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Quantifying Carbon Emission Reduction by Adopting Electric Vehicles Using a Smart Device

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Abstract: Deforestation and population growth have significantly impacted the environment and quality of life, with internal combustion engine (ICE) vehicles emitting greenhouse gases like CO2 and CO. Tailpipe emissions account for 24% of global air pollution. Sustainable solutions are crucial to limit global temperature increases to below 2°C above pre-industrial levels, aligning with the Paris Agreement's objectives. This study focuses on developing a smart metering device to quantify carbon emission reductions achieved through electric vehicle (EV) adoption. Employing Verified Carbon Standards (VCS) methodologies, the device translates these reductions into tradable carbon credits. The key novelty lies in real-time monitoring and precise emissions quantification using a microcontroller-based system integrated with IoT platforms for cloud-based analytics. The methodology involves measuring energy consumption, determining baseline and project emissions, and implementing an efficient metering topology to ensure accurate calculations. The system was validated through a pilot study in collaboration with Kerala State Electricity Board Limited, utilizing a TATA Nexon EV as a test case. This approach addresses the critical need for scalable and reliable emissions monitoring to bridge gaps in carbon accounting. By quantifying the environmental benefits of EV adoption, the project supports national policies promoting sustainable transportation and aligns with global climate goals under the Paris Agreement. Additionally, the study proposes a framework for standardizing methodologies to evaluate socio-environmental benefits, fostering alignment with net-zero emission targets. This innovative solution provides policymakers, industries, and researchers with a robust tool to incentivize carbon trading and accelerate the transition to low-carbon transportation systems.

Keywords: Emission Reduction, Carbon Credits, Carbon Markets, Electric Vehicle, Smart Metering Device

1. INTRODUCTION

India is exploring alternatives to internal combustion engine (ICE) vehicles, which emit significant carbon monoxide emissions and air pollution. This has led to concerns about climate change, air pollution, and limited use of fossil fuels. Electric vehicles (EVs) are a solution, providing cleaner, more efficient, and technologically advanced transportation [1]. EVs run on electrical energy stored in batteries, reducing greenhouse gas emissions. As EV emissions decrease, quantification of carbon emission reduction is necessary, as each tonne of reduction is marketable and known as carbon credits. India is the third-largest emitter of CO_2 and has the second-largest road network globally. About 56% of India's transport sector emissions are attributed to road transport, according to the Community Emissions Data System [2]. Figure 1[3] shows the advantages of adopting electric vehicles.

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Figure 1. Advantages of Electric Vehicles

The adoption of electric vehicles (EVs) faces significant challenges in areas with heavy deforestation and population growth. These areas often lack infrastructure, such as poor road networks and limited electrical access, which are required for charging stations. Rapid urban growth also increases the demand on existing infrastructure, making it difficult to create and maintain charging networks. Energy supply and grid capacity are critical challenges, as population expansion drives up electricity consumption, leading to greater dependency on fossil fuels. Economic restrictions also impede widespread adoption, with high initial prices and restricted financing alternatives. Renewable energy integration into the electricity grid can help reduce dependence on fossil fuels, and sustainable infrastructure development can be a promising approach. Cities and transportation systems can be designed to be more EV-friendly, with charging networks, public EV-based transportation, and grid systems supporting sustainable energy use. EV adoption can stimulate local economies through job creation in manufacturing, maintenance, and service sectors. Governments and private sector partnerships can explore innovative financing models to make EVs more affordable.

Carbon credits are economic certificates that represent the elimination of one ton of carbon dioxide equivalent. They are used to reward companies that use fewer practices to reduce their carbon footprint. Governments can limit greenhouse gas emissions by setting emissions caps, which determine the maximum number of tonnes of CO_2e an agency can emit. The Kyoto Protocol, a United Nations treaty, originated the idea of applying a cap-and-trade solution to carbon emissions [4].

