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Assessment of the Carbon Credit Potential of An Electric Vehicle Charging Station

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ABSTRACT

The electric vehicle charging station (EVCS) based carbon credit potential in present study was evaluated for the Shell Recharge Charging Station at Pimple Nilakh, Pune, Maharashtra. The objective was to determine whether carbon credits could provide incentive for the establishment of EVCSs. The calculations were carried out with the Verified Carbon Standard (VCS) Methodology VM0038 for Electric Vehicle Charging Systems, Version 1.0. We show that the system can produce about 191 carbon credits per year. These credits are worth a potential monetary value of up to ₹ 7,96,947.50 in the Indian voluntary market, and up to ₹ 9,92,372.74 in the international compliance market, depending on the prevailing carbon credit values. This is at a maximum of approximately 31% more value than the annual profit generated from the charging station in the Indian voluntary market. Therefore, these carbon credits have potential to be a useful way to speed up the adoption of green mobility by rewarding the creation of electric vehicle charging infrastructure. The results of this assessment showed the potential of EVCSs to provide sustainable transportation support and generate economic benefits through carbon credit monetization. The present work highlighted the need to standardize the validation and trading of carbon credits generated from green mobility.

Key Words	Carbon credit, Carbon Market, Electric Vehicle Charging Station, Sustainable transportation, Verified Carbon Standard
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1.0 INTRODUCTION

There is unequivocal warming of the climate system (Qin et al. 2013). In the past century, NASA reports a 1°F temperature rise, resulting in things like droughts and intense hurricanes (Kaddo, 2016). Since 1750, human activities, specifically fossil fuel use, have caused a around 50% CO_2 increase (Center for Science Education, 2024; NASA Science, 2024; Riebeek and Simmon, 2010). In 2019, transport sector was responsible for 2,277.63 million metric tons of CO_2 in India, up 375% from 1990. By 2030, emissions could increase by 65 percent and 197 percent by 2050, with road transport the largest emitter. As a result, (Riehle et al., 2023) to overcome this challenge, the Indian government also introduced initiatives such as FAME II with greater EV subsidies, PLI scheme for Advanced Cell Chemistry (ACC) battery storage for increased adoption of EVs (Sinha and Sharma 2021). India's current energy investments take up about 3% of its GDP. This is especially notable considering that corporate and financial institutions have also funded renewable energy initiatives at unprecedented levels, rising to a record of USD 14.5 billion in the fiscal year 2021–2022, a 72% increase from the pre pandemic period of 2019–2020. EVs emit less than gasoline cars even when manufacturing and charging are taken into account (Annual G20 Report, 2022). Renewable sources of energy, such as wind and solar, can still reduce the amount of greenhouse gas emissions generated by electricity generation for EVs, but that doesn't necessarily mean they'll eliminate it. The emission reductions from EVs may exceed those of gasoline cars as renewable energy costs fall. (EPA US 2023, Moseman 2022).

Carbon trading is a carbon market which allows businesses to buy and sell carbon credits. One credit equals a ton of CO2 or equivalent gases. While the Chicago Climate Exchange, European Climate Exchange, and soon India's MCX are all major exchanges. The United Nations' Kyoto Protocol had begun officially in 1997 with the introduction of Certified Emission Reduction Certificates (CERs) (Yuvika, 2011). The Carbon Credit Trading Scheme (CCTS) was born in 2023, and the Green Credits Program is currently in draft and operates voluntarily. There are two primary carbon markets (Dhrishti IAS, 2023). In Voluntary Markets, companies are willing to offset their carbon emissions in order to meet sustainability goals. In 2020, verified credits brought in over $2 billion and big names like Google, Apple, and Microsoft took part. (CHOOOSE, 2023, Dhrishti IAS, 2023). Policies such as the 'cap and trade' system govern Compliance Markets. In Q1 2021, Tesla sold carbon credits to traditional manufacturers, earning USD 518 million. Companies might buy billions of carbon credits per year to restore trust, pushing prices to $238, market value over $1.1 trillion by 2050 (Jennifer L., 2024) and 53% of Forbes 2000 net zero companies are planning to use carbon credits (Eikelenboom et al., 2024). BEE and MoEFCC will manage India's Compliance Carbon Market, which is expected by 2026, covering 11 sectors (Yin, 2023). Carbon credit values are higher in compliance markets than in voluntary one (Carbon Offset Guide, 2024). This is supplemented by the Green Credits Program, which promotes ecofriendly activities (Shukla, 2024). In 2023, Evansa installed South Australia's first carbon credit generating EV charging station in accordance with the Verra measurement standard (Noodoe, 2023). Unlike other EV charging stations that require grid upgrades to handle the load, the Indian Oil solar powered EV stations reduce load by 80% and tap into a $15 billion carbon credit market (Gupta, 2020).

