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**TECHNO-ECONOMIC ANALYSIS OF VEHICLE-TO-GRID TECHNOLOGY
IN NEPAL**

by

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**A THESIS REPORT
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ABSTRACT

The study uses computational model for carrying out a V2G economic assessment. Several factors are considered by the model in its calculations, factors that serve to make it comparable to real-world situations, include battery deterioration, distance driven, how often you charge, the quantity of V2G cycles of both being charged and released, EVs tariff rate, as well as the price of new batteries. To testify the concept, EV users are divided into distinct four groups —'Elder', 'Jobholder', 'Cabman' and 'Busman'—based on its unique features purposing to find out the situations in which V2G energy storage service per EV user of each group is most profitable. The typical brand of EV commonly used by each group in the context of nepal is taken for the study. The technical parameters of these vehicles and driving characteristics of each groups are taken as input. As V2G service has not been introduced in Nepal's power grid till now and so, no tariff rate related to V2G in Nepal. Hence, three hypothetical scenarios have been created considering three V2G rate — Rs. 9/kWh, Rs. 11.7/kWh, and Rs. 17/kWh and also conducted a sensitivity analysis. By the time a user's battery degrades and needs to be replaced, the goal of the study is for them to have earned enough money for the payment of a new battery via V2G and still turn a profit. The rate Rs. 11.7/kWh is the highest existing EV charge rate according to tariff rate of NEA. The findings indicate that, after deducting the price of a new battery, the overall net profit earned through V2G per EV user is significantly negative for every group in every scenario. Even at the highest consider rate Rs. 17/KWh, the maximum loss Rs. 15,37,930 incurred per 'Busman' user and the minimum loss is Rs 1,66,336 incurred per Elder user. Hence, it can be conclude that in the context of nepal, it is no longer feasible for every user to keep their battery deteriorating and replacing after 1 to 3 years in the above scenarios' rate. Thus, the model helps to analyze the economic aspect of technology 'V2G' from the perspective of per EV user. Further, the technical aspects of the technology is analyzed in real time estimation of V2G capacity for efficient use of EVs as shared energy storage (SES). It implements an algorithm designed to estimate V2G capacity at half-hour intervals through real-time EV scheduling taking a case study of Sajha Yatayat. The algorithm is integrated into the System for Building Energy Management, that calculates the potential V2G capacity used for peak shaving and valley filling considering fictitious demand of building (excluding EVs) and the anticipated charging patterns of EVs that are attached to the structure. The study depicted valley filling by 17% at time 23:00 hours and peak shaving by 19.9% at 18:00 hours in the taken case study.

Keywords: Battery degradation, Economic earnings, Electric vehicles, V2G

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CHAPTER ONE: INTRODUCTION

1.1 Background

The application of electric vehicles are trends from the past few years till now [1]. It is effective for decarbonization of transport [2]. Communities around the world are becoming increasingly concerned about the production of power from fossil fuels because of the substantial carbon emissions and the negative environmental effects of other pollutants [3]. Technological advancements have caused the cost of electric vehicles (EVs) to decrease [4]. Lithium-ion batteries (LiBs) are essential to the shift towards electric transportation, having experienced an 85% decrease in production costs over the past decade [5]. In Nepal, electric vehicles (EVs) are becoming more popular as concerns over air pollution rise and the country's reliance on imported fossil fuels grows [6]. Various challenges in implementing EV-based transportation are being tackled globally, and developing countries looking to invest in their electric transport sector must carefully study these trials, errors, and successes to identify key factors that need attention [7]. It may serve as distributed energy storage devices to supply the grid with a service (V2G). With its bidirectional mode of operation as vehicle-to-grid (V2G), the EV that functions as a load in the grid-to-vehicle (G2V) mode during charging may also function as an energy provider during the discharging mode [8]. It offers the chance to control rising electricity prices and demand surges by serving as a collective energy store that offers demand shifting or peak shaving. Also, it offers more than simply EV power; it also regulates frequency and voltage and stores renewable energy. [9]. The quick response of Energy Storage Systems (ESS) to fluctuations in nominal frequency and imbalances between supply and demand allows them to supply or absorb power, offering a level of stability that traditional network assets cannot match [10].

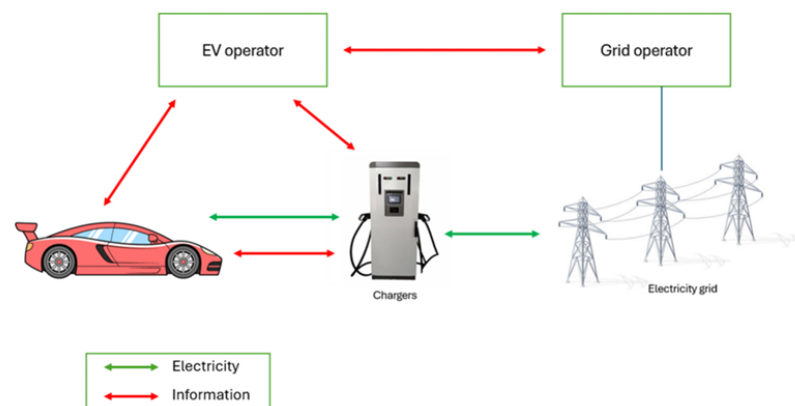


Figure 1.1: Integrating EVs into the grid[3]

Vehicle-to-Grid (V2G) technology, through the use of bidirectional charging stations, enables electric vehicles (EVs) to connect to the power grid and function as energy storage units. This configuration enables electricity to flow to and from the grid and the vehicle, as illustrated in Figure 1.1 . In this way, EVs can serve as decentralized energy storage resources, contributing to grid services and supporting the overall efficiency of the electrical energy system [3].

1.1.1 E-mobility in Nepal

The transportation sector is a significant global source of greenhouse gas (GHG) emissions, and its impact is rapidly increasing due to rising urbanization and vehicle usage, especially in developing nations. For countries like Nepal, which currently have a small but fast-expanding vehicle fleet, it is essential to urgently pursue the decarbonization of the transport sector. Doing so will not only help reduce GHG emissions but also decrease air pollution and its associated health risks, lower the financial burden of importing petroleum products, and enhance national energy security. Recognizing these benefits, the Government of Nepal (GoN) incorporated electric mobility (e-mobility) goals in its initial Nationally Determined Contributions (NDC), filed to the United Nations Framework Convention on Climate Change (UNFCCC) in October 2016, and reaffirmed these targets in the updated NDC submitted in December 2020 [11].

Number of EVs

The precise count of electric vehicles (EVs) across different segments is currently unavailable. Data from multiple sources, such as the Department of Customs and the Department of Transport Management (DoTM), must be consolidated to accurately identify trends. Table 1.1 presents the most recent data from DoTM on both internal combustion engine (ICE) vehicles and EVs across various categories [12].

EV Charging Stations

Table 1.2 shows the number of various types of charging stations installed in various locations of Nepal. Cimex Inc., the authorized dealer of BYD electric vehicles, has already set up 30 fast-charging stations and is in the process of adding 17 more during the fiscal year 2023–24. Additionally, USAID’s Urja Nepal project has deployed 23 fast chargers across seven sites in Bagmati Province, in collaboration with two private firms: Yatri Design Studio and E-Stop (a subsidiary of thee GO). Laxmi-Hyundai, another key EV distributor, also has plans to establish charging stations at 43 different locations. Most of these

Table 1.1: Number of ICEs and EVs in 2023) [12]

S.N	Vehicle Type	ICSs	EVs
1	Motor cycle	4,266,566	18,004
2	Three wheelers	92,476	66,855 + 714
3	Car/jeep/Van	322,119	500 (Taxi) + 12,071 (cars)
4	Microbus	11,715	2,032 (Microbus/jeep/Van)
5	Minibus	18,740	
6	Bus	64,647	102
7	Truck/Mini truck	144,501	
8	Pick up	90,512	
9	Tractor	184,282	
10	Others	9,019	
Total		5,204,577	100,278

existing and upcoming stations operate at Level 2, which typically delivers a full charge within 4 to 6 hours [12].

Table 1.2: List of EVs Charging Stations in Nepal, 2023 [12]

Name of the Company/Brand	Number	Remarks
Hyundai and CG	22	
Thee GO Group/CG Group	29	48 being developed
MG Motors	10	
BY	25	
KIA	17	
TATA	14	8 being developed
Sundar Yatayat	3	
NEA	51	Proposed (500 across the country)
Sajha	20 of 1.1 MW	Inaugurated on 11th April 2024

1.1.2 System Load Curve (Maximum Demand)

In Nepal, there is typically a significant gap between electricity demand during off-peak and peak hours as shown in Figure 1.2. The high peak load over short durations is a major factor contributing to electricity shortages, frequent power outages, and reduced power quality. During peak hours, utilities face substantial pressure to meet consumer electricity demand, whereas during off-peak times, even a relatively small amount of generation is sufficient to fulfill demand. This high peak demand creates the need for additional

power plants that operate only for short periods, making the overall power unreliable and economically inefficient [13].

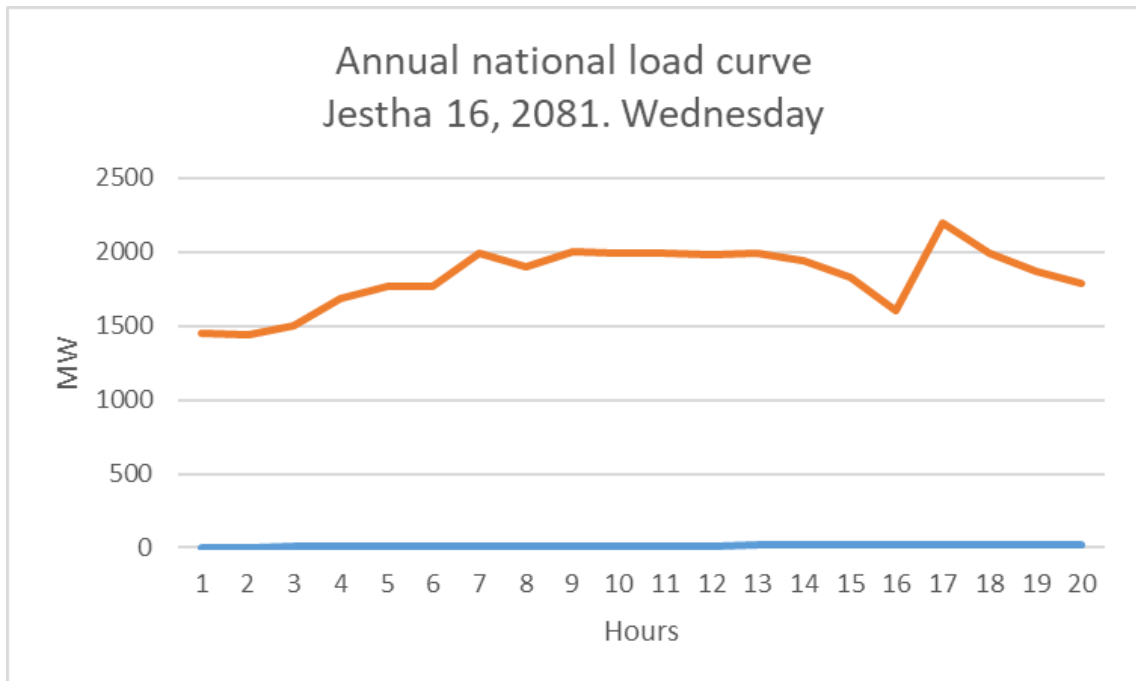


Figure 1.2: Annual national peak load curve Jestha 16, 2081 [14]

1.1.3 Vehicle to Grid Technology

The concept known as Vehicle-to-Grid (V2G) technology involves utilizing parked vehicles to supply electricity back to the power grid [15]. At first glance, this idea might seem questionable in terms of practicality and usefulness. However, it is supported by a compelling statistic: in the United States, the average car is driven for only about 5% of the day. Studies further reveal that even during peak traffic periods, nearly 90% of vehicles remain parked [16]. Additionally, many of these cars do not use even half of their total driving range on a daily basis. As a result, parked vehicles represent largely untapped energy resources and could even be considered negative value due to the costs associated with parking them [17]. To determine the feasibility of V2G technology, it is essential to perform a cost-benefit analysis. This analysis should consider factors such as the estimated number of vehicles participating in V2G, the total energy storage capacity available in these vehicles, and the power demands of the electrical grid. Studies have explored the advantages of implementing this technology and its potential impact on the energy system [15]. Three features are considered important for a V2G enabled vehicle as shown in Figure 1.3.

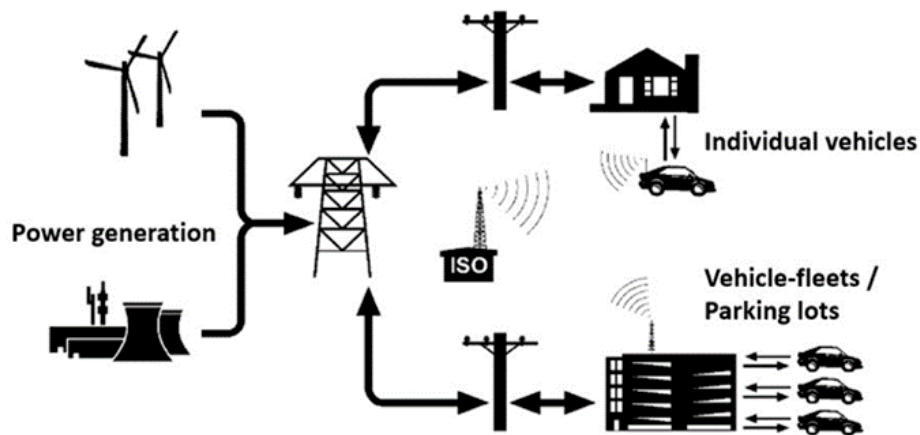


Figure 1.3: A schematic representation of V2G technology

1. Power supply to the grid
2. Communication networks that enable the grid to connect with and utilize power from vehicles.
3. An accurate measurement system for monitoring the flow of power[15]

V2G, is a smart grid technology that enables electric vehicles (EVs) to not only utilize the grid's energy to both charge their batteries but also return any unused stored energy to it as required. The major Components of V2G are given below:

1. Bi-directional Charger: permits both directions of power flow—charging the EV and discharging power to the grid.
2. Smart Grid Communication: Ensures seamless data exchange between the EV, charging station, and utility provider.
3. Energy Management System (EMS): Controls and optimizes when and how the energy is stored or released [15].

