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BIDIRECTIONAL CHARGING: UNLOCKING THE POTENTIAL OF VEHICLE-TO-GRID (V2G) TECHNOLOGY IN KOSOVO

Fatbardha Mehani[1,2], Arta Grajçevci[1]

Abstract: As Kosovo navigates the global shift toward renewable energy and sustainable mobility, Vehicle-to-Grid (V2G) technology stands out as a transformative innovation for the country's energy infrastructure. By enabling bidirectional energy flow between electric vehicles (EVs) and the power grid, V2G allows EVs to function as decentralized energy storage units, supporting the grid during periods of peak demand and compensating for fluctuations in renewable energy generation. In a nation where, renewable energy sources such as solar and wind power are steadily expanding, V2G technology offers a unique opportunity to address pressing challenges in grid stability, peak load management, and the seamless integration of intermittent renewable resources. Leveraging the capabilities of V2G can not only enhance Kosovo's energy efficiency and grid reliability but also reduce its reliance on fossil fuels and improve the overall flexibility of its power system. This paper explores the strategic role of V2G in stabilizing Kosovo's grid and optimizing renewable energy integration. It provides an analysis of EV adoption trends, the readiness of existing grid infrastructure, and the potential scale of V2G-enabled vehicle fleets. Key technical considerations, including the deployment of bidirectional chargers and the adaptation of smart grid technologies, are also discussed. Additionally, the paper highlights economic and regulatory pathways to facilitate V2G adoption, focusing on the need for incentives, market mechanisms to reward EV owners for grid services, and lessons learned from countries where V2G is already in practice. By examining case studies and tailoring best practices to Kosovo's unique context, the paper identifies actionable steps to harness V2G's potential for improving grid stability and managing peak loads effectively. Nevertheless, the potential of V2G is immense, but its success hinges on significant substantial funding, and the advancement of technology

Keywords: Vehicle-to-Grid (V2G), Bidirectional Charging, Electric Vehicles (EVs), Grid Stability, Renewable Energy Integration

INTRODUCTION

The global transition toward sustainable energy systems necessitates innovative solutions for grid flexibility and stability. V2G technology, which allows bidirectional energy flow between EVs and the power grid, has emerged as a promising mechanism to support renewable energy integration. V2G technology enables bidirectional energy exchange between EVs and the power grid, allowing EVs to function as mobile energy storage units that can supply power back to the grid when needed [1]. This capability supports grid stability and enhances the integration of renewable energy sources such as solar and wind [2]. The global push for sustainable transportation and energy efficiency has accelerated interest in V2G solutions. However, numerous challenges remain in implementing this technology at scale [3].

V2G is the technology consisting of energy transfer in two directions, either from the vehicle to the grid if the energy stored in the battery is high, or from the grid to the vehicle when the energy stored in the battery is low. Since the energy flows to the vehicle from the grid, and from the grid to the vehicle, there occurs a bi-directional energy flow. During the energy flow, conversion operations are made with power electronics circuits to fit the type of power. For the purpose of taking the voltage level of the current grid voltage to the appropriate level, firstly an AC/DC conversion system is carried out, and then the reduction is done with a descending converter. To transfer the DC energy in the battery to the grid, firstly, an additional operation is done with an increasing converter, and then the DC/AC conversion process is carried out. These operations are performed bi-directionally depending on the amount of energy in the battery. Hybrid electric vehicles usually charge their batteries through fuel, whereas electrical vehicles charge their batteries from the grid, thus having significant differences in charging circuitry. However, both are of considerable interest in V2G technology. The EV is plugged into a charge station, which is connected to a power converter, followed by a transformer connected to the main grid [4].

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[1] Kosovo Electricity Distribution Company, Kosovo
[2] Correspondence email: fatbardha.mehani@keds-energy.com

In a V2G ecosystem, grid operators manage the aggregate capacity of thousands of connected vehicles through an aggregator rather than handling each vehicle individually. The aggregator acts as a large, rapidly controllable resource, contracting with the grid via day-ahead and hour-ahead markets for regulation capacity. Communication occurs over secure data links, with the aggregator allocating grid commands to vehicles, tracking their locations via GPS, and serving as the interface for drivers through a web portal. This setup allows drivers to set profiles, check vehicle status, and monitor benefits, while ensuring vehicles are assigned to the correct control zones.

In Kosovo, where solar and wind power capacities are expanding, leveraging V2G can enhance energy efficiency, reduce reliance on fossil fuels, and improve grid reliability [5]. However, the adoption of V2G requires addressing technical, economic, and regulatory challenges. Despite growing interest in V2G, the technology remains underutilized in many developing energy markets, including Kosovo. A key factor limiting its adoption is the absence of a well-developed charging infrastructure [6]. Furthermore, concerns about battery degradation and the financial viability of V2G services delay widespread participation [7]. Addressing these challenges requires a comprehensive strategy involving policy reforms, technological advancements, and financial incentives to encourage EV adoption and integration into the grid.