This research determines the potential use of an EV charging station (EVCS) in Pune to mitigate greenhouse gas emissions and generate carbon credits. It quantifies CO2eq emissions avoided and evaluates if the credits can provide an incentive to more stations to support sustainable transportation and clean energy infrastructure in India. Davis, Caldeira and Matthews, (2010) point out that existing energy infrastructure is poised to emit a considerable amount of carbon dioxide by 2060, and substantial warming is unavoidable in the absence of extraordinary efforts to develop alternative solutions and to constrain the expansion of CO2 emitting infrastructure. As we showed in Gupta et al., (2019), even with a high investment cost, low carbon scenarios (such as EVs) can achieve performance close to or better than our business as usual scenario, and accommodate yearly economic growth of 5.8% from 2013 to 2050. (Srikanth, 2018) recommended that to accelerate the progress of electric vehicles in India, it will lead to job creation in manufacturing with a substantial lowering of vehicular emissions. Maharashtra's growing number of EV charging stations due to government incentives were mentioned by Jadhav et al., (2023). India's challenges to adopting EVs, such as high costs and limited infrastructure, were also highlighted by Kumar et al., (2020). To address deployment concerns, Pareek et al., (2020) reviewed EV charging station guidelines and technologies. Paul Sathiyan et al. (2022) suggested high polluting vehicle segments to be targeted for EV adoption. According to Munshi, Dhar and Painuly, (2022), policy incentives are important while Jois and Thimmaiah, (2023) examined the role of carbon credits in developing economies. Carbon credits can boost EV industry revenue, according to Singh, (2024). India's carbon trading future was explored by Paul, (2010) and Sarkar and Dash, (2011), while Rajput, Varshney and Chopra, (2018) and Garg and Arya, (2015) have advocated for public awareness and a particular statute governing carbon credit contracts. According to Prabhakant and Tiwari, (2009) the Government of India can earn €1901 million annually, while Subramanian and Balasubramanian (2022) suggests the use of carbon credits for renewable charging infrastructure.

Carbon Footprint of EV Charging Stations:
Production and transportation of construction materials (concrete, steel) and equipment during station setup cause carbon emissions. The energy source used to power the station determines how the station will emit. The fact is, that renewable energy reduces emissions, while fossil fuel based electricity increases the footprint substantially. Additionally, carbon emissions are generated from the periodic repair, replacement, and energy for diagnostic testing and maintenance activities.

The objective of this work is to evaluate the carbon credit potential of an electric vehicle charging station (EVCS) through the application of the Verified Carbon Standard (VCS) methodology. The importance of carbon credits as financial rewards to accelerate the development of EV infrastructure is a focus. The research demonstrates the importance of this work to India's energy policies and sustainability goals, in line with the country's carbon reduction and economic growth commitments related to green mobility.

2.0 MATERIALS AND METHODS

Data was collected from multiple sources for this study. Carbon credits and EV charging stations (EVCSs) were reviewed in the context of research papers. The electricity consumption data was based on visits to the Shell Electric Recharge Station. Emission factors were obtained from India GHG Program (2023) and Ministry of Power reports. We obtained EV sales data for 2023 from autopunditz.com, battery size, ARAI range for EVs, petrol vehicle mileage from manufacturer websites.

Carbon credits were calculated based on the Climate Neutral Business Network's use of the Verified Carbon Standard (VCS) Methodology, VM0038 for EV Charging Systems, in 2018. Since September 2018 this methodology has been available for study by scientists from various fields. In July 2020, SCS Global Services announced the first EV charger carbon offset project validated using this methodology. The VCS program is now managed by Verra, and is the most widely used voluntary greenhouse gas program, having reduced over 200 million tonnes of emissions, and is the only voluntary greenhouse gas program to be recognized as independent by the climate community.

EV charging systems are the focus of the VM0038 methodology, which quantifies emission reductions by replacing fossil fuel vehicle emissions with electricity. The monitoring parameters are based on CDM tools for additionality and emission reductions, and India is qualified under additionality as its EV market penetration is low. EV miles driven are calculated based on kWh consumption and electricity delivered from project chargers are measured. Emissions and fuel consumption are estimated using comparable fossil fuel vehicles. The regional fuel emission factors are used to calculate GHG emissions avoided, while project emissions are calculated by multiplying the electricity consumed by the EVs with regional GHG factors. Finally, the carbon credits are calculated as the difference between baseline and project emissions.