The advantages of the technology are:

1. Grid Stabilization: Helps in balancing supply and demand.
2. Renewable Integration: Stores excess renewable energy (like solar or wind) in EVs and supplies it back when needed.

3. Cost Savings: EV owners may earn incentives for providing power to the grid.
4. Energy Efficiency: Reduces the need for fossil fuel-based Peaker plants [18].

1.1.4 Battery Management and Health

The Battery Management System (BMS) is the brain behind battery health and operation. It performs the following key functions [19]:

1. Monitoring
 - (a) State of Charge (SoC): How much energy remains in the battery.
 - (b) State of Health (SoH): Battery degradation level.
 - (c) Voltage, current, and temperature of cells.
 - (d) Cycle count (number of charge/discharge cycles).
2. Protection
 - (a) Prevents overcharging or deep discharging.
 - (b) Prevents thermal runaway and overheating.
 - (c) Ensures cell balancing for uniform performance.
3. Control
 - (a) Regulates charge/discharge rates.
 - (b) Interfaces with the V2G controller for safe energy dispatch.
 - (c) Implements charging algorithms for efficiency and safety.

1.2 Significance of current work

The typical and novel numerical model developed by Gomes et al. [3] was used in the context of Nepal. This work thus offers a useful tool for evaluating the financial effects of the technology 'V2G' on various kinds of actual customers, allowing one to calculate the amount of money a user earned through the technology while also taking into account the

deterioration of battery. Further, dynamic EV scheduling for estimation of V2G capacity in real time is studied taking the real-case scenario of Sajha Yatayat EVs. The primary limitations on satisfying the load demand are taken into consideration while estimating the V2G capacity. The proposed algorithm maximize V2G capacity and optimize energy flow through peak shaving and valley filling, which ultimately enhance grid stability.

1.3 Limitation and Assumptions

1. Nepal does not have a set tariff rate for selling electricity through V2G technology. As a result, three hypothetical electricity selling price scenarios: Rs. 9/kWh, Rs. 11.7/kWh (the current highest electricity purchasing tariff rate for EVs in Nepal, and Rs. 17/kWh are taken, and performed a sensitivity analysis.
2. It was also established that users would always charge their cars at night utilizing slow charging at periods of reduced energy costs. According to data from Nepal Electricity Authority, the electricity cost for charging electric vehicles at night in Nepal was set at Rs.5.15/kWh.
3. It was decided that each user would only make 80% of battery capacity to avoid draining the battery to zero, it is offered for sale to the grid and thereby reducing its lifespan.
4. In this model, whenever a V2G cycle of charge and discharge occurs, the entire 80% of battery capacity is used up by the grid, and the user recharges the battery back to 100%.
5. For road use, each user use their car's full range EV_R , charge it to 100%, and then charge it again. Taking new battery cost 75 US\$/kWh which is equivalent to Rs. 10440 (according to exchange rate of Jan. 1, 2025) for these calculations.
6. Linear battery discharge with distance is taken for V2G capacity estimation.

CHAPTER TWO: LITERATURE REVIEW

Gomes et al. [3] research work aims to develop a unique numerical model for carrying out a Vehicle-to-Grid (V2G) services economic analysis. With Portugal's energy market and growing use of electric vehicles (EVs) in mind, this model makes it possible to calculate the possible financial gains for a specific user supplying through V2G. The number of charging and discharging cycles of V2G, distance traveled, charging frequency, battery degeneration, EVs electricity tariff rate, or the price of new batteries are only a few of the variables that the model takes into account while making its estimates. These elements produce trustworthy results that allow for a thorough examination that closely mirrors the actual circumstances of different people, particularly since the economic implications of V2G technology have not been examined from this angle in previous research. To evaluate the model, four hypothetical EV users with unique profiles were developed to explore which scenarios offer the greatest advantages for EV users when participating in energy storage services. The findings indicate that when electricity tariff rate of V2G is high (0.50 €/kWh), the V2G delivery may be very beneficial for consumers who drive their vehicles extremely infrequently (earnings of 624 € a month and after subtracting the price of new battery overall 1547 €). However, this is not the case when selling tariffs of electricity to the grid decrease to 0.30 or 0.20 €/kWh. Even with a low selling tariff rate 0.2/kWh, this service can also benefit users who use their automobiles frequently because it enables them to save money on buying a new battery, which can range from 300 to 1100 €.

Another research work done by Huda et al. [9] in the JAMALI grid found that using EVs can limit the supply by up to 8.8% (for gas) and 2.8% (for coal) during peak hours. Business-owned EVs with a natural tariff have the highest viability for supplementary services and have the potential to save up to 60.15% on charging costs. From the standpoint of the power provider, V2G might also increase yearly revenue by roughly 3.65% because it replaces gasoline.

Similarly, Gougha et al. [20] research work evaluated the possibility that electric vehicles might make money from the energy provided to a business facility in addition to money made from particular ancillary service sectors in the UK. The findings indicate that the highest expected return on investment, with a net present value of £8400 for each vehicle, is achieved by supplying energy to the wholesale electricity market along with extra revenue from the capacity market. This includes the cost of constructing the car-to-grid infrastructure and spans more than ten years for a vehicle that supplies energy to

the half-hour day ahead market three times a week. The analysis also demonstrates that the expenses of battery degradation related to vehicle-to-grid cycling have a significant impact on net income generation.

Zhang et al. [21] study provides an EV-discharging-optimization model based on vehicle-to-grid interaction (V2G) and evaluates the charging demand of EV users using GPSTrajectory data. First, the huge data of moving vehicle is cleaned and mined to determine the spatial temporal distribution of EV-charging demand while taking customers' willingness and dynamic energy consumption theory into account; Second, anticipated utility theory is used to build a probabilistic model of EV users' involvement in V2G-demand response, which takes into account user heterogeneity and reflects the interactive influence of users' choices; lastly, a regional grid scheduling model for EV discharging is developed. The findings demonstrate that the suggested model can investigate the possibility of user involvement in V2G within the research region, and in order to create a condition where both the grid and the users benefit, the V2G response resources can lessen grid volatility and allow users to receive specific advantages.

Aziz et al. [22] study for grid auxiliary services, particularly for Denmark's frequency control. DK1 (Western Denmark) and DK2 (Eastern Denmark) are the two distinct electrical networks in Denmark. Notwithstanding the fact that both grids are managed by the same transmission service operator (TSO), Energinet.dk, they differ in terms of capacity, supply makeup, and grid connections. According to a revenue comparison of passenger EV services, frequency regulation in DK2 generates more money than it does in DK1. However, it is predicted that faster battery degradation of EVs in DK2 may occur due to the higher frequency and variability of both up and down services.

A half-hourly V2G capacity estimation algorithm that integrates real-time EV scheduling into a Building Energy Management System (BEMS) was proposed by Kumar et al.[23]. It makes use of anticipated building loads and predicted EV charging profiles to estimate V2G capacity and coordinate with available renewable energy sources. Tested on Singapore's commercial, residential, and office buildings, the findings indicate that EVs can effectively serve as distributed energy storage in tall buildings. The findings demonstrated that EV fleets linked to high-rise buildings—typical in densely populated urban areas—can serve efficiently as dispersed energy storage devices. The studies of case, further confirmed that EVs can be efficiently utilized for shaving both dawn and evening peaks in residential structures, as well as afternoon peaks in commercial and office buildings. Optimal energy efficiency is guaranteed by real-time V2G capacity estimation utilization from EVs while still meeting the needs of their users.

Deng et al. [22] introduces an EV Reserve Function (EVRF) assessment framework that incorporates a trip chain that is dynamic and the interaction between the means of transportation network and the power grid (transportation-electricity coupling). Based on forecasted data on user behavior, the upcoming day EVRF is assessed. Throughout the day, EVs are managed in real time using a dispatch approach driven by the EVRF assessment, with user trip chains adjusted accordingly. The spatial-dispersion of time and SOC (State of Charge) changes of EVs, after serving as energy reserves, are then re-evaluated. For the dynamic evaluation of EV flexibility within the electricity-transportation system, the current state of EVs throughout each sub-period of evaluation aligns well with the response process's flexibility. This process can be redefined using the paper's suggested dynamic trip chain, which significantly enhances the evaluation of EV adaptability across several timescales. Several valuable conclusions and insights have been drawn from the paper such as by using the EVs' response behavior to guide the dispatching approach, the proposed dynamic assessment method allows for flexibility assessment over various timescales. This approach incorporates the real-time location and grouped EVs' status, leading to a highly accurate evaluation. The effectiveness of this flexibility assessment has been verified, and the results can be used for flexibility-based EV dispatching in subsequent periods. Furthermore, the flexibility dispatching strategy—based on Enhanced State of Charge Management (ESOCM) and Estimated Real-Time Mobility (ERTM) as dispatching boundaries—are able to adjust to the dynamic flexibility assessment procedure with ease. It ensures that the energy reserve demand and power instructions issued through the dispatching center are exactly met, with an error margin within $\pm 6.67\%$.

Quantitatively assessing the V2G capacity, including the power ranges for charging and discharging, for a PEV fleet using V2G technology ahead of time is crucial for V2G implementation. However, due to the unpredictable nature of driving habits of PEVs, forecasting charging demands is challenging, which complicates the evaluation of V2G capacity. Zhang et al. [24] developed a V2G fleet's aggregate model to capture the overall energy and power constraints of the whole plug-in electric vehicle (PEV) population. A numerical approach for evaluating the capability of large-scale PEVs for V2G is formulated according to the suggested aggregate model. The utilization of the assessment technique in optimizing the scheduling of charges and discharges for a V2G fleet that offers reserves is demonstrated. Numerical simulations are performed to verify the suggested approach. The correctness of the evaluation is assessed, and the benefits of providing reserves are compared with other methods. To ensure that the pre-evaluated V2G capacity can be realized while also fulfilling PEV charging requirements A heuristic smart charging technique in real-time operation based on laxity and state of charge is developed.

The aim of the study of [25] is to explore the current status and usage of electric vehicles (EVs) in Nepal, along with their future potential. To gather information, a quantitative research approach was employed, utilizing data from various journals, articles, official government websites, and industry reports. The key objective of this research is to understand the future prospects of electric vehicles and their applications within the Nepalese context. The study depicted that the current state of electric vehicles (EVs) in Nepal is still in its developmental phase, with limited vehicle availability and an underdeveloped charging infrastructure. Nevertheless, the Government of Nepal has implemented various initiatives to encourage EV adoption and has set an ambitious goal to replace all internal combustion engine (ICE) vehicles with EVs by 2030. The large-scale acceptance of EVs holds the potential to drastically lower air pollution and offer other environmental benefits. Despite this promise, several challenges remain, such as the high upfront cost of EVs, their limited driving range, inadequate charging facilities, and the scarcity of domestically produced EVs. Continued research is essential to pinpoint areas for improvement and to facilitate the broader adoption of electric vehicles across the country.

The study of Ghimire et al. [26] seeks to explore consumer preferences in Nepal through a stated preference approach. Data were gathered using a survey based on the conjoint analysis method, and the mixed logit model was applied for estimation. The results show that, in general, prospective vehicle buyers in Nepal tend to favor battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) over internal combustion vehicles (ICVs). Additionally, consumers expressed positive attitudes toward improved charging infrastructure and extended driving range. As expected, the coefficients for purchase price and fuel cost were negative, indicating that lower costs in these areas are preferred. The study also analyzes the combined effects of demographic characteristics, travel patterns, and environmental attitudes on consumer choices. The findings provide meaningful insights, revealing that consumer preferences for EVs are not uniform. Individuals with smaller households, lower monthly travel distances, stronger environmental awareness, and better knowledge of EVs are more inclined to adopt electric vehicles. Moreover, those who already have access to EV infrastructure are naturally more likely to choose BEVs and PHEVs. Elasticity analysis further suggests that lowering the purchase price has the most significant effect in boosting the likelihood of consumers opting for BEVs and PHEVs.

CHAPTER THREE: METHODOLOGY

3.1 Model Presentation for Economic viability

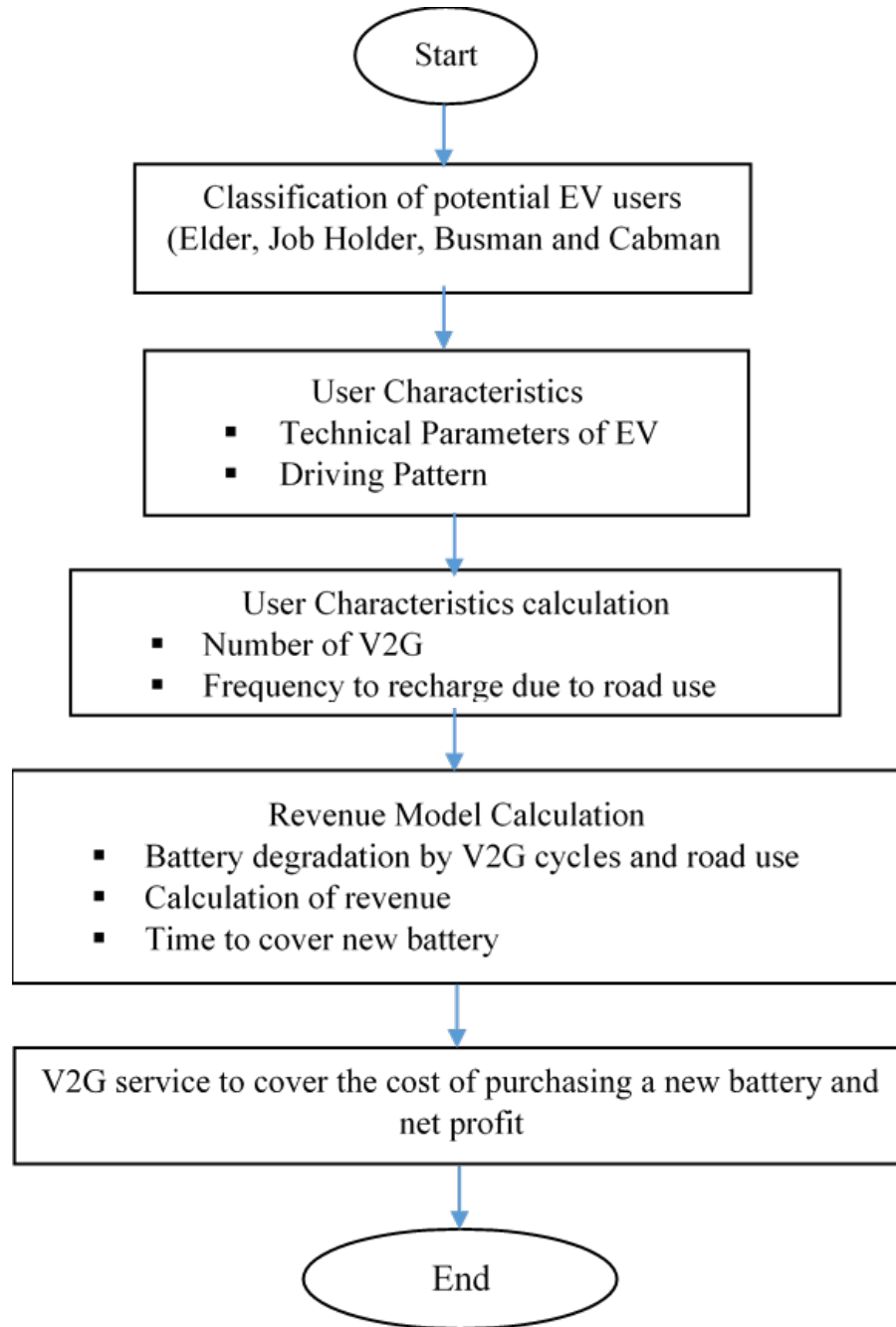


Figure 3.1: Flow chart to create economic model for V2G service

The flowchart for the development of numerical economic model is shown in Figure 3.1. At first, EV users are categorized into different groups based on their level of EV usage,

ranging from passive to active users. For each group, the specific EV brands most commonly used in Nepal by that group are selected for the study. These vehicles' attributes are displayed in Table 3.1 to 3.4. Then, technical parameters of the vehicles are given along with driving hours of the vehicle. Using those parameters, user characteristic calculations such as number of V2G, frequency to recharge due to road use are calculated. Finally, revenue model is generated accounting battery deterioration. It helps to calculate recovering the expense of a new battery via V2G delivery and net profit.