1. V2G TECHNOLOGY AND ITS ROLE IN GRID STABILITY

V2G technology facilitates energy exchange between EVs and the grid, allowing vehicles to store excess energy and supply it back during peak demand. Studies highlight the economic and technical viability of V2G in grid stabilization [8]. Furthermore, integrating battery aging considerations in bidirectional charging strategies can improve cost-effectiveness and sustainability [7]. Research also underscores the need for advanced charging algorithms to optimize V2G efficiency [9]. These insights reinforce the potential of V2G as a decentralized energy management tool.

Electric vehicles can transfer energy to the grid when the vehicle will not be used for a long time or when the electricity sales price is at its highest. Users can charge the battery when energy prices are low and provide both the current energy demand of the grid and gain financial benefits. While, if the energy of the electric vehicle battery is supplied to individual houses instead of the grid, it is called as the V2H technology. The operating modes of the bi-directional EV chargers are given in Figure 1. [10].

V2G systems contribute to power system stability by providing ancillary services such as frequency regulation, reactive power compensation, and spinning reserves [3]. These services are crucial for maintaining grid reliability, particularly as renewable energy penetration increases. However, effective deployment requires advanced control strategies and compensation mechanisms for EV owners who participate in ancillary service provision. Additionally, a case study on V2G response to frequency contingencies in national grids demonstrated that EVs can discharge power within seconds of an emergency, showcasing their potential for enhancing grid stability and security [11]. However, technical challenges such as inconsistencies in response rates and the need for improved control mechanisms highlight areas for further research [12].

The primary advantages of V2G technology include improved grid reliability, peak load reduction, and enhanced utilization of renewable energy [13]. By leveraging the aggregated energy storage of EVs, V2G can provide load balancing, frequency regulation, and voltage support [14]. Additionally, EV owners can benefit financially by participating in energy markets, selling excess stored energy back to the grid [15]. Despite these benefits, several challenges delay widespread V2G adoption. These include the need for robust grid infrastructure, advanced communication protocols for energy management, and battery degradation concerns due to frequent charging and discharging cycles (Cao). Furthermore, regulatory and market structures must evolve to facilitate seamless V2G integration and incentivize stakeholders [16].

2. EV ADOPTION TRENDS AND TRANSPORTATION INFRASTRUCTURE IN KOSOVO

While Kosovo's EV market is still in its early stages, projections indicate steady growth in EV adoption. Studies show that EV penetration is expected to increase in the coming years, supported by policy initiatives and infrastructure development [6]. However, limited charging

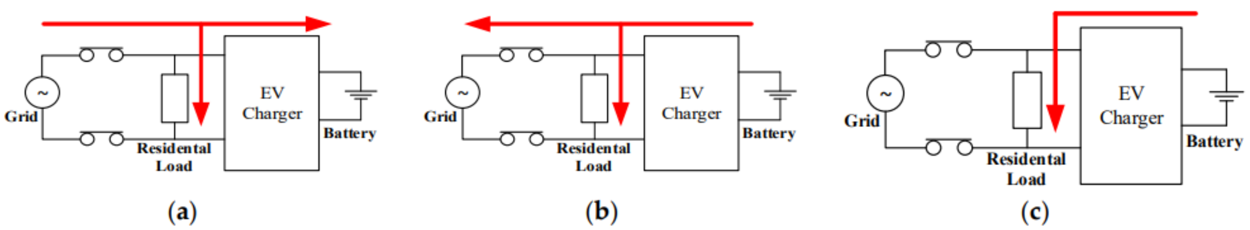

Figure 1: Operating modes of the bi-directional electric vehicle (EV) charger. (a) grid-to-vehicle (G2V) mode; (b) vehicle-to-grid (V2G) mode; (c) vehicle-to-home (V2H) mode [10]

infrastructure remains a key barrier. Comparative analyses of standard and fast EV charging highlight the importance of integrating V2G technology to enhance grid resilience and manage peak loads effectively [5].

As per transportation infrastructure, the chart in Figure 2. illustrates the evolution of Kosovo's Road network broken down by motorways, national roads, regional roads, and connecting roads between 2005 and 2024. It shows that connecting regional roads make up the largest share of the network, while national roads are the second-largest category. From an EV adoption and grid-readiness perspective, these trends imply that Kosovo's Road expansion is primarily focused on improving connectivity across smaller towns and rural areas, while incremental motorway development can support the placement of charging infrastructure along major corridors. This balanced expansion highlights the need to integrate EV charging solutions not just on highways but also along national and connecting roads to ensure comprehensive coverage for electric vehicle users.

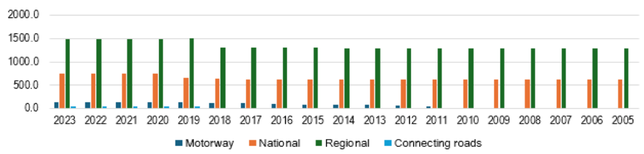

Figure 2: Roads of Kosovo according to categories 2005 - 2024 [17]

On the other hand, on the Figure 3. shows a steady rise in both passenger cars and transporting vehicles in Kosovo from 2011 to 2023, with lighter commercial vehicles (under 3.5 tons) growing more rapidly than heavier ones. Coupled with the roads chart on road categories, this trend suggests that Kosovo's expanding vehicle fleet, especially smaller and more frequently used vehicles, calls for broader, more distributed charging solutions across all road types (motorways, national, regional, and connecting roads) to support growing EV adoption.

