RESEARCH ARTICLE ISSN 2738-9898 (Print) ISSN 2738-9901 (Online)

Optimizing Electric Vehicle Range through Integrating Rooftop Photovoltaic Cells on Parking Vehicles in Nepal's Condition

Nabin Chandra Wagle, Lochan Kendra Devkota*, Debendra Bahadur Raut, Bibek Dhungana

Department of Automobile and Mechanical Engineering, Thapathali Campus, Institute of Engineering, Tribhuvan University, Kathmandu, Nepal

*Author to whom correspondence should be addressed; E-Mail: lochan.devkota@tcioe.edu.np

Received: 14 May 2026; Received in revised form: 10 July, 2026; Accepted: 25 July, 2026; Published: 31 July, 2026

Abstract

The widespread adoption of electric vehicles (EVs) in Nepal is currently hindered by range anxiety and a nascent charging infrastructure characterized by significant grid dependency and hour-long queues at charging stations. This study investigates the technical feasibility of extending EV range by integrating rooftop photovoltaic (PV) systems, focusing on the energy harvesting potential during parking periods in localized conditions. A high fidelity solar-assisted EV model was developed using MATLAB/Simulink, incorporating a monocrystalline PV array, a Perturb and Observe (P&O) maximum power point tracking (MPPT) controller, and a 40 kWh Lithium-ion battery system. Localized solar irradiance data was utilized to drive the simulation. The results demonstrate that a 5-hour parking period in peak sunlight increases the battery state of charge (SOC) from an initial 50% to an analytical peak of 70.3%. This 20.3% SOC gain corresponds to a range extension from 175 km to 235 km representing a 60 km boost in range. The model was validated against local market data, yielding a minimal validation error of 3.34%. This study provides a localized modeling approach and contributes to sustainable transportation solutions by promoting renewable energy use in EV systems. The findings support the potential of solar-assisted EVs as a practical and environmentally friendly option in Nepal.

Keywords

Electric vehicle, PV Panel, State of Charge, Range Extension, Nepal Solar Potential

1. Introduction

Electric Vehicle (EV) technology is a topical concern in the contemporary world because it is the key to emission reduction and energy efficiency targets in the transportation sector. The relatively limited range gives rise to a psychological phenomenon called range anxiety in EV users, which is labelled as one of the most crucial barriers in EV adoption, specifically during the early adoption phase, eventually hindering the utility of EVs. While improvements in battery technology will increase the range of EVs and serve to diminish range anxiety in the future, researchers have studied the specifics of range anxiety and come across a variety of solutions proposed and applied in diverse regions [1].

Depending upon the speed of the vehicle, there will be a variation in the amount of air that enters the vehicle. If the vehicle moves at low speed, then there will be less airflow. If the vehicle moves at a higher speed, then there will be more airflow. This air will be utilized to produce the necessary power required for charging the battery in the EV's [2]. Researchers from other countries have also put much focus on the incorporation of solar energy and electric vehicles. By using torque analysis, the power consumption modelling of a Proton Savvy model to improve the driving range of the solar-powered vehicle [3].

Despite several pilot projects and feasibility studies, Nepal lacks localized modeling and optimization studies that integrate PV parking solutions with EV performance analysis. Most existing work either focuses on solar potential mapping or EV adoption statistics without connecting both domains. Due to the increasing number of electric vehicles in Nepal, the charging stations is not increasing. The vehicle has to wait for more than an hour for its number to charge in the charging stations. Due to the implementation of rooftop photovoltaic cells on electric vehicles, they can charge not only in charging stations but also in parking lots when the vehicle is parked for several hours. The primary objective of this research is to evaluate the feasibility of extending the driving range of an EV through rooftop solar integration, specifically quantifying the energy harvest during parking durations under Nepalese environmental conditions.

Solar energy, being a renewable energy source that reduces carbon emissions, is used as an alternative source. This research highlights the research gaps and energy calculations in those sources and illustrates the final selections of different parts that will be used for the system design. It also outlines the factors affecting the range of solar-powered electric vehicles.

The sun radiates approximately 3,846×1026 watts of energy distributed on the earth's surface in the form of light or other radiation, and the energy transmitted is utilized by collecting radioactive light, converting it directly into heat or electricity by photoelectric conversion[4]. Nepal has good potential for solar energy with average solar radiation of 4.4 to 5.5 kWh/m^2 and around 300 sunny days in a year [5]. The electric vehicle operates on an electric/current principle. It uses a battery pack (batteries) to provide power for an electric motor. The motor uses the received power (voltage) from the batteries to rotate the transmission and turn the vehicle's wheels. The electric vehicle consists mainly of four main parts: the potentiometer, batteries, direct current (DC) controller, and motor [6].

The cells' semiconductor material produces direct current (DC) electricity as a result of this excitement. An inverter converts the DC into an alternating current (AC). The inverter modifies the frequency of the AC, enabling effortless control over the motor's rpm or speed [7]. A good aspect of his research is that he included a distributed energy management system, where he proposed the idea of transferring additional power from individual cars to base station batteries. This will boost overall efficiency and thus save energy. However, this paper lacks thorough information regarding technical implementation and does not address potential challenges of solar-powered cars, such as budgetary constraints and the effects of weather. Therefore, future studies in this field ought to concentrate on closing these gaps to create workable and efficient solutions for the creation of solar-powered autonomous vehicles [8].

According to analysis, a day's worth of good solar power is about four to six hours of optimal measurement at noon. This indicates that even in the event of no sunshine or cloudy weather, the backup batteries can be utilised to power the driverless vehicles resulting from the converted solar energy [9]. That there was a 20% average decrease in the power output of solar panels on a rainy day [10].