Carbon offsets are investments in projects or activities that eliminate greenhouse gas emissions by removing carbon dioxide emissions from the air and trapping them inside for a period. They are created by independent companies and sold to companies that emit CO2 [5]. India has implemented several initiatives to reduce carbon emissions and promote carbon trading, in line with its Nationally Determined Contributions under the Paris Agreement. These include the Carbon Credit Trading Scheme (CCTS), 2023, which establishes a national carbon market for trading Carbon Credit Certificates (CCC), and the Indian Carbon Market (ICM), which supports this trading [6], [7]. The Bureau of Energy Efficiency (BEE) sets sectoral emission reduction targets under the Energy Conservation Act, 2001, supported by the Perform, Achieve, and Trade (PAT) Scheme [8]. India's National Action Plan on Climate Change (NAPCC) promotes renewable energy, efficient energy use, and the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) Scheme [9], [10]. To reduce GDP emission intensity by 33-35% by 2030, India incentivises renewable energy through Renewable Purchase Obligations (RPOs) and promotes carbon sequestration through afforestation programs like the Green India Mission. These policies, combined with carbon pricing mechanisms, position India as a leader in climate change mitigation, enabling both domestic and international carbon trading and advancing sustainable development [11].

Global warming is caused by the accumulation of carbon dioxide from various pollution sources, leading to the need for government and private organisations to implement carbon credit projects to reduce greenhouse gas emissions. Carbon credits remove one tonne of carbon dioxide or its equivalent from the air. The work in [12] discusses the concept and importance of carbon credits, highlighting their financial importance and motivating firms to adopt cleaner business practices. It also highlights India's emerging significance in the global market for carbon offsets, highlighting its unique position in selling excess credits to developed nations due to lower greenhouse gas emissions. The work in [13] provides an overview of carbon credits and their trading in India, highlighting the emergence and scope of these credits. It highlights firms and organisations that have advanced in carbon credit trading and suggests that India could benefit from technological improvements in handling carbon finance projects through the Infrastructure Development Finance Company (IDFC) in partnership with the World Bank.

The research [14] explores the various policies to reduce carbon emissions from light-duty vehicles (LDV) through short-term regulations like fuel economy standards and incentives for manufacturers and consumers. It also discusses the potential impact of taxes on petrol and carbon emissions on producers and consumers. The study also examines the long-term decarbonization of the transportation sector by considering light-duty, medium-duty, and heavy-duty vehicle (HDV) fleets.

Carbon trading is the purchase and sale of credits allowing a company to emit a specific amount of carbon dioxide or other greenhouse gases. Governments approve these strategies to gradually reduce overall carbon emissions and mitigate their impact on climate change [15]. The objective of this research is to minimize carbon emissions by implementing electric automobiles using a financial model. To quantify the decrease in carbon emissions in the transportation sector in Kerala by implementing electric vehicles using Verified Carbon Standards techniques. To create a smart gadget and an algorithm for real-time monitoring and administration of electric vehicle charging stations, as well as the calculation of carbon credits.

The introduction is structured to provide a comprehensive overview of the research's context, objectives, and significance. The subsequent sections are organized as follows: Section 2 details the methodology, including the process of converting carbon dioxide equivalent reductions into carbon credits and the metering topology for data collection from EV charging stations. Section 3 discusses the hardware development and implementation of a solar-powered EV charging station. Section 4 presents the results, and Section 5 concludes the paper with future research directions and potential advancements in the field.

2. METHOD

The goal is to create a process chart for turning carbon dioxide equivalent reductions into carbon credits and introduce a metering topology for collecting required data from EV charging stations, which has to be monitored in real time. This covers the vehicle's energy consumption as well as the distance travelled. Since solar power is best at reducing carbon emissions, a completely solar-powered EV charging station shall be considered for the analysis of carbon emission reduction. Hence a stand-alone solar-powered EVCS with three different charging levels is designed. However, first, the criteria for determining the reduction in GHG emissions must be considered.

2.1. Carbon Credits

Carbon credits are a crucial part of market-based strategies to reduce greenhouse gas emissions and combat climate change. They grant the right to emit one metric ton of CO_2 or equivalent amount of other GHGs, with governments or regulatory bodies setting a cap on the total amount of GHGs emitted by companies, sectors, or countries. Under this cap-and-trade system, companies are either allocated or required to purchase carbon credits corresponding to their allowed emissions. If a company emits less than its allocated credits, it can sell its excess credits to other companies that may have exceeded their emission limits. This creates a financial incentive for companies to reduce their emissions: reducing emissions means having surplus credits, which can be sold for profit. Additionally, carbon credits are also generated through carbon offset programs, which involve initiatives such as renewable energy projects, reforestation, and methane capture that reduce or absorb GHG emissions. These projects, often implemented in developing countries, generate credits that can be sold in the carbon market, further promoting global efforts to reduce emissions. The carbon credit system has spurred significant investments in clean energy, energy efficiency, and other sustainable practices, especially in sectors like manufacturing, energy, and transportation. By putting a price on carbon emissions, it pushes companies to adopt greener technologies and reduce their carbon footprint to avoid financial penalties. It also encourages corporations to invest in carbon offset projects, contributing to a reduction in global GHG levels.