In this paper, we assume the use of average vehicle models that represent Indian traffic and MPG ratings from government/industry data. Baseline emissions are calculated from standard factors for internal combustion engines and project emission for EVs from grid energy mix. They allow for a consistent comparison and, obviously, more accurate data and ground reality will deliver better results.

$$BE_y = \sum_{i,f} ED_{i,y} * EF_{j,f,y} * 100 * IR_i^{y-1} / (AFEC_{i,y} * MPG_{i,y}) \tag{1}$$

Where:
BE_y = Baseline emissions in year y (tCO2e)
$ED_{i,y}$ = Electricity delivered by project charging systems serving applicable fleet i in project year y (kWh)
$EF_{j,f,y}$ = Emission factor for the fossil fuel f used by comparable fleet vehicles j in year y (tCO2e/gallon)
IR_i^{y-1} = Technology improvement rate factor for applicable fleet i

$AFEC_{i,y}$ = Weighted average electricity consumption per 100 miles rating for EVs in applicable fleet i in project year y (kwh/100 miles)
$MPG_{i,y}$= Weighted average miles per gallon rating for the fossil fuel vehicles comparable to each EV in applicable fleet i, in project year y (miles per gallon)

$$AFEC_{i,y} = \sum_a (EV_{a,i,y} * EVR_{a,i,y}) / \sum_a EVR_{a,i,y} \qquad (2)$$

Where:
$EV_{a,i,y}$ = Electricity consumption per 100 miles rating for model a EV in applicable fleet i in project year y (kWh/100 miles)
$EVR_{a,i,y}$= Total number of model a EV in applicable fleet i on the road by project year y (cumulative number of EVs)

$$MPG_{i,y} = \sum_a (MPG_{a,i,y} * EVR_{a,i,y}) / \sum_a EVR_{a,i,y} \qquad (3)$$

Where:
$MPG_{a,i,y}$ = Mile per gallon rating for the fossil fuel vehicle model deemed comparable to each EV model a from applicable fleet i in project year y (miles/gallon)
$EVR_{a,i,y}$ = Total number of EV models within applicable fleet i on the road by project year y (cumulative number of EVs)

Project Emissions

$$PE_y = \sum_{i,j} EC_{i,j,y} * EFkw_{i,j,y} \qquad (4)$$

Where:
PE_y = Project emissions in year y (tCO2e)
$EC_{i,j,y}$= Electricity consumed by project chargers sourced from region j serving applicable fleet i in project year y (kwh/year)
$EFkw_{i,j,y}$ = Emission factor (average) for the electricity sourced from region j consumed by project charging systems serving applicable fleet i in year y (tCO2e/kWh)

Net GHG Emission Reductions and Removals

Net GHG emission reductions must be calculated as follows, including the application of a discount factor D_y to adjust pro-rata where EV fleet credits have been issued within the project region:

$$ER_y = \left(BE_y - PE_y - LE_y\right) * D_y \qquad (5)$$

Where:
ER_y = Net GHG emissions removals/ reductions in year y (tCO2e)
LE_y = Leakage in year y (tCO2e)
D_y = Discount factor to be applied in year y (%)
Where:

$$D_y = ERC_y\left(ERF_y + ERC_y\right) \tag{6}$$

Where:
ERC_y = Sum of GHG credits issued by all projects under this methodology (or others which support the introduction of EV charging systems) across this project's applicable fleet i categories within this total project region in project year y-1 (tCO2e)
ERF_y = Sum of GHG credits issued by all projects under methodologies which support the introduction of EV fleets located within this project's total region where the applicable fleet i categories are the same for both this EV charging system project and projects introducing EV fleets21, in project year y-1 (tCO2e)
Where no GHG credits have been issued for projects that introduce EV fleets in the EV charging system project's region, D_y will be 1 (i.e., there is no discount applied).

Case Study Design

In this work, we assume an electric vehicle charging station in Pune. This station was selected because of its simple design, high visibility, and consumer trusted brand. In addition, the charging station has minimal staff requirement as it is a self-service charging station for the customer.

Pimple Nilakh, 411027 Pune, Maharashtra, India; Shell Recharge Charging Station. The Shell fuel pump is in the same premises and the charging station is alongside it. The car parking bays and two ports for charging with one DCFC occupy roughly 200 sqft area.