Allam's research further supported the feasibility of enhancing vehicle range with the incorporation of solar power by comparing the performance of a pure electric autonomous vehicle and an electric autonomous vehicle equipped with a polycrystalline solar panel [11]. Arrange photovoltaic cells on autonomous vehicles to enlarge the available space of the solar panels [12] . Based on the battery information shared by different researchers, lithium-ion batteries should be chosen as the energy storage system of the design. The most suitable candidate for autonomous vehicles is lithium- ion batteries, in terms of range extension, lithium-ion batteries outperform lead-acid batteries as more energy can be stored by them due to their higher energy density [13] [14]. They can be designed smaller in size and lighter, which reduces the weight of the vehicle, thereby increasing the distance travelled. Furthermore, lithium-ion batteries have fast charging capability, and a low self-discharge rate [2] [14]. The sensitivity to overcharging of lithium-ion batteries can be solved by equipping them with a charge controller and battery management system, which help regulate the charging current [15]. The charge controller monitors the batteries of the vehicles from being overcharged or undercharged [16]. A maximum power point tracking (MPPT) solar charger, was selected as the controller because it is simple to connect and contains features that improve solar energy capture [17]. The battery management system is very useful to be incorporated in autonomous vehicles. This is because the installation of the BMS can help in tracking multiple battery parameters such as the state of charge (SoC), state of health (SoH), and state of function (SoF) [18]. The electric motor receives the electrical energy to drive the wheel while the motor controller adjusts the energy flow of the motor in accordance with the throttle [19].

There is very limited research that evaluates photovoltaic assisted electrical vehicle systems under Nepalese solar irradiation conditions, seasonal variations and operating characteristics. Most of the studies analyze solar charging while in motion and the potential of utilizing idle parking periods for passive solar energy harvesting remains largely unexplored. To address these gaps, this study develops a comprehensive MATLAB/Simulink model integrating a solar energy with Electric vehicle under Nepal-specific solar conditions.

2. Methodology

The start of the research would be the research about the existing systems and processes regarding the range extenders of electric vehicles. Among the possible range extenders, solar energy is one of the best options and is cost-effective. About reviewing the findings and literature, the work would proceed in the sequence shown in Figure 1.

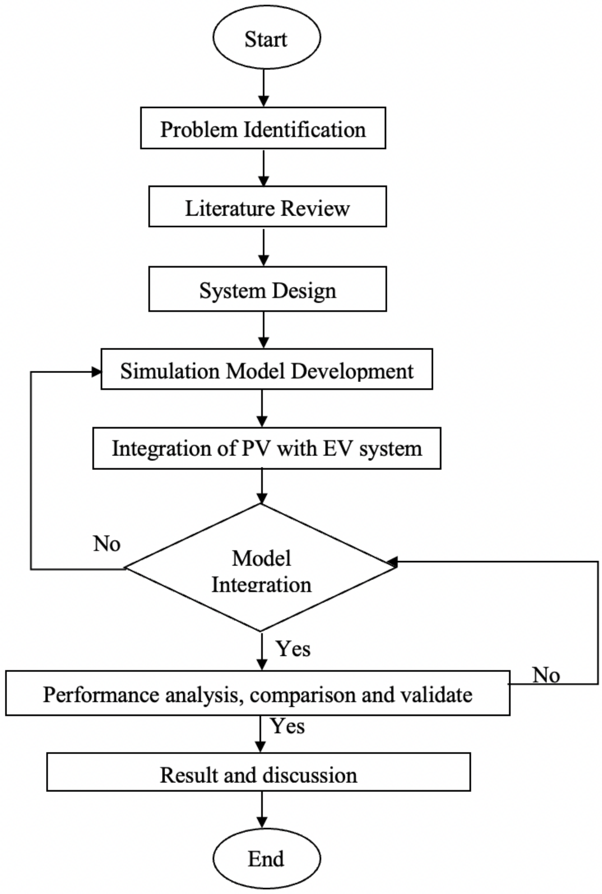

Figure 1: Flow diagram of research process

The key components in the vehicle are: Electric motor, motor controller, rechargeable batteries solar panels.

2.1 Vehicle Design

The design of an autonomous vehicle is based on a GEM e6 electric shuttle. It is an eco-friendly alternative to shuttle vans, SUVs, and 6-seater golf carts. It is federally classified as a low-speed vehicle powered by electricity with a maximum speed of 35 km/h. It is driven with tilt steering that can be adjusted effortlessly and is fully powered by electricity with no carbon emissions. Figure 2 shows a picture of GEM e6.

Figure 2: A GEM e6 electric shuttle [20]

Taking the parameters of the GEM e6 electric shuttle as a reference, the dimensions, speed, and weight of the car prototype are illustrated in the Table 1.

Table 1: Parameters of the Vehicle Prototype

S.N	Parameters	Values
1.	Length	4240 mm
2.	Height	1860 mm
3.	Width	1410 mm
4.	Wheelbase	3404 mm
5.	GVW	1361 kg
6.	Average speed	35 km/h
7.	Seating Capacity	6

Using SOLIDWORKS as the 3D CAD design platform and obtaining a similar vehicle design, a modified vehicle design is created, which will be used as a prototype to incorporate solar panels and is shown in Figure 3.

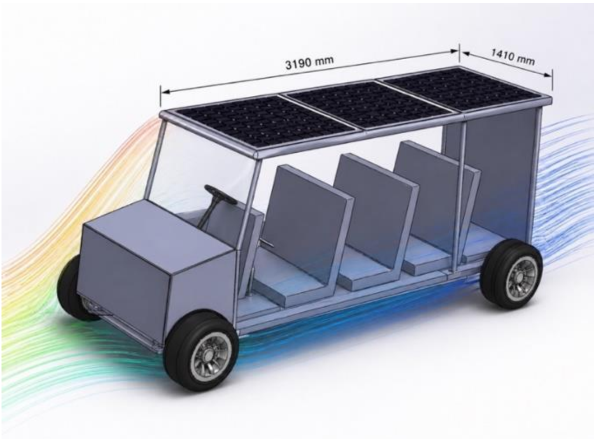

Figure 3: Solar panel mounted on the vehicle prototype

To reduce the pressure on the grid to charge the EV, the installation of Solar PV panels on the EV rooftop is proposed, which shows the integration of Solar panels on the rooftop of the vehicle. The methodology involves determining the drive cycle, calculating vehicle force, power, and energy, and measuring rooftop area to extend EV range. The rooftop Solar Photovoltaic (RTSPV) system supplements Electric Vehicle battery (EVB) charging during operation, augmenting battery range.