However, the effectiveness of carbon credits in achieving meaningful reductions in emissions has faced criticism and challenges. One key issue is "carbon leakage," where companies move their operations to countries with less stringent environmental regulations to avoid the costs associated with carbon pricing, effectively undermining the system's global impact [16]. Another issue is the over-allocation of carbon credits, particularly in early phases of cap-and-trade programs, where governments may grant more credits than necessary, reducing the urgency for companies to cut emissions. Moreover, not all carbon offset projects are equal in terms of environmental benefits, and there have been instances where the claimed emission reductions from certain projects were either overstated or not verifiable. Despite these challenges, carbon credits remain a valuable tool in the broader fight against climate change. With proper enforcement, stricter regulations, and improvements in the transparency and quality of carbon offset projects, the system has the potential to drive large-scale reductions in global emissions while supporting sustainable economic development.

2.2. Verified Carbon Standards (VCS)

VCS is a widely recognized system that provides international standards for reducing and eliminating carbon emissions and is responsible for defining and allocating carbon credits which comes under Verra, which leads the way in global climate action and sustainable development [17]. VCS sets various standards and methodologies for sustainable development. The methodology that needs to be used with electric vehicle charging stations is outlined in VM0038. The applicability conditions mentioned in the VCS methodology are:

- Only light-duty vehicle (LDV) using Level 1 (L1) and Level 2 (L2) chargers, heavy-duty vehicle (HDV), and plug-in hybrid electric vehicle (PHEV) Battery Electric Vehicles (BEVs) using Direct Current Fast Chargers (DCFCs) are eligible to use the methodology.
- The EV models that make up the project's applicable fleet should be equivalent in class and passenger/load capacity to their baseline conventional fossil fuel vehicles.
- The project proponent shall keep an inventory of all EV chargers included in the project, including their L1/L2/DCFC classifications and unique identifiers, to ensure that double counting of emission reduction will not occur.
- The project documentation should include the classification of chargers concerning performance voltage and power specification.
- The methodology should be applied to EV charging systems that use Associated Infrastructure (AI) to supply electricity to and from renewable energy sources, on-site batteries, and EVs; however, the AI needs to have sufficient metering systems.
- The projects can only be approved if it is meant to be large-scale projects that are expected to reduce annual emissions by more than 60,000 tCO_2e.
- The project proponent must provide evidence of ownership of the reduction in emissions, which can be done by entering into a contract with the owner of the charging system and by disclosing credit ownership to EV drivers.

Two points can be used as standards to measure the reduction of carbon emissions: Baseline Emissions (BE) and Project Emissions (PE). The net GHG emission reduction is calculated by comparing the BE and PE. In the context of the VCS, **baseline emissions** are the estimated emissions that would occur in the absence of carbon offset projects. It serves as a metric to evaluate emissions reductions achieved by a project. VCS evaluates a project's effectiveness in reducing carbon emissions and awards carbon credits by comparing project emissions to baseline emissions. To determine BE, the electricity used to charge the applicable vehicle fleet is converted to distance multiplied by the emission factor for fossil fuels used by comparing fleets to travel the same distance. Clear and accurate models are important to reduce underestimation or overestimation of emissions reductions. When calculating emission reductions, emissions such as the negative increase in emissions resulting from activities outside the project boundaries are also taken into account. When assessing the emissions of a fleet of fossil fuel-powered vehicles, or baseline comparable fleet, that is equivalent in size to an applicable fleet of electric vehicles, baseline emission is utilized. A typical baseline emission as per VCS
[18] can be calculated by equation 1.

where,

$$BE_y = \frac{\sum_{i,f} Ed_{i,y} * EF_{j,f,y} * 100 * ITF_y^{y-1}}{AEC_{i,y} * MPL_{j,y}} \qquad (1)$$

BE_y is the baseline emission for every year y[tCO_2e];

- $Ed_{i,y}$ is delivered power by the project charging systems that serve the applicable fleet i, during the year y (kWh);
- $EF_{j,f,y}$ is the corresponding emission factor of fossil fuel f used by comparable fleet j in the year y [$kgCO_2e/l$];
- ITF_y is the improvement in technology factor for the applicable fleet, i;
- $AEC_{i,y}$ is the average electricity consumption by the applicable fleet, i (kWh/100km);
- $MPL_{j,y}$ is the average mileage of comparable fleet j using fossil fuel (km/l).