Fig. 1: Shell Recharge Charging Station Area for Cars

Fig. 2: 3.3 kW AC Chargers for 2-wheelers and 3-wheelers

Table 1: Chargers at Shell Recharge Charging Station

Vehicles Charged	Charger	Max power	Quantity
Cars supporting CCS 2	DCFC	120kW	1 (with 2 ports)
2-wheelers	AC	3.3kW	2
3-wheelers	AC	3.3kW	1

For our system, we shall consider only the 120kW DC fast charger. It has two CCS 2 (Combined Charging System Type 2) ports. This charger can share the load among the ports, i.e. it can split power to charge two cars simultaneously.

Fig. 3: 120 kW DCFC with 2 CCS 2 ports

The charging station operates 24/7 but serves about 40 cars daily, with varying power usage per charge based on battery size. Assuming each car charges for 100 miles, daily consumption is 788.4 kWh, equating to 6.57 hours of DC charging. The 120 kW charger operates for 6 hours daily.

Several key components are covered by the project boundary according to the VM0038 methodology. It includes the electric vehicle (EV) car models used for calculating the average electricity consumption (AFEC) and the miles per gallon (MPG). Second, it indicates the geographical area in which the EV charging station is located. Lastly, it includes the EV charging system itself (including electricity supply sources and related infrastructure for its operation).

Table 2: Gases Considered for Baseline Emissions

Source	Gas	Included?	Justification/Explanation
Fossil fuel combustion of vehicles displaced by project activities	CO_2	Yes	Main emission source
	CH_4	No	May be excluded for simplification
	N_20	No	May be excluded for simplification
	Other	No	Not Applicable

Assumptions and Limitations

The analysis is conducted for simplicity assuming the fleet is made up entirely of BEV LDV 4 wheelers. Lack of data on road EV models in Pune and India makes 2023 national sales data (India is a nascent EV market with less than 5% penetration) used. If a given model is petrol manual, petrol manual vehicles are chosen as comparable models and if a given model is not petrol manual, a similar sized model from the same manufacturer is used. MPG and AFEC values have been derived from ARAI ratings and are adjusted by 30 per cent to factor in the difference in real world performance. CO2 emissions are used to calculate baseline emissions, and equivalent factors are not available for other gases. The discount factor is set equal to one, as no GHG credits are issued for EV fleets, and leakage is considered zero, as per VM0038 methodology. For LDVs, the technology improvement rate is set to the default value of one, and the petrol emission factor from 2015 is used as these factors are not overly sensitive to time.

3.0 Results and Discussion

3.1 AFEC and MPG Calculation

Table 3: EV Sales 2023

Sr. No.	EV Model	Total Sales in 2023
1	Tata Tiago Electric	34853
2	Tata Nexon Electric	21072
3	Tata Tigor Electric	10765
4	MG Comet	6628
5	Mahindra XUV 400	6231
6	MG EZS	5970
7	Citroen eC3	2360
8	BYD Atto 3	2078
9	Hyundai Ioniq 5	1228
10	Kia EV6	658
11	Hyundai Kona	501

Source: (Team Auto Punditz, 2024)

Table 4: KWh/100 Miles Rating

Sr. No.	EV Model	Battery size (Kwh)	ARAI Range (km)	kWh/100 miles
1	Tata Tiago Electric	19.2	250	17.65314332
2	Tata Nexon Electric	30	325	21.21772033
3	Tata Tigor Electric	26	315	18.97245892
4	MG Comet	17.3	230	17.28936704
5	Mahindra XUV 400	34.5	375	21.1469946
6	MG EZS	50.3	461	25.08002047
7	Citroen eC3	29.2	320	20.97460062
8	BYD Atto 3	60.48	521	26.68301413
9	Hyundai Ioniq 5	58	631	21.12805221
10	Kia EV6	77.4	708	25.1286137
11	Hyundai Kona	39.2	452	19.93464285

(Source for battery size and ARAI range – Data from manufacturer websites. ARAI in MIDC for simplicity in comparison)

Table 4 gives the calculated values of kWh/100 based on the battery size and ARAI Range of the EV models.

$$kWh/100\ miles\ rating\ =\ Battery\ size/\ Range\ *100\ *0.7 \qquad (7)$$

The factor 0.7 because the value obtained was reduced by 30% as the real-world range is considered 30% less than ARAI) (MotorBeam Team, 2014).