The monthly Direct Normal Irradiation (DNI) data indicate a clear seasonal variation in solar energy availability over the year, which has important implications for the performance of photovoltaic (PV) systems integrated with electric vehicles. As shown by the data, DNI values are relatively moderate during the winter months, with 4.29 kWh/m² in January and 4.48 kWh/m² in February, followed by a significant increase in March, reaching a peak value of 5.21 kWh/m². High irradiation levels are also observed during April (4.96 kWh/m²) and October (5.05 kWh/m²), indicating favorable solar conditions during the pre-monsoon and post-monsoon periods [21].

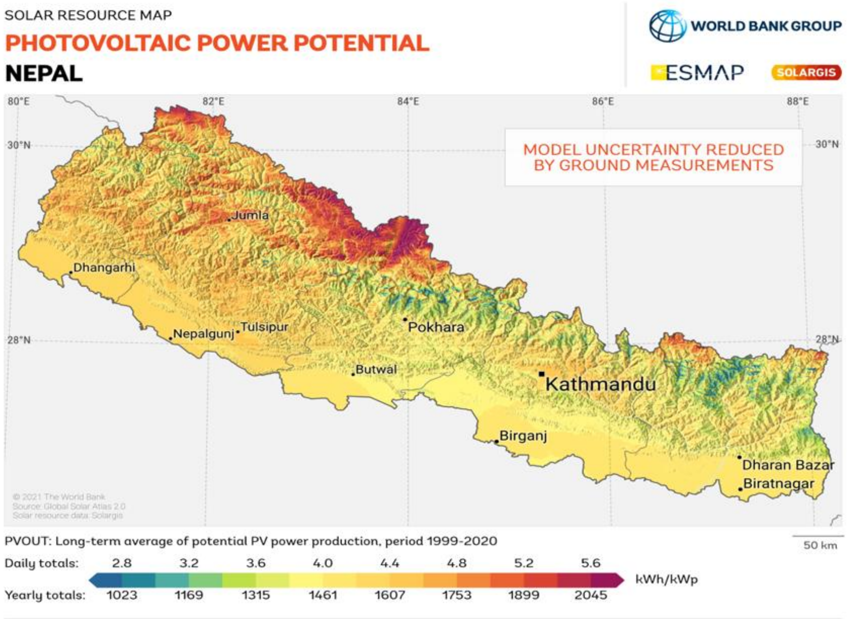

Figure 4: Photovoltaic Power Potential of Nepal [22]

Figure 4 represents the average photovoltaic power potential of Nepal during 1999-2020. The map indicates that the solar energy resources are abundant across the country, with average daily PV output ranging from 2.8 to 5.6 kWh/kW. The highest solar potential is observed in the western and northwestern regions, particularly around Jumla and Karnali, whereas lower values occur in parts of the eastern mountainous regions. Overall, the figure highlights Nepal's significant potential for photovoltaic electricity generation and supports the expansion of solar energy technologies for both grid-connected and off-grid applications.

Based on the solar resource assessment and the energy requirements of the electric vehicle, the design specifications of the proposed rooftop PV system were determined. The detailed design parameters of the PV system are presented in Table 2.

Table 2: Design Specifications of PV Solar System

Parameters	Specifications
Input voltage(V_{in})	250-350 V
Output voltage (V_{o}))	500 V
Rated power	1050 W
Switching frequency	5 kHz
Voltage ripple	1%
Current ripple	5%
Panel area	4.49 m^2
Solar irradiance	1000 W/m^2
PV Efficiency	0.19

To regulate the variable output voltage of the PV array and provide the required charging voltage for the EV battery, a boost converter was designed. The design specifications of the proposed boost converter are summarized in Table 3.

Table 3: Design of PV solar converter (Boost converter)

Parameters	Specifications
Output current (I_o)	200 A
Current ripple (ΔI)	20 A
Voltage ripple(ΔV)	5 V

2.2 MATLAB PV Model for System

Figure 5 shows a MATLAB/Simulink-based photovoltaic (PV) generation subsystem developed for the proposed PV-assisted electric vehicle. The model consists with the irradiance and temperature input blocks, photovoltaic array, voltage and current measurement blocks, maximum power point tracking (MPPT) controller, pulse-width modulation (PWM) generator and DC-DC boost converter. Monocrystalline photovoltaic panels were selected due to their high efficiency and compact size. The total available rooftop area was measured to be approximately 4.49 m^2.