Table 3.1: Key Features of Tata Tiago Long Range [27]

Characteristics	Value
Price (Rs)	2,999,000
Maximum Speed (Km/hr)	120
Acceleration (0 to 60 Km/hr in sec)	5.7
Transmission	Automatic
Capacity of Battery (kWh)	24
Battery cycles till 80% of its capacity is reached	1500
Type of motor	PM Synchronous Motor
Power of an Electric Motor (kW)	49.01
Torque of an Electric Motor (Nm)	114
Charging Time	8.7 hours with a 15 A charger

Table 3.2: Key Features of BYD ATTO 3 [28]

Characteristics	Value
Price (Rs)	6,780,000.00
Acceleration (0 to 100 Km/hr in sec)	9.7
Transmission	Automatic
Capacity of Battery (kWh)	60.48
Battery cycles till 80% of its capacity is reached.	1500
Type of Motor	Permanent Magnet Synchronous Motor
Power of an Electric Motor (kW)	100
Torque of an Electric Motor (Nm)	310
Charging Time	45 minutes via 80 kW charger

Table 3.3: Key Features of CHTC Electric Vehicle

Characteristics	Value
Price (Rs)	11,500,000
Maximum Speed (Km/hr)	1200
Acceleration	–
Transmission	Automatic
Capacity of Battery (kWh)	161
Battery cycles till 80% of its capacity is reached	3000
Type of Motor	Permanent Magnet Synchronous Motor
Power of an Electric Motor (kW)	165
Torque of an Electric Motor (Nm)	1100
Charging Time	60 minutes via 90 kW charger

Table 3.4: Key Features of Tata Xpress-T Sedan [29]

Characteristics	Value
Price (Rs)	3,699,000
Maximum Speed (Km/hr)	80
Acceleration	–
Transmission	Automatic
Battery cycles till 80% of its capacity is reached	1500
Type of Motor	72 Volt three phase AC Induction Motor
Power of an Electric Motor (kW)	48.64
Torque of an Electric Motor (Nm)	170
Charging Time (in minutes)	145

3.2 User Characteristics

Four kinds of EV customers have been identified, and the typical EV brand that is widely accessible for each group is used with user characteristics. This study enables us to assess a variety of users, ranging from the people who drive their vehicles frequently (such as 'Cabman' drivers) to those who use it infrequently (like 'Elder'), as well as those who fall in between, such as 'Job Holder' and 'Busman'. The specific details of each user's characteristics (such as daily kilometers traveled, duration of vehicle use, number of charge and discharge cycles for V2G and road usage etc.) will be outlined in Tables 3.5 to 3.8. The characteristics "Car", "Bc", "Cbat" and "EVR" are derived from real-world data about

typical brand of EV of each group of user. The number of V2G cycles (NC_{V2G}) performed by each user each month is influenced by the availability time of each user, which depends naturally on how often they use their vehicle. The model assumes that a user has more opportunity to use V2G services if they have more "free" time (i.e., drive less frequently). Thus, the authors selected the characteristics " NC_{V2G} " and "vehicle use" to examine various user scenarios, focusing on vehicle usage and the resulting availability of time for the V2G service. As V2G service has not been introduced in Nepal's power grid till now and so, no tariff rate related to V2G in Nepal. Hence, three hypothetical scenarios have been created considering three V2G rate — Rs. 9/kWh, Rs. 11.7/kWh, and Rs. 17/kWh and also conducted a sensitivity analysis. It was also established that Owners and users would always charge their cars utilizing delayed charging during night, when energy costs are lower. According to data from Nepal Electricity Authority, the electricity cost for charging electric vehicles at night in Nepal was set at Rs.5.15/kWh. However, it was agreed that each user would only get 80% of battery capacity accessible to the grid for purchase, to prevent draining the battery to zero percent and thereby reducing its lifespan. In this model, whenever a V2G cycle of charge and discharge occurs, the entire 80% of capacity of battery is used by the grid, and again the user fully recharges the battery. During driving, EV user use their car's entire range and charge it to 100%, again. Taking the price of new battery 75 US\$/kWh which is equivalent to Rs. 10440 (according to exchange rate of Jan. 1, 2025) for these calculations.

Table 3.5: "Elder" user characteristics

Characteristics	Value
Car	Tata Tiago Long Range
Battery (B_c)	24 KWh
C_{bat}	1500 cycles
EVR	315 KM
NC_{V2G}	20 cycles per month, i.e., On weekdays, five times every week
Vehicle use	0 hr every day over the course of five business days; 2 hours on Friday and Saturday (8 days a month)
AvN_{Kmday}	15 Km each Friday and Saturday (3.94 kilometers on average per day of the month)
$N_{Km/month}$	120 Km
FR_{Road}	146
NC_{Road}	0.2083
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 250560

Tata Tiago Long Range brand of EV taken for the ‘Elder’ user group features is shown in Table 3.5. Normally, ‘Elder’ users are retired people who are comparatively inactive and so, the authors consider the high probability of availability for V2G service.

Table 3.6: “Job Holder” user characteristics

Characteristics	Value
Car	BYD ATTO 3
Battery (B_c)	60.48 KWh
C_{bat}	1500 cycles
EVR	420 KM
NC_{V2G}	10 cycles per month, i.e., two times every week on weekdays; once every two Saturdays.
Vehicle use	1 hour everyday on six business days of the week; 2 hours on Saturday
AvN_{Kmday}	5 Km each working day; 20 Km on Saturday (Average of 6.57 Km each day of the month)
$N_{Km/month}$	200 Km
FR_{Road}	63.92
NC_{Road}	0.475
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 631411.2

BYDATTO3 brand of EV taken for the ‘Job holder’ user group features is shown in Table 3.6. Authors consider the user of this group utilize EV for commuting purpose.

CHTC Electric Vehicle brand of EV taken for ‘Busman’ user group features is shown in Table 3.7. Authors consider the user of this group utilize EV for commercial purpose and so availability of EV for V2Gservice is low.

Tata Xpress-T sedan brand of EV taken for the ‘Cabman’ user group features is shown in Table 3.8. Normally, ‘Cabman’ users are very busy and so, the authors consider very low availability of EV for V2G service.

Table 3.7: “Busman” user characteristics

Characteristics	Value
Bus	CHTC Electric Vehicle
Battery (B_c)	161 KWh
C_{bat}	1500 cycles
EVR	200 Km
NC_{V2G}	5 cycles per month, i.e., one time during a week on Saturday and every weekend (to be specified)
Vehicle use	6 working days a week, for 6 hours each day; 0 time on Saturday (24 days each month)
AvN_{Kmday}	100 Km/day during working days (Average of 78.9 Km/day of the month)
$N_{Km/month}$	2400 Km
FR_{Road}	2.53
NC_{Road}	12.02
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 1,680,840

Table 3.8: “Cabman” user characteristics

Characteristics	Value
Car	Tata Xpress-T sedan
Battery (B_c)	24 KWh
C_{bat}	1500 cycles
EVR	277 KM
NC_{V2G}	2 cycles per month, i.e., every two Saturdays
Vehicle use	Every day of the week, 16 hours a day, with the exception of Saturdays every two weeks (29 days a month)
AvN_{Kmday}	200 Km/day except every two weeks on Saturday (Average of 190.68 Km/day of the month)
$N_{Km/month}$	5800 Km
FR_{Road}	1.45
NC_{Road}	20.97
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 250560

3.3 User characteristics calculation

Every month of the year, on average, there are

$$AvN_{Days/month} = \frac{N_{days/year}}{N_{months/year}} \quad (3.1)$$

where $N_{days/year}$ is the typical quantity of days in a given month of the year and $N_{months/year}$ represents the total months in a year. Mean of daily kilometers traveled by each user is

$$AvN_{Km/day} = \frac{N_{Km/month}}{N_{days/month}} \quad (3.2)$$

where $N_{Km/month}$ is the kilometers travel by each user per month. The recharging frequency (in days) of the EV for every user is determined by the car's usage in the road environment, with EV_R representing the vehicle's range and it is given as

$$FR_{Road} = \frac{EV_R}{AvN_{Km/day}} \quad (3.3)$$

Finally, the monthly total of charging cycles in a road environment is calculated as

$$NC_{Road} = \frac{AvN_{Days/month}}{FR_{Road}} \quad (3.4)$$

3.4 Revenue model calculation

3.4.1 Estimation of battery deterioration per month and per year due to V2G operations and road usage cycles

Monthly battery deterioration brought on the V2G cycles is

$$BMD_{V2G} = \frac{NC_{V2G}}{C_{bat}} \times 0.8 \quad (3.5)$$

Where NC_{V2G} is the monthly amount of V2G cycles that must be completed with the grid, and C_{bat} is the battery's cycles till it falls to 80%. Here, the amount of battery capacity made accessible for grid consumption is 80%. Similarly, monthly battery deterioration due to road use is

$$BMD_{Road} = \frac{NC_{Road}}{C_{bat}} \quad (3.6)$$

Here, the capacity of battery made available for the road use is 100% which means every user drives their EV for the full range of the battery before charging it again. The total

monthly deterioration of battery is

$$\text{Total}_{\text{Bmd}} = \frac{\text{Bmd}_{\text{V2G}}}{\text{Bmd}_{\text{Road}}} \quad (3.7)$$

Annual deterioration of battery due to V2G cycles is

$$\text{Bad}_{\text{Road}} = \text{Bmd}_{\text{Road}} \times N_{\text{months/year}} \quad (3.8)$$

Hence, total deterioration of battery is

$$\text{Total}_{\text{Bad}} = \text{Bad}_{\text{V2G}} + \text{Bad}_{\text{Road}} \quad (3.9)$$

3.4.2 Estimation regarding the monthly and yearly income through V2G

The gross profit due to V2G service in a month is

$$M_{\text{rV2G}} = \text{NC}_{\text{V2G}} / \text{times} B_c \times \text{PS}_{\text{ele}} \quad (3.10)$$

Where B_c is the battery capacity with which V2G service is provided (i.e. 80%) and PS_{ele} is the selling price of electricity.

EV charging costs per month as a result of V2G cycles is

$$C_{\text{CostsV2G}} = \text{NC}_{\text{V2G}} / \text{times} B_c \times \text{PP}_{\text{ele}} \quad (3.11)$$

where PP_{ele} is the buying electricity tariff rate for the user to charge the EV.

EV charging costs per month as a result of road environment cycles is

$$C_{\text{CostsV2G}} = \text{NC}_{\text{V2G}} / \text{times} B_c \times \text{PP}_{\text{ele}} \quad (3.12)$$

Remember, when driving, the entire battery capacity is available.

Total monthly expenses for EV charging is

$$\text{TM}_{\text{Costs}} = C_{\text{CostsV2G}} + C_{\text{CostsRoad}} \quad (3.13)$$

$$\text{TA}_{\text{Costs}} = \text{TM}_{\text{Costs}} \times N_{\text{months/year}} \quad (3.14)$$

After subtracting the costs associated with the road environment, the profit earned through V2G in a month is

$$\text{Total}_{\text{NMprofitV2G}} = \text{NM}_{\text{profitV2G}} - C_{\text{costsRoad}} \quad (3.15)$$

The net yearly profit made by the user from using the V2G delivery is

$$\text{NA}_{\text{profitV2G}} = \text{NM}_{\text{profitV2G}} \times A_{\text{CostsRoad}} \quad (3.16)$$

where $A_{\text{CostsRoad}}$ is the yearly expense of EV charging because of the use of the road environment.

3.4.3 Estimation of the period required to make money through V2G to compensate a new battery

Necessary duration for V2G service to compensate the new battery cost in months is

$$T_{\text{months}} = \frac{C_{\text{nb}}}{\text{NM}_{\text{profitV2G}}} \quad (3.17)$$

Where C_{nb} is the new battery cost.

Conversion into years,

$$T_{\text{years}} = \frac{T_{\text{months}}}{N_{\text{months/year}}} \quad (3.18)$$

Profit for the user after the period of T years relates to the period required to accumulate enough income to purchase a new battery.

$$P_{\text{Tbat}} = \text{NA}_{\text{profitV2G}} \times T_{\text{bat}} \quad (3.19)$$

After subtracting the price of replacing their EV's battery, the overall net profit that each user obtained is

$$\text{NP}_{\text{V2G}} = P_{\text{Tbat}} - C_{\text{nb}} \quad (3.20)$$

3.5 Using Dynamic EV arranging to Estimate V2G Availability

For the technical analysis of EVs, the computational of the V2G capacity is assessed by dynamic scheduling on the grid's peak shaving and valley filling in the context of Nepal

is evaluated. It consists of EV charge Scheduling algorithm and V2G capacity estimation. In fact, charge scheduling algorithm is a fundamental block to estimate the capacity of V2G which are explain in detail below.