Table 5: Comparable MPG Rating

Sr. No.	EV Model	Comparable Model	Comparable kmpl Rating ARAI (petrol manual)	Comparable MPG Rating
1	Tata Tiago Electric	Tata Tiago	20.09	33.0818012
2	Tata Nexon Electric	Tata Nexon	17.44	28.7180992
3	Tata Tigor Electric	Tata Tigor	19.28	31.7479904
4	MG Comet	MG Hector	13.79	22.7077172
5	Mahindra XUV 400	Mahindra XUV 300	18.24	30.0354432
6	MG EZS	MG Astor	15.4	25.358872
7	Citroen eC3	Citroen C3	19.3	31.780924
8	BYD Atto 3	Kia Carens	21	34.58028
9	Hyundai Ioniq 5	Hyundai Creta	17.4	28.652232
10	Kia EV6	Kia Seltos	17	27.99356
11	Hyundai Kona	Hyundai Venue	17.5	28.8169

(Source for kmpl rating – Data from manufacturer websites. ARAI in MIDC and petrol manual for simplicity in comparison)

Table 5 gives the calculated comparable MPG values based on the ARAI mileage of the comparable manual petrol vehicle.

$$MPG\ rating\ =\ Comparable\ kmpl\ Rating\ ARAI\ *\ 2.3524 * 0.7 \quad (8)$$

MPG = 235.24 / litres per 100 km

Conversion factors: 1 gall = 3.785 litres, 100 km = 62.15 miles.

The factor 0.7 because the obtained value was reduced by 30% as the real-world range is considered to be 30% less than ARAI) (MotorBeam Team, 2014). Thus,

We can calculate the AFEC and MPG values using the data in Table 1 and 2, respectively and the equation (2) and (3), respectively:

$$AFEC_{i,y}\ = \mathbf{19.71\ kWh/100\ miles} \quad (9)$$

$$MPG_{i,y}\ =\ \mathbf{30.36\ miles\ per\ gallon} \quad (10)$$

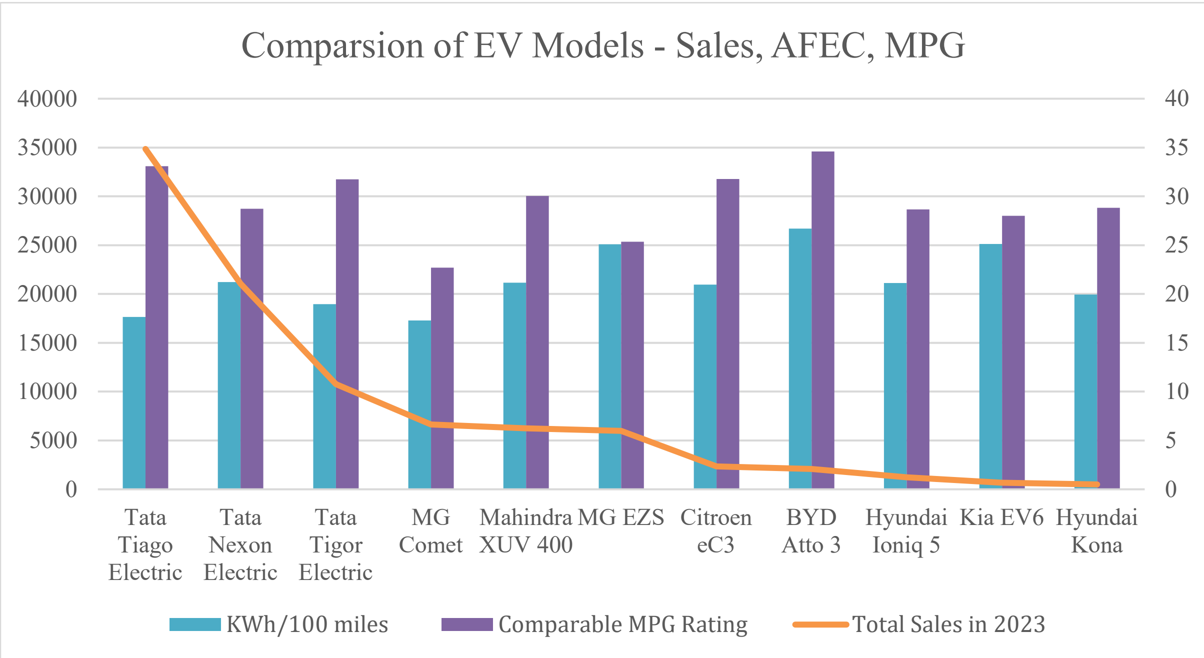

Fig. 4: Comparison of EV Models - Sales, AFEC, MPG

Table 6: Baseline and Project Emissions Calculation

18.90948862	**BEy**	**Baseline emissions in year y (tCO2e)**
13160	EDi, y	Electricity delivered by project charging systems serving applicable fleet i in project year y (kwh)