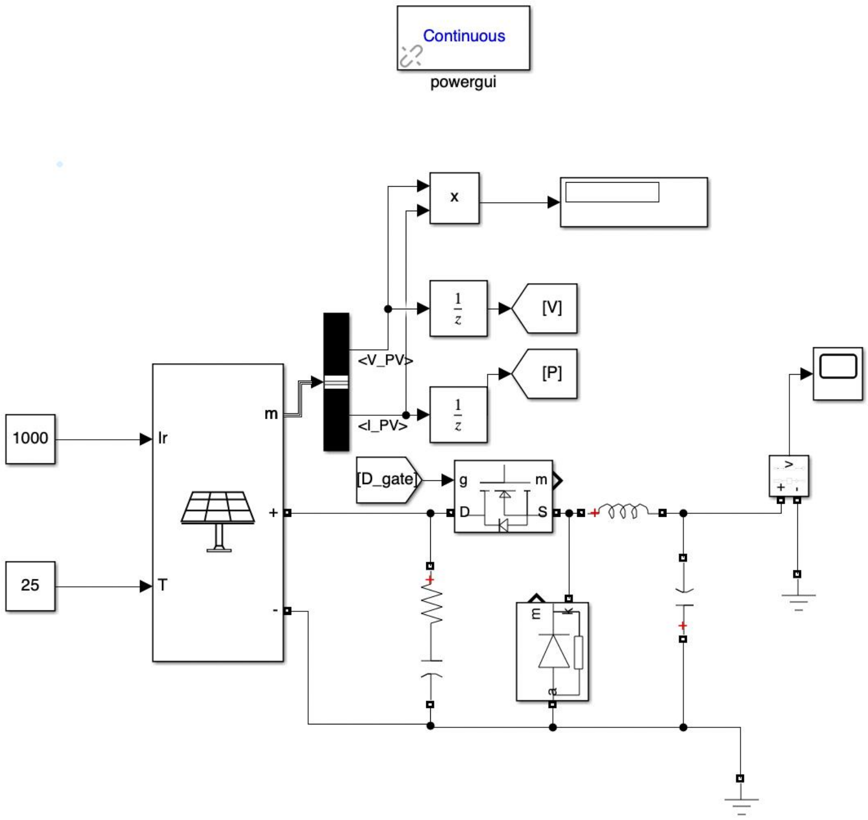

Figure 5: MATLAB/Simulink PV model for system

2.3 MATLAB function for MPPT controller

The output power of a photovoltaic (PV) system varies nonlinearly with solar irradiance, temperature, and operating voltage. To ensure that the PV subsystem operates at its maximum possible efficiency under varying environmental conditions, a Maximum Power Point Tracking (MPPT) control technique is employed. MPPT continuously adjusts the operating point of the PV system so that it delivers maximum power to the electric vehicle's DC bus or battery. The algorithm for MPPT controller is:

```
function D = fduty(Vpv,Ppv,Vprev,Pprev,duty)
dD=0.001;
Dmin=0.1;
Dmax=0.95;
if isempty(duty)
   duty=0.5;
end
dP=Ppv-Pprev;
dV=Vpv-Vprev;

if dP>0
   if dV>0
      D=duty-dD;
   else
      D=duty+dD;
   end
else
   if dV>0
      D=duty+dD;
   else
      D=duty-dD;
   end
end
D=max(min(D,Dmax),Dmin);
```

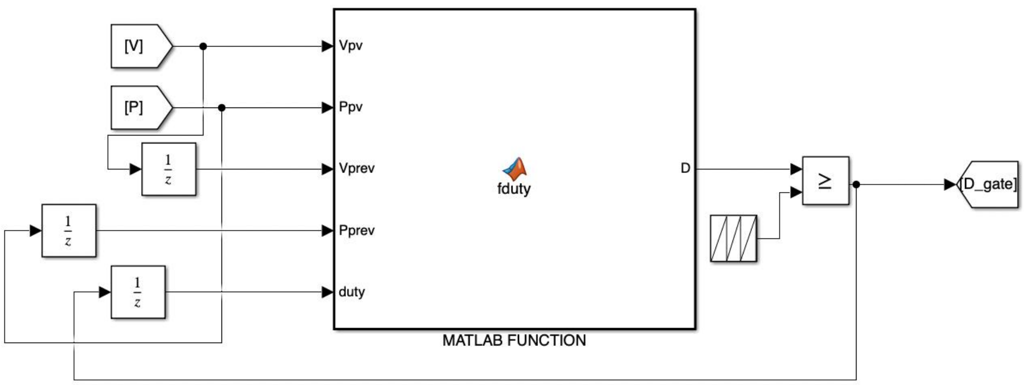

Figure 6: MPPT Controller

Figure 6 shows the MATLAB/Simulink implementation of the MPPT controller based on the Perturb and Observe (P&O) algorithm. Owing to its simplicity, low computational complexity, and reliable performance, the P&O algorithm was selected for this study. The controller continuously monitors the PV voltage and current, calculates the instantaneous power, and compares it with the previous operating point. Based on the change in power and voltage, the duty cycle of the boost converter is adjusted to ensure that the PV array operates at its maximum power point, thereby maximizing the charging efficiency of the electric vehicle battery under varying environmental conditions.

2.4 MATLAB Model for EV Powertrain System

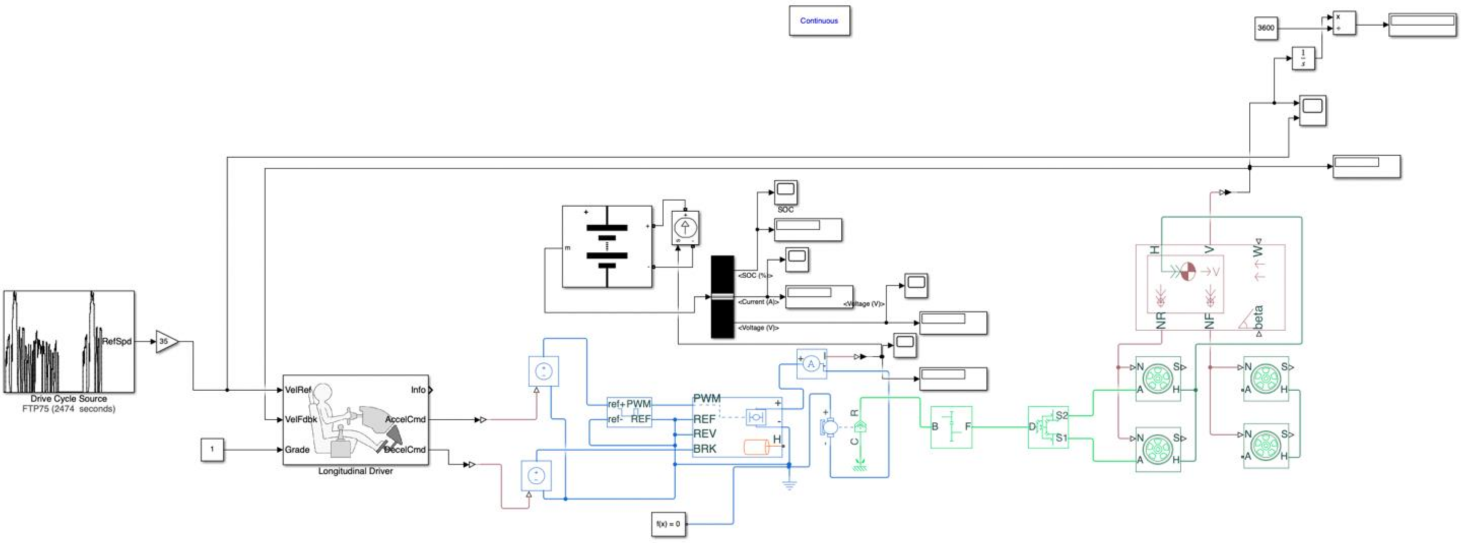

Figure 7. MATLAB Model for EV system

The complete MATLAB/Simulink model developed for the proposed photovoltaic-assisted electric vehicle is illustrated in Figure 7. This model represents an electric vehicle (EV) powertrain and control system built in MATLAB Simulink, integrating electrical, mechanical, and control subsystems. It includes a battery pack supplying DC power, a power electronics stage (DC-DC converter and inverter), and electric motors driving the wheels through a drivetrain. The internal combustion engine (ICE) is modeled alongside the electric drive, with a supervisory control block managing power split, torque requests, and operating modes (electric, hybrid, regenerative braking). Sensors measure speed, torque, voltage, current, and state of charge, feeding back into controllers such as PWM control for the inverter and braking logic. The lower section shows the driver input and drive cycle, while the right side models vehicle dynamics (longitudinal motion, load, and braking). Overall, the model simulates energy flow, control strategy, and vehicle performance of a hybrid vehicle under realistic driving conditions.