3.5.1 EV Charge Scheduling Algorithm

It used an procedure designed for real-time estimation of V2G (Vehicle-to-Grid) capacity using dynamic scheduling [23] of electric vehicles which is shown in Figure 3.2. The algorithm calculates the available V2G capacity by considering key constraints, such as satisfying load demand and maintaining the ability to charge the EVs effectively. The dynamic scheduling algorithm introduced adopts a modeling-based scheduling method to address the limitations of current scheduling techniques. The model consist of the projected demand of load building excluding EVs and the anticipated patterns of EVs charging. The required inputs include the building's half-hourly predicted load demand for the day ahead excluding EVs P_j^l , forecasted profile of EV charging $P_l^{(EV,i)}$ and the amount of charging intervals allotted to each EV. Subscript j denotes every half-hour throughout the day i.e. $j = 1, 2, 3, \dots, 48$ and subscript i denotes EV ID i.e. $i = 1, 2, 3, \dots, n$ where n represents all of the EVs. Every half an hour, the charging schedule is refreshed as 30 minutes interval is used.

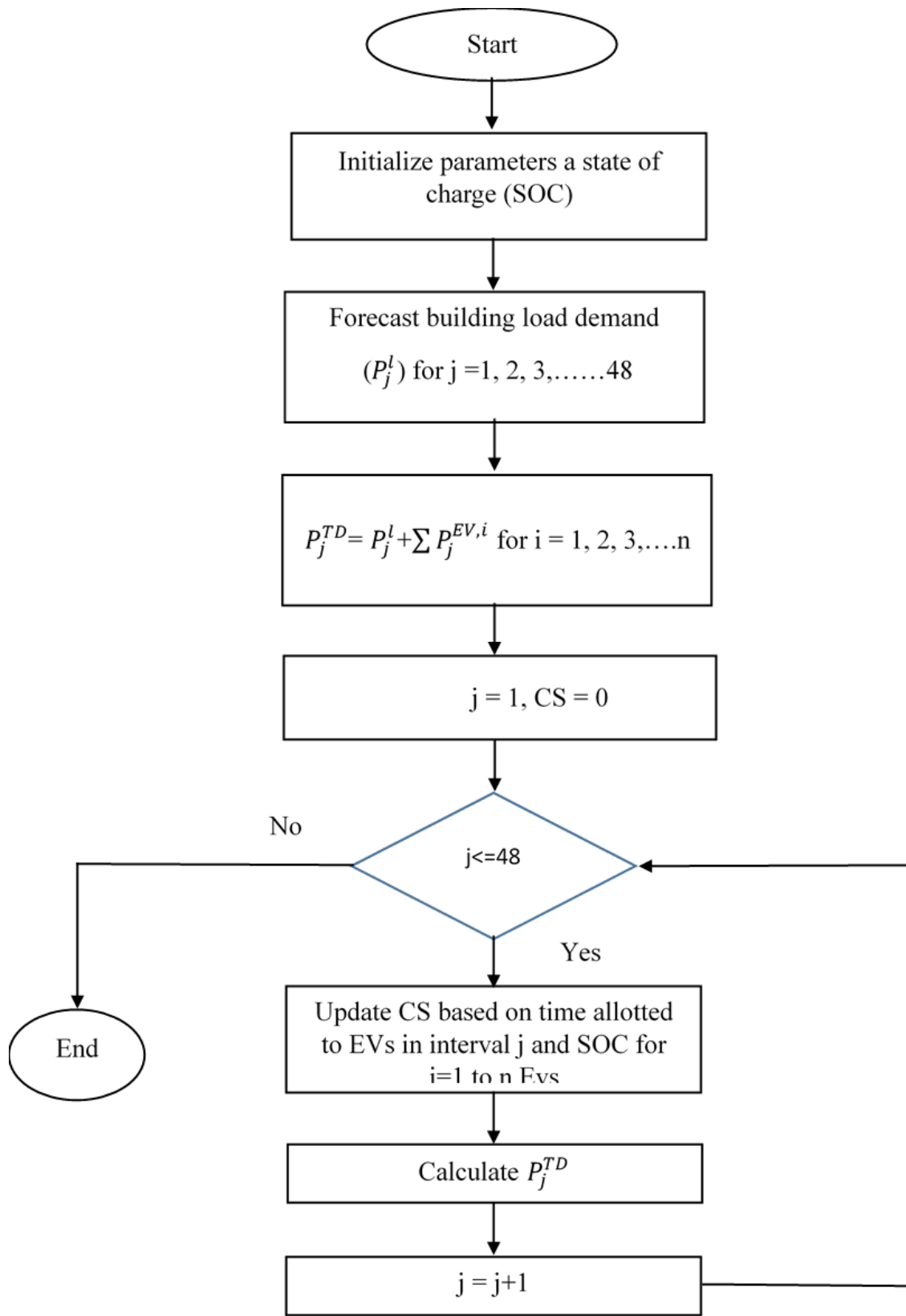


Figure 3.2: Flowchart of Scheduling method for EV charges

Utilizing the charge schedule (CS) matrix, the form

$$CS_{(n,48)} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,48} \\ \vdots & \ddots & \ddots & \vdots \\ x_{n,1} & x_{n,2} & \cdots & x_{n,48} \end{bmatrix} \quad (3.21)$$

where

$$x_{ij} = \begin{cases} 00, & \text{Idle} \\ 01, & \text{Charging} \\ 10, & \text{V2G} \end{cases} \quad (3.22)$$

x_{ij} is the control signal for charging or discharging the battery. The signal that controls a single EV connected to the building through a station for charging is indicated by CS matrix each row, which spans the 48 half an hour intervals.. Flowchart of EV charge scheduling algorithm can be explained further in the form of steps.

Step I: Initializing the parameters a SOC for each EV.

Step II: Forecasting load demand of an EV-free building

Step III: Finding total demand (load demand with EVs) using following equations

Let k_i be the sum of all intervals needed to charge the i^{th} EV, and let m_i be the i^{th} EV departure time. The overall Evs demand is provided by

$$P_j^{(EV,i)} = \begin{cases} 0, & 1 \leq j < (m_i - k_i - 1) \text{ and } j \geq m_i \\ P_l^{(EV,i)}, & (m_i - k_i - 1) \leq j < (m_i - 1) \end{cases} \quad (3.23)$$

Thus, the valley filling is given as

$$P_j^{TD} = P_j^l + \sum P_j^{(EV,i)} \quad (3.24)$$

During V2G service in the system, $\sum P_j^{(EV,i)}$ is negative and thus, peak shaving of the system load.

Step IV: EVs initial value of the charge schedule matrix is zero.

Step V: EVs values in the charging schedule matrix are updated and changed according to EVs that are allowed to be charged at any given time.

Step VI: Repetition of fifth step for all the 48 intervals.

3.5.2 Calculating V2G Capacity

Estimating the capacity of V2G in real time is essential for effective control and optimal performance of V2G operations. The following criteria are used to estimate V2G capacity.

Maximum V2G Power and Stable Power

The power evaluations of the utilized electronic converters to charge as well as discharge EV batteries determine the limitations on the highest and continuous V2G power. The power ratings of the battery can be neglected because EV batteries usually have higher power ratings than converters.

V2G Energy Available

The main objective of an electric vehicle is to meet transportation necessity of its user. Therefore, it's essential to ensure both chargeability (the ability to reach the required state of charge by departure) and drivability before using the EV for secondary functions like Vehicle-to-Grid (V2G) services. Each EV's present state of charge, the intended final charge level and the lowest required charge level that must be reached by the end of the current charging period before the vehicle departs all affect how much V2G energy is available from each EV. Only an EV charging scheduling system can provide chargeability and drivability, which therefore serves as the foundational component for estimating V2G capability. This computation is performed at the start of every half an hour interval. The maximum amount of energy that each vehicle can deliver during a specific interval T is defined as follows.

$$E_i^{(V2G \max)} = P_i^{(V2G \text{ cont})} \times T \quad (3.25)$$

The vehicle's capacity to provide V2G energy during the current half-hour interval is determined as

$$E_i^{v2g} = (\text{SOC}_i^{\text{current}} - \text{SOC}_i^{\text{min}}) \cdot C_i \quad (3.26)$$

where C_i is the i_{th} vehicle energy capacity.

$$E_i^{(v2g \text{ available})} = \begin{cases} 0, & E_i^{v2g} \leq 0 \\ E_i^{v2g}, & 0 < E_i^{v2g} < E_i^{(v2g \max)} \\ E_i^{(v2g \max)}, & E_i^{v2g} \geq E_i^{(v2g \max)} \end{cases} \quad (3.27)$$

$E_i^{(\text{v2g available})}$ is limited to $E_i^{(\text{v2g max})}$ in order to limit power output of electric vehicles beyond the capacity of various power-converting electrical devices for charging and discharging. The entire amount of V2G power and energy that can be provided by a fleet of EVs is expressed as follows:

$$E^{(\text{v2g total})} = \sum_{i=1}^n E_i^{(\text{v2g available})} \quad (3.28)$$

$$P^{(\text{v2g total})} = \sum_{i=1}^n P_i^{(\text{v2g})} \quad (3.29)$$

3.5.3 Case Study

The methods that is proposed by [23] is used to study a case scenario on public office of Sajha Yatayat situated in Kathmandu valley and the characteristics of EV is shown in Table 3.9. It is the office having the largest number of electric buses. The number of EVs travelling in Kathmandu valley of the office is forty. The author visited Sajha Yatayat

Table 3.9: Sajha Yatayat EV Bus Characteristics (Kathmandu Valley, $n = 40$)

Characteristics	Value
Bus Type	CHTC Electric Vehicle
Battery Capacity (B_c)	161 kWh
Electric Vehicle Range (EVR)	200 km

office and found that the vehicles usually departure from 6:00 AM to 7:00 AM and arrives in between 6:00 PM to 7:00 PM after completing four trips in each route. Table 3.10 is formulated based on the consideration that all EVs departure at 6:00 AM and arrives at 6:00 PM and in each route number of EVs is eight. Hence, the office building's connected

Table 3.10: Route-wise Daily Distance and SOC Details

Route	Distance (km/trip)	Distance (km/day)	SOC at 6:00 AM	SOC at 18:00 (SOC ^{init})
Laghankhel – Buspark	14.28	57.12	100%	71.44%
Laghankhel – Budhanikantha	17.18	68.72	100%	65.64%
Godhawari – Ratnapark	17.67	70.68	100%	64.66%
Lamatar – Ratnapark	17.33	69.32	100%	65.34%
Airport – Thankot	21.48	85.92	100%	57.04%

electric vehicle fleet is capable to deliver V2G power during the evening peak period (from 18:00 to 21:00). Energy from EVs with higher state of charge (resulting from shorter travel distances compared to their maximum range) can be utilized to reduce part of the building's

load either to charge additional EVs or throughout evening peak periods or in urgent need of charging. These EVs can then be recharged while it's off-peak at night (21:00 to 6:00 hours) when electricity is more affordable.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Numerical model for economic viability

The results obtained from calculations using above equations is shown in Table 4.1 In this

Table 4.1: Model results for the $PS_{ele} = 11.7 \text{Rs./KWh}$

Characteristic	Elder	Job Holder	Busman	Cabman
BmdV2G	1.07%	0.53%	0.27%	0.11%
BmdRoad	0.014%	0.032%	0.8%	1.4%
TotalBmd	1.08%	0.56%	1.07%	1.5%
BadV2G	12.8%	6.4%	3.2%	1.28%
BadRoad	0.167%	0.38%	9.62%	16.78%
TotalBad	12.97%	6.78%	12.82%	18.06%
CcostV2G (Rs.)	1977.6	2491.77	3316.6	197.76
CcostRoad (Rs.)	25.7	147.9	9966.2	2591.9
TMCcosts (Rs.)	2003.3	2639.7	13283	2789.7
TACcosts (Rs.)	24040	31677	159396	33475
MrV2G (Rs.)	4493	5661	7535	449
NMprofitV2G (Rs.)	2515	3169	4218	252
TotalNMprofitV2G (Rs.)	2489	3021	-5748	-2340
NAprfitV2G (Rs.)	30182	38030	50618	3018
TotalNAprofitV2G (Rs.)	29873	36254	-68978	-28084
Tmonths	99.6	199.2	398.5	996.2
Tyears	8.3	16.6	33.2	83
PTyears (Rs.)	250560	631411.2	1680840	250560
Tbat	1.54	2.95	1.56	1.11
PTbat (Rs.)	46554	112182	78992	3343
NPV2G (Rs.)	-204006.07	-519228.83	-1601847.49	-247216.80

scenario, the 'Elder' and 'Job Holder' groups get positive total yearly net profit through V2G service in a road environment after subtracting the yearly recharge expenses. However, all user's groups net profit through V2G service is negative after deducting the price of replacing the battery. Further, all the groups need to replace the battery below 3 years. The 'Elder' group need should change the battery every 1.54 years, but "Cabman" needs to do it every 1.11 years.

4.1.1 Charge-discharge cycles every month

The Figure 4.1 shows how many on-road charge-discharge cycles and Vehicle-to-Grid (V2G) cycles each user completes each month. Users of electric cars (EVs) are presumed to fully recharge their vehicles whenever necessary in this scenario, whether due to V2G or on driving usage, ensuring the battery reaches 100% each time. However, for V2G cycles, only 80% of the battery capacity is used. After each V2G discharge, users pay Rs. 5.15/kWh for power to fully recharge their EVs overnight. Users only recharge the battery for on-road use when it runs low, returning it to full capacity when needed..

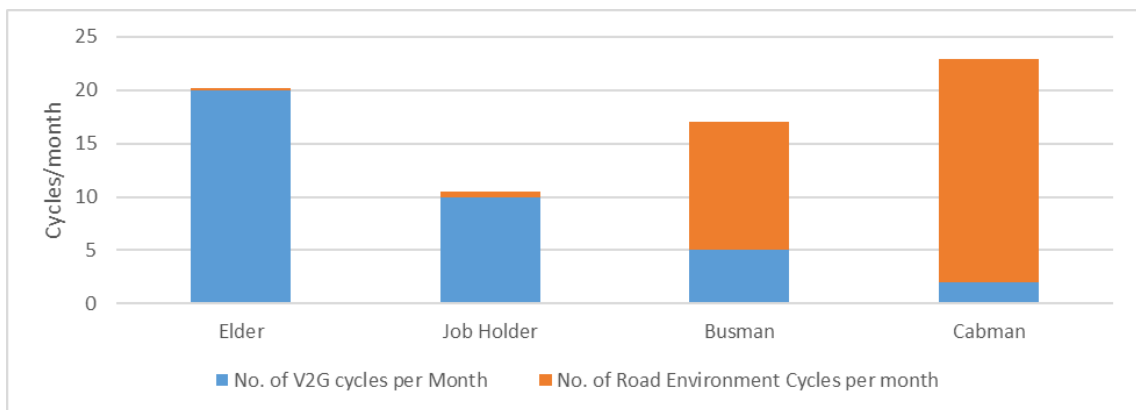


Figure 4.1: Charge and discharge cycles number for each user

The results show charging and discharging cycles number dedicated monthly for V2G service is most for 'Elder' User while least is for 'Cabman'. The 'Busman' manage a good equilibrium between the quantity of charges for driving and V2G.