0.008599255	EFj,f,y	Emission factor for the fossil fuel f used by comparable fleet vehicles j in year y (tCO2e/gallon)
1	$IRi,$	Technology improvement rate factor for applicable fleet i
19.7100666	$AFECi,y$	Weighted average electricity consumption per 100 miles rating for EVs in applicable fleet i in project year y (kwh/100 miles)

The values in Table 6 put into equation (1) give us the value of baseline emissions:

$BE_y =$ **18.91 tCO2e** (11)

Table 7: Values for Calculating Project Emissions

Value	Parameter	Explanation
284723.727 kWh	$EC_{i,j,y}$	As per the VM0038 methodology approach A for DCFC, $EC_{i,j,y} = ED_{i,y}/0.923$
0.00071 tCO2/kWh	$EFkw_{i,j,y}$	According to Indian Power Sector's CO2 Baseline Database, the weighted average emission factor of the Indian grid FY2021-22, considering renewable energy, is 0.71 tCO2/MWh (India GHG Program, 2015)

Thus, the project emissions are:

$$PE_y = \ 186.59\ tCO2e \tag{12}$$

3.2 Carbon Credit Potential

The leakage is assumed zero as the VM0038 methodology does not consider it. Applying the discount factor of one, the carbon credits generated per charger can be calculated.

The ER value obtained using equation (5) and the calculated BE and PE values:

ER_y **= 191.03 tCO2e** (13)

Rounding up, ER_y **= 191 tCO2e** (14)

Carbon credits generated/year = 191 (15)

3.3 Voluntary Market Value

As carbon credit values in the Indian Voluntary Market vary from US$2 to US$50 (Thomson Reuters Foundation, 2023) and no standard average exists, we'll analyse compliance markets in different countries.

Table 8: India Voluntary Market – Potential Carbon Credit Value

India Voluntary Market	Value per CC	Potential Value Generated per Year
Lower range	US$2	₹ 31,877.90
Higher range	US$50	₹ 7,96,947.50

3.4 Compliance Market Value

Table 9 shows the potential monetary value that can be generated by the system under different compliance markets across the globe. The latest carbon credit values have also been applied which have been sourced from (CarbonCredits.com, 2024). The latest currency conversion factors have been used.

Table 9: Compliance Markets – Potential Carbon Credit Value

Compliance Markets	Value per Carbon Credit	Potential Revenue
European Union	€ 57.36	₹ 9,92,372.74
UK	£ 34.39	₹ 6,94,026.65
California	$ 28.66	₹ 4,56,810.31
Australia	$ 33.75	₹ 5,37,939.56
New Zealand	$ 58.50	₹ 9,32,428.58
South Korea	$ 6.11	₹ 97,386.98
China	$ 12.12	₹ 1,93,180.07

