. The synergy between EVs and renewable energy integration aligns with the collaborative effort to bolster grid resilience and sustainability. (Karduri, 2018)

The fundamental transition to sustainable transport, aligns with the contribution of V2G technology to grid resilience. Alotaibi et al. (2018) explored a thorough review of smart grids, envisioning a sustainable future intertwined with renewable energy resources. Smart grids provide a robust framework for accommodating EVs, offering enhanced control mechanisms and optimizing energy flow, thus contributing to grid stability. (Alotaibi, 2020)

Deivanayagam (2017) highlights the concept, status, and challenges associated with V2G technology. Despite its promise, technical complexities, and standardization issues present obstacles to seamless V2G integration within existing infrastructure. (Deivanayagam, 2017)

The exploration of V2G technology's integration within the grid aligns with the transition toward sustainable transportation. Leveraging EV batteries as dynamic assets for grid stabilization embodies a progressive step towards grid reliability, environmental sustainability, and efficient energy management.

1.4 Types of Grid Stabilization Services that EV Batteries Can Provide

1. Frequency Regulation

EV batteries are adept at providing frequency regulation services to the grid. They can respond rapidly to frequency fluctuations by charging or discharging power as needed, aiding in maintaining grid frequency within permissible limits. The rapid response time of EV batteries aligns with the critical requirement for real-time frequency management in stabilizing power systems. (Sarah LaMonaca, 2022)

2. Peak Shaving

EV batteries offer peak shaving capabilities by storing surplus energy during low-demand periods and discharging it during peak consumption hours. This strategy mitigates spikes in demand, alleviating stress on the grid during peak hours and promoting the efficient use of energy resources. (Noor Aziz, 2019)

3. Voltage Support

The ability of EV batteries to provide voltage support is instrumental in grid stabilization. They can inject power into the grid during voltage sags or absorb excess power during voltage surges, thereby ensuring grid voltage remains within acceptable limits. This function contributes significantly to maintaining grid stability during fluctuations in power quality. (M.A. López, 2014)

4. Spinning Reserve

EV batteries can serve as spinning reserves, ready to inject power instantaneously in response to unexpected demand or supply fluctuations. By functioning as reserve capacity, EV batteries enhance the grid's ability to address sudden imbalances between supply and demand, ensuring grid reliability. (Ivan Pavic, 2015)

5. Black Start Capability

In the event of a blackout or grid failure, EV batteries equipped with bidirectional power flow capabilities can provide black start support. (W Yan, 2021) These batteries can supply power to critical infrastructure or initiate the startup sequence for grid restoration, expediting the recovery process.

6. Grid Ancillary Services

EV batteries contribute to providing ancillary services such as grid frequency support, contingency reserves, and ramp-rate control. (Alfonso Damiano, 2014) Their flexibility in responding to grid signals and adjusting power output aids in meeting the dynamic requirements of the grid, enhancing its operational stability.

The integration of EV batteries into grid stabilization services unfolds a realm of possibilities, showcasing their versatility and adaptability in addressing diverse grid challenges. These functionalities underscore the pivotal role EVs play in augmenting grid stability and resilience, positioning them as dynamic assets within the evolving energy landscape.

1.5 Benefits of using EV Batteries for Grid Stabilization

1. Flexibility and Rapid Response

EV batteries exhibit inherent flexibility, allowing them to swiftly respond to grid signals or operational commands. Their ability to charge or discharge power rapidly enables immediate adjustments to address grid imbalances or fluctuations in supply and demand (Sarah LaMonaca, 2022). This agility in response significantly contributes to stabilizing the grid in real-time, enhancing its reliability.

2. Scalability and Distributed Resources

The widespread deployment of EVs equates to a vast network of distributed energy storage resources. Leveraging these distributed batteries as decentralized energy assets provides scalability in supporting grid services without relying on centralized storage facilities (Kempton, 2005). This decentralized approach fosters grid resilience by minimizing vulnerability to single-point failures and optimizing resource utilization.

3. Grid Resilience and Reliability

Utilizing EV batteries for grid stabilization bolsters its resilience against disruptions. These batteries act as backup power sources during grid outages, ensuring continuous supply to critical infrastructure or during emergency situations (Ivan Pavic, 2015). The availability of EVs equipped with bidirectional power flow capabilities enhances grid reliability and resilience.

4. Cost Savings and Efficiency

The integration of EV batteries into grid stabilization practices offers cost-effective solutions for utility operators. By tapping into underutilized EV batteries during off-peak hours, utilities can minimize infrastructure costs and optimize energy management. (Noor Aziz, 2019) This strategy improves the overall efficiency of the system while minimizing the necessity for additional investments in grid infrastructure.

5. Support for Renewable Integration

Electric vehicle batteries are pivotal in enabling the integration of renewable energy sources into the grid. They absorb surplus renewable energy during periods of high generation and supply it when needed, addressing the intermittency of renewables and ensuring a more seamless integration into the grid. (M.A. López, 2014) This capability supports increased renewable energy penetration while maintaining grid stability.

6. Environmental Benefits

Leveraging EV batteries for grid stabilization is in line with sustainability objectives, leading to a decrease in greenhouse gas emissions. Through the optimization of energy consumption, diminished dependence on fossil fuels, and the promotion of cleaner energy integration, EV batteries play an active role in advancing the shift towards a more environmentally friendly energy ecosystem. (Alotaibi, 2020)

The multiple benefits of using EV batteries for grid stabilization underscore their transformative potential in revolutionizing the energy landscape. From enhancing grid reliability and flexibility to supporting renewable integration and cost savings, these benefits underscore the key role EV batteries play in promoting a resilient and sustainable grid.

Chapter 2. Implementation of V2G Technology for Grid Stabilization

2.1 Technical Considerations for Implementing V2G Technology

The implementation of V2G technology signifies a transformative shift in the use of electric vehicles (EVs) beyond their conventional role as transportation tools. This chapter delves into the technical aspects critical for the effective implementation of V2G technology. V2G introduces a bidirectional energy flow paradigm where EV batteries not only receive energy from the grid but also have the capability to discharge stored energy back to the grid, thereby contributing to grid stability, power quality, and demand management. The successful integration of V2G necessitates addressing various technical considerations ranging from EV battery technology to grid infrastructure and communication protocols.

Battery Technology and Management

At the core of V2G implementation lies battery technology and management systems. Lithium-ion batteries, prevalent in EVs due to their energy density and cycling characteristics, confront challenges concerning degradation over charge-discharge cycles. Recent studies, (M Mao, 2019) emphasize the significance of efficient battery-to-grid and vehicle-to-grid (B2G/V2G) integration, focusing on the practical implementation of bidirectional energy transfer, thereby optimizing battery usage and ensuring longevity while maintaining performance. Furthermore, the effect of V2G integration on grid stability has been examined in-depth. (AM Koufakis, 2016)

Charging Infrastructure

The development of an efficient charging infrastructure serves as the backbone for V2G deployment. Both on-board and off-board chargers necessitate design alterations to facilitate bidirectional power flow and accommodate diverse charging standards and protocols. Insights from the integration of electric vehicles into smart grids (DB Avancini, 2021), (T Mao, 2019) provide valuable reviews on V2G technologies and optimization techniques, offering strategies for seamless energy exchange between EVs and the grid.

Additionally, global EV sales records have been crucial in understanding market dynamics and growth patterns (MRH Mojumder, 2022), (K Clement-Nyns, 2011).

Grid Integration and Power Electronics

Efficiently incorporating Vehicle-to-Grid (V2G) into the grid necessitates robust power electronics capable of managing bidirectional power flow. Vehicle inverters and grid-tie converters are pivotal in maintaining grid stability, regulating voltage, and mitigating harmonics. An examination of the influence of V2G technologies on distribution systems and utility interfaces has highlighted the essential role of these systems in enhancing grid resilience. (S Vadi, 2019)

Communication and Control Systems

Efficient communication and control systems are pivotal for orchestrating V2G operations seamlessly. Robust communication frameworks and control strategies are essential for managing power flow, optimizing charging schedules, and ensuring grid stability. Furthermore, the design of a bi-directional inverter for wireless V2G systems presents innovative approaches to enhance V2G system architectures. (S Vadi, 2019)

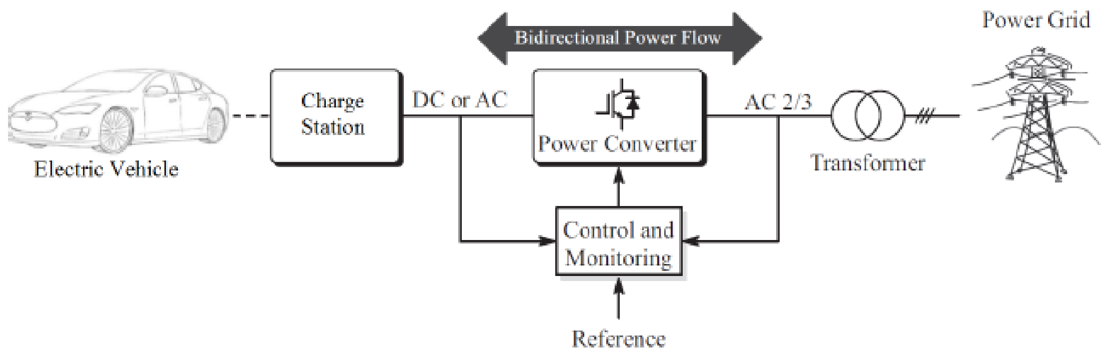

Figure 2.1 Block diagram of the V2G structure

Source: Energies Journal (S Vadi, 2019) (page 5, accessed on December 20, 2023)

Standards and Regulations

Establishing standardized protocols and regulatory frameworks is paramount for the widespread adoption of V2G. Reports from reputable organizations like the International Energy Agency (IEA) highlight the global outlook and trends in EVs, providing critical insights into the market and technological advancements. Additionally, studies on the impact of EVs on the grid system shed light on the necessary regulations and standards required for seamless integration (MDSA Khan, 2018), (Murat Yilmaz, 2013).

In conclusion, the successful implementation of V2G technology necessitates a comprehensive approach addressing diverse technical considerations. Battery management, charging infrastructure, grid integration, communication systems, and regulatory frameworks collectively form the foundation of an effective V2G ecosystem. Continuous advancements in technology, market insights, and regulatory guidelines are imperative to overcome challenges and realize the full potential of V2G, contributing significantly to a sustainable and resilient energy future.

2.2 Economic Considerations for Implementing V2G Technology

The integration of Vehicle-to-Grid (V2G) technology not only presents significant technical challenges but also raises crucial economic considerations. This chapter delves into the economic aspects pivotal for the successful deployment and sustainable operation of V2G systems. V2G technology offers a potential avenue to optimize the utilization of electric vehicle (EV) batteries, transforming them into valuable grid resources that can influence various economic facets, including market dynamics, investment strategies, and cost-benefit analyses.

Balancing the requirements, costs, and advantages of Vehicle-to-Grid (V2G) entails considerations among three primary stakeholders: vehicle manufacturers, vehicle owners, and grid operators:

- Vehicles necessitate the capability for bidirectional electricity flow between the vehicle and the grid.
- Manufacturers must price the V2G feature at a level enticing to customers.
- Vehicle owners should receive adequate compensation for permitting the grid operator to utilize the vehicle for grid services while ensuring personal use remains available.
- Grid operators need to derive sufficient benefits from vehicle availability to offset the added expenses of monitoring, controlling vehicle-grid

interactions, compensating owners, and managing the system efficiently. (Steward, 2017)

Cost-Benefit Analysis

Implementing V2G technology involves substantial initial investments in infrastructure, including charging stations, grid connection upgrades, and bidirectional power electronics. A comprehensive cost-benefit analysis is essential to evaluate the economic viability of V2G implementation. Research has emphasized the need to consider various parameters such as energy market prices, grid services revenues, and potential savings in battery replacement costs. (MRH Mojumder, 2022)

Revenue Streams and Market Participation

One of the key economic benefits of utilizing EV batteries for grid stabilization is the potential for revenue generation. Through vehicle-to-grid (V2G) technology, EVs can provide services to the grid, such as frequency regulation, peak shaving, and demand response. Grid operators can pay for these services, creating a new revenue stream for EV owners, charging infrastructure providers, and other stakeholders.