Project Emissions describe the carbon emissions produced during the construction and operation of the carbon offset project. During the project, we measure and track emissions to measure the overall effectiveness of the project in reducing indoor emissions. Project emissions can be calculated by multiplying the power used by project chargers by the average emission factor of the electricity they consume. For some vehicles with on-site batteries, vehicle-to-grid (V2G) technology should also be considered. This situation creates a negative impact on project emissions. The PE of a year can be calculated by in equation 2.

$$PE_y = \sum_{i,y} EC_{i,y} * EFP_{i,y} \quad (2)$$

where,

- $EC_{i,y}$ is the energy consumption by project chargers for the applicable fleet, i (kWh);
- $EFP_{i,y}$ is the average emission factor of the electricity consumed by project chargers ($kgCO_2/kWh$)

Thus the **Net Emission Reduction** can be obtained by equation 3

$$ER_y = (\mathrm{BE}_y - \mathrm{PE}_y) * \mathrm{Dy} \quad (3)$$

where,

- ER_y is the Emission Reduction
- BE_y is the Baseline Reduction
- PE_y is the Project Emission
- D_y is the Discount factor applied in year y

2.3. Carbon Credit Life Cycle

As a financial-based project of VCS, the quantification of CO2 emission reduction and calculation and issuance of carbon credits requires a professional procedure. Figure 2 shows the block diagram of the procedure for the generation, validation/verification and issuance of carbon credits in carbon markets. The procedures included are:

- Role of Project Owner: The identification of the issue and implementation of the project along with the calculation of carbon credits are included in this phase.
- Validation and Registration of the Process: This phase includes registration of the project after the documentation of the process as per the approved methodology by VCS is validated by Designated Operational Entity (DOE). This phase starts when the project is identified and runs in parallel with the first phase.
- Verification and Issuance: In this phase, the project activity is monitored and verified by DOE. After verification, carbon credits are issued.
- Trading: In this phase the issued credits are marketed in carbon credit markets to those organisations whose emissions are larger than the "cap" imposed by the government.

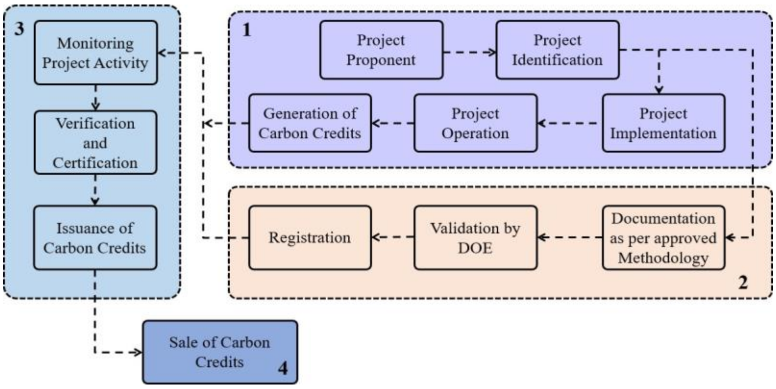


Figure 2. The block diagram representing procedure for generation, validation and issuance of carbon credits.

2.4. EV Charge Station Monitoring and Management System

A day-by-day increase in the sales of electric vehicles in Kerala has been witnessed in the last few years. From the data available from the Parivahan Dashboard [19], total EV sales in Kerala account for about 1.2 lakhs and counting. It contributes around 3.5% of total EV sales in India. Figure 3 shows the hike in EV sales in Kerala in the past two years. It is expected to have 3.4 lakhs EVs on road by 2030 in Kerala. Replacing this huge number of ICE vehicles with EVs contributes to reducing carbon emissions, which is to be monitored and converted into carbon credits. Accurate and real-time energy consumption monitoring by the chargers is necessary to calculate the reduction in carbon emissions in accordance with the VCS methodology. This can be accomplished by installing intelligent metering equipment based on algorithms in the charging stations. The device's main component is the Main Control Unit (MCU).