4.1.2 Monthly deterioration of the battery

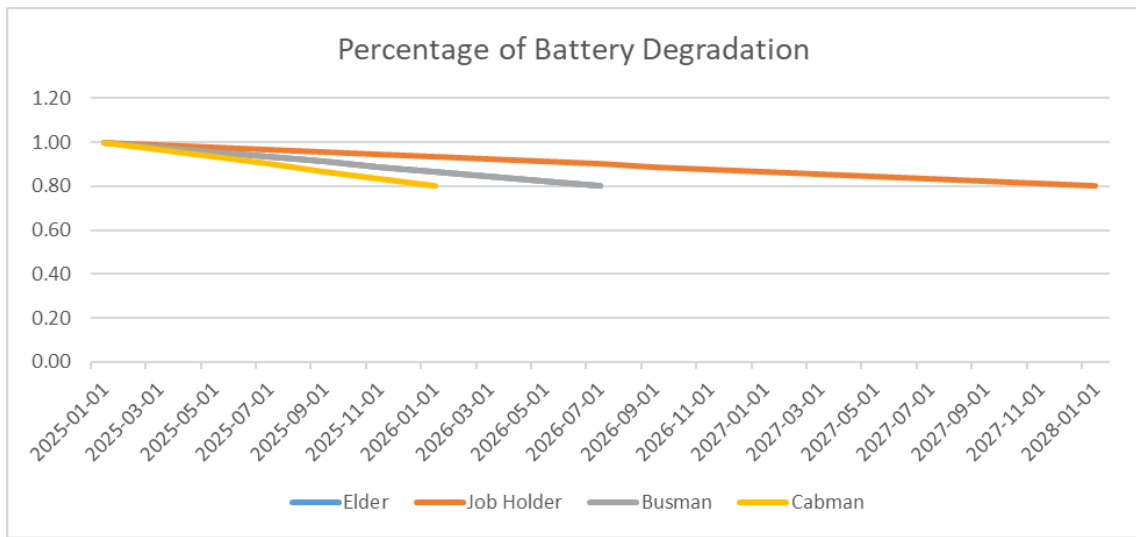


Figure 4.2: Percentage of battery deterioration of every user’s EV battery

The amount of V2G delivery and road usage cycles that every owners’ completes can shorten the battery’s lifespan. As shown in Figure 4.2, “Job Holder” battery user has the maximum time to be 80% of its capacity, which is considered a critical limit for maintaining best battery health. In contrast, the “Elder”, “Busman” and “Cabman” users engage in high frequent V2G usage and road usage high often, suffer high rate of deterioration of battery having their batteries lifespan maximum of two years.

The battery degradation rate of “Elder” and “Busman” is approximately same and so, these graphs coincide to each other. ‘Elder’ user’s battery lasts 1.54 years, the ‘Job Holder’ user’s battery lasts 2.95 years, ‘Busman’ user’s battery lasts 1.56 years and the ‘Cabman’ user’s battery lasts 1.11 years.

4.1.3 Yearly spending on entire recharges of EV

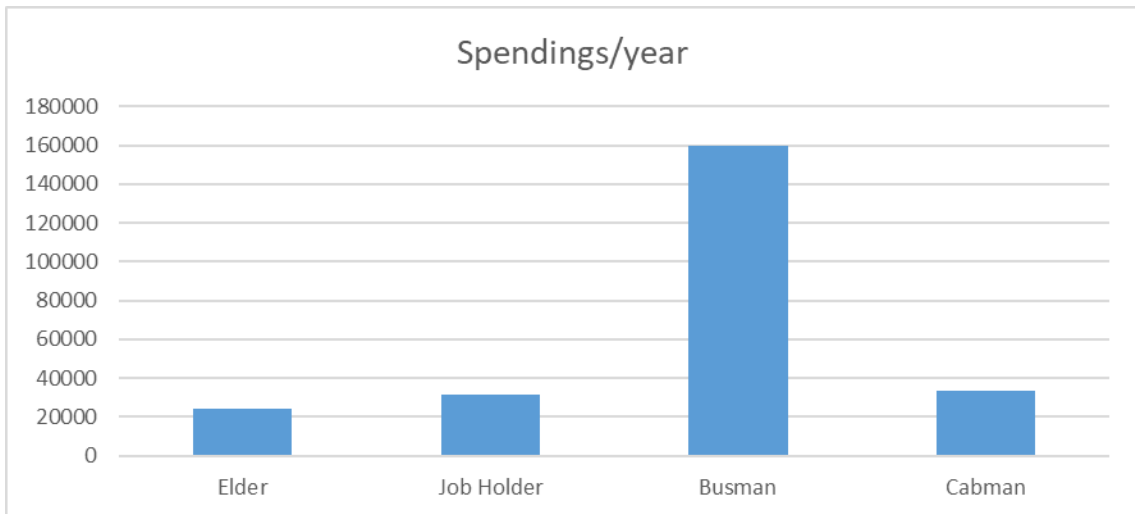


Figure 4.3: Yearly spending on entire recharges of a EV for each user

Figure 4.3 shows The total cost per user per year to recharge their EVs, covering the price of road usage and vehicle-to-grid (V2G) cycle recharging. In this case, the ‘Busman’ users incur notably higher costs compared to the other users. This is mainly due to the higher battery capacity of “Busman” user EV.

4.1.4 Yearly profit earned from V2G

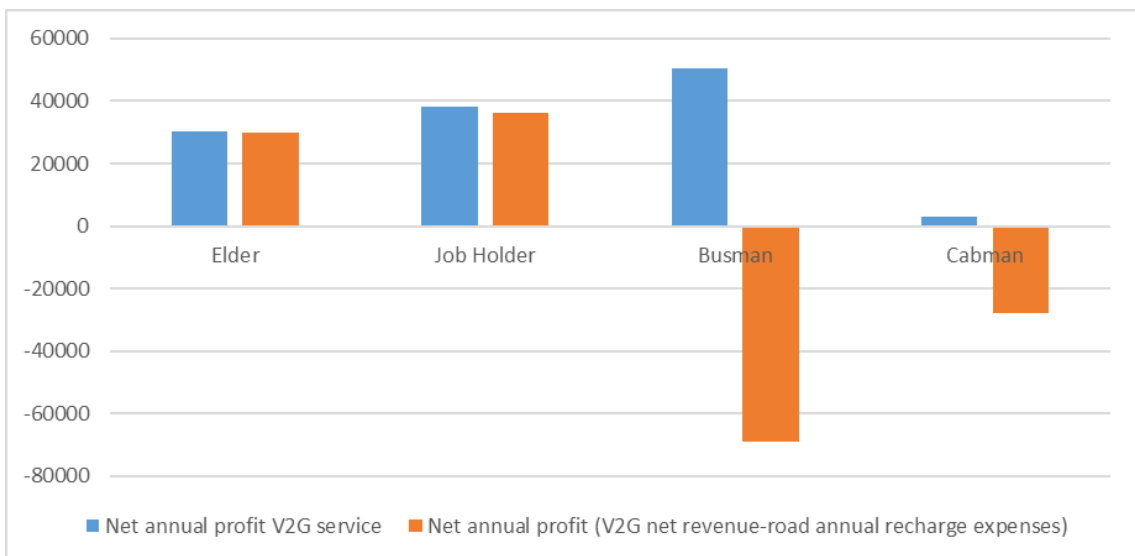


Figure 4.4: Annual profit gain by each user through V2G service

The Figure 4.4 displays two distinct values: the dark blue bars represent yearly earnings of every user exclusively through V2G. This gain accounts only for the revenue generated

by V2G and the costs associated with recharging for the V2G service. The dark red, in contrast, indicate the yearly net profit for each user, which is calculated by subtracting the annual recharging expenses for usage on roads from the V2G service gain. The graph depicts that ‘Elder’ and ‘Job Holder’ two bars are pretty much the same which is because of the low yearly recharge costs done by since the yearly recharge costs are so low. However, net annual profit obtained by deducting road annual recharge expenses is negative for ‘Busman’ and ‘Cabman’ which is due to intensive road use.

4.1.5 V2G service period to recover the amount of a new battery

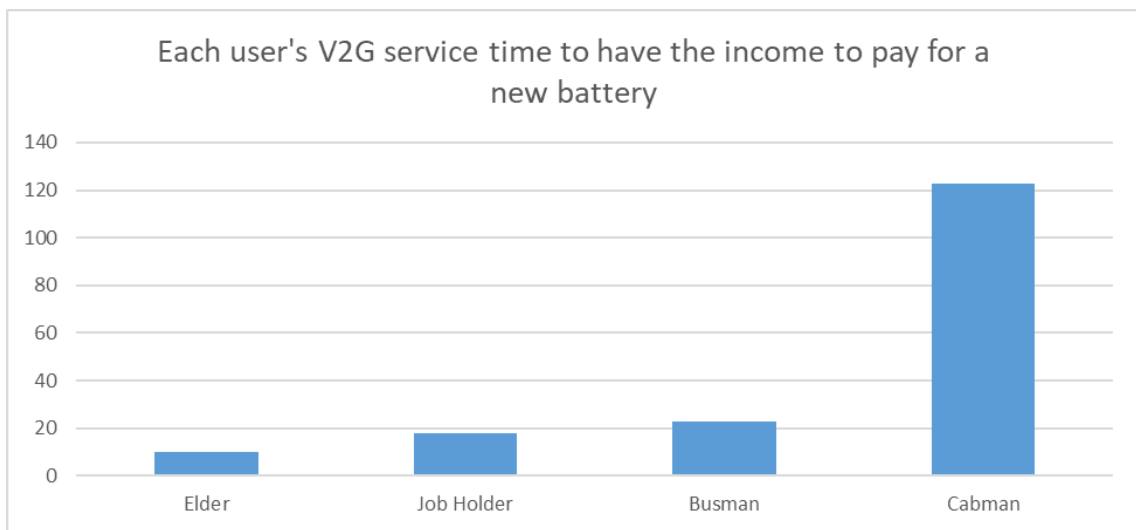


Figure 4.5: V2G service period to recover cost of a new battery

The Figure 4.5 shows every user period to engage in the V2G service to earn enough income to recover the amount of a fresh battery. For instance, ‘Elder’ user may have save enough money for a new battery after only around 10 years of participating in the V2G service. The amount of time each user needs to save enough to recover a price of a fresh battery is straightly linked with V2G cycles quantity they complete each month.

4.1.6 Periods for the battery replacement

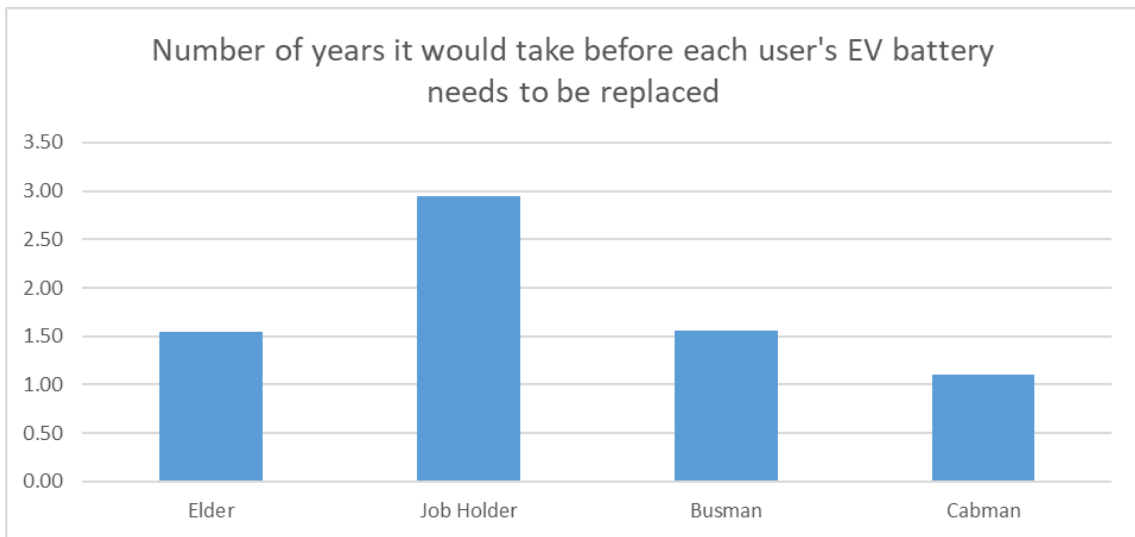


Figure 4.6: Periods for the battery replacement

The Figure 4.6 shows how long the car battery lasts in each situation, highlighting the time period taken for the replacement after the vehicle battery's lifespan under each condition. It is evident that a battery's lifespan will be shortened due to its increased use, whether for V2G or on driving..