Participating in grid stabilization services may qualify for incentives or subsidies from governmental agencies promoting renewable energy integration. These financial incentives can contribute to offset initial investments and operational costs. The revenue streams are contingent on the effective implementation of V2G technology and the ability of the integrated system to respond to grid signals promptly. The regulatory framework and market mechanisms for compensating grid services should be well-defined to encourage participation and ensure a fair distribution of benefits. (H Patil, 2020) (M Umair, 2023)

Grid Infrastructure Investments

Implementing a pilot program to integrate EV batteries into the grid for stabilization requires a significant initial investment. This includes the development of smart charging infrastructure, V2G technology, and communication systems. The costs associated with retrofitting existing charging stations or establishing new ones, as well as upgrading the grid to accommodate bidirectional energy flow, must be considered. (F Un-Noor, 2017)

The government, in collaboration with private stakeholders, is likely to share the initial investment burden. Financial incentives, grants, or subsidies could be provided to EV manufacturers, charging infrastructure providers, and utilities involved in the project. The initial investment is a critical factor in determining the overall economic viability of the program. (KM Tan, 2016)

Operational Costs:

Operational costs include maintenance, monitoring, and management of the integrated system. Regular maintenance of charging infrastructure, EV batteries, and associated grid equipment is essential to ensure reliable performance. Monitoring systems must be in place to track the state of charge, health, and performance of EV batteries. Operational costs also include the expenses associated with managing the communication and control systems that enable V2G technology.

While operational costs are ongoing, they are expected to be offset by the benefits derived from grid stabilization. The ability to provide grid services during peak demand periods or frequency regulation can generate revenue streams that contribute to covering these operational costs. (H Patil, 2020)

Consumer Adoption and Incentive Schemes

Encouraging consumer adoption of V2G technology requires effective incentive schemes and policy support. Governments and regulatory bodies play a crucial role in fostering V2G adoption by offering incentives such as tax credits, subsidies for infrastructure development, and preferential electricity tariffs for V2G participants. Economic models have emphasized the need for targeted incentive schemes to accelerate V2G uptake. (H Patil, 2020) (Murat Yilmaz, 2013)

Market Dynamics and Industry Evolution

The widespread adoption of V2G technology has the potential to reshape energy markets and influence the automotive and energy industries. The increased integration of renewable energy sources and the proliferation of EVs with V2G capabilities can disrupt traditional market dynamics. Forecasting economic shifts, industry evolution, and market penetrations is essential for stakeholders to adapt and capitalize on emerging opportunities. (MDSA Khan, 2018)

Economic considerations are integral to the successful deployment and sustainability of V2G technology. Conducting comprehensive cost-benefit analyses, exploring diverse revenue streams, evaluating grid investments, incentivizing consumer adoption, and anticipating market dynamics are crucial aspects. Collaboration between policymakers, utilities, industry players, and researchers is essential to navigate the economic landscape, unlock potential benefits, and foster the growth of V2G technology.

2.3 Comparison of the Environmental Benefits of Using EV Batteries Versus Traditional Grid Stabilization Methods

2.3.1 Environmental Benefits of EV Batteries

The introduction of electric vehicles (EVs) has significant environmental benefits and makes them key to combating climate change and improving local air quality. These benefits include reduced greenhouse gas (GHG) emissions, a lower carbon footprint from renewable energy, and reduced urban air pollution, which improves public health. (Stephen P. Holland, 2016)

Greenhouse Gas Emissions Reduction

The transition from internal combustion engine vehicles to EVs plays a crucial role in reducing greenhouse gas emissions. As emphasized by various studies including Stanelyte (Daiva Stanelyte, 2022), EVs produce zero tailpipe emissions, notably reducing carbon dioxide (CO_2) emissions responsible for climate change. The extent of GHG emission reduction, however, relies on the energy sources employed for EV charging.

Lower Carbon Footprint with Renewable Energy Charging

Charging electric vehicles with renewable energy sources such as solar, wind, or hydropower significantly diminishes their carbon footprint. Studies such as those highlighted by Goodenough and Park (2013) (Goodenough, 2018) and Notter et al. (Notter, 2010) affirm that utilizing clean energy sources during EV charging substantially mitigates environmental impact by circumventing emissions linked to fossil fuel-based electricity generation.

Mitigation of Urban Air Pollution:

EVs make substantial contributions to curbing air pollution in urban settings. Research by Faizal et al. (M. Faizal, 2019) underscores that vehicles with internal combustion engines emit pollutants detrimental to air quality and public health, such as nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs). By eliminating tailpipe emissions, EVs play a crucial role in reducing these harmful pollutants, thereby improving local air quality.

Grid Flexibility and Resilience

Studies, such as the work of Murat Yilmaz and Philip T. Krein (2013), underscore the adaptability and resilience of EV batteries in stabilizing the grid. Bidirectional energy transfer during peak demand helps stabilize voltage and frequency, contributing to grid flexibility and minimizing the vulnerability to localized outages. (Murat Yilmaz, 2013)

The environmental benefits associated with the introduction of electric vehicles, including reduced greenhouse gas emissions, lower carbon emissions through renewable energy tariffs and reduced urban air pollution, underline their key role in promoting sustainable transport. These benefits, supported by various studies and research, emphasize the importance of switching to electric vehicles for a greener and healthier future.

2.3.2 Comparison with Traditional Grid Stabilization Methods

1. Conventional Fossil Fuel-Based Methods

Traditional methods for grid stabilization often involve fossil fuel-based power plants, which are less environmentally friendly. These plants release pollutants and CO2 during power generation, contributing significantly to air pollution and climate change. The carbon footprint associated with these methods is substantially higher compared to using EV batteries.

2. Environmental Impact

The deployment of EV batteries for grid stabilization minimizes the need for additional infrastructure, such as power plants or transmission lines. In contrast, traditional methods require continuous infrastructure development, leading to habitat disruption, land use changes, and environmental degradation. (KM Tan, 2016)

Several studies, such as those by Shahrukh Adnan Khan et al. (2018) and Muhammad Umair et al. (2023), have conducted comprehensive analyses highlighting the environmental advantages of leveraging EV batteries for grid stabilization. These studies emphasize the significance of reducing emissions and enhancing energy efficiency through EV battery integration into the grid. (MDSA Khan, 2018) (M Umair, 2023)

In conclusion, the comparison between utilizing EV batteries and traditional methods for grid stabilization unequivocally favors the environmental benefits of EV battery integration. These batteries not only aid in reducing carbon emissions and enhancing energy efficiency but also contribute to grid flexibility and resilience. As technology advances and EV adoption grows, leveraging these batteries for grid stabilization emerges as a sustainable and eco-friendly approach.

2.4 Potential for Negative Environmental Impacts and How To Mitigate Them

The integration of Vehicle-to-Grid (V2G) technology presents several environmental advantages, but its implementation may carry potential negative impacts. This chapter delves into the possible adverse effects and discusses mitigation strategies to ensure the sustainable deployment of V2G systems.

2.4.1 Potential Negative Environmental Impacts:

1. **Battery Manufacturing and Disposal**

Concerns have been raised about the environmental impact of both the production and disposal of EV batteries. The extraction of raw materials and manufacturing processes contribute to carbon emissions, resource depletion, and environmental pollution. Furthermore, inadequate recycling mechanisms may lead to improper disposal, causing soil and water contamination. (Murat Yilmaz, 2013)

2. **Grid Stability and Reliance on EV Batteries**

Over-reliance on EV batteries for grid stability could potentially strain these batteries, impacting their lifespan and efficiency. Studies have indicated that excessive charge-discharge cycles may accelerate degradation, leading to increased waste and environmental burden. (KM Tan, 2016)

3. **Energy Source for Charging**

The energy sources utilized for charging EVs significantly impact the environmental footprint. If the charging primarily relies on fossil fuel-based power plants, it could negate the positive impacts of V2G, increasing emissions and environmental degradation. (KM Tan, 2016)

2.4.2 Mitigation Strategies:

1. **Sustainable Battery Manufacturing and Recycling**

Implementing stringent regulations and standards for sustainable battery manufacturing and efficient recycling processes is crucial. Research by Murat Yilmaz and Philip T. Krein (2013) emphasizes the importance of advancing recycling technologies to minimize environmental impact. (Murat Yilmaz, 2013)

2. **Diversification of Grid Stabilization Methods**

Diversifying grid stabilization methods by incorporating a mix of smart grid technologies, energy storage systems and renewable energy sources beyond EV batteries can alleviate strain on these batteries. This approach, highlighted by Muhammad Umair et al. (2023), ensures a balanced and sustainable grid operation. (M Umair, 2023)

3. **Promotion of Renewable Energy for Charging**

Promoting the adoption of renewable energy sources, such as solar or wind power, for EV charging is crucial. Research conducted by Kang Miao Tan et al. (2016)

emphasizes the importance of embracing clean energy to mitigate the carbon footprint associated with EV charging. (KM Tan, 2016)

2.4.3 Collaborative Policy Framework and Technological Innovations

Stringent Environmental Policies

Establishing stringent policies and regulations that govern battery production, disposal, and energy sourcing can enforce environmentally responsible practices. Collaborative efforts among governments, industries, and research institutions are vital for formulating and implementing these policies. (Kempton, 2005)

Technological Advancements

Continued research and development aimed at enhancing battery efficiency, lifespan, and recycling processes are imperative. Breakthroughs in battery technology and smart grid infrastructure can mitigate environmental impacts. (T Mao, 2019)

While the implementation of V2G technology presents challenges and potential negative environmental impacts, proactive measures through stringent policies, technological advancements, and diversified energy strategies can effectively mitigate these concerns. Collaborative efforts and continued research are pivotal in ensuring a sustainable and environmentally friendly integration of V2G systems.

2.5 Economic Analysis of Electric Vehicle Battery Usage for Grid Stabilization in Romania

The economic analysis of utilizing electric vehicle (EV) batteries for grid stabilization in Romania involves assessing both the costs and benefits associated with implementing such a system. This analysis considers various factors, including the initial investment, operational costs, potential revenue streams, and broader economic impacts.

In Romania, the number of registered electric cars has surpassed 42,000, with a notable increase of 35% in 2023 compared to the previous year. The Dacia Spring leads with over 16,000 registrations, followed by Tesla's Model Y and Model 3. These top three models account for more than 60% of all registrations in 2023. The Volkswagen eUP! secured the fifth position with around 500 registrations, while the Renault ZOE dropped from the podium. Other notable entries in the top 10 include the Hyundai Kona, VW iD3, Renault Megane E-Tech, BMW i3, and Nissan Leaf. (Analiză LEKTRI.CO, 2024) Because we don't know the total number for some of these registered models, some assumptions will be made with the following logic:

- For Tesla Model Y and Model 3, it's assumed that each model has 2.5 times the registrations mentioned in the text.
- For Volkswagen eUP! no specific information is provided, so an assumption of around 500 registrations is made.
- Hyundai Kona and VW iD3 are assumed to have registrations in the range of 100 to 150, considering they are below Dacia Spring but still in the top 10.
- Renault Megane E-Tech is assumed to have approximately 1,000 registrations based on the text.
- BMW i3 is assumed to have around 350 registrations and Nissan Leaf around 300 registrations.