2.5 Vehicle Parameters used for Simulation in MATLAB

The proposed model is simulated in MATLAB using vehicle parameters. Reference drive cycle is considered to implement the vehicle parameters along with the irradiance curves, which are designed to test. MATLAB simulation is implemented using subsystems in MATLAB 2023b version, and the simulation model parameter is shown in Table 4.

Table 4: Vehicle Parameters

Parameters	Specifications
Vehicle mass (m)	1361 kg
Frontal Area (A_f)	2.295 m^2
Drag coefficient (C_d)	0.28
Rolling resistance coefficient (C_r)	0.015
Vehicle speed (v)	35 km/h
Acceleration (a)	0 m/s^2
Road grade angle (α)	0^0
Air density (ρ)	1.2 kg/m^3
Gravity (g)	9.81 m/s^2

The longitudinal dynamics of the electric vehicle were modelled by considering the major resistance forces acting on the vehicle during motion. The total tractive force required to propel the vehicle is given by:

Total Tractive Force [23]

$$F_{total} = F_{ad}+F_r+F_g+F_i \quad (1)$$

where F_{ad} is the aerodynamic drag force, F_r is the rolling resistance force, F_g is the grade resistance force, and F_i is the inertial force.

The drive power required by the electric motor was calculated from the product of the total tractive force and the vehicle speed. Drive power calculation is an essential component of electric vehicle modeling because it determines the power demand under different driving conditions. The calculated drive power is subsequently used to estimate motor torque, battery current, energy consumption, and vehicle driving range in the MATLAB/Simulink model. The drive power is expressed as:

$$P_{drive} = F_{total} \text{ x } v \quad (2)$$

where P_{drive} is the drive power (W), F_{total} is the total tractive force (N), and v is the vehicle speed (m/s).

The battery state of charge (SOC) was determined using the battery energy balance equation expressed as

$$SOC(t) = SOC(t_0) - \frac{1}{C}\int_{t0}^{t} \mathrm{I(t)}\, dt \quad (3)$$

where SOC(t) is the battery state of charge at time t, $SOC(t_0)$ is the initial state of charge, I(τ) is the battery current, and C is the battery capacity. This equation was used to evaluate the charging and discharging behavior of the battery throughout the simulation.

3. Results and discussion

The performance of the proposed photovoltaic-assisted electric vehicle was evaluated using the MATLAB/Simulink model developed in this study. Simulations were carried out to investigate the influence of rooftop photovoltaic charging on battery state of charge (SOC) and vehicle driving range under a standard driving cycle and Nepalese solar irradiance conditions. To demonstrate the effectiveness of the proposed approach, two simulation scenarios were considered: (i) the electric vehicle operating without photovoltaic assistance and (ii) the electric vehicle operating with rooftop photovoltaic integration. The simulation results were analyzed by comparing the battery SOC and the corresponding driving range over a simulation period of 18,000 s (5 h). The comparison highlights the contribution of photovoltaic charging to improving battery performance and extending the driving range of the electric vehicle.

3.1 Range Calculation in MATLAB Simulink

Figure 8: SOC without PV integration

Figure 8 presents the MATLAB/Simulink model used to evaluate the longitudinal dynamics and energy consumption of a solar-assisted electric vehicle by calculating aerodynamic drag, rolling resistance, inertial, and grade resistance forces. The State of Charge (SOC) profile illustrated in the figure shows a constant increase over the simulation period. At the initial time (0 seconds), the SOC is approximately 50%, during the period at 18,000 seconds. The nature of the curve indicates that there is no charging and discharging throughout the observed duration.

3.2 Range Calculation in MATLAB Simulink with PV Integration

The developed MATLAB/Simulink model represents a photovoltaic (PV) assisted electric vehicle (EV) system integrating renewable energy generation, power conversion, energy storage, and vehicle dynamics. The model is structured into several interconnected subsystems, including the PV array, DC–DC boost converter, battery energy storage system, motor drive, and vehicle control unit.