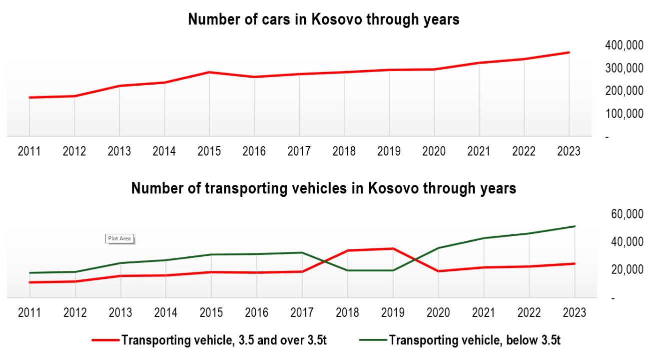

Figure 3: Number of cars and transporting vehicles in Kosovo through years [17]

Expanding the EV fleet also presents economic opportunities. A well-implemented V2G program could provide revenue streams for EV owners by allowing them to sell excess electricity back to the grid [18].

3. CONSIDERATIONS FOR V2G IMPLEMENTATION

The successful implementation of V2G technology necessitates significant investment in grid infrastructure, including bidirectional chargers, smart meters, and energy management systems [2]. Energy storage plays a critical role in enabling V2G, as EV batteries must efficiently manage charge-discharge cycles while maintaining longevity [1]. Additionally, smart grid capabilities must be enhanced to handle dynamic interactions between EVs and the electricity network [13]. Furthermore, research has shown that integrating smart charging strategies can reduce grid congestion and enable a more efficient allocation of electricity resources. A study on the feasibility of full EV integration into European power systems found that strategic planning and investment in bidirectional charging infrastructure are critical for preventing grid overloads and ensuring stable power supply [19]. In Kosovo, addressing these infrastructure needs will be key to realizing the full potential of V2G. Recent advancements in wireless charging present new opportunities for V2G applications by improving user convenience and enabling seamless energy transfers [14]. Wireless charging can be integrated with renewable energy sources such as solar photovoltaics and wind power, enhancing sustainability in the transportation and energy sectors. However, challenges such as energy transfer efficiency, infrastructure costs, and interoperability remain another key barrier to widespread adoption [15]. The interaction between V2G systems and the power grid can influence power quality by introducing voltage fluctuations, harmonic distortion, and reactive power imbalances (Cao). Proper management of these effects is crucial to ensuring stable grid operation. Studies indicate that optimized charging and discharging schedules, along with advanced inverter technologies, can mitigate adverse impacts on power quality [1].

Given Kosovo's rising electricity consumption and winter peak loads (January 2023 and December 2022) in Figure 4., V2G technology could serve as a demand management tool. By allowing EVs to discharge power back to the grid during high-demand periods, V2G can help balance seasonal variations and alleviate strain on the electricity network, particularly during peak winter months. EVs can charge during off-peak hours (e.g., early morning) and supply energy back to the grid during peak hours (e.g., evening). This bidirectional interaction enhances grid stability, reduces reliance on expensive peak-time generation, and supports the integration of renewable energy. However, implementing V2G in Kosovo requires sufficient charging infrastructure, regulatory frameworks, and incentives for EV owners to participate in energy exchange programs.

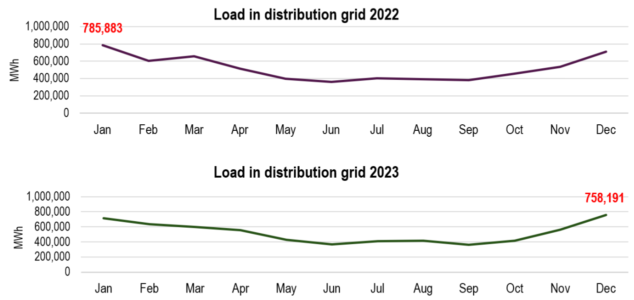

Figure 4. Electricity load trends in distribution grid in Kosovo (2022-2023) [20] [21]

Successful V2G implementation depends on supportive regulatory frameworks and market mechanisms. International case studies emphasize the need for grid-friendly incentives, dynamic electricity pricing, and standardized protocols to facilitate V2G adoption [18]. In Kosovo, policy interventions should focus on integrating V2G into national energy strategies, establishing V2G tariff structures, and promoting smart charging infrastructure. Countries that have successfully integrated V2G into their energy markets, such as Denmark and the Netherlands, have established market mechanisms that compensate EV owners for providing grid services [19]. Lessons from these regions can inform Kosovo's approach to developing a functional and sustainable V2G ecosystem. This presents a significant opportunity for a more regulated and controlled integration of electric vehicles, as opposed to the current unstructured approach.