Based on the lektri.co analysis cited in the above segment and the assumptions used, we have the following information on EVs in Romania:

Table 2.1 EV registrations 2023 Romania with assumptions

Rank	Model	Total Registered	2023 Registrations
1	Dacia Spring	16,000+	6,877
2	Tesla Model Y	5,390*	2,156
3	Tesla Model 3	2,872*	1,149
4	Volkswagen eUP!	~500	~500
5	Hyundai Kona	~600	~100*
6	VW iD3	~700	~150*
7	Renault Megane E-Tech	~1,000	~1,000
8	BMW i3	~400	~350*
9	Nissan Leaf	~350	~300*

Source: ((Analiză LEKTRI.CO, 2024) accessed on January 27, 2024)

To analyze the economic implications, it's crucial to understand the battery capacities of the different EV models. For instance, Dacia Spring, with a battery capacity of 25 kWh, Tesla Model Y and Tesla Model 3 both, ranging from 57.5 to 75 kWh, are likely to be significant contributors. On the other hand, the Volkswagen eUP! and BMW i3, with capacities around 36.8 kWh and 40 kWh, respectively, contribute but to a lesser extent. (EV Database, n.d.)

In Ulas Balan Baloglu's study, V2G is identified as a participation-based system, with its supply capacity dependent on two crucial factors: the probability of participation (POP) and the state of charge (SOC) of the participating electric vehicle (EV). The POP value is influenced by various factors, emphasizing the importance of motivating EV owners to authorize the participation of their vehicles. The SOC is represented in percentage points, ranging from 0 (empty) to 100 (full). (Ulas Baran Baloglu, 2016)

Considering the SOC properties, a study suggests that for effective V2G participation, SOC values should be greater than 50%. This ensures that the EVs are suitable for both driving and grid services. However, it is also acknowledged that SOC values below 20% may lead to voltage problems, and below 50% could result in undesirable driving conditions. (Ulas Baran Baloglu, 2016)

Table 2.2. EV Battery Capacities

Model	Battery Capacity (kWh)	V2G Supply Capacity (kWh)
Dacia Spring	25	12.5
Tesla Model Y	~60	30
Renault Zoe	52	26
Tesla Model 3	55	27.5
Renault Megane E-Tech	60	30.0
BMW i3	~40	20
Volkswagen eUP!	36.8	18.4
Hyundai Kona	~63	31.5
VW iD3	58	29.0

Source: (EV Database, accessed on January 28, 2024)

Given an estimated energy price of 0.2 euro/kWh, the following profits are calculated in a year for the different models, based on periods of time the EV is plugged, using the following formula:

$$\text{Profit} = \text{V2G Supply Capacity} \times \text{Energy Price} \times \text{Hours plugged in} \times 365$$

Table 2.3. Profits / EV for 365 days

Model	Profit 6H (Euros)	Profit 9H (Euros)	Profit 12H (Euros)
Dacia Spring	547.5	821.25	1095
Tesla Model Y	1314	1971	2628
Renault Zoe	1137.6	1706.4	2275.2
Tesla Model 3	1237.5	1856.25	2475
Renault Megane E-Tech	1314	1971	2628
BMW i3	876	1314	1752
Volkswagen eUP!	800.64	1200.96	1601.28
Hyundai Kona	1361.7	2042.55	2723.4
VW iD3	1251.6	1877.4	2503.2

Source: Author

In a study conducted by Jingli Guo et al., it is reported that employing smart charging and discharging via Vehicle-to-Grid (V2G) technology has the potential to improve battery life. To optimize benefits, proactive management methods need adjustment to alleviate the impact of V2G services on battery degradation. (Jingli Guo, 2019) Because this is not fully tested and the infrastructure is not there yet, the table will be re-calculated with a degradation cost of 0.1 euro / kWh, taking into consideration the natural degradation of the EV battery, based on the study from Ulas Baran Baloglu and Yakup Demir. (Ulas Baran Baloglu, 2016)

Table 2.4. Profits / EV for 365 days with degradation included.

Model	Profit 6H (Euros)	Profit 9H (Euros)	Profit 12H (Euros)
Dacia Spring	273.75	410.625	547.5
Tesla Model Y	657	985.5	1314
Renault Zoe	568.8	853.2	1,137.6
Tesla Model 3	618.75	928.125	1,237.5
Renault Megane E-Tech	657	985.5	1314
BMW i3	438	657	876
Volkswagen eUP!	400.32	600.48	800.64
Hyundai Kona	680.85	1,021.275	1,361.7
VW iD3	625.8	938.7	1,251.6

Source: Author

As discussed earlier according to the study of Ulas Baran Baloglu (Ulas Baran Baloglu, 2016) the supply capacity is also influenced by POP, or probability of participation. To calculate profits on a national scale, taking into consideration only the models mentioned in Table 2.1. and the total registrations or assumed registrations of said model, we could use the following formula:

Profit = V2G Supply Capacity × Energy Price × POP (based on how many hours plugged in) x 365 x number of registered vehicles

POP values will be adjusted depending on the hours plugged in, so an estimation is made for 6 hours to be 65%, 9 hours 50% and for 12 hours 35%. Using the above formula, the values from Table 2.1. Table 2.2. and Table 2.4. we get the following data:

Table 2.5. Total profits as per the estimated total EVs in Romania

Model	POP 6H (65%)	POP 9H (50%)	POP 12H (35%)
Dacia Spring	€2,847,000	€3,270,000	€3,052,000
Tesla Model Y	€2,306.31	€2,651.75	€2,473.25
Renault Zoe	€10,707.76	€12,304.80	€11,454.64
Tesla Model 3	€1,145.77	€1,324.22	€1,235.63
Renault Megane E-Tech	€439.05	€492.75	€459.90
BMW i3	€1,138.80	€1,314.00	€1,226.40
Volkswagen eUP!	€260.21	€300.24	€280.22
Hyundai Kona	€530.26	€612.38	€570.86
VW iD3	€282.34	€328.55	€306.64

Source: Author

The calculations presented in this chapter provide a valuable insight into the potential economic revenues of V2G technology. However, it is essential to acknowledge that many of these calculations are based on estimations due to the early stage of this technology's implementation. As of now, high-level data for V2G is limited, and various assumptions and approximations were necessary to derive the economic potential revenues for electric vehicle (EV) owners. It is important to recognize that as technology advances, these estimations may evolve, and real-world data will become more robust.

Chapter 3. Case Studies of EV Battery Usage for Grid Stabilization

3.1 Examples of Successful Implementations

Electric Vehicle (EV) batteries have been implemented in various projects globally to enhance grid stability and support energy management. Several noteworthy case studies underscore the successful integration of EV batteries for grid stabilization, demonstrating their adaptability and effectiveness in mitigating grid challenges.

Example 1:

Nissan and Enel in in Denmark (2016): Nissan collaborated with Italian utility Enel to deploy a V2G pilot project in Denmark. Nissan LEAF electric vehicles were used to store and supply energy to the grid, showcasing the potential of V2G integration. The collaboration demonstrated the potential for electric vehicles to contribute to grid stability by providing energy back to the grid during peak demand, showcasing the viability of V2G technology. (Nissan & Enel Denmark, 2016)

Example 2:

The University of Delaware has been actively involved in V2G research. In one project, a fleet of electric school buses was used to provide grid services by supplying excess energy during peak demand periods. The University of Delaware's projects, including the use of electric school buses for grid services, aimed to show the feasibility of using V2G to support grid reliability. Results may include data on the successful integration of electric vehicles into grid operations. (University of Delaware, 2014)

Example 3:

Pacific Gas and Electric (PG&E) in California (Various): PG&E conducted several V2G trials, including partnerships with BMW and Google. These projects aimed to test the capabilities of electric vehicles to support grid reliability and provide ancillary services. The ChargeForward program involved implementing V2G technology in BMW electric vehicles. Through this technology, participating BMW EVs could provide excess energy back to the grid, helping to balance supply and demand. The program explored demand response strategies, allowing BMW to manage the charging and discharging of electric vehicles based on grid conditions. This flexibility could potentially ease strain during periods of high demand or supply fluctuations.

(BMW i ChargeForward Program, 2015) (BMW ChargeForward, n.d.)

Example 4:

UK Power Networks conducted a trial involving Nissan and Enel to explore the use of V2G technology. Electric vehicle owners were incentivized to supply energy back to the grid during peak demand, showcasing the potential for consumer participation. (Nissan & Enel UK, 2016)

Example 5:

The eV2g project, also recognized as Electric Nation, was a UK-based initiative with the objective of examining the influence of electric vehicles (EVs) on local electricity networks, particularly focusing on smart charging and V2G technologies. Its primary aim was to assess the viability of utilizing V2G technology for balancing local electricity demand and supply. The project sought to comprehend the potential advantages and challenges linked with the integration of EVs into the grid. Participants in the project included electric vehicle owners who volunteered to take part in smart charging and V2G trials. These trials allowed researchers to assess how EVs could be effectively managed to support the grid during peak demand periods. (Electric Nation, n.d.) (Electric Nation Project Results, 2022)

3.2 Lessons Learned and Best Practices for Future Projects

The successful implementations of Electric Vehicle (EV) batteries in various grid-stabilizing projects provide valuable insights and lessons for future endeavors. Drawing from the experiences of these projects, several key lessons and best practices emerge:

1. Collaborative Partnerships Yield Success

The collaborations between automakers, utilities, and technology companies, as demonstrated in the Nissan and Enel projects in Denmark and the PG&E trials in California, emphasize the importance of strong partnerships. Collaborative efforts allow for the pooling of expertise and resources, fostering innovation and the effective integration of EVs into grid operations.

2. Diverse Applications Enhance Viability

The versatility of EVs in grid support, showcased by the University of Delaware's use of electric school buses and BMW's ChargeForward program, underscores the importance of exploring diverse applications. Future projects should consider a range of use cases, such as leveraging different types of EVs and exploring various grid services, to maximize the potential benefits and address specific grid challenges.

3. Consumer Participation is Key

Projects like the UK Power Networks trial and the Electric Nation initiative highlight the significance of involving electric vehicle owners in grid support initiatives. Incentivizing consumers to supply energy back to the grid during peak demand fosters a sense of participation and showcases the potential for widespread community engagement. Future projects should focus on strategies to encourage and reward consumer involvement in grid support activities.

4. Flexibility and Demand Response Strategies

The ChargeForward program and UK Power Networks trial showcase the importance of flexibility and demand response strategies. Integrating Vehicle-to-Grid (V2G) technology allows for dynamic management of charging and discharging based on grid conditions. Future projects should explore and implement intelligent demand response strategies, enhancing the adaptability of EVs to address grid fluctuations.

5. Data Collection and Analysis for Informed Decision-Making

Lessons from the Electric Nation project emphasize the crucial role of data in understanding the impact of EVs on local electricity networks. Future projects should prioritize comprehensive data collection and analysis to assess the effectiveness of grid support initiatives. Informed decision-making based on real-world data can guide the development of more robust and scalable solutions.

6. Public Awareness and Education

The success of initiatives like Electric Nation, which involved electric vehicle owners in smart charging and V2G trials, highlights the importance of public awareness and education. Future projects should invest in outreach programs to inform and engage the public, fostering a better understanding of the role EVs can play in supporting the grid.

In conclusion, the experiences of these successful implementations provide a foundation for future projects seeking to integrate EVs into grid stabilization efforts. By embracing collaborative partnerships, exploring diverse applications, encouraging consumer participation, implementing flexibility, prioritizing data-driven decision-making, and promoting public awareness, future projects can build on these lessons to create more resilient and efficient energy systems.

Chapter 4. Future Directions for EV Battery Usage for Grid Stabilization

4.1 Overview of Current Trends in EV Battery Technology and Grid Stabilization

The latest developments in electric vehicle (EV) technology represent a key milestone in the automotive industry, catalyzing a paradigm shift towards sustainable transport. These innovations include improvements in battery energy density, charging infrastructure, vehicle design, and ongoing research into innovative materials and manufacturing techniques. Together, these developments contribute to increased range, reduced charging time and a higher driving experience for electric vehicle users.