4.1.7 Net profit after deducting the battery cost

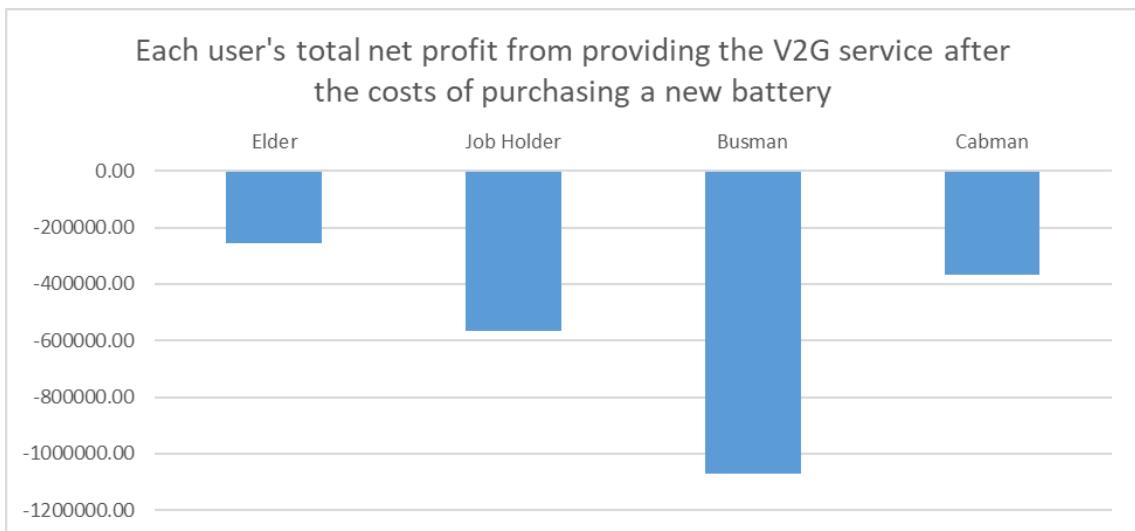


Figure 4.7: Net profit after deducting the battery cost

The entire net profit for every user participating in V2G, following factoring in the expense of the fresh battery cost, is shown in Figure 4.7. It is clear that with a transaction cost of

11.7 Rs/kWh, all the user are in losses after covering the price of a fresh battery. It implies that at the selling tariff rate, the service does not seem beneficial. Without participating, their EV battery would last longer throughout the monthly V2G cycles. Although the V2G helps offset new battery cost, it might not be worth speeding up battery degradation, especially when storage prices are still high.

4.1.8 Sensitivity analysis

For each of the four users, the above calculations were done at electricity selling tariff rate Rs. 9/KWh and Rs. 17/KWh are presented in Table 4.2 and Table 4.3 respectively where the value of battery deterioration being same for different selling prices is not shown.

Table 4.2: Model results for the $PS_{ele} = 9\text{Rs./KWh}$

Parameter	Elder	Job Holder	Busman	Cabman
MrV2G (Rs.)	3456	4354.56	5796	345.6
NMprofitV2G (Rs.)	1478.4	1862.8	2479.4	147.8
TotalNMprofitV2G (Rs.)	1453	1715	-7486.983	-2444.052
NAprofitV2G (Rs.)	17740.8	22353.4	29752.8	1774.1
TotalNAprofitV2G (Rs.)	17432	20578	-89844	-29328
Tmonths	169.5	338.9	677.9	1694.8
Tyears	14.1	28.2	56.5	141.2
PTyears (Rs.)	250560	631411.2	1680840	250560
Tbat	1.54	2.95	1.56	1.11
PTbat (Rs.)	27363.7	65939.2	46430.7	1965.1
NPV2G (Rs.)	-223196	-565472	-1634409	-248595

For each of the four users, the above calculations were done at electricity selling tariff rate Rs. 9/KWh and Rs. 17/KWh are presented in Table 4.2 and Table 4.3 respectively where the value of battery deterioration being same for different selling prices is not shown.

Table 4.3: Model results for the $PS_{ele} = 17 \text{Rs./KWh}$

Parameter	Elder	Job Holder	Busman	Cabman
MrV2G (Rs.)	6528	8225.28	10948	652.8
NMprofitV2G (Rs.)	4550.4	5733.504	7631.4	455.04
TotalNMprofitV2G (Rs.)	4524	5585	-2335	-2137
NAprofitV2G (Rs.)	54604	68802	91577	5460
TotalNAprofitV2G (Rs.)	54295	67026	-28019	-25642
Tmonths	55.06	110.12	220.25	550.63
Tyears	4.59	9.18	18.35	45.89
PTyears (Rs.)	250560	631411.2	1680840	250560
Tbat	1.54	2.95	1.56	1.11
PTbat (Rs.)	84223	202956	142910	6048
NPV2G (Rs.)	-166336	-428455	-1537929	-244511

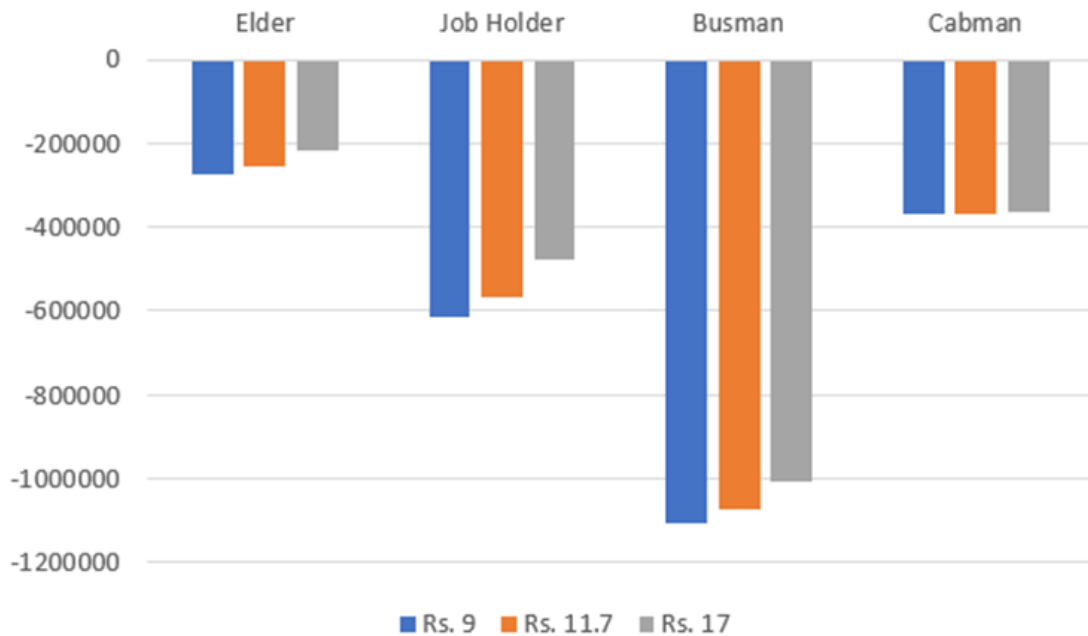


Figure 4.8: Overall net profit after buying fresh battery

Figure 4.8 displays a sensitivity analysis graph that highlights how the net entire profit for every user fluctuates after deducting the cost of new battery, based on various costs of sale for electricity which depicts that the entire net profit for every user groups in all cases, the cost of a new battery is negative after accounting.

4.1.9 V2G Capacity Estimation of Sajha Yatayat office Building

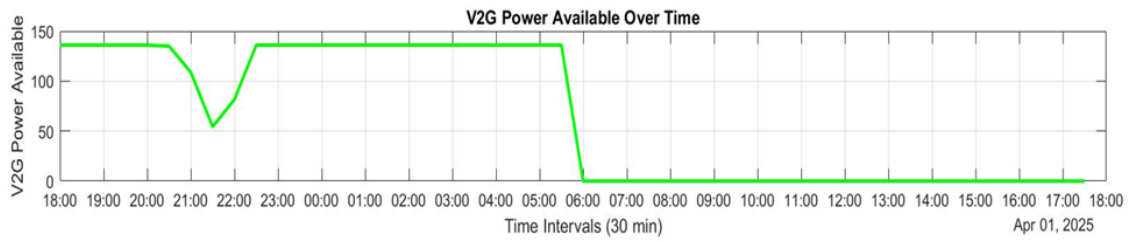


Figure 4.9: Estimation of V2G power for Sajha Yatayat Building

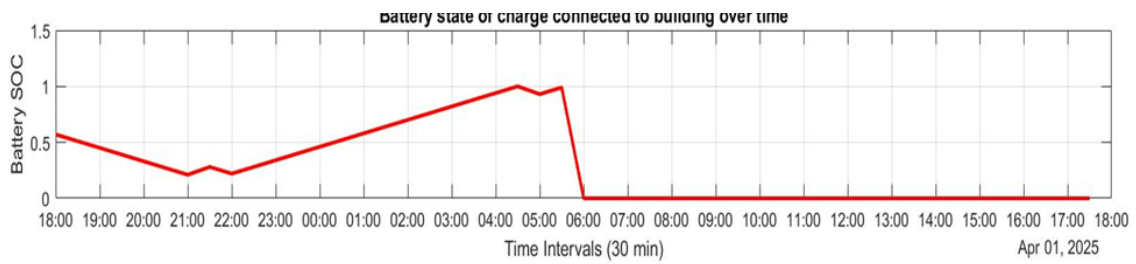


Figure 4.10: Average current State of Charge connected to building

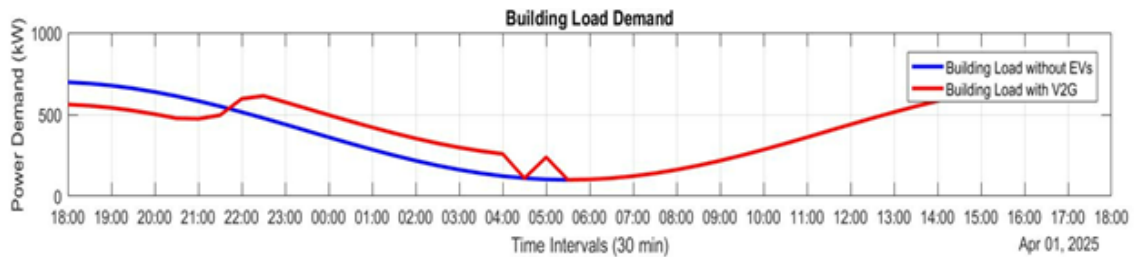


Figure 4.11: Peak Shaving and valley filling with EVs

The anticipated V2G capacity per half an hour interval for 24 hours (between 18:00 of April 01, 2025 and 18:00 of April 02, 2025) is depicted in Figure 4.9. Figure 4.10 displays the mean SOC of the current time. A minimum SOC threshold of 25% is set for V2G discharging to ensure that no EV's battery level falls below this limit. Typically, EVs don't emit less than 15–20%. to maintain better battery health and longevity. It is reflected from the Figure 4.9 that the available V2G power begins to decline after 20:30, dropping to approximately 50 kW by 21:30. Following this, power from the V2G commence to rise again after 21:30, coinciding with rise in the mean SOC of the current time because of charging activity. The power from V2G reaches its peak value of around 140 kW at 22:30. The reduction in power from V2G in between 20:30 and 21:30 is attributed to the drop in mean of SOC of the current time caused by discharging, as shown in Figure 4.10. Though availability of V2G power is high, power provided to grid is limited because of maximum

power limit of the converter. Here, level 2 charger is used whose maximum power limit is 3.4 KW.

The EVs are charged to their target state of charge (SOC) by 04:30 hours, achieving a smooth valley-filling effect. However, from 04:30 to 05:30 hours, the final SOC fluctuates by in between around 1.2 to 0.94. The fluctuation is caused due to charging rate 0.07% and discharging rate 0.06% of battery capacity that was taken during modelling. Figure 4.11 displays the load demand of building with as well as without the influence of EV charging and discharging. The valley filling's flat surface observed from 21:30 to 04:30 hours is regulated through real time scheduling. At 23:00 hours, the total demand of building with EVs is 575 KW while the building's load demand without EVs is 477.6 KW and the demand due to EVs is 97.4 KW. Thus, valley filling by 17%. Further, at 18:00 hours the load demand of building is 700 KW without EVs and the building's overall load demand with V2G service at 18:00 hours is 560.5 KW. Thus, V2G service provided by the EVs is 139.5 KW. Thus, peak shaving by 19.9%.

When demand was at its highest, from 18:00 hours to 21:30 hours, the tariff rate is high and at that time, power is provided to grid from vehicle. However, charging of EV is done at low tariff rate during 21:30 to 4:30 hours. From the economic perspective of load power supplier also, V2G service is beneficial to some extent. It helps to decrease the system peak load and increase the base load which ultimately profits to power suppliers as cost of supply power decrease and revenue increase.

CHAPTER FIVE: CONCLUSION

V2G technology is a novel innovation where EVs act as distributed sources. **However, in the context of Nepal, the findings depict that the entire net profit earned through V2G, after subtracting the cost of new battery, is drastically negative for entire groups in every hypothetical electricity selling tariff rate scenarios: Rs. 9/KWh, Rs. 11.7/KWh and Rs. 17/KWh. Thus, it becomes not feasible for every user to continue deterioration of their battery at these rates as the battery need to replace after 1 to 3 years.**

The EV users are divided into four groups based on the activeness and in the all groups, the entire net profit earned through V2G after deducting the cost of new battery is significantly negative. The probable reasons are **low selling price of electricity and high purchasing cost of new battery**. Though, entire net yearly profit through V2G after subtracting the yearly cost of recharging in a road environment is positive for ‘Elder’ and ‘Job Holder’ EV users, the time period for replacing the battery is short for both groups. **The decrease in the cost of battery and increase in the selling price of electricity to grid by EV users might make V2G technology profitable in the future .**

The technical benefits of V2G service - peak shaving and valley filling is demonstrated through case study. This study introduces an algorithm that determines the capacity for V2G in real time by employing dynamically scheduling connected EVs to Sajha Yatayat building’s energy management system (BEMS). Estimating the capacity for V2G in real time of EVs is essential for utilizing them as dispersed energy storage units. The method verified using the case study discovered that factors like EVs’ arrival and departure periods, load demand, and battery size have a influence on their V2G capacity. Accurately determining the capacity of V2G in real-time of EVs is vital for their proper use as decentralized energy storage systems for peak shaving and valley filling. **The case study results show that at 23:00 hours, valley filling by 17% and at 18:00 hours , peak shaving by 19.9%.**

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APPENDIX A: PUBLICATION

Conference paper

Notifications

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[IOEGC16] Editor Decision

2025-03-31 07:04 AM

Niroj Bhujel, Jeetendra Chaudhary, Sujan Adhikari:

We are pleased to inform you that your manuscript titled "Techno-economic analysis of vehicle to grid technology into the grid in Nepal" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

Techno-economic analysis of vehicle to grid technology in Nepal

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Abstract

The study develops a novel numerical model for performing an economic evaluation of Vehicle-to-Grid (V2G) services. The model takes into account several parameters in its calculations, such as battery degradation, distance traveled, charging frequency, the number of V2G charge-discharge cycles, electricity purchase and sale prices, and the cost of new batteries which helps to make it analogous to real world scenario. To validate this model, the EV users are classified into four distinct groups with unique features—'Elder', 'Job holder', 'Cabman' and 'Busman'—aiming to identify the situations in which offering this energy storage service is most advantageous for EV users. For each group, the typical brand of EV used in nepal is taken. Currently, there is no established tariff rate for selling electricity through V2G technology in Nepal. Therefore, we evaluated and compared three hypothetical electricity selling price scenarios: Rs. 9/kWh, Rs. 11.7/kWh (equivalent to the existing highest electricity purchasing tariff rate for EVs in Nepal), and Rs. 17/kWh, and conducted a sensitivity analysis. The objective is that, by the time a user needs to replace their battery due to degradation, they will have earned enough from the V2G service to cover the cost of a new battery and still make a profit. The results show that the total net profit from the V2G service, after accounting for the cost of a new battery, is significantly negative for all groups in each scenario. At selling rate Rs. 17/KWh, the highest loss is Rs. 15,37,930 for Busman and lowest loss is Rs 1,66,336 for Elder user. Though, the hypothetical rate Rs. 17/KWh is high tariff in the context of nepal, it becomes impractical for all users to continue degrading their battery and replacing after 1 to 3 years in this rate.