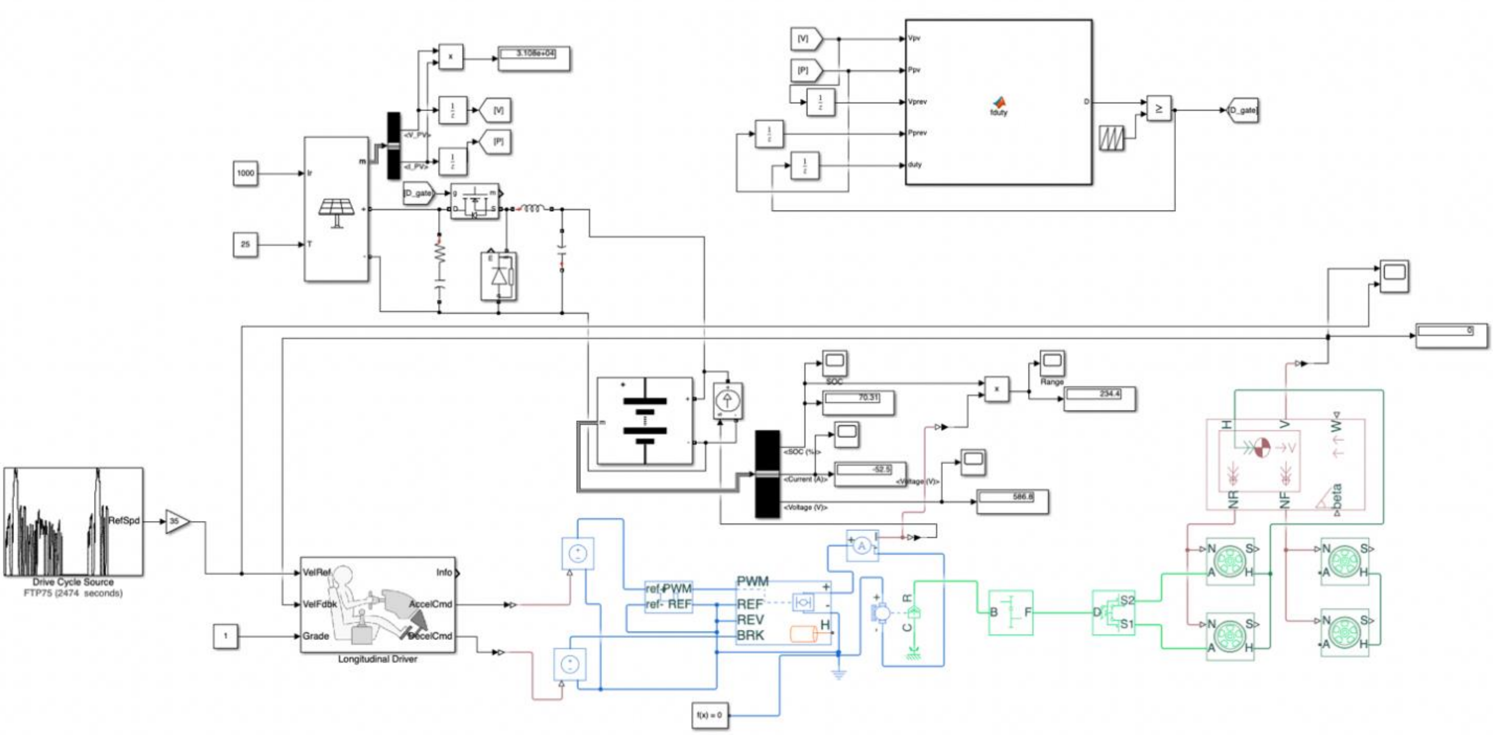

Figure 9: Simulink with PV connection

The State of Charge (SOC) profile illustrated in Figure 9 demonstrates a gradual and consistent increase over the simulation period. At the initial time (0 seconds), the SOC is approximately 50%, which steadily rises to nearly 70% at 18,000 seconds. The linear nature of the curve indicates a uniform rate of charging throughout the observed duration.

Figure 9 illustrates the variation of the electric vehicle (EV) driving range as a function of simulation time under continuous solar photovoltaic (PV) charging conditions. The simulation was carried out for a duration of 18,000 seconds (5 h) using a MATLAB/Simulink-based model. The obtained curve shows a monotonic linear increase in vehicle range from approximately 175 km to 235 km over the simulation period.

Similarly, Figure 10 illustrates the variation of the battery SOC with time for the proposed photovoltaic-assisted electric vehicle during a simulation period of 18,000 seconds. The initial SOC of the battery was at 50%. The SOC curve exhibits a smooth and nearly linear rise to approximately 70.3% throughout the simulation time.

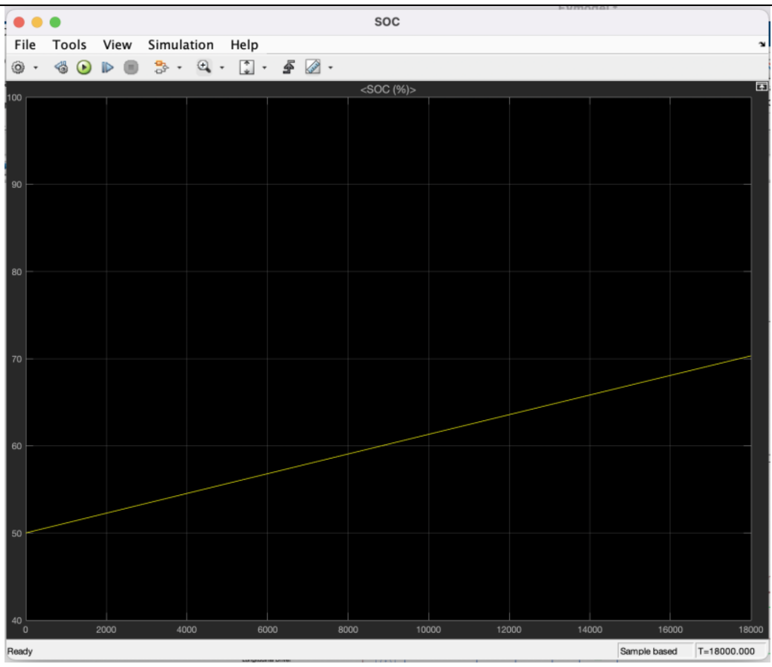

Figure 10: Increasing SOC of the battery with time

The variation of the estimated driving range of electric vehicle with time under continuous PV charging is shown in Figure 11. At the beginning of the simulation, the battery SOC was at 50%, corresponding to an initial driving range of approximately 175 km. As solar energy was harvested and stored in the battery, the battery capacity gradually increased, resulting in a continuous enhancement of the vehicle driving range reaching 235 km. This corresponds to an additional driving range of nearly 60 km. This confirms the technical feasibility of integrating rooftop photovoltaic panels with electric vehicle under Nepalese environment conditions.