4. QUANTITATIVE ANALYSIS OF BATTERY STORAGE AND V2G GRID INTEGRATION IN KOSOVO

Vehicle-to-Grid (V2G) technology allows EVs not only to charge from the grid but also to discharge stored energy back when needed. This capability helps balance supply and demand, supports renewable integration, and can provide ancillary services (like frequency regulation) to the grid. In a country like Kosovo, with a relatively small and developing grid, and historically high dependence on fossil fuels, V2G-enabled EVs can:

- Alleviate peak load stress,
- Enhance grid stability,
- Encourage renewable energy use, and
- Potentially reduce overall energy costs and emissions.

4.1. Transition Scenario & Distributed Storage Potential

The adoption and storage estimates provide insight into the potential impact of electric vehicle (EV) integration on energy storage capacity. At a fleet penetration rate of 20%, in Kosovo approximately 73,764 EVs would be in operation, while a higher penetration of 70% would result in around 258,173 EVs. Each EV is assumed to have a 50kWh battery, with 70% of its capacity available for grid services [22]. Under these conditions, the total effective energy storage would reach approximately 2.58 GWh at 20% penetration ($73{,}764 \times 50\,\text{kWh} \times 0.7 \approx 2.58\,\text{GWh}$) and 9.04 GWh at 70% penetration ($258\,173 \times 50\,\text{kWh} \times 0.7 \approx 9.04\,\text{GWh}$). This highlights the significant potential of EVs as a distributed energy resource, capable of enhancing grid flexibility and supporting energy stability. Even if only about 50% of these vehicles are connected during peak hours, the aggregated storage can significantly buffer short-term fluctuations. The Figure 5. shows the maximum monthly load (in MWh/h) for Kosovo during 2022 and 2023, with the highest peak in 2022 occurring on January 24, at 23:00 with 1429MWh and in 2023 on February 8, at 23:00 with 1413 MWh [20] [21]. These winter peaks underscore the grid's vulnerability to high demand during cold seasons. Within the Transition Scenario widespread adoption of EVs with V2G functionality could supply several gigawatt-hours of distributed storage. Such stored energy could be fed back into the grid during peak periods (like those highlighted in red on Figure 5.), thereby smoothing demand spikes enhancing overall grid stability

4.2. Grid Stability and Peak Load Management

Scientific studies [22] [23] have demonstrated that V2G technology can provide rapid response services to balance supply and demand. A distributed network of EV batteries can regulate frequency by quickly injecting or absorbing power, mitigate variability by compensating for intermittent renewable sources provide reserve capacity reducing reliance on expensive peaking power plants [24] and, this could work also in Kosovo's case.

If we take the days on which the grid reaches peak load based on Figure 5., on 24.01.2022 the grid reached a peak load of approximately 1,429 MW and on 08.02.2023 it reached 1413 MWh, we can discuss the peak load management with a 20% penetration rate and 70% penetration rate of EVs.

Max load 2022 (MWh/h)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	1429	1291	1,311	1,077	857	721	768	764	699	879	1,135	1,372
Max load 2023 (MWh/h)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	1,265	1,413	1,179	1,219	809	767	873	870	744	961	1,207	1,401

Figure 5: Maximum load per month in Kosovo 2022-2023 [20] [21]

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Peak load support for the date 24.01.2022:

- With a 20% EV penetration rate, around 2.58 GWh of energy storage would be available, and assuming 50% of these vehicles are connected to the grid, approximately 1.29 GWh (2.58 GWh×0.5=1.29 GWh) could be dispatched, providing about 54 minutes of peak load support (1.29 GWh / 1.429 GW =0.902 hours ≈ 54 minutes). In a scenario with 70% EV penetration, the available storage would increase to 9.04 GWh, and with half of the vehicles connected, around 4.52 GWh (9.04 GWh×0.5=4.52 GWh) could be utilized. This would extend peak load support to over 3 hours and 9 minutes (4.52GWh / 1.429GW=3.163 hours ≈ 3 hours and 9 minutes), demonstrating the potential of EVs as a valuable grid resource for managing energy demand fluctuations and enhancing system resilience.

Peak load support for the date 08.02.2023:

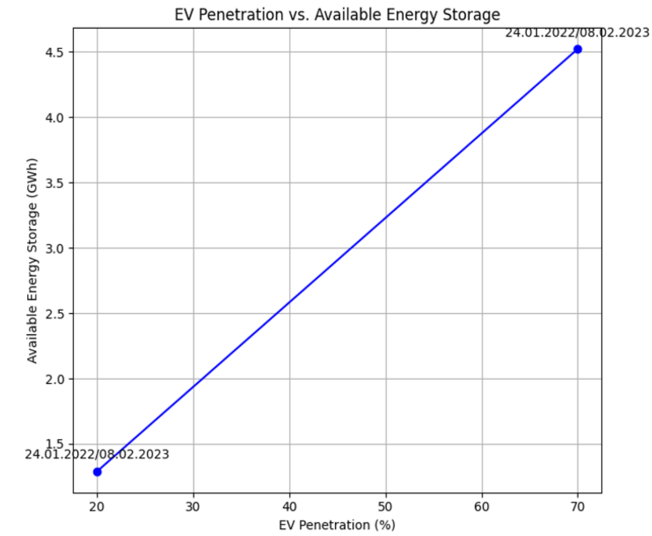
- With a 20% EV penetration rate, around 2.58 GWh of energy storage would be available, and assuming 50% of these vehicles are connected to the grid, approximately 1.29 GWh (2.58 GWh×0.5=1.29 GWh) could be dispatched, providing about one hour of peak load support (1.29 GWh / 1.413GW =0.912 hours ≈ 55 minutes). In a scenario with 70% EV penetration, the available storage would increase to 9.04 GWh, and with half of the vehicles connected, around 4.52 GWh (9.04 GWh×0.5=4.52 GWh) could be utilized. This would extend peak load support to over 3 hours and 12 minutes (4.52GWh / 1.413GW=3.198 hours ≈ 3 hours and 12 minutes), demonstrating the potential of EVs as a valuable grid resource for managing energy demand fluctuations and enhancing system resilience.