It facilitates the uploading of charging station data to the cloud, where the project owner can retrieve the necessary data. The energy consumption is measured by a dedicated energy measurement/metering chip, and the MCU uploads the data with the aid of a SIM module or Wifi. The MCU controls a protection relay, which can be used to avoid problems with over-voltage or over-current [20]. Figure 4 gives a block diagram of the smart metering device.

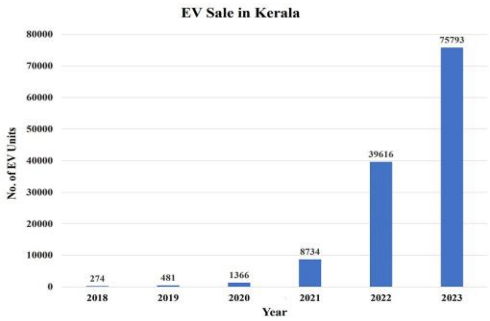
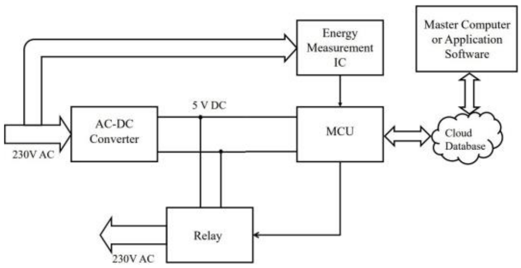


Figure 3. Graph showing annual EV sale in Kerala



.Figure 4. Block diagram for smart energy metering device

1. HARDWARE SETUP

A smart metering device for quantifying carbon emission reduction and thus calculating carbon credits is designed. This device has been tested and validated at KSEBL Vydhyudhi Bhavanam, Thiruvananthapuram by charging a TATA Nexon prime in AC001 level 1 charger (3.3 kW). Figure 5 shows the circuit diagram of the smart device developed in Easy EDA Pro software. It is a Printed Circuit Board (PCB) design software which allows 2D and 3D previews of the designed PCB. The circuit is designed to monitor the carbon emission reduction calculated from the energy used by the EV for charging Connected to pins marked "AC," the HLK-PM01 module receives AC voltage and transforms it into a steady DC voltage. Capacitors C1 (100nF) and C2 (10uF) smooth out the voltage in the output. The circuit as a whole, including the relay, HLW8012, Wemos D1 Mini, and other parts, is powered by this DC voltage. The voltage and current are measured using the HLW8012 (U17). It can sense and measure the power parameters from Vn_{in}, Vp_{in}, Vp_{out}, and Vn_{out}, which are connected to the ground and high-voltage lines [21]. The Wemos D1 Mini receives the measured data and processes it before sending it over a network (WiFi) [22]. Through the NPN transistor 2N65, the Wemos D1 Mini controls the relay. Through pin 2, the relay coil is linked to a 5V power source and is managed by the transistor's switching. The transistor permits current to flow through the relay coil in response to a control signal from the microcontroller (sent through the resistor), closing the relay contacts and enabling control of high voltage and load. When the relay is de-energized, a diode (1N4007) is used across the coil to prevent voltage spikes. The PC817 optocoupler provides isolation between the low-voltage control side and the high-voltage side [23]. It makes sure the microcontroller is shielded from any high-voltage spikes. The Wemos D1 Mini provides a control signal that powers the optocoupler. The use of a current-limiting resistor R18 (47Ω) serves to safeguard the optocoupler's LED. The circuit's brain is the Wemos D1 Mini. It processes and reads data from the HLW8012 and uses an optocoupler and transistor to control the relay. Programmable functions for the microcontroller include power monitoring, data transmission to a cloud server, and condition-based relay control.