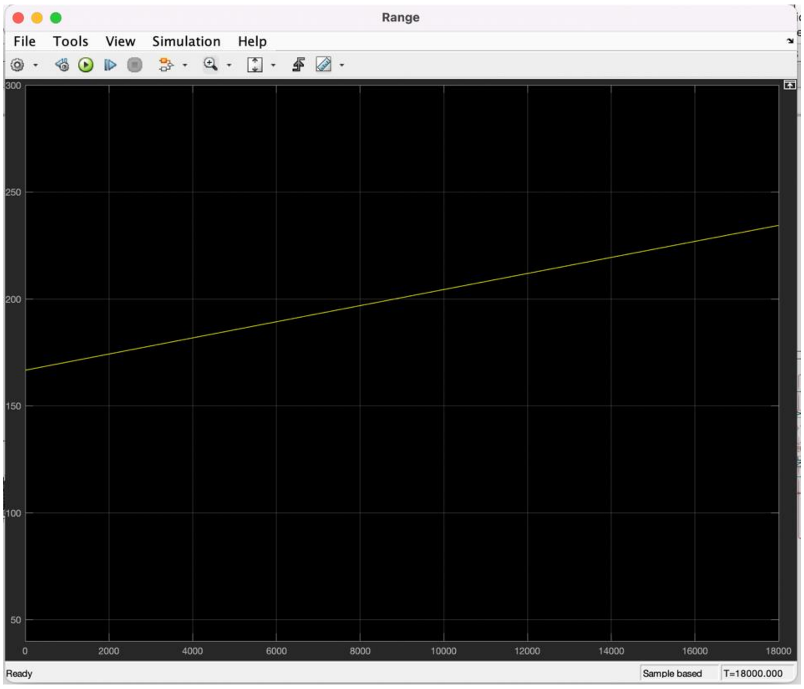

Figure 11: Increasing Range of PV-assisted electric vehicle

3.3 Mathematical Calculation

To validate the MATLAB/Simulink simulation results, analytical calculations were performed using the vehicle parameters and operating conditions adopted in this study. The calculations include the estimation of the total tractive force, drive power requirement, and battery state of charge (SOC) based on the governing equations presented in the methodology. The obtained analytical results were then compared with the simulation outcomes to verify the accuracy and consistency of the proposed photovoltaic-assisted electric vehicle model.

Battery Capacity=40 kWh

Vehicle Power Demand

Aerodynamic drag force, F_{ad} = 72.7 N

Rolling Resistance force, F_r = 200 N

Inertial force, F_i = 0 N

Grade resistance force, F_g = 0 N

Total Tractive Force, F_{total} = 272.7 N

Drive power, $P_{drive} = F*v$

where

F = 272.7 N

v = 35 km/h = 9.72 m/s

P_{drive} = 2650 W

Drivetrain Efficiency, $P_{battery}$ = 2789.5 W

$SOC_{initial}$= 50%

$SOC(t)$ = 70.3%

The analytical results confirm that for a 40 kWh battery, an increase in SOC from 50% to 70.3% corresponds to an energy gain of over a simulation period of 18,000 seconds (5 h). The results demonstrate that the integrated photovoltaic system provides sufficient energy to steadily increase the battery charge without fluctuations or interruptions, thereby validating the effectiveness of the proposed PV-assisted EV system.

3.4 Comparison with current models

To evaluate the practical applicability of the proposed photovoltaic-assisted electric vehicle system, the simulation results were compared with the performance of commercially available electric vehicles. Real-world battery State of Charge (SOC) and driving range data were collected from three representative electric vehicle models. The average distance travelled per 1% SOC was determined for each vehicle and used to validate the range improvement predicted by the proposed MATLAB/Simulink model.

Table 5 presents the battery SOC and corresponding driving distance of the BYD Dolphin under real operating conditions. The average distance travelled per 1% SOC was calculated from the recorded vehicle data.

Table 5: BYD Dolphin (Motor power: 70 kW, Battery capacity: 44.9 kWh)

Vehicle	Initial		Final		Total distance travelled
	SOC	Km running	SOC	Km running	
Vehicle 1	99%	9335 km	31 %	9585 km	250 km
Vehicle 2	91%	5565 km	6%	5825 km	260 km
Vehicle 3	83%	252 km	42%	394 km	142 km

The BYD Dolphin travelled an average distance of 3.34 km per SOC.

Table 6 presents the battery State of Charge (SOC) and corresponding driving distance data for the Tata Punch electric vehicle.

Table 6: Tata Punch (Motor power: 90 kW, Battery capacity: 35 kWh)

Vehicle	Initial		Final		Total distance travelled
	SOC	Km running	SOC	Km running	
Vehicle 1	100%	895 km	57%	1098 km	203 km
Vehicle 2	89%	2684 km	52%	2790 km	106 km
Vehicle 3	92%	3031 km	17%	3220 km	189 km

The average distance travelled per SOC of Tata Punch vehicle is 2.9 km.

Table 7 presents the battery State of Charge (SOC) and corresponding driving distance data for the Dongfeng Nammi electric vehicle.

Table 7: Dongfeng Nammi (Motor power: 70 kW, Battery capacity: 42.3 kWh)

Vehicle	Initial		Final		Total distance travelled
	SOC	Km running	SOC	Km running	
Vehicle 1	66%	4615km	50%	4658 km	43km
Vehicle 2	65%	6385 km	34%	6487 km	102 km
Vehicle 3	82%	2728 km	28%	5203km	175 km

Based on the data presented, the Dongfeng Nammi achieved an average driving distance of 2.7 km per 1% SOC. Considering all three commercial electric vehicles, the overall average driving distance was found to be approximately 2.9 km per SOC. Since the proposed rooftop photovoltaic system increased the battery SOC by approximately 20%, the corresponding improvement in the vehicle driving range was estimated to be about 58 km.

3.5 Validation with real data

The proposed MATLAB/Simulink model was validated using real-world electric vehicle data. The predicted driving range was compared with the range estimated from commercial electric vehicles, and the percentage error was calculated to evaluate the model accuracy.

- Range from Matlab Simulink: 60 km in 20 % SOC increase
- Range from real market data: (20% SOC * 2.9 km per 1% SOC) = 58 km range

$$\text{Percent Error} = \left| \frac{\text{Measured} - \text{Actual}}{\text{Actual}} \right| \times 100\%$$

Percent Error = (2/60) * 100%

= 3.34 %

The validation was based on the relationship between battery SOC and driving range. According to the simulation results, a 20.3% increase in SOC achieved through photovoltaic charging corresponded to an additional driving range of about 58 km. Real world vehicle specifications indicate that an average range of about 2.9 km is obtained per 1% SOC. Therefore, a 20% increase in SOC would provide an actual range extension of approximately 58 km. The percentage error between simulated and practical values was calculated as 3.34%, indicating good agreement between the developed MATLAB/Simulink model and real vehicle performance.