These values illustrate how even partial participation can substantially alleviate peak demand stress.

On Figure 6. are represented two graphs that illustrate key aspects of the introduced scenarios. They were generated using assumptions and data from the analysis.

EV Penetration vs. Available Energy Storage: This graph plots the cumulative available battery capacity (in GWh) as a function of fleet penetration. Assuming each EV has a 50kWh battery with 70% of that available for grid services, full penetration (100%) would yield approximately 12.91 GWh. At 20% penetration, about 2.58 GWh is available, increasing to roughly 9.04 GWh at 70% penetration. With a blue line demonstrating how energy storage capacity increases linearly from approximately 1.29GWh at 20% EV penetration to 4.5 GWh at 70% penetration. Both dates (24.01.2022 and 08.02.2023) are represented by a single line because they share identical available energy storage values. This represents the total energy storage potentially available from electric vehicles to support the grid.

EV Penetration vs. Peak Load Support Hours vs: By assuming that only about 50% of the EV fleet is connected during peak periods, we calculate the effective energy available to support a 1413 MW peak load referring to the highest load during 2023 and a 1429MW peak load during 2022. Both dates follow nearly identical trajectories, with support time increasing from roughly 54-55 minutes at 20% EV penetration to approximately 3 hours and 9 minutes at 70% penetration. This illustrates how V2G can help mitigate peak demand.



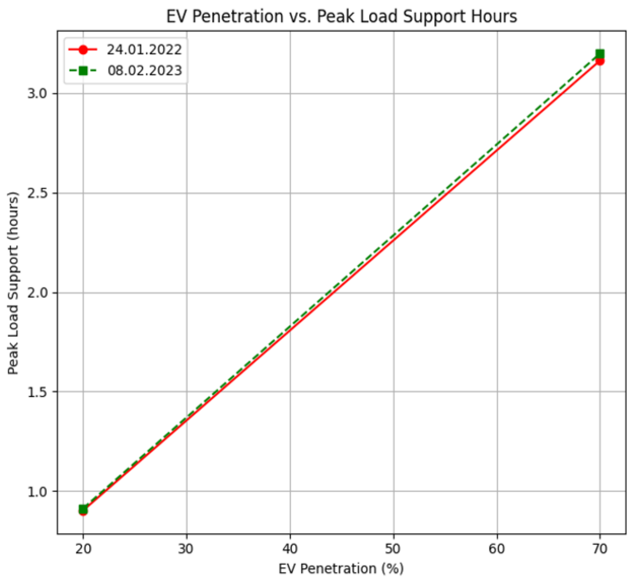


Figure 6: Impact of EV Penetration on Available Energy Storage and Peak Load Support Duration

4.3. Readiness of Kosovo's Existing Power System for V2G technology integration

Kosovo's electricity sector is highly dependent on coal-fired power plants, particularly Kosovo A and Kosovo B. The operating capacity is considered to be around 1,236 MW, of which lignite-fired thermal power plants (TPP) account for around 77.69%, while the rest consists of Ujmani HPP, RES in transmission and other RES (hydropower plants, solar panels and wind power plants) with 22.31% [21]. However, due to aging infrastructure and frequent breakdowns, Kosovo often imports electricity, especially during peak demand periods (e.g., winter). Kosovo's renewable energy sources (hydropower, wind, and solar) are growing but still insufficient to meet demand, leading to reliance on imports. This is a major challenge for the EV transition, as a shift to electric mobility could increase demand further unless smart grid solutions and battery storage are integrated.

As per infrastructure assessment the Kosovo Energy Regulatory Office (ERO) reports indicate ongoing modernization efforts. However, challenges remain in order to support the V2G technology such as low distribution network capacity and smart grid technologies. Upgrades are required to manage the bidirectional flows introduced by V2G systems. Current systems are transitioning toward digital, real-time management. Yet, significant investment is needed to fully implement communication protocols and automated control systems that coordinate distributed energy resources [21].

Mass EV adoption without proper planning could strain the grid and increase electricity consumption, especially in a country like Kosovo, which is already reliant on coal plants and imports. The integration of electric vehicles (EVs) into the power grid poses challenges related to peak demand and grid stability. Without controlled charging, EV adoption could lead to Kosovo's grid overload. However, strategic solutions can optimize charging behavior and enhance system efficiency.