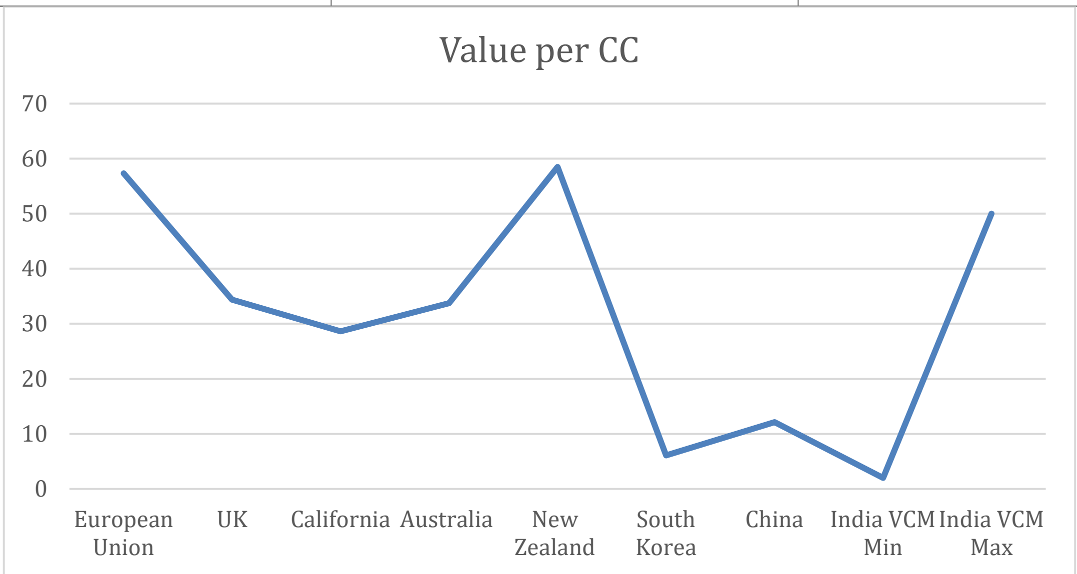

Fig. 5: Value per CC in Different Markets

3.5 Financial Analysis

The financial analysis reflects current trends which shows increasing carbon credit values in both voluntary and compliance markets. It is because of more demand for decarbonization solutions. It should be kept in mind that the credit values are highly volatile, influenced by policy changes, market dynamics, and regional demand-supply factors. This may cause changes in revenue generation and affect the financial planning of EVCS operators. In such instances, stable credit pricing and demand with strong policies is decisive for sustained revenue generation.

Annual Revenue through Charging

As per the pricing given at the Shell Recharge Charging station, the price charged is ₹ 24/ kWh. However, the discount for a long-term subscription may cost 17.5-19.99/unit. Thus, we assume that on average the price charged is 20/ kWh. Since our system is expected to produce 2,62,800 kWh per year, we find that at a competitive price,

$$Annual\ Revenue = ED_{i,y} * Price\ per\ kWh \tag{16}$$

$$Annual\ Revenue\ through\ charging\ = INR\ ₹\,52{,}56{,}000 \tag{17}$$

Initial Investment Cost

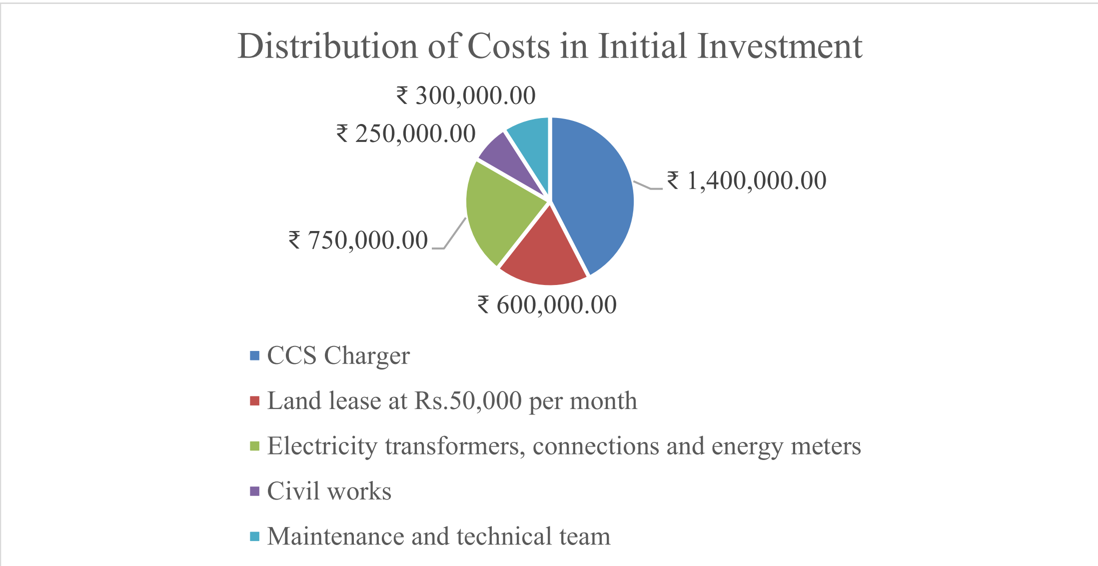

Fig. 6: Distribution of Costs in Initial Investment (Acharya, 2024)

Thus, the initial investment totals to about **₹ 33,00,000.00**.

3.6 Operation Cost

The operation cost is the yearly cost required for the operation of the charging station. The electricity tariff in Pune is ₹ 6/unit, according to (TATA AIG Team, 2023). Thus,

$$\text{Electricity cost} = EC_{i,j,y} * Electricity\ tariff \tag{18}$$

Table 10: Operation Cost

Activity/ Infrastructure	Cost
Electricity Cost	₹ 17,08,342.36
Land lease at Rs.50,000 per month	₹ 6,00,000.00
Maintenance and technical team	₹ 3,00,000.00
TOTAL	₹ 26,08,342.36

Net Profit

Ignoring inflation and growth, average annual profit for 10 years = **₹ 25,78,491.87** (19)

This is without considering the value generated from carbon credits.