4. Conclusions

This study successfully developed and validate a localized model form PV integrated EVs in Nepal. The integration of 4.49 m^2 of PV area on an LSV prototype demonstrated a 20.3% increase of SOC from an initial value of 50% to approximately 70.3% with 58 km range extension over a 5 hour of charging period, with a validated model accuracy of 96.66%. The gradual rise in SOC confirmed the effectiveness of the MPPT algorithm and boost converter in extracting and transferring maximum power from the photovoltaic array to the battery system. The developed model was validated using practical operating data obtained from locally available electric vehicle including BYD Dolphin, Tata Punch EV and Dongfeng Nammi. During the comparison between simulation and market data yielded a percentage error of only 3.34% indicating good agreement and demonstrating the reliability of the proposed model. The results further suggest that passive charging during vehicle parking can partially alleviate charging station congestion and reduce dependence on grid electricity, which is particularly important in Nepal, where charging infrastructure is still developing. The future research will focus on the integration the synergy between PV charging and enhanced regenerative braking systems could further maximize energy recovery in the stop-and-go traffic typical of Kathmandu.

Conflicts of Interest Statement

The authors declare no conflicts of interest for this study.

Data Availability Statement

The data supporting the findings of this study are presented in the manuscript. Additional data will be provided upon request.

References

1. AEPC. (2022). *Review of the Sustainability of Selected Solar Mini-Grid and Solar Irrigation Systems Promotion of Solar Technologies for Economic Development (POSTED) NTNC Complex*. www.giz.de
2. Allam, E. M., Metwalley, S. M., & Muhammad, N. (2018). Improving Electric Vehicle Performance Using Photovoltaic Cells. *International Journal of Clean Coal and Energy*, *07*(01), 1–19. https://doi.org/10.4236/ijcce.2018.71001

3. An, T. (2021). Study of a new type of electric car: Solar-powered car. *IOP Conference Series: Earth and Environmental Science*, *631*(1). https://doi.org/10.1088/1755-1315/631/1/012118
4. Babalola, P. O., & Atiba, O. E. (2021). Solar powered cars - a review. *IOP Conference Series: Materials Science and Engineering*, *1107*(1), 012058. https://doi.org/10.1088/1757-899x/1107/1/012058
5. Çeven, S., Albayrak, A., & Bayır, R. (2020). Real-time range estimation in electric vehicles using fuzzy logic classifier. *Computers & Electrical Engineering*, *83*, 106577. https://doi.org/10.1016/j.compeleceng.2020.106577
6. Chandran, D., & Joshi, M. (2016). Electric Vehicles and Driving Range Extension – A Literature Review. *Advances in Automobile Engineering*, *05*(02). https://doi.org/10.4172/2167-7670.1000154
7. Chiou, R. Y., Ertekin, Y., & Tseng, T.-L. B. (2016). *MAKER: Autonomous Solar-Powered Vehicle as a Learning Tool in Robotics and Green Energy*.
8. De Pinto, S., Lu, Q., Camocardi, P., Chatzikomis, C., Sorniotti, A., Ragonese, D., Iuzzolino, G., Perlo, P., & Lekakou, C. (2016, December 19). Electric Vehicle Driving Range Extension Using Photovoltaic Panels. *2016 IEEE Vehicle Power and Propulsion Conference, VPPC 2016 - Proceedings*. https://doi.org/10.1109/VPPC.2016.7791674
9. Sagaria, S., Duarte, G., Neves, D., & Baptista, P. (2022). "Photovoltaic integrated electric vehicles: Assessment of synergies between solar energy, vehicle types and usage patterns." Journal of Cleaner Production, 361, 131402. https://doi.org/10.1016/j.jclepro.2022.131402
10. GEM, "GEM e6," GEM. [Online]. Available: https://www.gemcar.com/gem-e6/. [Accessed: Jul. 10, 2026].
11. *Global Solar Atlas*. (2026). https://globalsolaratlas.info/download/nepal
12. Habib, A. K. M. A., Hasan, M. K., Issa, G. F., Singh, D., Islam, S., & Ghazal, T. M. (2023). Lithium-Ion Battery Management System for Electric Vehicles: Constraints, Challenges, and Recommendations. In *Batteries* (Vol. 9, Number 3). MDPI. https://doi.org/10.3390/batteries9030152
13. Hariprasad, A., Priyanka, I., Sandeep, R., Ravi, V., Shekar, O., & Students, U. G. (2020). *Battery Management System in Electric Vehicles*. www.ijert.org
14. Hu, K., Wu, J., & Liu, M. (2018). Exploring the Energy Efficiency of Electric Vehicles with Driving Behavioral Data from a Field Test and Questionnaire. *Journal of Advanced Transportation*, *2018*. https://doi.org/10.1155/2018/1074817
15. *ISL Products*. (2026). https://shop.islproducts.com/bldc-j57-107-36-4800-04/
16. Hefei Junmuhe Electrical Co., Ltd., "Electric Vehicle Charging Products," JMHPOWER. [Online]. Available: https://jmhpower.com/product/. [Accessed: Jun. 30, 2026].
17. Jurecki, R. S., & Stańczyk, T. L. (2021). A methodology for evaluating driving styles in various road conditions. *Energies*, *14*(12). https://doi.org/10.3390/en14123570
18. Mohsen, S. K. (2019). Running the Car by Solar Power. Technical Report, Computer Engineering Department, College of Computers and Information System, Umm Al-Qura University, Makkah, Saudi Arabia. https://doi.org/10.13140/RG.2.2.16003.45601
19. Kretchmer, B., Monahan, R., Garcia, A., Garner, E., Sims, B., Njoku, N., Lahey, M., Monteiro, N., & Kim, H. (2017). Solar Powered Electric Vehicle. Senior Design Project

Report, Department of Mechanical and Civil Engineering, Purdue University Northwest, Hammond, IN, USA.

20. Liang, X., Tanyi, E., Zou, X., & Johansson, S. (2016). Charging Electric Cars from Solar Energy. Bachelor's Thesis, Blekinge Institute of Technology, Karlskrona, Sweden.
21. Hussin, M. A., Abdalla, A. N., Ishak, R., Abdullah, R., & Ali, Z. M. (2011, June). Study on improving electric vehicle drive range using solar energy. In *International Conference on Electrical, Control and Computer Engineering 2011 (InECCE)* (pp. 373-376). IEEE.
22. Mruzek, M., Gajdáč, I., Kučera, Ľ., & Barta, D. (2016). Analysis of Parameters Influencing Electric Vehicle Range. *Procedia Engineering*, *134*, 165–174. https://doi.org/10.1016/j.proeng.2016.01.056