Keywords

Electric vehicles, V2G, Economic earnings, Battery degradation

1. Introduction

The application of electric vehicles are trends from the past few years till now [1]. It is effective for decarbonization of transport [2]. The generation of electricity from fossil fuels has become a major concern for communities worldwide due to its significant carbon emissions and the harmful effects of other pollutants on the environment [3]. Technological advancements have caused the cost of electric vehicles (EVs) to decrease [4]. Lithium-ion batteries (LiBs) are essential to the shift toward electric transportation, having experienced an 85% decrease in production costs over the past decade [5]. In Nepal, electric vehicles (EVs) are becoming more popular as concerns over air pollution rise and the country's reliance on imported fossil fuels grows [6]. Various challenges in implementing EV-based transportation are being tackled globally, and developing countries looking to invest in their electric

transport sector must carefully study these trials, errors, and successes to identify key factors that need attention [7].

It can potentially act as distributed energy storage devices to provide a service to the grid (V2G) [8]. Here, the EV that acts as a load in the grid-to-vehicle (G2V) mode during charging can act as an energy source with its bidirectional mode of operation as vehicle-to-grid (V2G) while in the discharging mode [8]. It provides an opportunity to manage increasing electricity costs and demand spikes to act as an aggregated energy store providing peak shaving or demand shifting. Also, it provides a range of services beyond just powering the EV like frequency and voltage regulation or renewable energy storage [9]. The quick response of Energy Storage Systems (ESS) to fluctuations in nominal frequency and imbalances between supply and demand allows them to supply or absorb power, offering a level of stability that traditional network assets cannot match [10].

1.1 Literature Review

Gomes et al.[3] research aims to develop an innovative numerical model for conducting an economic analysis of Vehicle-to-Grid (V2G) services. This model calculates the potential earnings for a user providing V2G services to the grid operator, taking into account Portugal's electricity market and the growing adoption of Electric Vehicles (EVs) in the country. The findings indicate that V2G services can be very profitable when electricity sale prices are high (0.50 €/kWh), particularly for users with minimal car usage, generating profits of 624 € per month and 1547 € in total after the cost of a new battery. However, when the electricity sale prices decrease to 0.30 or 0.20 €/kWh, the benefits are significantly reduced.

Another research work done by Huda et al. [9] on a techno-economic analysis of the vehicle-to-grid (V2G) system in the JAMALI grid found that by using Electric Vehicles (EVs), the supply during peak hours can be reduced by as much as 2.8% for coal and 8.8% for gas. EVs owned by businesses, particularly those used as operational vehicles with a natural tariff, show the greatest potential for providing ancillary services and can reduce charging costs by up to 60.15%. Similarly, Gougha et al.[11] research assessed the potential for electric vehicles to generate income by supplying energy to a commercial building, along with revenue from specific ancillary service markets in the UK. The findings indicate that providing energy to the wholesale electricity market, combined with additional earnings from the capacity market, leads to the highest projected return on investment. This results in a net present value of £8400 per vehicle over 10 years, assuming the vehicle supplies energy three times per week to the half-hour day-ahead market, and includes the cost of installing the vehicle-to-grid infrastructure.

The research work of Borge et al. [12] introduces an innovative method that combines the use of Vehicle-to-Home (V2H) and Vehicle-to-Building (V2B) systems, applicable in various scenarios such as when building employees own EVs, use company shared car fleets, or lease vehicles. Energy recharged at workers' homes during the night is supplied to the building during working hours, helping to lower peak demand, reduce carbon intensity, and achieve energy cost savings. The findings indicate that this approach is feasible, can be applied to other situations, and significantly contributes to improved energy efficiency, reduced peak demand in buildings, and

increased adoption of electric vehicles for commuting to workplaces.

The results from the paper of Lei et al. [13] indicate that the Distribution System Operator (DSO) can generate marginal revenue not only through an optimal day-ahead bidding strategy but also by managing the charging and discharging schedules of EVs. Furthermore, EV users can lower their charging costs by charging during low electricity price periods and earn additional revenue by exporting power to the grid during high price periods.

Zhang et al. [14] paper examines the charging demands of electric vehicle (EV) users using GPS trajectory data and introduces an EV-discharging optimization model based on vehicle-to-grid (V2G) interaction. The findings demonstrate that the proposed model effectively explores the potential for user involvement in V2G within the study area. Additionally, the V2G response resources help reduce grid fluctuations and allow users to gain certain benefits, creating a mutually beneficial outcome for both the grid and the users.

Aziz et al. [15] paper analyzed the utilization of electric vehicles (EVs) for grid ancillary services, especially for frequency regulation in Denmark. Denmark has two different electricity grids: DK1 (Western Denmark) and DK2 (Eastern Denmark). A comparison of the revenue from services provided by passenger EVs shows that frequency regulation in DK2 generates higher revenue than in DK1. However, due to higher frequency and fluctuations in both up and down services in DK2, there are concerns about the faster battery degradation of EVs in this area.

The study done by Sagaria et al. [16] examines the degradation of Lithium-ion batteries in battery electric vehicles (BEVs) and calculates the compensation costs when BEVs are utilized as primary energy storage systems through vehicle-to-grid (V2G) technology. We present a new co-simulation interface in MATLAB Simulink that integrates a V2G model, a BEV mobility model, and a battery degradation model to assess the degradation of BEV batteries and the results show that V2G enhances the battery degradation by 9% to 14% over 10 years.

1.2 Significance of current work

The typical and novel numerical model developed by Gomes et al. [3] was used in the context of Nepal. This work thus offers a valuable resource for analyzing the economic impact of V2G technology on various types of real-world EV users enabling calculation of the

financial earnings a user can generate from the grid by offering V2G services, while also accounting for the added battery degradation. The paper also forecasts the future of this technology, proposing that the service could become profitable and important in the years ahead as storage costs keep falling.

2. Methodology

2.1 Model Presentation

To implement the model, EV users are categorized into different groups based on their level of EV usage, ranging from passive to active users. For each group, the specific EV brands most commonly used in Nepal by that group are selected for the study. The specific details of each user's characteristics (such as the number of V2G charge-discharge cycles, number of road environment charge-discharge cycles, daily kilometers traveled, hours of vehicle use, recharging frequency, etc.) will be outlined in Tables 1 to 4. The characteristics "Car", " B_c ", " C_{bat} " and " EV_R " are derived from real-world data about typical brand of EV of each group of user. The number of V2G cycles (NC_{V2G}) performed by each user each month is influenced by their available time, which naturally depends on how often they use their vehicle. This model assumes that a user with more "free" time (i.e., less frequent car use) has greater opportunities to engage in V2G services. Thus, the authors selected the characteristics " NC_{V2G} " and "vehicle use" to examine various user scenarios, focusing on vehicle usage and the resulting availability of time for the V2G service.

Nepal does not have a set tariff rate for selling electricity through V2G technology. As a result, three hypothetical electricity selling price scenarios: Rs. 9/kWh, Rs. 11.7/kWh (the current highest electricity purchasing tariff rate for EVs in Nepal[17]), and Rs. 17/kWh are taken, and performed a sensitivity analysis. It was also established that users/owners would always charge their cars at night using slow charging, when energy prices are lower. According to data from Nepal Electricity Authority[17], the electricity cost for EV charging during the night in Nepal was set at Rs.5.15/kWh. It was decided that each user would only make 80% of battery capacity available for sale to the grid, to prevent depleting the battery to 0% and thereby reducing its lifespan. In this model, each time a V2G charge-discharge cycle occurs, the entire 80% of battery capacity is consumed

by the grid, and the user recharges the battery back to 100%. For road use, each user charges their vehicle to 100%, uses its full range EV_R , and then charges again. Taking the cost of new battery 75 US\$/KWh[5] which is equivalent to Rs. 10440 (according to exchange rate of Jan. 1, 2025) for these calculations.

2.2 User Characteristics

The EV users are classified into four groups and for each group, the commonly used typical brand of EV is used which are given in tables 1 to 4 along with user characteristics. This analysis enables us to assess a variety of users, ranging from those who use their vehicle frequently (such as 'Cabman' drivers) to those who use it infrequently (like 'Elder'), as well as those who fall in between, such as 'Job Holder' and 'Busman'.

Tata Tiago Long Range brand of EV taken for the

Table 1: 'Elder' user characteristics

Characteristics	Value
Car	Tata Tiago Long Range
Battery (B_c)	24 KWh
C_{bat}	1500 cycles
EV_R	315 KM
NC_{V2G}	20 cycles per month i.e. 5 times a week on weekdays
Vehicle use	0 hr per day during five working days of the week; two hours in Friday and Saturday (8 days a month)
AvN_{Kmday}	15 Km each Friday and 15 Km each Saturday (Average of 3.94 Km's per day of the month)
$N_{Km/month}$	120 KM
FR_{Road}	146
NC_{Road}	0.2083
PS_{ele}	Rs. 11.7/KWh
PP_{ele}	Rs. 5.15/KWh
C_{nb}	Rs. 250560

'Elder' user group features is shown in Table 1. Normally, 'Elder' users are retired people who are comparatively inactive and so, the authors consider the high probability of availability for V2G service.

BYD ATTO 3 brand of EV taken for the 'Job holder' user group features is shown in Table 2. Authors consider the user of this group utilize EV for commuting purpose.

CHTC Electric Vehicle brand of EV taken for 'Busman' user group features is shown in Table 3. Authors consider the user of this group utilize EV for commercial purpose and so availability of EV for V2G service is low.

Tata Xpress-T sedan brand of EV taken for the 'Cabman' user group features is shown in Table 4. Normally, 'Cabman' users are very busy and so, the authors consider very low availability of EV for V2G

Table 2: 'Job Holder' user characteristics

Characteristics	Value
Car	BYD ATTO 3
Battery (B_c)	60.48 KWh
C_{bat}	1500 cycles
EV_R	420 KM
NC_{V2G}	10 cycles per month i.e. twice a week on weekdays; once every two weekends
Vehicle use	one hour per day during six working days of the week; two hours in Saturday
AvN_{Kmday}	5 km's each working day of the week; 20 km's in Saturday (Average of 6.57 Km's per day of the month)
$N_{Km/month}$	200 KM
FR_{Road}	63.92
NC_{Road}	0.475
PS_{ele}	11.7/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 631411.2

Table 3: 'Busman' user characteristics

Characteristics	Value
Car	CHTC Electric Vehicle
Battery (B_c)	161 KWh
C_{bat}	1500 cycles
EV_R	200 KM
NC_{V2G}	5 cycles per month i.e. Once a week on Saturday and once in a weekend to be defined
Vehicle use	Six hours a day during the six working days of the week; Zero hours on Saturday (24 days a month)
AvN_{Kmday}	100 km a day during six working days of the week (Average of 78.9 Km's per day of the month)
$N_{Km/month}$	2400 KM
FR_{Road}	2.53
NC_{Road}	12.02
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs.1680840

Table 4: 'Cabman' user characteristics

Characteristics	Value
Car	Tata Xpress-T sedan
Battery (B_c)	24 KWh
C_{bat}	1500 cycles
EV_R	277 KM
NC_{V2G}	2 cycles per month i.e. Every two Saturday
Vehicle use	Sixteen hours a day every day of the week except on every two weeks Saturday (29 days a month)
AvN_{Kmday}	200 km a day except on every two weeks Saturday (Average of 190.68 Km's per day of the month)
$N_{Km/month}$	5800 KM
FR_{Road}	1.45
NC_{Road}	20.97
PS_{ele}	11.7 Rs/KWh
PP_{ele}	5.15 Rs/KWh
C_{nb}	Rs. 250560

service.

2.3 Calculating user Characteristics

The average number of days per month of the year is $AvN_{Days/month} = \frac{N_{days/year}}{N_{months/year}}$ where $N_{days/year}$ is the average number of days during a month of the year

and $N_{months/year}$ is the number of months per year.

The average number of Kilometers travel by each user per day is

$$AvN_{Kmday} = \frac{N_{Km/month}}{AvN_{days/month}}$$

where $N_{Km/month}$ is the kilometers travel by each user per month.

The recharging frequency (in days) of the EV for each user is determined by the car's usage in the road environment, with EV_R representing the vehicle's range and it is given as

$$FR_{Road} = \frac{EV_R}{AvN_{Kmday}}$$

Finally, the number of charging cycles in road environment per month is calculated as

$$NC_{Road} = \frac{AvN_{Days/month}}{FR_{Road}}$$

2.4 Each User Energy Consumption Share

Table 5: Share of each user group in total energy consumption

User Groups	Annual Energy Consumption Units KWh	Share of each user groups
Elder	5765	5%
Job Holder	7263	6%
Busman	38460	32%
Cabman	69221	57%

The 'Cabman' and 'Busman' consumes around 90% of total electricity consumption and these users are more active users whose majority of electricity consumption (for Cabman almost all) in road environment. However, the 'Elder' and 'Job holder' consumes only around 10% of total share. These users almost all electricity consumption for V2G service and thus more frequently available for the service.

2.5 Calculating the revenue model

The revenue model developed by Gomes et al. [3] is utilized for the calculation.

2.5.1 Battery Degradation

Monthly degradation of battery due to V2G cycles is $BMD_{V2G} = \frac{NC_{V2G}}{C_{bat}}$

Where NC_{V2G} is the number of V2G cycles to be carried out with the grid per month. And C_{bat} is the battery cycles until it drop to 80%. Here, the battery capacity made available to be consumed by the grid is 80%. Similarly, monthly degradation of battery due to road use is

$$BMD_{Road} = \frac{NC_{Road}}{C_{bat}}$$

Where NC_{Road} is the number of road environment cycles to be carried out with the grid per month. Here, the battery capacity made available for the road use is 100% which means each user uses the entire range of their EV's battery in a road environment and only then charges again.