Time-of-Use (ToU) tariffs and demand response mechanisms have proven effective in shifting EV charging to off-peak hours, thereby reducing stress on the grid. For instance, California has successfully shifted most of EV charging to off-peak hours through ToU pricing, demonstrating the potential for similar policies in other regions [25].

On January 24, Kosovo's electricity demand peaked at 1,429 MWh at 23:00, and on February 8, 2023, it peaked at 1,413 MWh at 23:00. If 100,000 EVs participated in V2G, each discharging 10kWh, they could collectively supply 1,000 MWh reducing the peak load by approximately 70% on January 24, 2022 and about 71% on February 8, 2023, thereby decreasing reliance on electricity imports. In addition to stabilizing peak demand, V2G technology enhances renewable energy integration by addressing the inherent variability of solar and wind power [26]. Kosovo, being located in the Balkans, receives a significant amount of solar radiation throughout the year. The yearly solar energy yield in Kosovo ranges between 1,095-1,387 kWh/kW [27], integrating solar-powered EV charging hubs could reduce dependency on fossil fuel-based electricity. EVs equipped with V2G capabilities can absorb excess electricity generation during low-demand periods, dispatch stored energy during high-demand hours, and serve as decentralized energy storage units that support overall grid stability [24]. However, effective implementation of V2G technology requires bidirectional chargers capable of efficiently managing both charging and discharging cycles while complying with international technical standards [23]. Additionally, strategic placement of charging infrastructure along Kosovo's 2,434 km road network, including motorways, national roads, and regional connections, is crucial to ensuring widespread accessibility. To fully capitalize on these advancements, smart grid adaptation is necessary, incorporating secure communication protocols for real-time data exchange between EVs and grid operators, automated control systems for dynamic load balancing, and integration with renewable energy forecasts to optimize energy storage and dispatch [24]. Despite these potential benefits, Kosovo's existing grid infrastructure is not fully prepared for large-scale EV adoption. Investments in transformer capacity expansion and digitalization of grid operations are essential to prevent system overloads. These strategies underscore the necessity for coordinated investments, policy alignment, and ongoing modernization efforts to ensure a stable and sustainable electricity system.

4.4. Economic and Regulatory Pathways

The economic evaluation of transitioning Kosovo's vehicle fleet to electric vehicles (EVs) with Vehicle-to-Grid (V2G) integration reveals a promising long-term outlook despite the higher initial investments in EVs, bidirectional charging infrastructure, and grid upgrades. While upfront costs are significant, lower operational and maintenance expenses, coupled with revenue generated from grid services such as frequency regulation and demand response, promise favorable long-term economics [26] [22]. In this context, regulatory and market mechanisms, including tax breaks, subsidies, and the establishment of competitive markets for ancillary services, are vital to accelerating both EV and V2G adoption, as demonstrated by early-adopter markets in Denmark, the Netherlands, and the UK [23]. Based on realistic assumptions, if EV penetration in Kosovo grows from 20% to 70% over a ten-year period within a total fleet of approximately 368,818 vehicles (2023), the number of EVs could increase from about 73,764 to 258,173. With each EV featuring a 50kWh battery, of which 70% (approximately 35 kWh) is available for grid services and assuming that only 50% of the fleet is connected during peak periods, the total available energy for V2G can be calculated. For example, at 20% penetration, 73,764 EVs × 35 kWh × 0.5 results in roughly 1.29GWh available, which, when sold at a market rate of 50 EUR/MWh over for instance 200 operating days, since availability of EVs for grid services during peak demand periods is limited [22], generates an estimated annual revenue of approximately 12.9 million EUR. At 70% penetration, similar calculations yield about 45.2 million EUR per year. These revenue streams create strong financial incentives for EV owners, who can offset charging costs and earn additional income, as well as for grid operators, who benefit from a decentralized energy source that reduces reliance on expensive peak power plants.

In the Kosovo power market, regulating revenue streams from V2G participation to create financial incentives for EV owners involves establishing a framework that integrates distributed energy resources into existing market structures. One approach would be to allow pooling batteries by combining the stored energy of many EVs so that, together, they form a larger unit that can sell power to the grid, allowing individual EV owners to benefit from participating in ancillary services markets even if their single vehicle's battery capacity is small. This would require the Kosovo Energy Regulatory Office to develop clear standards for bidirectional charging, metering, and data reporting, ensuring that the energy exchanged through V2G is accurately measured and fairly compensated. Additionally, market mechanisms such as feed-in tariffs or competitive bidding for ancillary services could be introduced to determine the compensation for frequency regulation, demand response, and other grid services provided by EVs. Regulatory measures should also ensure transparency and non-discriminatory access, perhaps through pilot programs that allow testing and refinement of these frameworks. Given Kosovo's evolving power market, characterized by a relatively small scale and a reliance on imported energy, such policies would not only offset EV charging costs for owners but also enhance grid stability and reduce peak demand pressures, ultimately contributing to a more resilient and sustainable energy system.

Moreover, the transition offers broader economic advantages, including reduced fuel import dependence, substantial national fuel savings, and significant reductions in CO_2 emissions that help Kosovo meet EU climate goals and lower health-related costs from pollution. Although investments in charging infrastructure and grid upgrades are required, these costs are expected to decrease over time due to declining battery prices, the emergence of secondary EV markets, and supportive government incentives, making the overall investment in EVs and V2G integration a sound economic decision in the next decade.

