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SUMO Simulation Based Carbon Credit System to Incentivize Green Mobility

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Abstract*: The transportation sector is a significant contributor to global emissions, with road transport as a major contributor. Traditional emission control strategies such as carbon taxes, cap-and-trade systems and policy regulations often lack an effective mechanism for tracking individual vehicle emissions in real time. This paper proposes a SUMO Simulation based Carbon Credit Allocation System that collects real time data from simulation to monitor and quantify emissions per trip. The system creates a virtual representation of vehicles that allows precise emission tracking. It is facilitated with a credit-based incentive mechanism that rewards eco-friendly driving behaviors. The project ensures accuracy in emission estimation, while the credit allocation encourages sustainable transportation choices. Additionally, the system enhances transparency by providing data-driven insights for both policymakers and individuals via dashboard. Testing on two major factors demonstrated that high-speed driving results in 44% more CO□ emissions compared to low-speed driving, whereas rough driving styles generate significantly higher emissions than normal driving. By leveraging real-time processing and adaptive learning models, the proposed system operates with high efficiency. It ensures scalable and accurate emission assessments, making it a capable solution for sustainable green mobility.*

Keywords: SUMO Simulation, Carbon Credits, Emission Estimation, Green Mobility, Incentives

I. INTRODUCTION

The transport sector is a major source of global carbon dioxide (CO□) emissions which contributes about 21% of the overall emissions [10]. In India, the transport sector contributes around 29% of the country's overall emissions; and more than 90% of CO2 emissions originate from this sector, with road transport being the major contributor [1].To combat climate change and reduce emissions, some nations have started using different policy tools such as carbon taxes, command-and-control, NEV(New Energy Vehicle) policy and cap-and-trade[4,15]. Despite extensive research in this domain, there is a lack of a robust and widely accepted system for estimating emissions of an individual vehicle per trip.Moreover, existing credit systems are not effectively accepted by the people worldwide.

In order to bridge this research gap, our project combines SUMO simulation of the Pune region with a predefined carbon credit system proposed by us, to analyse and regulate vehicular emissions and incentivize green-driving. There are various factors that affect the total emissions of a vehicle. Fuel Type, Speed, Route, Driving Behaviour and Vehicle mode are the major factors we have considered in our project; wherein separate simulations are done for each factor. SUMO is an open-source microscopic traffic simulator, capable of supporting multi-modal traffic and generating emission outputs for every second, while efficiently processing real-world road networks.SUMO's ability to simulate custom traffic scenarios and import real-world maps makes it an ideal choice for our study's requirements.

A carbon credit is an umbrella term for any tradable certificate or permit to emit one ton of carbon dioxide or mass of any other greenhouse gas with a Carbon dioxide equivalent (tCO2e) to one ton of carbon dioxide [2,9]. It is used as an incentive for rewarding the drivers, to encourage people to reduce their carbon emissions [7].The carbon credit system proposed by us suggests a predefined credit allocation that incentivizes green transportation choices. Unlike other tradable carbon credit systems, the proposed system allocates credits depending on the emissions and driving

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behaviours observed during SUMO simulations. The system replicates real environmental policies and encourages environmentally responsible driving behaviour.

The rest of the paper is as follows- Section 2 describes a literature review of earlier work. Section 3 provides an elaborate description of the Methodology which consists of Architectural Diagram and the Carbon Credit. Section 4 presents results and analysis and the possible implications for policy and practice in encouraging sustainable transport. At last, conclusions are drawn in Section 5. Section 6 consists of references.

II. LITERATURE REVIEW

Paper Number	Title	Author	Year	Summary
[3]	City-level estimation of vehicle CO□ emission factors regarding driving behaviors: The case of Tianjin, China.	Haipeng Ye	2025	Most Chinese city-level studies rely on top-down approaches that miss private vehicle CO_2 emissions owing to data unavailability. To fill this gap, bottom-up approaches based on travel activity and region-specific factors are needed. Precise city-level estimates are vital for local carbon reduction goal setting and attainment.
[5]	Mitigating urban heat and air pollution considering green and transportation infrastructure	Aijia Wang et al.	2024	The system of carbon credits is a market-based approach intended to curb the emission of greenhouse gases by enabling organizations to acquire tradable credits for reducing their emissions below an established baseline. The credits may be sold to others that have exceeded their allowance, encouraging economical environmental stewardship.
[8]	Research on the Carbon Credit Exchange Strategy for Scrap Vehicles Based on Evolutionary Game Theory	Wu, Quan, et al.	2023	This research investigates vehicle owners' and the government's willingness to implement carbon credit approaches for junk vehicles with evolutionary game theory. The game model formulated with MATplotlib simulation analysis, concluded that initial willingness has an inverse proportion to cooperation time. Government involvement is based on positive regulatory verification benefits and strategy selection relies on initial willingness and other determinants.
[7]	Daily Travel Mode Choice Considering Carbon Credit Incentive (CCI)- An Application of the Integrated Choice and Latent Variable (ICLV) Model	Gong, Lei, et al.	2023	In this study, the Integrated Choice and Latent Variable (ICLV) model was employed to examine daily transportation mode choices of residents under carbon credit incentives. Results show that the ICLV model outperformed the multinomial logit model and demographics had an impact on incentives. Carbon credits effectively encouraged public transport, but the effect on green travel modes differed. Employing incentives and enhancing monitoring systems can increase carbon credits' contribution to encouraging sustainable transportation options.
[11]	The Influence of Logistics Decisions on Transport Decarbonization	Tavasszy, L.	2021	A Simulation Study The research employs an agent-based model to examine the effect of carbon credit policies on logistics decision-making. It concludes that logistics operators maximize fleet composition by