Battery Energy Density Enhancements

Advances in battery technology are fundamental to transforming the efficiency and capabilities of electric vehicles. Research highlighted in studies by Goodenough and Park (Goodenough, 2018) and Xu et al. (Xiaolong Xu, 2020) underscores the significance of advancements in battery energy density, enabling electric vehicles to attain augmented range while maintaining compact battery sizes. Innovations in battery chemistry, electrode materials, and cell construction techniques have significantly elevated energy storage capacities.

Charging Infrastructure Evolution

The development of charging infrastructure is a cornerstone in promoting the widespread adoption of electric vehicles. Studies by Al-Hanahi (Al-Hanahi, 2021) and Yilmaz and Krein (Murat Yilmaz, 2013) emphasize the pivotal role played by investments in fast charging networks and the deployment of high-performance chargers. These initiatives have substantially shortened charging times, amplifying the practicality of daily electric vehicle usage. Moreover, the introduction of ultra-fast charging stations has notably expedited charging processes, rendering long-distance journeys more convenient.

Vehicle Design Innovations

Innovations in vehicle design have contributed significantly to the overall efficiency and appeal of electric vehicles. Faizal et al. (M. Faizal, 2019) highlights the influence of streamlined aerodynamics, light material uses and optimized energy management systems. Together, these improvements increased range and operational efficiency. In addition, improvements in regenerative braking systems and energy recovery technologies have further optimized energy use, increasing mileage per charge.

Research in Innovative Materials and Manufacturing Techniques

Ongoing research efforts focus on advancing battery technology by exploring innovative materials and manufacturing techniques. References such as Singh et al. (Singh M, 2013) and Notter et al. (Notter, 2010) illuminate the search for alternative materials like solid-state electrolytes or lithium-sulfur batteries to enhance battery performance and reduce production costs. Furthermore, advancements in manufacturing techniques, such as roll-to-roll manufacturing and automated assembly processes, aim to streamline production and bolster cost-effectiveness.

The recent advances in electric vehicle technology, including battery energy density, charging infrastructure, vehicle design, and research into innovative materials and manufacturing techniques, have helped transform the capabilities and appeal of electric vehicles. These developments, supported by scientific research, have significantly contributed to increased range, reduced charging times, and improved overall driving experiences, thereby accelerating the global transition to sustainable transport.

4.2 Future Directions and Potential Innovations in This Area

4.2.1 Advancements in Battery Technology

Battery technology constitutes a fundamental building block for electric vehicles (EVs), fundamentally shaping their capabilities, performance, and widespread adoption. The continuous development and innovation of battery technology continues to play a decisive role in the development and success of electric mobility.

Lithium-Ion Batteries in EVs

Lithium-ion (Li-ion) batteries serve as the cornerstone of electric vehicle technology due to their high energy density, reliability, and proven track record. These batteries have undergone significant refinements in lithium-ion chemistry, electrode materials, and manufacturing processes, resulting in better performance, higher energy density, and lower costs.Studies referenced by Goodenough and Park (Goodenough, 2018) and Notter et al. (Notter, 2010) accentuate the substantial enhancements witnessed in lithium-ion chemistry, electrode materials, and manufacturing procedures.

Emerging Battery Technologies

The pursuit of emerging battery technologies, namely solid-state batteries, represents the next frontier in electric vehicle development. Solid-state batteries represent a promising innovation in EV battery technology, as highlighted in research by Xu et al. (Xiaolong Xu, 2020), offering potential advantages such as higher energy density, improved safety, and shorter charging times compared to conventional lithium-ion batteries.

Future Implications of Emerging Technologies

Research and development in emerging battery technologies, particularly solid-state batteries, could revolutionize the electric vehicle industry. If these technologies mature and become commercially viable, they could overcome many of the limitations associated with traditional lithium-ion batteries, thereby facilitating wider consumer adoption of electric vehicles.

The evolution of battery technology, particularly the dominance of lithium-ion batteries in powering EVs and the promising emergence of solid-state batteries, marks significant strides toward enhancing the efficiency, range, and appeal of electric vehicles. These advancements, supported by credible research findings, underscore the pivotal role of ongoing innovation in battery technology for shaping the future of electric mobility.

4.2.2 Grid Integration and Smart Technologies

The integration of electric vehicles into the electric grid promises to be a significant development. Articles by Kang Miao Tan, Ramachandaramurthy and Jacopo Torriti highlight the role of smart technologies and network integration strategies in electric vehicles.

Smart Charging and Grid Interaction

Smart charging algorithms and bidirectional V2G systems, discussed by Kang Miao Tan, are expected to evolve further. These technologies will enable more efficient energy flow management, optimizing charging schedules based on grid conditions and user preferences. (KM Tan, 2016)

Vehicle-to-Everything (V2X) Integration

The concept of Vehicle-to-Everything (V2X), an extension of V2G, encompasses broader interactions between vehicles and external entities like homes, buildings, and other infrastructure. This innovation will enable EVs to not only support the grid but also act as decentralized energy storage units or backup power sources during outages. (KM Tan, 2016)

4.3 Implications for Energy Policy and the Future of the Electric Grid

4.3.1 Implications of EV Battery Technology for Energy Policy

Renewable Energy Integration

The integration of electric vehicles into the grid has profound implications for energy policy, particularly in promoting renewable energy adoption. Articles by Camacho and Kang Miao Tan emphasize the synergy between EVs and renewable energy sources, envisioning a future where EVs serve as energy storage units, optimizing the use of intermittent renewable energy.

Energy policies should incentivize the co-location of renewable energy generation facilities with EV charging infrastructure. This approach promotes local energy production and consumption, fostering energy independence and reducing reliance on fossil fuels. (OMF Camacho, 2014) (KM Tan, 2016)

Grid Resilience and Stability

The future of the electric grid heavily relies on EVs contributing to grid stability. Policies need to encourage and facilitate V2G integration, as highlighted by Kang Miao Tan and Ramachandaramurthy. Enabling regulatory frameworks that incentivize grid-supportive behavior of EVs during peak demand periods is crucial for ensuring grid resilience.

Energy policies should enable EVs to participate in energy markets by providing ancillary services such as frequency regulation and voltage support. Clear regulations and market mechanisms that compensate EV owners for contributing to grid stability can accelerate V2G adoption. (KM Tan, 2016)

4.3.2 Shaping the Future Electric Grid

Grid Modernization and Flexibility

The future electric grid will undergo substantial modernization to accommodate the evolving landscape of EVs. Jacopo Torriti and Gupta et al. underscore the necessity for grid flexibility and adaptability to handle the increased load from charging infrastructure and the variability in energy demand due to EVs. (Rudraksh S. Gupta, 2021)

Policies focusing on demand-side management strategies, as suggested by Jacopo Torriti, are crucial. Time-of-use pricing, smart grid technologies, and incentives for load shifting can balance energy demand, reducing stress on the grid during peak periods. (Torriti, 2017)

Collaborative Policy Frameworks

A collaborative approach among policymakers, utilities, industries, and communities is vital for shaping the future electric grid. G. Krishna and Rudraksh S. Gupta et al. stress the importance of inclusive policy frameworks that foster innovation, incentivize infrastructure development, and ensure equitable access to EV charging facilities. (Krishna, 2021) (S Hosseinpour, 2015)

In conclusion, the implications of EV battery technology on energy policy and the electric grid have many sides, ranging from incentivizing renewable energy adoption to reshaping grid operations. Robust policy frameworks that encourage grid modernization, foster renewable energy integration, and facilitate collaborative efforts among stakeholders will be pivotal in realizing a sustainable and resilient electric grid of the future.

Chapter 5. Development of a Web Application to Monitor and Analyze Real-Time Energy Production and Consumption

5.1 Data Acquisition and Storage

5.1.1 Data Collection and Storage Process

The foundation of the data acquisition process is in a Python script that runs in a serverless environment on AWS Lambda. (AWS Lambda, n.d.) This script runs at a 15-minute interval to access real-time energy consumption and production data from Transelectrica. (Transelectrica Widget, n.d.) Using the publicly accessible interface provided by Transelectrica, the script efficiently extracts the datapoints required for analysis. Figure 5.1 shows a snippet of the page from where the data is periodically extracted.

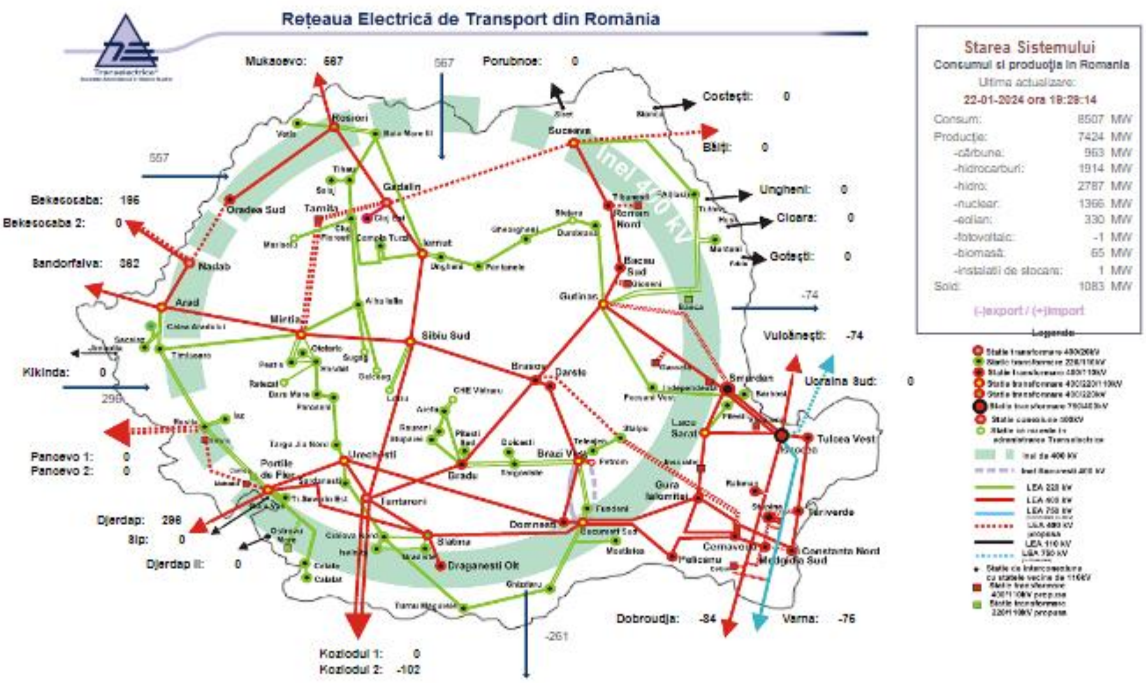

Figure 5.1. The Electrical Transmission Network in Romania

Source: (Transelectrica, accessed on January 22, 2024)

Once the data is acquired, it is systematically stored in a MongoDB database. (MongoDB docs, n.d.) The script is designed to store this information in designated collections in the database structure. A primary collection named "energy_reports" serves as a repository for real-time energy production and consumption data. In addition, separate collections are designated to store predictive data obtained from Transelectrica's consumption and production forecasts, namely "production_energy_forecast" and "energy_forecast_consumption".

In addition to consumption and production data, the script records information on various energy sources. This includes different types of energy such as coal, hydrocarbons, water, nuclear, wind, solar and biomass. The script is configured to capture the proportional contribution of each energy source, thereby facilitating a comprehensive analysis of the energy mix and its environmental impacts. The way this script is built can be accessed in the following GitHub repository: https://github.com/ZsoltDemeter/lambda-functions .

5.1.2 Data Structure and Types

The MongoDB database structure is designed to accommodate the various datasets from Transelectrica. Using a NoSQL database framework, it offers the flexibility to accommodate changing data types and structures. The database architecture revolves around collections built to efficiently store and isolate real-time consumption, production, predictive data and energy resource details.

In the "energy_reports" collection, the data reflects the current energy consumption and production values and the different energy types produced at the given time. Each entry is accompanied by timestamps that allow for temporal analysis and pattern recognition. For predictive data collections ("energy_forecasting_production" and "energy_forecasting_consumption"), a similar approach is used to catalog the forecasted values, allowing comparative analysis with real-time data. In Figure 5.2, a segment of the MongoDB database is presented, illustrating the structure of the data and how it is saved.