5. CONCLUSION

In conclusion, integrating V2G technology into Kosovo's power system presents a promising pathway toward enhanced grid stability, improved renewable energy integration, and significant economic benefits. Our analysis indicates that leveraging the aggregated battery capacity of EVs can mitigate peak load stresses, reduce dependency on costly peak power generation, and generate substantial revenue through ancillary services such as frequency regulation and demand response. Although Kosovo's current energy market faces challenges, mainly due to its reliance on coal-fired power plants, aging infrastructure, and limited charging networks, the long-term advantages, including lower operational costs, reduced fuel imports, and reductions in CO_2 emissions if the EVs with V2G are supplied with renewable energy, suggest that the upfront investments in EV and V2G infrastructure are reasonable in a near future.

Future research should focus on optimizing bidirectional charging protocols and refining smart grid management systems to better predict and control EV charging patterns. Moreover, pilot projects and demonstration programs are essential to validate theoretical models and facilitate the development of a regulatory framework that ensures transparent, fair participation of EV owners in the power market. It would be practical to gradually integrate the V2G (Vehicle-to-Grid) system, given that Kosovo is in the early stages of electric vehicle (EV) adoption, allowing for a measured approach to infrastructure development and market readiness. Continued investment in grid modernization, along with supportive policies and incentives, will be critical to fully unlocking the potential of V2G. Ultimately, a coordinated approach that brings together technological innovation, regulatory reform, and stakeholder engagement can pave the way for a resilient, sustainable, and economically feasible energy future for Kosovo.

REFERENCES

[1] R. C. Sánchez, C. Vidal, M. Díaz, E. Contreras, G. Guggisberg and I. Rivas, "An Overview of Challenges and Benefits Associated to the Development of Vehicle to Grid Technology," in CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies, 2021.

[2] T. Harighi, R. Bayindir, S. Padmanaban, L. Mihet-Popa and E. Hossain, "An Overview of Energy Scenarios, Storage Systems and the Infrastructure for Vehicle-to-Grid Technology," Energies, vol. 11, no. 8, 2018.

[3] F. Mohammadi and M. Mirhashemi, "An Overview of Ancillary Services Provided by Vehicle-to-Grid Systems," in 3rd Asia Power and Electrical Technology Conference, 2024.

[4] S. Vadi, R. Bayindir, A. M. Colak and E. Hossain, "A Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies," Energies, vol. 12, no. 19, 2019.

[5] A. Falkoni, A. Pfeifer and G. Krajačić, "Vehicle-to-Grid in Standard and Fast Electric Vehicle Charging: Comparison of Renewable Energy Source Utilization and Charging Costs," Energies, vol. 13, no. 6, 2020.

[6] A. Limani Bejtullahu, D. Pozhegu, F. Caka, J. Jaha, S. Boshnjaku, S. Vela and Z. Veselaj, "An overview of electric vehicles in Kosovo," Kosovo United States Alumni (KUSA) Energy and Environment Team, Prishtinë, 2024.

[7] K. Schwenk, S. Meisenbacher, B. Briegel, T. Harr, V. Hagenmeyer and R. Mikut, "Integrating Battery Aging in the Optimization for Bidirectional Charging of Electric Vehicles," IEEE Transactions on Smart Grid, vol. 12, no. 6, pp. 5135-5145, 2021.

[8] J. Jaworski, N. Zheng, M. Preindl and B. Xu, "Vehicle-to-Grid Fleet Service Provision Considering Nonlinear Battery Behaviors," IEEE Transactions on Transportation Electrification, vol. 10, no. 2, pp. 2945-2955, 2024.

[9] X. Tang, C. Sun, S. Bi, S. Wang and A. Y. Zhang, "A Holistic Review on Advanced Bi-directional EV Charging Control Algorithms," ACM SIGEnergy Energy Informatics Review, vol. 1, no. 1, pp. 78-88, 2021.

[10] M. Kwon, S. Jung and S. Choi, "A high efficiency bi-directional EV charger with seamless mode transfer for V2G and V2H application," in IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, 2015.

[11] B. C. P. Sturmberg, K. Lucas-Healey, L. Jones, L. Hapuarachchi and J. van Biljon, "Vehicle-to-grid response to a frequency contingency in a national grid – successes and shortcomings," Research Square, 2024.

[12] R. H. Mojumder, F. A. Antara, H. B. Alamri and M. Alsharef, "Electric Vehicle-to-Grid (V2G) Technologies: Impact on the Power Grid and Battery," Sustainability, vol. 14, no. 21, 2022.

[13] U. Gazder, "Overview of Opportunities and Challenges to Vehicle-to-Grid Integration and Bahrain Perspective," Green and Low-Carbon Economy, vol. 2, no. 4, pp. 252-258, 2024.

[14] P. K. Joseph, E. Devaraj and A. Gopal, "Overview of wireless charging and vehicle-to-grid integration of electric vehicles using renewable energy for sustainable transportation," IET Power Electronics, vol. 12, no. 4, pp. 627-638, 2019.