				switching to alternative fuels and minimizing empty miles. The research indicates that a carbon credit system for urban freight permits can have a significant impact on emissions reduction.
[12]	Multivariate analysis of fuel consumption related to eco-driving: Interaction of driving patterns and external factors	Lois, David, et al.	2019	The study explores the benefits of eco-driving through a field trial in two Spanish cities. It found that driving behaviour, external factors like traffic congestion and road slope, significantly influence fuel consumption, providing valuable insights into driving behaviours.
[13]	Vehicle emission computation through microscopic traffic simulation calibrated using genetic algorithm	Wei, Yun, et al.	2019	The research seeks to create an effective vehicle emission computation system through traffic simulation and emission modeling integration. A relational database was employed for storing vehicle data and calibrating the IVE model. The system gave emission results as good as those of the IVE software while enhancing efficiency. The research concentrates on passenger vehicles, buses, and trucks in controlling CO,NOx, and CO2 but is applied only to urban environments.
[14]	Automating synthetic trip data generation for an agent-based simulation of urban mobility	Dos Santos, Paul.	2019	Microscopic traffic simulation in Cape Town, South Africa, is applied by the study to simulate vehicle emissions through SUMO, which is an agent-based simulation platform. Vehicular interactions and factors of emission are captured by the study through in-built emission models and HBEFA model. The study highlights the function of real-time data in calibration and offersrecommendationsfor HBEFA emission modeling.
[16]	SUMO (Simulation of Urban Mobility) - an open-source traffic simulation	Krajzewicz, Daniel, et al.	2002	The paper discusses simulating large-scale urban traffic networks with the SUMO framework by employing the Gipps model for vehicle motion and the Dijkstra algorithm for routing. It suggests network automation through SUMO-NETCONVERT and Dynamic User Equilibrium for realistic routing of traffic.
[17]	A Carbon Credit-Based Incentive Mechanism for City Vehicle Emission Reduction	Zhen, D.,et al.	2025	The research suggests a mechanism of carbon credit trading for urban vehicles, targeting commercial fleets and ride-sharing vehicles. It proposes a cap-and-trade system under which vehicles that go beyond their emission limit need to buy extra credits, whereas low-emission vehicles can sell surplus credits. With this system in place, emissions can be curbed by as much as 20% and promote green alternatives.

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III. METHODOLOGY

PROJECT ARCHITECTURE

In order to achieve an efficient and transparent distribution of carbon credits in road transport, this study utilizes a simulation-driven approach based on the Simulation of Urban Mobility (SUMO). Next, the methodology is used to recreate live vehicle movements through an artificially created urban environment, with the code cleverly adapted to facilitate the estimation of CO_2 emissions per vehicle type, on a per route basis, across all drivables based on distance. This emission data is used to compute carbon credits, which are then distributed to vehicles to encourage eco-friendly driving habits and sustainable mobility.

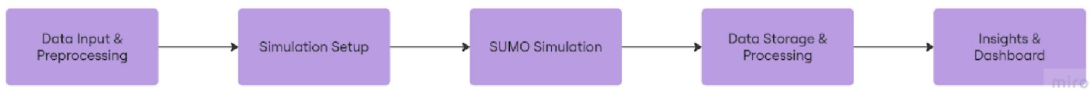

Fig.1. Architectural Diagram

Data Input & Preprocessing

The Pune region network was selected as the study area. For this, OpenStreetMap (OSM) data was obtained using JOSM (Java OpenStreetMap Editor). The extracted data was converted into a SUMO-compatible network file using netconvert. Additionally, trip definitions were generated using randomTrips.py, which assigns unique vehicle identifiers, departure times and designated source-destination edges. To enhance realism, a Python script modified the trips by assigning departure positions (departPos), enabling a natural traffic flow. These trips were then processed using duarouter to define individual routes between source and destination edges for each vehicle, forming the basis of our traffic simulation.