We shall use the value of carbon credit in the Compliance Market of China as a reference since it is a developing country like India and has a large carbon footprint.

Figure 5 shows the carbon credit value that could be generated in addition to annual revenue in the form of a percentage of annual revenue from charging and net profit from charging.

3.7 Scope in Maharashtra

According to a Ministry of Power Report 2024, India has 12,146 public charging stations, with Maharashtra having 2,782 (excluding heavy duty vehicle stations). If all stations are like the one studied, each generating 191 carbon credits, Maharashtra can save about 5,31,362 credits which will amount to 5,31,362 tCO_2 emissions avoided and earn ₹ 53,74,26,965 in revenue.

The carbon credit potential of the electric vehicle (EV) charging station analysed in this study provides important insight into the financial viability and environmental impact of such infrastructure. The potential to generate carbon credits is evident based on the calculated emissions reduction (ER) of 191 tCO_2e per year per charger. The finding reinforces the importance of EV charging stations in helping to mitigate for greenhouse gas (GHG) emissions.

We then considered both voluntary and compliance carbon markets in evaluating the financial implications. Carbon credits in the Indian Voluntary Market were estimated to be in the range of ₹ 31,877.90 to ₹ 7,96,947.50 per year for the system, depending on the value per credit. Carbon credit in the Indian Voluntary Market generates extra profit up to 30.9%. It would encourage more charging stations to be built. Nevertheless, for more precise estimations, we used the values of carbon credits in the compliance markets of different countries. The system valued compliance market from ₹ 97,386.98 to ₹ 9,92,372.74 per year, and is of significant revenue generation potential.

In addition, the financial analysis showed potential for charging revenue, with an annual revenue of ₹ 52,56,000. But that must be weighed with operating costs – including electricity costs and initial investment. The total initial investment made was ₹ 33,00,000 and operating costs (electricity and maintenance) were approximately ₹ 26,08,342.36. These costs, however, amounted to ₹ 25,78,491.87, on average, over 10 years, accounting for inflation and growth, and the charging station was profitable. Additionally, given the market size, the potential contribution of such charging stations to emissions reduction is significant, for example in Maharashtra.

The carbon footprint of EV charging stations varies with charging habits such as frequency, time of day, and charging duration. Charging during peak grid demand often increases emissions if fossil fuels are used to meet the load. These variations make it challenging to standardize emissions reductions, as they depend on user behaviour and grid energy mix.

Our findings highlight the potential of carbon credits to incentivize EVCS development. There is urgent need to create supportive carbon credit monetization as part of green mobility initiatives. Standard guidelines for carbon credit validation is the need to implement and attract investment. Public-private collaborations is the key for this. Private entities can contribute in innovation with required capital investments. Ultimately, it's the base to achieve sustainability goals, targeting both economic and environmental benefits.

4.0 CONCLUSIONS

The research objectives of the study were successfully achieved, as the study offers key insights into the potential of electric vehicle (EV) charging stations to reduce emissions and be financially viable. Carbon credit potential from charging stations is high, the study revealed. Although the initial investment costs and operating expenses are incurred, the charging station is profitable. More carbon credits and government subsidies would make financial viability even better. Particularly, Maharashtra has great potential in carbon credit generation which is one of the broader impacts of EV charging stations not only reducing emissions but also generating substantial financial returns. We show how charging systems could earn carbon credits, and therefore promote sustainable transportation and reduce emissions. This enforces the role of carbon credits in incentivizing infrastructure and expert consultation on registering, monetizing, and trading credits on global markets. Standardizing carbon credit calculations, exploring financing mechanisms for green mobility and integrating blockchain for transparent trading, alongside optimizing EV chargers for energy efficiency are future research foci. Further, infrastructure deployment and renewable energy integration models should be scalable.

The findings highlight the potential of carbon credits in promoting EVCS development. It demands the need-based changes in futures renewal of policies. Supportive framework is the key for integration of carbon credits into India's and sustainability strategies. Standard trading mechanisms are required for widespread adoption to get carbon credits. Collaboration between public and private sectors is very essential to expand the EVCS network. These efforts will led to reduce carbon emissions, nurturing a synergistic way for sustainable transportation and economic growth.

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