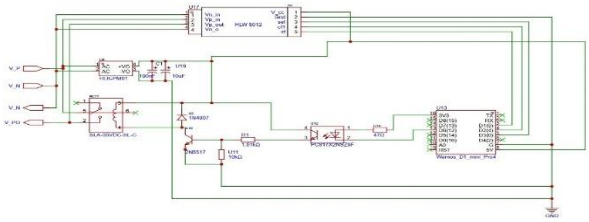


Figure 5. Circuit Diagram for the Smart Metering Device

1.1. Hardware Development

The hardware development procedure entailed building the designed PCB and integrating it with the required components to create a working prototype. Key steps in the hardware development included:

- **Component placement and soldering:** All components were carefully positioned on the PCB according to the design and soldered to provide solid electrical connections.
- **Software Coding:** An integration between the HLW8012 sensor and the Wemos D1 small was developed for measuring energy. Based on the energy data, the software determined emission reductions and forwarded the results to an external application named Blynk, which is a low-code IoT software platform, for live tracking and analysis.
- **Testing and Debugging:** Initial testing had done to ensure that the circuit worked properly. Any difficulties discovered during testing were rectified by fine-tuning the soldering and modifying component placements as needed.
- **Final Validation:** The fully built hardware underwent extensive testing to verify it satisfied all performance and reliability requirements.

Figure 6 shows the smart real-time metering device developed for quantifying emission reduction

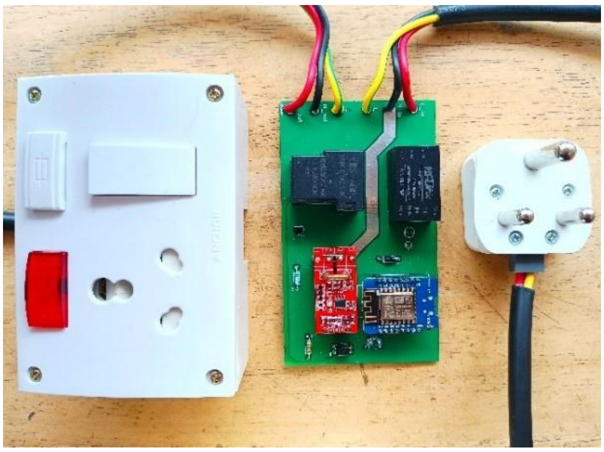


Figure 6. Smart Device for Quantifying Emission Reduction by Adopting EV

1.2. Device Implementation

The device has been tested and validated in the level 1 charger point in KSEBL Vydhuthy Bhavanam, Thiruvananthapuram. A TATA Nexon Prime was considered for validating the device and charged for 60 minutes. The live emission reduction calculation has been validated by theoretical method. Figure 7 shows the smart device's real-time emission reduction monitoring implementation by charging a TATA NEXON Prime EV with the specifications given in Table 1 [24] in a level 1 AC charging station at KSEBL Vydhyuthi Bhavanam, Pattom, Thiruvananthapuram. Figure 8 shows the charging data from the vehicle.

Table 1. Battery Specification of TATA Nexon Prime

Nominal Voltage	3.2 V
Ah per Cell	15.75Ah
No. of Cells in series	100
No. of cells in parallel	6
Total cells	600
Total nominal Voltage	320V
Total Capacity (Ah)	94.5Ah
Total Energy (Wh)	30.2kWh