[15] S. Hossain, M. Rokonuzzaman, S. K. Rahman, A. A. K. M. Habib, W.-S. Tan, M. Mahmud, S. Chowdhury and S. Channumsin, "Grid-Vehicle-Grid (G2V2G) Efficient Power Transmission: An Overview of Concept, Operations, Benefits, Concerns, and Future Challenges," Sustainability, vol. 15, no. 7, 2023.

[16] A. Damiano, G. Gatto, I. Marongiu, M. Porru and A. Serpi, "Vehicle-to-Grid Technology: State-of-the-Art and Future Scenarios," Journal of Energy and Power Engineering, vol. 8, no. 1, pp. 152-165, 2014.

[17] K. A. o. S. (KAS), "Transportation statistics," KAS, Prishtina, 2024.

[18] J. Li and A. Li, "Optimizing Electric Vehicle Integration with Vehicle-to-Grid Technology: The Influence of Price Difference and Battery Costs on Adoption, Profits, and Green Energy Utilization," Sustainability, vol. 16, no. 3, 2024.

[19] M. Kühnbach, M. Klobasa, A. Stephan, B. Lux, F. Frank, A. Surmann, J. Kähler, W. Biener, Z. Kamaci and R. John, Potential of a full EV-power-system-integration in Europe and how to realise it., Freiburg, Karlsruhe (Germany): Fraunhofer Institute for Solar En-ergy Systems ISE, Fraunhofer Institute for Systems and Innovation Research ISI., 2024.

[20] E. R. O. (ERO), "Annual report," ERO, Prishtina, Kosovo, 2022.

[21] E. R. O. (ERO), "Annual report," ERO, Prishtina, Kosovo, 2023.

[22] W. Kempton and J. Tomić, "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue," Journal of Power Sources, vol. 144, no. 1, pp. 268-279, 2005.

[23] E. Sortomme and M. A. El-Sharkawi, "Optimal Scheduling of Vehicle-to-Grid Energy and Ancillary Services," IEEE Transactions on Smart Grid, vol. 3, no. 1, pp. 351-359, 2012.

[24] H. Lund and W. Kempton, "Integration of renewable energy into the transport and electricity sectors through V2G," Energy Policy, vol. 36, no. 9, pp. 3578-3587, 2008.

[25] C. B. Jones, W. Vining, M. Lave, T. Haines, C. Neuman, J. Bennett and D. R. Scoffield, "Impact of Electric Vehicle customer response to Time-of-Use rates on distribution power grids," Energy Reports, vol. 8, pp. 8225-8235, 2022.

[26] IEA, "Global EV Outlook 2023," IEA, Paris, 2023.

[27] W. Bank, "Long term average PVOUT, period 1994-2018," 2019.

BIOGRAPHY

Fatbardha Mehani is a senior professional with over seven years of experience in the electricity distribution sector, currently serving as Quality and Sustainability Manager at Kosovo Electricity Distribution Company (KEDS). She is responsible for the strategic implementation and continuous improvement of the Integrated Management System (IMS), ensuring full alignment with ISO 9001, ISO 14001, and ISO 45001 standards across all operational units. Ms. Mehani has been instrumental in integrating sustainability into corporate governance, leading the development of the first joint Sustainability Report for KEDS & KESCO and overseeing ESG data collection and reporting in accordance with GRI standards. Her expertise spans carbon footprint analysis, resource efficiency, and stakeholder engagement. In addition to her managerial responsibilities, she has contributed extensively to national capacity-building efforts, serving as a certified expert in occupational health and safety, trainer of digital media skills, and internal auditor of QHSE management systems. Ms. Mehani holds a Professional Master's degree in Energy Efficiency from the University of Prishtina

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and a Master of Science in Electrical Energy and Energy Markets from the University of Business and Technology in Prishtina. She earned her Bachelor's degree in Power Engineering from the Faculty of Electrical and Computer Engineering, University of Prishtina. Her qualifications are further supported by certifications in sustainability reporting (GRI), ISO standards and occupational health & safety.

Arta Grajçevci is a dedicated energy professional in Kosovo's electricity sector. She currently serves as Head of the Dispatch Center at Kosovo Electricity Distribution Company (KEDS). Her career reflects both technical expertise and a commitment to advancing the role of women in a traditionally male dominated industry. Ms. Grajçevci's professional journey has been marked by steady progression within KEDS. She began as an intern in the Procurement and System Operation departments, later advancing to Reporting Analyst and Network Engineer roles. In 2024, she was appointed Head of the Dispatch Center, a role that highlights her leadership, analytical skills, and ability to manage complex operational challenges. Her academic background is equally impressive. Ms. Grajçevci holds a Master's degree in Electrical Engineering and Energy Trade from the University of Business and Technology in Prishtina and a Bachelor's degree in Power Engineering from the University of Prishtina. She also pursued ESL studies at Kent State University in US. Beyond her professional and academic achievements, Arta is recognized as a role model for young engineers and women in energy. She has been featured in initiatives such as Women Powering Energy: Leading by Example. Through her work, she champions diversity, youth empowerment, and gender equality, inspiring the next generation of energy professionals.