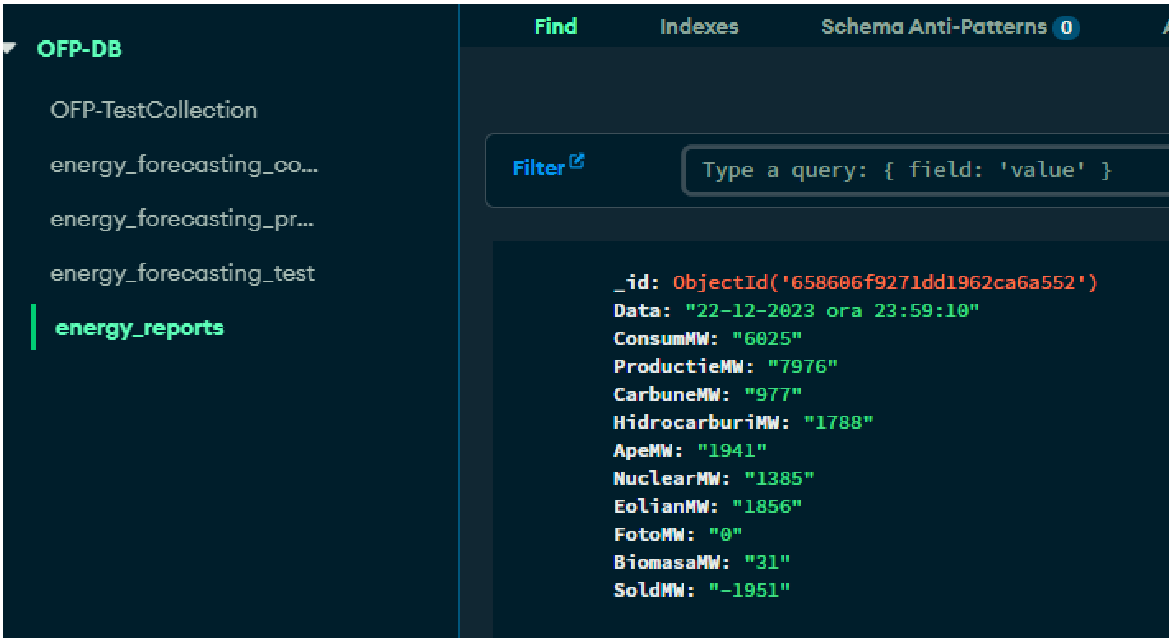

Figure 5.2. Energy Reports collection

Source: Author (Personal mongoDB database, accessed on January 21, 2024)

5.2 Backend Development and Database Interaction

5.2.1 Development of Node JS Express App

Creating a Node.js Express (Express API, n.d.) application is crucial for seamless interaction with the MongoDB database and effective retrieval of data. This back-end framework is designed to act as an intermediary between the database and front-end components, simplifying data transfer and data management. Node.js Express includes functions for creating secure connections to the MongoDB database. This includes configuring connection settings, authentication procedures, and leveraging appropriate libraries or middleware for data interaction.

5.2.2 Handling Data Retrieval

A fundamental aspect of backend development revolves around the creation of robust APIs responsible for facilitating the retrieval, modification and manipulation of data. Using appropriate query mechanisms and efficient data access methods, the Node.js

Express application uses designated API endpoints to retrieve real-time energy consumption and production data from the different MongoDB collections.

The GET/energy_reports endpoint serves as a gateway to retrieve real-time energy consumption and production data stored in the "energy_reports" collection. When receiving requests from the frontend, this endpoint facilitates the transmission of instantaneous energy indicators accompanied by timestamps for temporal analysis.

The GET/energy_forecasting_production and GET/energy_forecasting_consumption endpoints are specifically used to access forecasting energy consumption and production data in the respective MongoDB collections. These endpoints allow the frontend to retrieve forecasted energy metrics based on selected dates, facilitating predictive analysis and planning.

When invoked, these GET endpoints efficiently retrieve data in a structured format, ensuring that the information transmitted is organized and formatted according to defined schemas. The acquired data is then sent to the frontend, ready for seamless integration and display within the Angular application.

The designated GET endpoints act as intermediaries between the back-end database and the Angular front-end. They embed the logic to perform database queries, retrieve relevant data, and package the responses into a standard format for easy consumption by front-end components. The way these endpoints are built can be accessed at the following GitHub repository: https://github.com/ZsoltDemeter/node-express .

5.3 Frontend Development and User Interface

5.3.1 Angular App Development

The frontend aspect of the project is based on the development of an Angular application serving as an admin panel. Angular's comprehensive framework allows you to create a modular and responsive user interface, promoting a seamless user experience: https://ofp-admin-panel.netlify.app .

The application is built around a component-based architecture that divides the user interface into reusable and independent components. This modularity makes the application easy to maintain, reusable and scalable.

The Angular application is connected to the backend Node.js Express APIs, making it easy to retrieve real-time data from MongoDB collections. Specifically, it uses APIs designed to access and retrieve real-time energy consumption and production data.

5.3.2 Real-Time Data Display

Utilizing the ChartJS (ChartJS docs, n.d.) library, the app incorporates line chart components for visually depicting real-time energy consumption and production trends. These graphs dynamically update as new data is fetched, offering users a comprehensive visualization of the energy metrics.

In addition to displaying consumption and production trends, an imbalance graph is integrated into the UI. This graph illustrates the difference between production and consumption, highlighting instances where surplus energy production could be stored in EV batteries.

Building on the existing line chart graphs depicting real-time consumption and production imbalances, four new indicators have been introduced below the graphs to enhance the user's understanding of energy dynamics.

On the left side, the first indicator illustrates the estimated potential energy available for storage, showcasing surplus energy produced but not consumed on the current day. This surplus, calculated by subtracting consumption from production, represents energy that could potentially be stored in EV batteries, emphasizing insights into effective energy utilization strategies.

The second indicator on the left computes the estimated potential energy for stabilizing the grid, depicting the energy deficit where consumption exceeds production. This energy can be utilized to stabilize the grid by drawing from EV batteries, providing a proactive approach to grid management.

Addressing losses from overproduction, the third indicator assesses the value of energy lost during overproduction, calculated at a rate of 0.2 euros per kilowatt-hour (kWh). This quantifies the potential financial impact of surplus energy that exceeds market demand, encouraging considerations for optimizing production levels.

Finally, the fourth indicator delves into losses from underproduction on the right side, portraying the value of energy lost when production falls short of consumption. Here, the energy stored in EV batteries serves as an alternative source to balance the grid, offering a strategic solution to mitigate energy shortfalls.

These indicators serve as decision-making tools, offering a nuanced view of energy imbalances within the V2G system. They highlight opportunities for energy storage solutions and provide insights into potential strategies for surplus energy utilization.

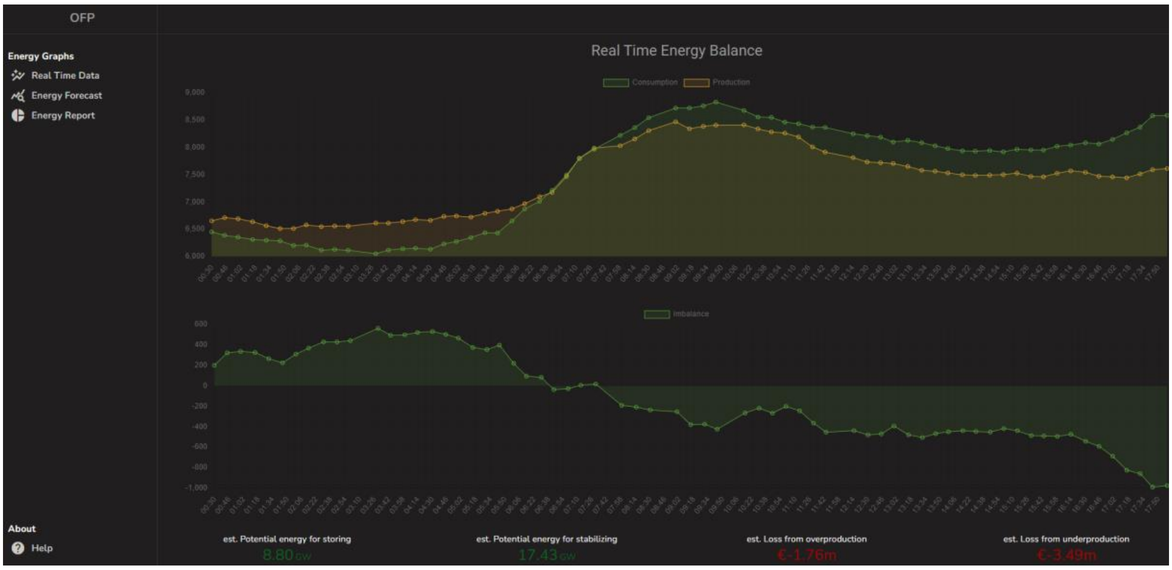

Figure 5.3. Real Time Data display.

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 21, 2024)

5.3.3 Energy Forecasting Page

Similar to the real-time data display, the forecasting page showcases line graphs portraying forecasted consumption and production trends. These graphs dynamically update based on the selected date, enabling users to visualize future energy metrics.

Complementing the consumption and production predictions, an imbalance graph delineates the projected difference between forecasted production and consumption. This visualization aids in understanding potential energy surplus or deficit scenarios.

Figure 5.4. Energy Forecast display.

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 22, 2024)

5.3.4 Energy Report Page

The energy report page contains a comprehensive breakdown of the types of energy produced in the last 24 hours. Using data from MongoDB, the Angular application creates a pie chart that illustrates the distribution of coal, hydrocarbon, water, nuclear, wind, solar, and biomass energy sources.

The pie chart offers interactivity, displaying energy values in megawatts (MW) and percentages when you hover over each segment. Also, text labels and corresponding values are shown below the chart for detailed understanding.

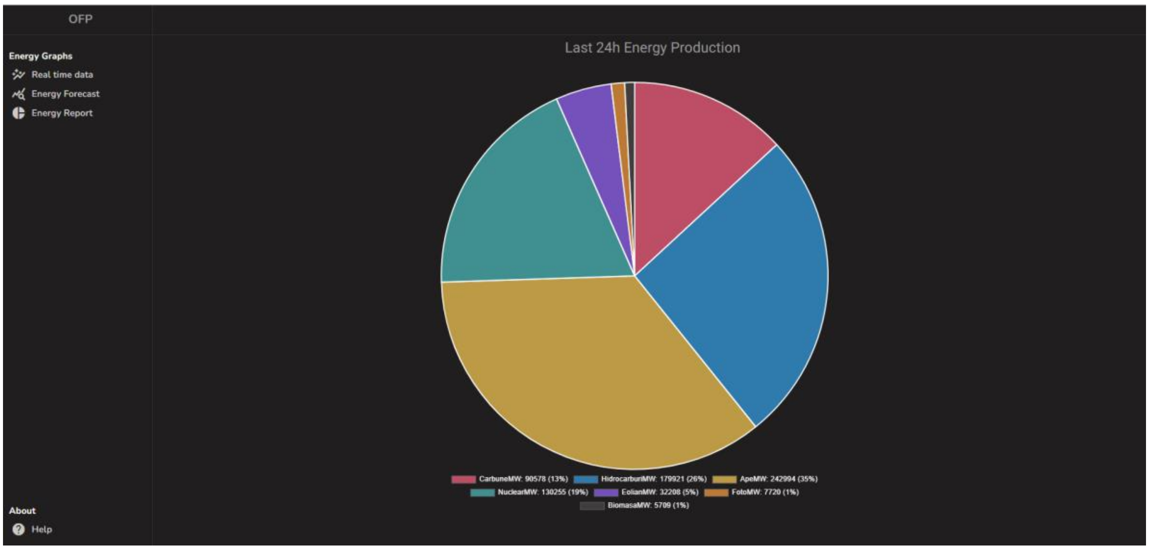

Figure 5.5. Energy Report display

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 21, 2024)

5.4 Integration and Functionality

5.4.1 Integration of Backend and Frontend

The successful integration of backend and frontend components remains a fundamental goal in this phase. The focus is on creating robust connections to facilitate data flow and communication between the Node.js Express backend and the Angular frontend.