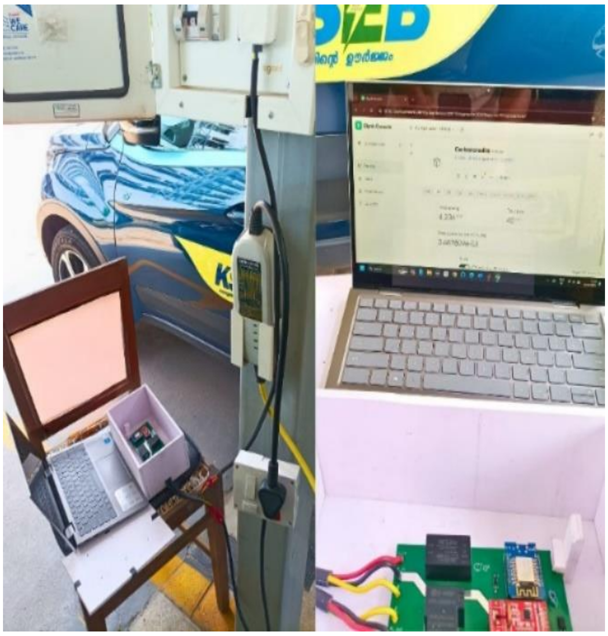


Figure 7. Smart Device Real-time Monitoring the Emission Reduction

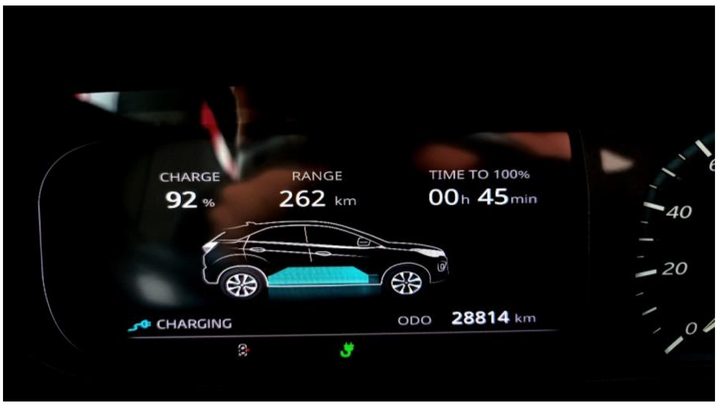


Figure 8. Vehicle Charging Data

2. RESULTS AND DISCUSSION

2.1. Carbon Emission Reduction

The calculation of net carbon emission reduction by the adoption of EVs in Kerala is discussed in the section. Considering the baseline emission (equation 1) and project emission (equation 2), the net emission can be calculated using the equation 3. The required data such as electricity usage and emission factor of electricity source is collected from the online dashboard of KSEBL. The carbon credits obtained are calculated as the metric ton of CO_2e reduction. Before calculating the sample emission reductions, certain assumptions are made such as:

- Only a single fleet of cars that includes five TATA NEXON EVs and five TATA TIGOR EVs and its comparable fleets with diesel engines are considered.
- The data is collected for five months and average consumption is calculated for one year.
- Discount factor depends on other projects of this typology in the region. Considering there are no such projects, the discount factor is given as D_y =1
- Improvement in Technology factor for one year, $ITF_{i,y}$ =1
- Leakage emission is not considered in this project.
- The Source of electricity is purely from the PV system.

Table 2 shows the data required for the calculation of carbon emission reduction.

Table 2. Calculation Data

Parameter	Value
Electricity delivered, $Ed_{i,y}$	17575 kWh
Emission factor of Diesel, $EF_{j,f,y}$	2.64 $kgCO_2e/L$
Average Electricity Consumption, $AEC_{i,y}$	12.05 kWh/100km
Average Mileage for diesel engine, $MPL_{j,y}$	24.07 km/L
Electricity Consumption by project chargers, Ec_i	17575 kWh
Emission factor for source electricity in Kerala, $EFP_{i,y}$	0.041 $kgCO_2e/kWh$

From the above data and above equations, net carbon emission is calculated as:

- **Baseline Emission (BE)**, from equation 1: **15996.9 $kgCO_2e$**
- **Project Emission (PE)**, from equation 2: **720 $kgCO_2e$**
- **Emission Reduction (ER)**, estimated from equation 3: **15275 $kgCO_2e$ / 15.27 tCO_2e**

Carbon Credits earned from the emission reduction account for 15.27 in numbers. Considering the distance covered is the same, Table 3 shows the monthly CO2e emission by a comparable fleet using both petrol and diesel fuels and by an applicable fleet of electric vehicles.

Table 3. Monthly CO_2 Emission based on Vehicle Classification on fuel

Months	Petrol (kg)	Diesel (kg)	Electric (kg)
July	1109	1290	616
August	1202	1398	667
September	930	1081	516
October	1373	1527	729
November	720	838	400

Figure 9 shows that average monthly CO2e emission has been halved by the adoption of EVs in Kerala from the tabulated data.