The total monthly degradation of battery is

$$\text{Total}_{Bmd} = Bmd_{V2G} + Bmd_{Road}$$

Annual degradation of battery due to V2G cycles is

$$Bad_{V2G} = Bmd_{V2G} \times N_{months/year}$$

Hence, total degradation of battery is

$$\text{Total}_{Bad} = Bad_{V2G} + Bad_{Road}$$

2.5.2 Revenue generated by V2G service

The gross monthly profit due to V2G service is

$$M_{rV2G} = NC_{V2G} \times B_c \times PS_{ele}$$

Where B_c is the battery capacity used for V2G service (i.e. 80%) and PS_{ele} is the selling price of electricity. Monthly expenses for charging the EV due to V2G cycles is

$$C_{CostsV2G} = NC_{V2G} \times B_c \times PP_{ele}$$

Where PP_{ele} is the purchase price of electricity by the user to charge the EV.

Monthly expenses for charging the EV due to road environment cycles is

$$C_{CostsRoad} = NC_{Road} \times B_c \times PP_{ele}$$

Remember, in the case of road use, the full battery capacity available. Total monthly costs for charging the EV is

$$TM_{Costs} = C_{CostsV2G} + C_{CostsRoad}$$

Total annual costs for charging the EV is

$$TA_{Costs} = TM_{Costs} \times N_{months/year}$$

Net monthly profit through V2G service is

$$NM_{profitV2G} = M_{rV2G} - C_{CostsV2G}$$

After deducting the expenses in road environment, the net monthly profit through V2G service is

$$\text{Total}_{NMprofitV2G} = NM_{profitV2G} - C_{CostsRoad}$$

The user's net annual profit through V2G service is

$$NA_{profitV2G} = NM_{profitV2G} \times N_{months/year}$$

Necessary number of months of V2G service to compensate the cost of new battery is

$$T_{months} = \frac{C_{nb}}{NM_{profitV2G}}$$

Where C_{nb} is the cost of new battery. To convert months into years,

$$T_{years} = \frac{T_{months}}{N_{months/year}}$$

The user's profit after T years relates to the number of years required to accumulate enough income to purchase a new battery is

$$P_{Tyears} = NA_{profitV2G} \times T_{years}$$

After deducting the costs for changing the battery in their EV, the total net profit that each user obtained is

$$NP_{V2G} = P_{Tbat} - C_{nb}$$

3. Results and Discussion

Table 6 shows results obtained from calculations using above equations.

Table 6: Model results for the selling price

$$PS_{ele} = 11.7Rs./KWh$$

	Elder	Job Holder	Busman	Cabman
Bmd_{V2G}	1.0667%	0.5333%	0.2667%	0.1067%
Bmd_{Road}	0.0139%	0.0317%	0.8013%	1.3980%
$Total_{Bmd}$	1.08%	0.5%	1.07%	1.5%
Bad_{V2G}	12.8%	6.4%	3.2%	1.28%
Bad_{Road}	0.167%	0.380%	9.616%	16.776%
$Total_{Bad}$	12.9%	6.7%	12.8%	18.05%
$C_{CostV2G}$	1977.6	2491.776	3316.6	197.76
$C_{CostRoad}$	25.7	147.9	9966.3	2591.9
TM_{Costs}	2003	2639	13282	2789
TA_{Costs}	24040	31676	159395	33475
M_{rV2G}	4492.8	5660.928	7534.8	449.28
$NM_{profitV2G}$	2515.2	3169.152	4218.2	251.52
$Total_{NMprofitV2G}$	2489.4	3021.2	-5748.2	-2340.4
$NA_{profitV2G}$	30182	38029	50618	3018
$Total_{NAprofitV2G}$	29873	36254	-68978	-28084
T_{months}	119.2	213.94	272.63	1470.6
T_{years}	9.9	17.8	22.7	122.5
P_{Tyears}	299900	678000	1150000	369900
T_{bat}	1.54	2.95	1.56	1.11
P_{Tbat}	46553	112182	78992	3343
$NP_{V2G} (Rs.)$	-204006	-519229	-1601847	-247217

In this scenario, the 'Elder' and 'Job Holder' groups get positive total net annual profit through V2G service after deducting the annual recharging costs in a road environment. However, all user's groups net profit through V2G service is negative after accounting for the costs of battery replacement. Further, all the groups need to replace the battery below 3 years. The 'Elder' group need to replace the battery every 1.54 years while 'Cabman' need to replace the battery every 1.11 years.

3.1 Charging-Discharging cycles

The Fig. 1 illustrates the number of Vehicle-to-Grid (V2G) and on-road charge-discharge cycles each user completes on a monthly basis. In this scenario, it is assumed that users fully recharge their electric vehicles (EVs) whenever needed, whether due to V2G or on-road usage, ensuring the battery reaches 100% each time. However, for V2G cycles, only 80% of the battery capacity is used. After each V2G discharge, users recharge their EVs to full capacity overnight, at an electricity rate of Rs. 5.15/kWh. For on-road usage, users only recharge the battery when it is depleted, bringing it back to full capacity as necessary.

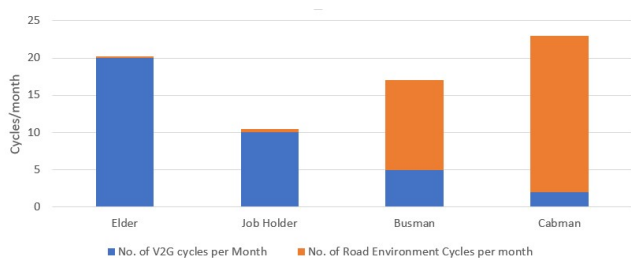


Figure 1: Number of charge and discharge cycles each user completes every month

The results shows that most monthly charge-discharge cycles allocated for V2G service is for 'Elder' User while least is for 'Cabman'. The 'Busman' maintains better balance between the number of charges due to road usage and V2G usage.

3.2 Degradation of battery

The lifespan of the battery can be reduced based on the number of V2G and on-road cycles each user performs. As shown in Fig. 2, the battery of the 'Job Holder' user takes the longest to reach 80% of its capacity, which is considered a critical threshold for maintaining optimal battery health. In contrast, the 'Elder', 'Busman' and 'Cabman' users, who engage in more frequent V2G usage and drive more often, experience faster battery degradation, with their batteries lasting between one and two years.

The battery degradation rate of 'Elder' and 'Busman' is approximately same and so, these graphs coincide to each other. Each user's timeline concludes when their battery reaches the end of its lifespan: the 'Elder' user's battery lasts 1.54 years, the 'Job Holder' user's battery lasts 2.95 years, 'Busman' user's battery lasts 1.56 years and the 'Cabman' user's battery also lasts 1.11 years.

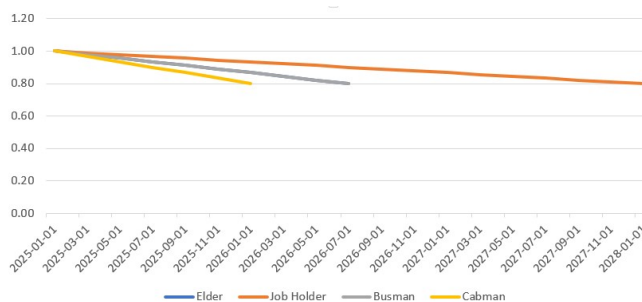


Figure 2: Percentage of battery degradation of each EV user's battery

3.3 Expenses and Profit from EV

Figure 3 displays two distinct values: the blue bars represent the annual profit each user earns exclusively from their V2G service. This profit accounts only for the earnings from V2G and the costs associated with recharging for the V2G service. The yellow, in contrast, represent each user's annual net profit, which is calculated by subtracting the annual recharging expenses for road use from the V2G service profit. The graph depicts that 'Elder' and 'Job Holder' two bars are quite similar which is due to the minimal annual recharge expenses done by these two users from using their EV on the road. However, net annual profit obtained by deducting road annual recharge expenses is negative for 'Busman' and 'Cabman' which is due to intensive road use.

4. Sensitivity Analysis

For each of the four users, the above calculations were done at electricity selling price of Rs. 9/KWh and Rs. 17/KWh are presented in Table 7 and Table 8 respectively where the value of battery degradation being same for different selling prices is not shown. Table 8 shows the net profits for each user from offering the V2G service, taking into account the costs of buying a new battery and the different hypothetical electricity selling prices explored in this study. Fig. 4 displays a sensitivity analysis graph that highlights how each user's net profit fluctuates after deducting battery replacement costs, depending on different electricity selling rates which depicts that the total net profit for each user groups after purchasing a new battery is negative in all scenario.

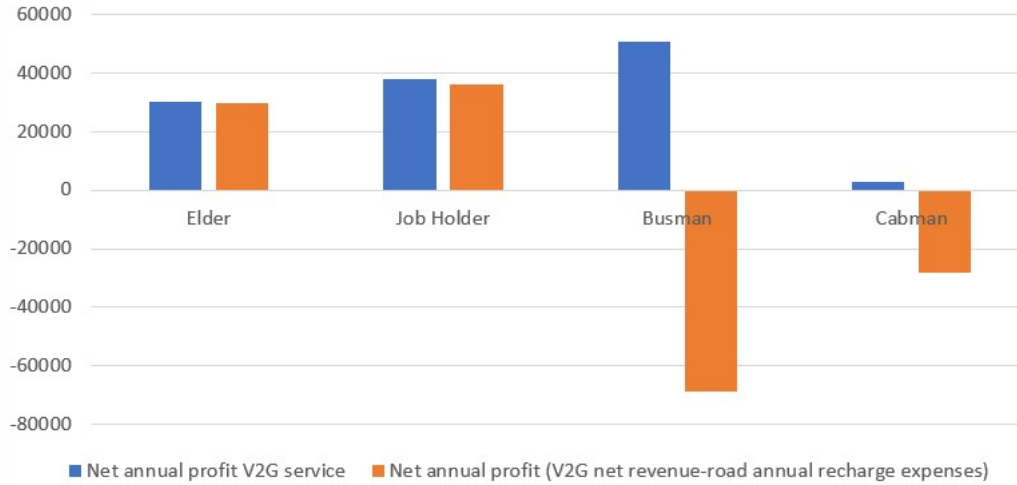


Figure 3: Annual profit gain by each user through V2G service

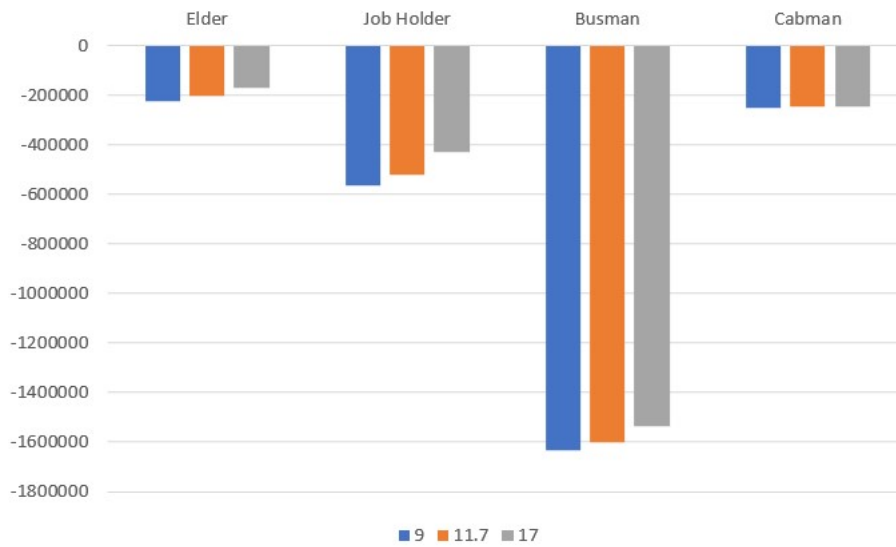


Figure 4: Total net profit for each user groups after purchasing a new battery based on various electricity selling prices

Table 7: Model results for the selling price $PS_{ele} = 9Rs./KWh$

	Elder	Job Holder	Busman	Cabman
M_{rV2G}	3456	4354.5	5796	345.6
$NM_{profitV2G}$	1478.4	1862.7	2479.4	147.8
$TotalNM_{profitV2G}$	1452.6	1714.8	-7486.9	-2444
$NA_{profitV2G}$	17740.8	22353.4	29752.8	1774
$TotalNA_{profitV2G}$	17431	20578	-89843	-29328
T_{months}	202.8	363.9	463.8	2502
T_{years}	16.9	30.3	38.6	208.5
P_{Tyears}	299900	678000	1150000	369900
T_{bat}	1.54	2.95	1.56	1.11
P_{Tbat}	27363.7	65939.2	46430.7	1965
NP_{V2G} (Rs.)	-223196	-565472	-1634409	-248595

Table 8: Model results for the selling price $PS_{ele} = 17Rs./KWh$

	Elder	Job Holder	Busman	Cabman
M_{rV2G}	6528	8225.3	10948	652.8
$NM_{profitV2G}$	4550.4	5733.504	7631.4	455.04
$TotalNM_{profitV2G}$	4524.6	5585.5	-2334.9	-2136.8
$NA_{profitV2G}$	54605	68802	91577	5460
$TotalNA_{profitV2G}$	54296	67027	-28020	-25642
T_{months}	65.9	118.2	150.7	812.9
T_{years}	5.5	9.8	12.5	67.7
P_{Tyears}	299900	678000	1150000	369900
T_{bat}	1.54	2.95	1.56	1.11
P_{Tbat}	84223	202956	142910	6048
NP_{V2G} (Rs.)	-166336	-428455	-1537930	-244512

5. Conclusion

V2G technology is a novel innovation where EVs act as distributed sources. However, in the context of Nepal, the results show that the total net profit from the V2G service, after accounting for the cost of new battery, is significantly negative for all groups in each hypothetical electricity selling price scenarios: Rs. 9/KWh, Rs. 11.7/KWh and Rs. 17/KWh. Thus, it becomes impractical for all users to continue degradation of their battery at these rates as the battery need to replace after 1 to 3 years. If the prices of energy storage decrease significantly, it may become viable to offer V2G services even with above three sell-back prices.

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APPENDIX B: PLAGIARISM TEST REPORT

Niroj Bahadur Bhujel

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