The backend APIs are integrated into the Angular application. RESTful API endpoints act as mediators, allowing real-time energy consumption, production, and resource data to be retrieved and forwarded to the frontend.

Leveraging Angular's data binding mechanisms, the frontend easily connects to backend APIs. This mapping enables real-time and predictive energy indicators to be dynamically displayed and updated within the user interface, promoting an interactive and informative experience for users.

5.4.2 Usability and User Experience

Angular's framework helps to create a user-friendly interface based on intuitive design principles. The emphasis is on smooth navigation, clear presentation of data and responsive design, fostering an environment conducive to user interaction and understanding.

Efforts are aimed at a clear and comprehensible presentation of energy indicators and forecasts. The use of graphical representations, such as line charts and pie charts, helps users quickly understand consumption, production trends and energy source breakdowns, making interpretation easier.

Interactive components within the user interface promote user engagement and ease of interaction. Features like dropdowns for date selection and hover-over tooltips on charts provide users with additional contextual information, enriching the overall experience.

5.4.3 Deployment Strategies

The deployment strategy for the developed systems involves leveraging specific platforms tailored to host different components of the project.

The Angular application is deployed using Netlify (Netlify docs, n.d.), providing a hosting environment for the frontend interface. Netlify offers a user-friendly platform for effortless deployment, ensuring accessibility and scalability of the Angular app.

The backend Node.js Express API is hosted on an AWS EC2 instance (AWS EC2, n.d.), enabling robust and scalable deployment. The API is accessed via the URL https://3.79.231.199, and specific endpoints, including /reports for energy reports, /production-forecast for production forecasts, and /consumption-forecast for consumption forecasts, offer access to the stored data.

The EC2 instance serves as the hosting environment for the API, with configurations ensuring continuous availability. An SSH key makes it easy to access your GitHub repository from a Linux terminal inside your EC2 instance, allowing you to easily retrieve and update the code.

The PM2 process manager is used on the virtual machine to maintain API functionality beyond the shutdown of the VM. This ensures that the API file (app.js) continues to run even when the virtual machine is not actively accessed, ensuring uninterrupted service availability.

To address browser security concerns associated with insecure connections, an SSL certificate was acquired from zerossl.com. (zero ssl, n.d.) The SSL certificate was integrated into the Node.js Express app deployed on AWS EC2, enabling the API's transition to a secure HTTPS protocol accessible via https://3.79.231.199, ensuring secure communication between clients and the API.

Implementing SSL effectively resolved potential browser limitations that could have prevented API requests due to insecure connections. By securing the API endpoint with SSL, it meets modern browser security standards, enabling secure and uninterrupted data retrieval from the backend.

5.5 Data Analysis and outcome

In this section, we delve into a more detailed exploration of the critical role that data analysis plays in predicting energy production trends. Moreover, we discuss how these insights drive the integration of Electric Vehicle (EV) batteries for grid stabilization. Leveraging real-time and predictive data from Transelectrica not only facilitates a better understanding of energy consumption patterns but also allows for the development of proactive strategies to enhance grid stability and sustainability.

The predictive analysis begins with a careful examination of real-time data, providing a snapshot of the current energy production landscape. Below the energy production graphs, two indicators play a crucial role in estimating the potential for integrating EV batteries for grid stabilization.

First two in indicators on the left (Figure 5.6) signify the potential energy that could be harnessed with V2G technology, first indicator shows the energy that went into overproduction in the given day, this energy or part of this energy could be stored in EV batteries, making them potentially mobile energy storage units. In this case an estimated 8.8 GW of energy was lost because of overproduction.

The second indicator shows that an estimated 17.43 GW of energy went into deficit in the given day. Knowing this deficit is crucial for grid management, as it highlights potential strain on the energy infrastructure.

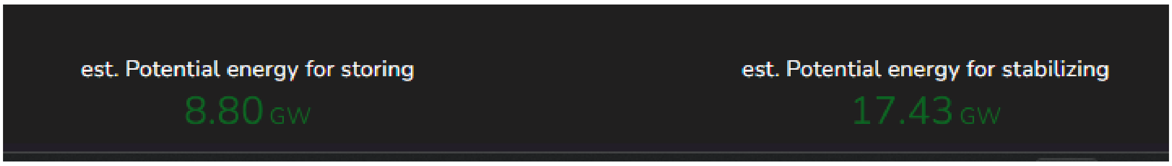

Figure 5.6. Potential energy for storing & stabilizing.

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 21, 2024)

The following two indicators show potential loses which occur because of overproduction or underproduction. The first indicator on the left (Figure 5.7) is showing a value estimation of the energy that went into overproduction. As mentioned earlier, this value is calculated at a rate of 0.2 euros per kilowatt-hour (kWh).

The indicator on the right is showing the value estimation of energy which went into deficit. This situation implies that there was insufficient energy supply to meet the demand, which may lead to disruptions, economic losses due to potential blackouts or the need to acquire additional energy from alternative, potentially more expensive sources.

If V2G technology were implemented, part of these losses could be mitigated, as electric vehicles equipped with bidirectional charging capabilities could contribute surplus energy back to the grid during periods of underproduction, potentially offsetting the financial impact and enhancing overall energy efficiency. (MRH Mojumder, 2022)

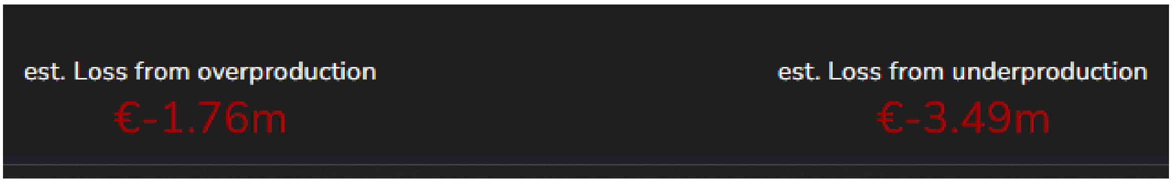

Figure 5.7 Potential energy loses.

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 21, 2024)

These estimations are based on data collected at 15-minute intervals, and while informative, a more frequent data collection would enhance precision, providing a more accurate representation.

In Figure 5.8, the peaks indicate periods of energy surplus, while the troughs signify energy deficit. Understanding these patterns is pivotal for the effective utilization of EV batteries for grid stabilization.

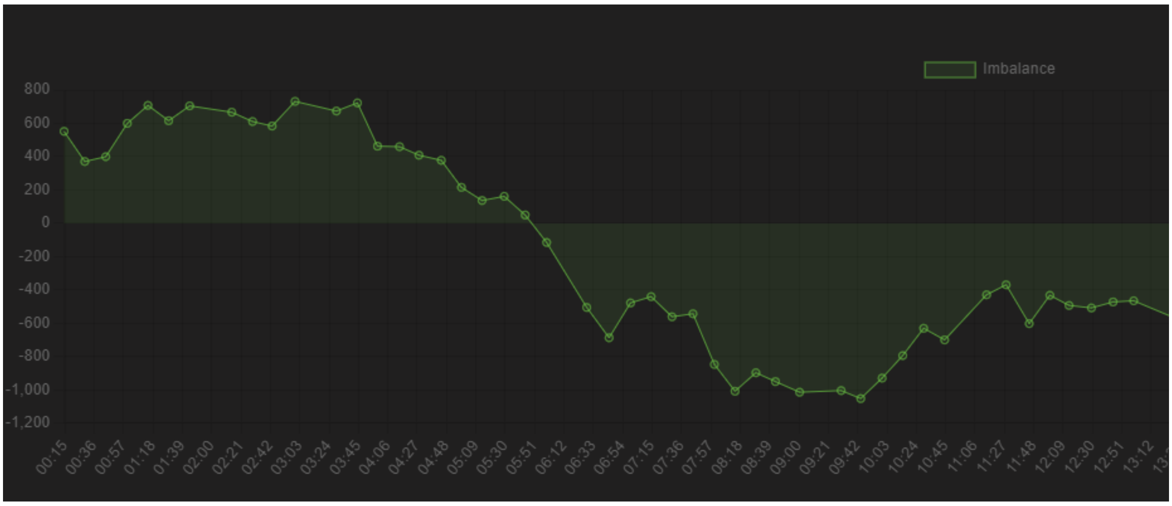

Figure 5.8 Imbalance graph

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 20, 2024)

Figure 5.9 indicates periods of overproduction in the energy grid, presenting a notable challenge for grid operators. During these surplus periods, where renewable energy sources generate more power than the current demand, the excess energy often goes to waste. This situation not only leads to inefficient use of resources but also poses a challenge in maintaining the stability of the power grid.

By leveraging Vehicle-to-Grid (V2G) technology, excess energy during such periods can be stored in electric vehicle (EV) batteries. This not only helps stabilize the grid but also provides EV owners with the potential to sell back stored energy, contributing to a more efficient and dynamic energy ecosystem.

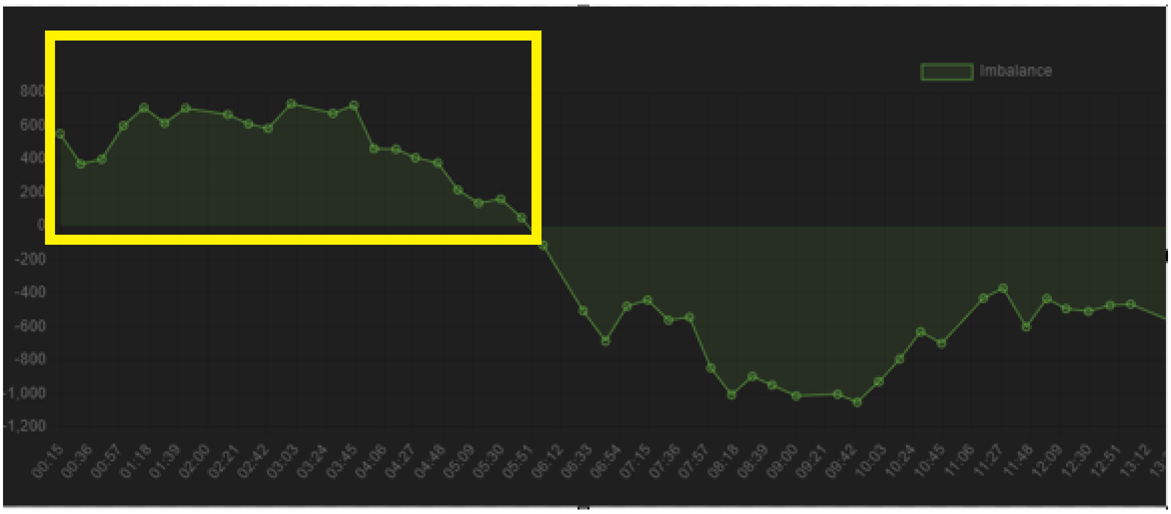

Figure 5.9. Overproduction

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 20, 2024)

Figure 5.10 indicates periods of underproduction. Underproduction in energy generation refers to situations where the actual production of energy falls below the anticipated or required levels to meet the demand. This discrepancy can result from various factors, such as insufficient capacity, technical issues in power plants, fuel shortages, or unexpected spikes in energy consumption.

During the highlighted periods, when energy generation lags behind consumption, Vehicle-to-Grid (V2G) technology could enable electric vehicles (EVs) to not only draw power from the grid but also contribute surplus energy back when necessary. This bidirectional flow would help address imbalances in energy supply and demand, enhancing grid reliability and flexibility.