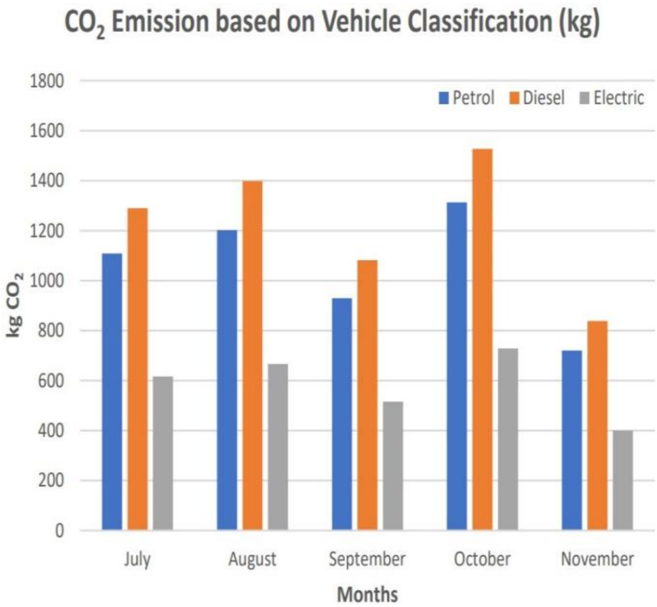
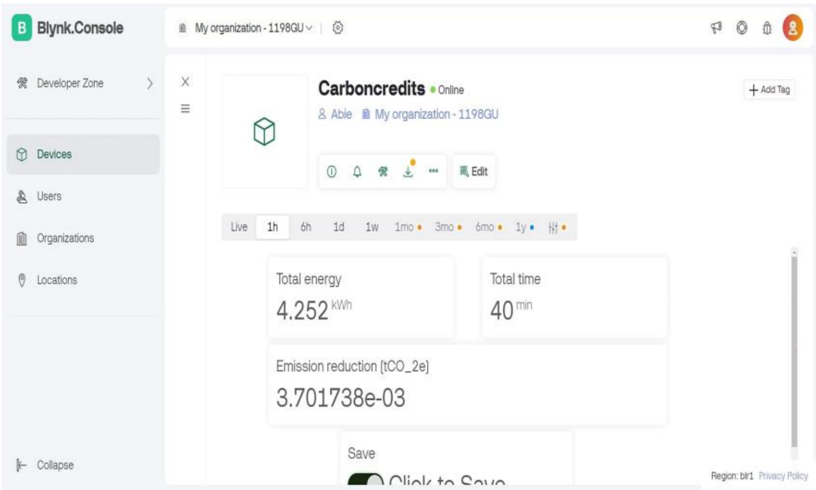


Figure 9. Monthly CO_2 Emission based on Vehicle Classification on fuel

2.2. Experimental Results

An external IoT-based application called Blynk tracks the experiment's results in real time with the implementation of the smart device to quantify carbon emission reduction. Figure 10 shows the real-time tracking of CO2e emission reduction in the Blynk dashboard. Key metrics, such as the total energy used by the EV charging station, the total duration of each charging session, and the resulting reduction in carbon emissions measured in tonnes of CO_2 equivalent (tCO_2e), are visualised in an easy-to-use manner on the Blynk dashboard. With the help of this real-time tracking, which enables quick feedback and analysis, it is possible to clearly understand the environmental advantages of using renewable energy sources to charge electric vehicles.

Figure 10. Realtime Monitoring the Emission Reduction in Blynk IoT Dashboard



3. CONCLUSION

The results of this study demonstrate a significant reduction in carbon emissions through the adoption of electric vehicles, with a focus on a sample of 10 TATA EVs. Kerala's total sales of EV 4-wheelers surpass 15,000 units, accounting for nearly 12% of the total EV sales in India. If these figures were scaled to represent all EV units, a more substantial reduction in emissions could be realized, contributing meaningfully towards achieving the targets outlined in the Paris Agreement. The smart device employed in the project accurately quantified real-time carbon emission reductions by measuring the energy consumption for EV charging and comparing it to conventional internal combustion engine vehicles. The findings suggest that transitioning to EVs leads to considerable emission reductions. Furthermore, integrating renewable energy sources into EV charging infrastructure has the potential to further mitigate carbon emissions, thereby enhancing environmental protection and addressing the adverse impacts of climate change. This project, developed in collaboration with Kerala State Electricity Board Limited (KSEBL), presents a comprehensive methodology for quantifying emissions within the road transport sector in Kerala. Future research could focus on developing standardized methodologies for evaluating the socio-environmental benefits of EV adoption, assessing the effectiveness of carbon credit programs in incentivizing emission reductions, and aligning the project's scope with global goals to achieve net-zero emissions by 2050 and limiting the world average temperature to well under 2^oC over the preindustrial level, while attempting to restrict the rise to 1.5^o C, per the Paris Agreement [25].

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