Energy underproduction can lead to a range of consequences, including power shortages, blackouts, and disruptions in electricity supply. These issues can result in inconvenience for consumers, economic losses for businesses, and potential risks to critical infrastructure. Additionally, underproduction may strain the stability of the electrical grid, leading to voltage fluctuations and frequency variations that can adversely impact the performance of connected devices and machinery.

Figure 5.10. Underproduction

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 20, 2024)

Predictive data, when harnessed effectively, becomes a powerful tool for optimizing the integration of EV batteries into the grid. By anticipating periods of overproduction and underproduction, we gain the ability to mobilize resources efficiently.

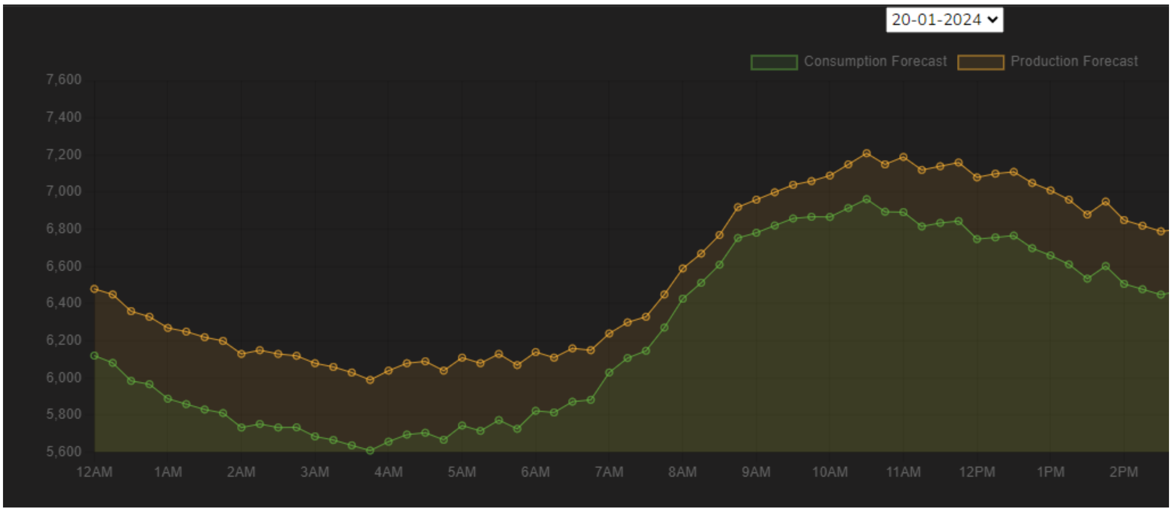

Figure 5.11 Predictive graphs

Source: Author (https://ofp-admin-panel.netlify.app/, accessed on January 20, 2024)

The integration of EV batteries into this predictive framework allows for strategic deployment during times of surplus energy. Engaging with EV owners to encourage them to plug in their vehicles becomes not only an act of grid stabilization but also a financial incentive.

This proactive approach aligns with the broader goals of creating a more resilient and sustainable energy infrastructure. It not only mitigates the challenges posed by overproduction and underproduction but also positions EVs as active participants in the larger energy ecosystem.

The analysis of real-time and predictive data from Transelectrica, complemented by indicators for potential energy storage and unsold energy value, serves as the foundation for a paradigm shift in grid management. By anticipating energy production trends and attaching financial value to surplus energy, we can make use of EV batteries strategically, enhancing grid stability and reducing reliance on non-renewable energy sources.

The integration of data analytics and electric vehicles establishes a symbiotic relationship, fostering a more adaptable, efficient, and sustainable energy environment. This progressive approach not only tackles present challenges but also sets the foundation for a future where renewable energy sources and electric vehicles collaborate to forge a greener and more sustainable energy ecosystem. The journey toward a smarter grid, propelled by data insights and innovative solutions, envisions a future where energy is not merely consumed but actively managed for the benefit of the environment and society as a whole.

5.6 Future Scope and Directions

Future enhancements may include the development and integration of predictive algorithms within the system. By leveraging machine learning or statistical modeling, the project can evolve to offer more accurate forecasting of energy consumption and production.

Future enhancements may also involve the development of a dedicated mobile application, targeting EV owners. This application would aim to offer real-time insights into periods of energy overproduction or underproduction, providing users with valuable information to optimize their EV charging behaviors. It would actively notify users during peak energy production or shortage hours, encouraging them to plug in their EVs, effectively contributing to grid stability by utilizing their vehicle batteries as a temporary energy storage solution. Connected to the user's EV, the application would facilitate participation in supporting the grid during peak hours. Users who plug in their EVs during these critical periods and provide surplus energy to the grid would be rewarded with redeemable points. These points could serve as a form of compensation for the users. Companies supporting the initiative might offer discounts or benefits to users accumulating these points. For instance, discounts at partner stores or the ability to reduce energy costs using acquired points could incentivize and reward active grid support.

Depending on the growth of the project and the participation of the stakeholders, there are many possibilities. The initiative can develop into a robust ecosystem that promotes energy efficiency, encourages sustainable practices, and creates beneficial collaboration between energy consumers and providers.

Expanding the scope by incorporating additional data sources beyond Transelectrica could enrich the system. Integrating data from renewable energy sources, weather patterns, or societal factors can offer comprehensive insights into energy production and consumption patterns.

Continual improvements in the frontend interface can enhance user interaction and experience. Implementing more interactive data visualization tools, customizable user preferences, and responsive design elements can further elevate usability.

Going beyond mere energy type breakdowns, future iterations of the project may incorporate advanced environmental impact assessment tools. This could involve sophisticated models to quantify and visualize the ecological footprint associated with various energy sources.

The ultimate aspiration lies in deploying and implementing the developed system in practical settings. Collaborations with utility providers or governmental agencies could pave the way for the application's real-world utilization, contributing to sustainable energy practices.

Chapter 6. Conclusions and Proposals

In conclusion, the prospects for Electric Vehicle (EV) battery usage in grid stabilization, particularly through Vehicle-to-Grid (V2G) technology, are promising but require further development and infrastructure investment before reaching mainstream adoption. While the commercial availability of V2G solutions is on the horizon, several challenges remain on the path to making this technology a ubiquitous tool in energy management.

The existing state of technology and infrastructure suggests that there are still hurdles to overcome before V2G becomes a commonplace solution for grid stabilization. However, the concept holds tremendous potential and is poised to revolutionize the energy industry as development progresses, and more electric vehicles (EVs) are integrated into the grid.

The economic impact in Romania is challenging to measure at present, but the web application developed provides a valuable tool for showcasing the energy losses and the untapped potential for energy storage. As EVs become more affordable and equipped with bidirectional energy flow capabilities in the coming years, the technology's promise will likely grow.

The ongoing development and adoption of bidirectional charging standards are essential factors in the evolution of V2G technology. Collaboration among various stakeholders, including automakers, utilities, and technology providers, is crucial for standardizing and implementing V2G effectively. The landscape is dynamic, and as more efforts are dedicated to addressing challenges, the technology is expected to gain traction.

Looking ahead, the continuous advancements in V2G technology are anticipated to enhance bidirectional capabilities in future EV models. As these innovations unfold, the potential for widespread adoption of V2G technology becomes increasingly feasible. It is only a matter of time before EVs equipped with bidirectional capabilities become more prevalent, contributing to the transformation of the energy landscape.

While the journey toward mainstream adoption of EV battery usage for grid stabilization may have its challenges and uncertainties, the overall trajectory is one of promise and potential transformation in the energy sector. As technology, infrastructure, and standards evolve, the vision of V2G as a mainstream energy management tool draws nearer, holding the promise of a more resilient and sustainable energy future.

Proposals for Future Directions

Investment in Infrastructure:

Governments and private entities should prioritize investments in infrastructure to support the widespread adoption of V2G technology. This includes expanding charging infrastructure, upgrading grid systems, and implementing smart grid technologies to facilitate bidirectional energy flow seamlessly.

Regulatory Frameworks:

Policymakers need to develop clear regulatory frameworks that incentivize the adoption of V2G technology while ensuring grid stability and reliability. This may involve implementing tariffs, subsidies, and standards to encourage participation from both EV owners and utilities.

Public Awareness and Education:

There is a need for public awareness campaigns and educational programs to inform consumers about the benefits of V2G technology and encourage EV adoption. By fostering a better understanding of how EVs can contribute to grid stabilization, consumers may be more inclined to participate in V2G programs.

Research and Development:

Continued investment in research and development is essential to overcome technical challenges and optimize V2G technology. This includes advancements in battery technology, grid management algorithms, and interoperability standards to maximize the potential of EVs as grid assets.

Collaborative Partnerships:

Stakeholders across the EV and energy sectors should collaborate to accelerate the deployment of V2G technology. This includes partnerships between automakers, utilities, technology providers, and government agencies to pilot projects, share best practices, and drive innovation in the space.

By implementing these proposals, stakeholders can work together to unlock the full potential of electric vehicle batteries, paving the way for a more sustainable and resilient energy future.

List of Tables and Figures

List of Tables

List of Figures

References

Alam, M. S. (2020). High-Level Penetration of Renewable Energy Sources Into Grid Utility: Challenges and Solutions. *IEEE Systems Journal*, 19078-19079. Retrieved December 12, 2023 from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9224611

Alfonso Damiano, G. G. (2014). Vehicle-to-Grid Technology: State-of-the-Art and Future Scenarios. *Journal of Energy and Power Engineering*, 155-163. Retrieved December 16, 2023 from https://iris.unica.it/bitstream/11584/95219/2/P35%232014%23JEPE%23exEEVC%23JEPE_Paper.pdf

Al-Hanahi, B. (2021). Charging Infrastructure for Commercial Electric Vehicles: Challenges and Future Works. *IEEE*, 121479. Retrieved November 14, 2023 from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9524919

Alotaibi, I. e. (2020). A Comprehensive Review of Recent Advances in Smart Grids: A Sustainable Future with Renewable Energy Resources. *Energies*, 1-4/10-14. Retrieved December 13, 2023 from https://www.mdpi.com/1996-1073/13/23/6269/pdf

AM Koufakis, E. R. (2016). Towards an optimal EV charging scheduling scheme with V2G and V2V energy transfer. *IEEE International Conference on Smart Grid Communications*, 1-4. Retrieved 12 17, 2023 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Towards+an+Optimal+EV+Charging+Scheduling+Scheme+with+V2G+and+V2V+Energy+Transfer&btnG=

Analiză LEKTRI.CO. (2024, January). Retrieved January 27, 2024 from https://sustenabilitate.biz/analiza-lektri-co-peste-16-800-de-masini-electrice-inmatriculate-in-2023-in-romania-cu-35-peste-2022/

AWS EC2. (n.d.). Retrieved December 27, 2023 from https://aws.amazon.com/ec2/

AWS Lambda. (n.d.). Retrieved December 26, 2023 from https://aws.amazon.com/pm/lambda

BMW ChargeForward. (n.d.). Retrieved January 22, 2024 from https://www.bmwchargeforward.com/

BMW i ChargeForward Program. (2015). Retrieved January 22, 2024 from https://www.press.bmwgroup.com/usa/article/detail/T0199502EN_US/the-bmw-group-together-with-pacific-gas-electric-company-announces-the-bmw-i-chargeforward-program?language=en_US

ChartJS docs. (n.d.). Retrieved December 20, 2023 from https://www.chartjs.org/docs/latest/

Chun-Hao Lo, N. A. (2013). Decentralized Controls and Communications for Autonomous Distribution Networks in Smart Grid. *IEEE TRANSACTIONS ON SMART GRID VOL. 4, NO. 1*, 66-67. Retrieved December 13, 2023 from https://web.njit.edu/~ansari/papers/13TSG.pdf

Daiva Stanelyte, N. R. (2022). Overview of Demand-Response Services: A Review. *Energies*. Retrieved December 13, 2023 from https://www.mdpi.com/1996-1073/15/5/1659

DB Avancini, J. R. (2021). A new IoT-based smart energy meter for smart grids. *International Journal of Energy Research*, 1-13. Retrieved December 28, 2023

from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=A+new+IoT%E2%80%90based+smart+energy+meter+for+smart+grids&btnG=
Deivanayagam, R. (2017). Vehicle-to-grid Technology: Concept, Status, and Challenges. *Journal of Undergraduate Research*, 5-6. Retrieved November 27, 2023 from https://www.researchgate.net/profile/Ramasubramonian_Deivanayagam/publication/319203183_Vehicle-to-grid_Technology_Concept_Status_and_Challenges/links/5cee42d2299bf109da7739f1/Vehicle-to-grid-Technology-Concept-Status-and-Challenges.pdf
Electric Nation. (n.d.). Retrieved January 22, 2024 from https://electricnation.org.uk/
Electric Nation Project Results. (2022). Retrieved January 22, 2024 from https://www.drive-electric.co.uk/news/electric-nation-v2g-project-results/
EV Database. (n.d.). Retrieved January 28, 2024 from https://ev-database.org/
Express API. (n.d.). Retrieved December 28, 2023 from https://expressjs.com/en/5x/api.html#express
Goodenough, J. B. (2018). How we made the Li-ion rechargeable battery. *Nature Electronics*. Retrieved November 13, 2023 from https://www.nature.com/articles/s41928-018-0048-6
H Patil, V. K. (2020). Grid integration of electric vehicles for economic benefits: A review. *Journal of Modern Power Systems and Clean Energy*.
International Energy Agency. (n.d.). Retrieved 01 20, 2024 from https://www.iea.org/energy-system/transport/electric-vehicles
Ivan Pavic, T. C. (2015). Value of flexible electric vehicles in providing spinning reserve services. *Applied Energy*, 60-73. Retrieved December 16, 2023 from https://orbilu.uni.lu/bitstream/10993/57691/1/Applied%202015%20Value%20of%20flexible%20electric%20vehicles%20in%20providing%20spinnging%20reserve%20services.pdf
Jingli Guo, J. Y. (2019). Impact Analysis of V2G Services on EV Battery Degradation - A Review. *School of Engineering and Applied Science*, 1-5.
K Clement-Nyns, E. H. (2011). The impact of vehicle-to-grid on the distribution grid. *Electric Power Systems Research*, 185-192. Retrieved December 20, 2023 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=The+impact+of+vehicle-to-grid+on+the+distribution+grid&btnG=
Karduri, R. K. (2018). Integrating Renewable Energy into Existing Power Systems: Challenges and Opportunities. *International Journal of Advanced Research in Management, Architecture, Technology and Engineering*, 213-220. Retrieved December 13, 2023 from https://www.researchgate.net/profile/Rajini-Karduri/publication/375910881_Integrating_Renewable_Energy_into_Existing_Power_Systems_Challenges_and_Opportunities/links/6563895ab1398a779db7f734/Integrating-Renewable-Energy-into-Existing-Power-Systems-Challen
Kempton, W. &. (2005). Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *Journal of Power Sources*, 1-4. Retrieved 11 13, 2023 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Vehicle-to-grid+power+implementation%3A+From+stabilizing+the+grid+to+supporting+large-scale+renewable+energy&btnG=
KM Tan, V. R. (2016). Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. *Renewable and Sustainable*

Energy Reviews, 721-730. Retrieved December 08, 2023 from https://e-tarjome.com/storage/uploaded_media/2022-07-30/1659158648_F2147-English-e-tarjome.pdf

Krishna, G. (2021). Understanding and identifying barriers to electric vehicle adoption through thematic analysis. *Transportation Research Interdisciplinary Perspectives*. Retrieved January 03, 2024 from https://www.sciencedirect.com/science/article/pii/S2590198221000713

M Mao, S. Z. (2019). Schedulable capacity forecasting for electric vehicles based on big data analysis. *Journal of Modern Power Systems and Clean Energy*, 1651-1660. Retrieved December 28, 2023 from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8964541

M Umair, N. H. (2023). The effect of vehicle-to-grid integration on power grid stability: A review. *IOP Conference Series: Earth and Environmental Science*, 1-6. Retrieved December 28, 2023 from https://iopscience.iop.org/article/10.1088/1755-1315/1281/1/012070/pdf

M. Faizal, S. Y. (2019). A Review On Challenges And Opportunities Of Electric Vehicles (EVS). *Journal of Mechanical Engineering Research and Development*, 127-134. Retrieved December 12, 2023 from https://www.researchgate.net/profile/Ir-Ts-Dr-Mohd-Faizal-Fauzan/publication/334989926_A_Review_on_Challenges_and_Opportunities_of_Electric_Vehicles_EVS/links/5d496b744585153e594065a1/A-Review-on-Challenges-and-Opportunities-of-Electric-Vehicles-EVS.pdf

M.A. López, S. d. (2014). Demand-side management in smart grid operation considering electric vehicles load shifting and vehicle-to-grid support. *International Journal of Electrical Power & Energy Systems*, 691-697. Retrieved December 21, 2023 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Demand-side+management+in+smart+grid+operation+considering+electric+vehicles+load+shifting+and+vehicle-to-grid+support&btnG=

MDSA Khan, K. K. (2018). Implementation of efficient B2G and V2G in practical cases. *Journal of Electronic Science and Technology*. Retrieved December 17, 2023 from https://www.journal.uestc.edu.cn/en/article/doi/10.11989/JEST.1674-862X.80715105?viewType=HTML

MongoDB docs. (n.d.). Retrieved December 16, 2023 from https://www.mongodb.com/docs/

MRH Mojumder, F. A. (2022). Electric vehicle-to-grid (V2G) technologies: Impact on the power grid and battery. *Sustainability*, 1-19. Retrieved December 17, 2023 from https://www.mdpi.com/2071-1050/14/21/13856/pdf

Murat Yilmaz, M. I. (2013). Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Utility Interfaces. *IEEE*, 5673-5684. Retrieved December 13, 2023 from http://prof.khuisf.ac.ir/images/Uploaded_files/06353961%5B8152766%5D.PDF

Netlify docs. (n.d.). Retrieved December 19, 2023 from https://docs.netlify.com/

Nissan & Enel Denmark. (2016). Retrieved January 22, 2024 from https://europe.nissannews.com/en-GB/releases/nissan-enel-and-nuvve-operate-world-s-first-fully-commercial-vehicle-to-grid-hub-in-denmark

Nissan & Enel UK. (2016). Retrieved January 22, 2024 from https://www.enel.com/media/explore/search-press-releases/press/2016/05/nissan-and-enel-launch-groundbreaking-vehicle-to-grid-project-in-the-uk

Noor Aziz, M. A. (2019). Vehicle to Grid (V2G) for Peak Shaving: New Trend, Benefits, and Issues. *International Journal of Computing and Communication Networks*, 35-36. Retrieved November 27, 2023 from https://ijccn.com/index.php/IJCCN/article/download/21/15

Notter, D. (2010). Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles. *Environmental Science & Technology, vol. 44, no. 17*, 6550-6556. Retrieved December 14, 2023 from https://pubs.acs.org/doi/pdf/10.1021/es903729a

OMF Camacho, P. N.-P. (2014). Electrical vehicle batteries testing in a distribution network using sustainable energy. *IEEE Transactions on Smart Grid*. Retrieved December 28, 2023 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Electrical+Vehicle+Batteries+Testing+in+a+Distribution+Network+using+Sustainable+Energy&btnG=

Rudraksh S. Gupta, A. T. (2021). Optimal allocation of electric vehicles charging infrastructure, policies and future trends. *Journal of Energy Storage*. Retrieved January 03, 2024 from https://www.sciencedirect.com/science/article/abs/pii/S2352152X2100983X

S Hosseinpour, H. C. (2015). Barriers to the wide adoption of electric vehicles: A literature review based discussion. *Portland International Conference on Management of Engineering and Technology (PICMET)*. Retrieved January 03, 2024 from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Barriers+to+the+Wide+Adoption+of+Electric+Vehicles%3A+A+Literature+Review+Based+Discussion&btnG=

S Vadi, R. B. (2019). A review on communication standards and charging topologies of V2G and V2H operation strategies. *Energies*, 1-7. Retrieved December 20, 2023 from https://www.mdpi.com/1996-1073/12/19/3748/pdf

Sarah LaMonaca, L. R. (2022). The state of play in electric vehicle charging services – A review of infrastructure provision, players, and policies. *Renewable and sustainable energy reviews*. Retrieved November 27, 2023 from https://www.sciencedirect.com/science/article/pii/S1364032121010066

Singh M, K. J. (2013). Thick electrodes for high energy lithium ion batteries. *IEEE Transactions On Power Electronics, vol. 28, no. 12*, A1196 - A1200. Retrieved December 14, 2023 from https://iopscience.iop.org/article/10.1149/2.0401507jes/pdf

Stephen P. Holland, E. T. (2016). Are there environmental benefits from driving electric vehicles? The importance of local factors. *American Economic Review*, 3702-3704. Retrieved November 27, 2023 from https://cdr.lib.unc.edu/downloads/h702qb947

Steward, D. (2017). Critical Elements of Vehicle-toGrid (V2G) Economics. *National Renewable Energy Laboratory*, 1-9. Retrieved January 27, 2023 from https://www.nrel.gov/docs/fy17osti/69017.pdf

T Mao, X. Z. (2019). Intelligent Energy Management Algorithms for EV-charging Scheduling with Consideration of Multiple EV Charging Modes. *Energies*, 2-15. Retrieved December 16, 2023 from https://www.mdpi.com/1996-1073/12/2/265/pdf

Torriti, J. (2017). Understanding the timing of energy demand through time use data: Time of the day dependence of social practices. *Energy research & social* *science*. Retrieved January 03, 2024 from https://www.sciencedirect.com/science/article/pii/S2590198221000713

Transelectrica Widget. (n.d.). Retrieved January 22, 2024 from https://www.transelectrica.ro/widget/web/tel/sen-harta/-/harta_WAR_SENOperareHartaportlet

Ulas Baran Baloglu, Y. D. (2016). Economic Analysis of Hybrid Renewable Energy Systems with V2G Integration Considering Battery Life. 244-247. Retrieved January 26, 2024 from https://pdf.sciencedirectassets.com/277910/1-s2.0-S1876610217X00027/1-s2.0-S1876610216317295/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEC8aCXVzLWVhc3QtMSJIMEYCIQD6tsQb8hDeetwiX3M4ZyPMZjHBVmniCb6bvhh2DB%2BWugIhALxpuMpQclKE55%2FKAMJU7%2BuNgWOBguXJ7MWO03

University of Delaware. (2014). Retrieved January 22, 2024 from https://www1.udel.edu/udaily/2014/may/electric-school-bus-052814.html

W Yan, Q. H. (2021). Feasibility Studies On Black Start Capability Of Distributed Energy Resources. *IET*, 1-5. Retrieved December 26, 2023 from https://strathprints.strath.ac.uk/79204/1/Yan_etal_ICRPG_2021_Feasibility_studies_on_black_start_capability_of_distributed.pdf

Xiaoli Sun, Z. L. (2019). Technology Development of Electric Vehicles: A Review. *Energies*, 1-2 / 18-19. Retrieved November 27, 2023 from https://www.mdpi.com/1996-1073/13/1/90/pdf

Xiaolong Xu, K. S. (2020). Recent Advances in the Interface Design of Solid-State. *Materials Horizons*, 30-32. Retrieved December 12, 2023 from https://ueaeprints.uea.ac.uk/id/eprint/77741/1/Accepted_Manuscript.pdf

zero ssl. (n.d.). Retrieved December 28, 2023 from https://zerossl.com/

Source Code

https://github.com/ZsoltDemeter/node-express

https://github.com/ZsoltDemeter/OFP-admin

https://github.com/ZsoltDemeter/lambda-functions

Application URL

https://ofp-admin-panel.netlify.app