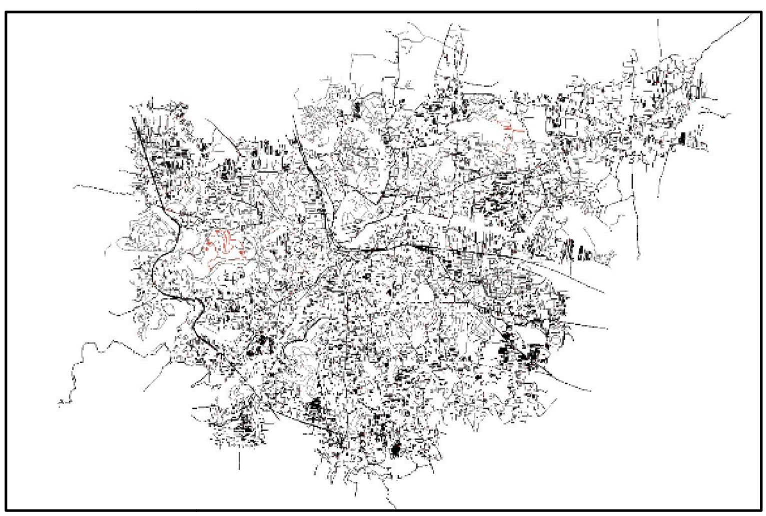

Fig. 2. Pune city network

Simulation Setup

Various vehicle types (vType) were specified within the simulated traffic, based on key characteristics such as vehicle class, maximum speed, acceleration, deceleration, and emission classification. The simulation consisted of different transport modes, including passenger cars, electric vehicles (EVs), buses, emergency vehicles, trucks, mopeds and motorcycles. Several factors like fuel type, speed, route, driving behavior, and vehicle mode influence total vehicle emission. Separate simulations were conducted for each factor to comprehensively analyze their impact. For scenario-

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specific simulations, predefined attributes were assigned for a set of vehicles that were monitored along with background traffic for each factor's simulation. This led to a controlled environment for analysis.

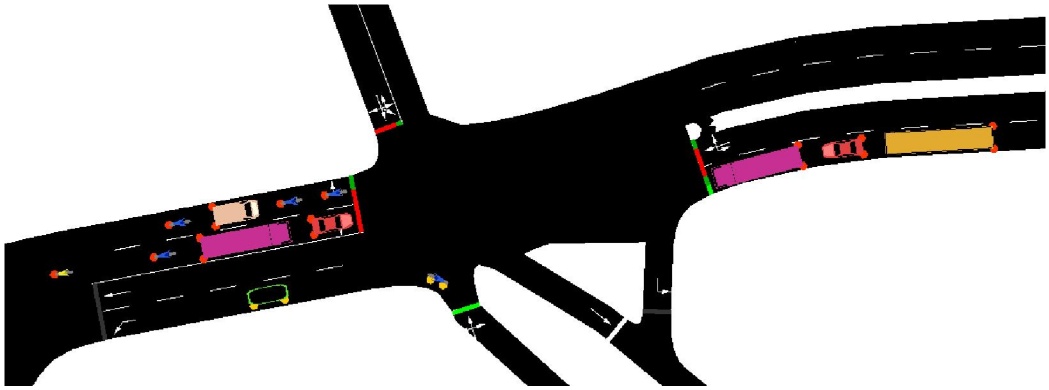

Fig. 3. SUMO Simulation

SUMO Simulation

The simulation can be visualized using the SUMO GUI, which provides real-time insights into traffic behavior. SUMO incorporates an enhanced emissions modeling framework based on HBEFA, which allows precise estimation of pollutants such as CO□, NO_x, HC,PMx and CO. By using the predefined configuration and route files, SUMO models vehicle movement across the network while simultaneously capturing key parameters such as speed, distance traveled, fuel consumption, and emissions (CO□, CO, HC, NO_x, PMx). A dedicated TraCI (Traffic Control Interface) Python script runs during the simulation that monitors real-time data for each test vehicle, including speed, distance, fuel consumption, electricity consumption, and emissions.

Data Storage & Processing

Once the simulation is complete, the collected data of emissions and other vehicle parameters is stored in structured formats such as .csv files for further analysis. Meaningful insights such as test case comparisons emission trends and credit allocation metrics are derived from the analysis of the emissions data.

Insights & Dashboard

The processed data is visualized through a user-friendly dashboard. This dashboard presents key insights such as emission trends, vehicle performance comparisons and carbon credits allocated to each vehicle. These credits can be used to reward or give penalty to the drivers. By displaying results through graphs and tables, it enables data-driven decision-making for urban planners and researchers. The structured methodology which incorporates realistic vehicle behaviors and calibrated test cases, enhances the reliability of results for urban traffic analysis,
reduction of total emissions and policy-making.

CARBON CREDIT ALLOCATION

The carbon credit system in this study is predefined to ensure a practical and meaningful vehicle emissions-based crediting objectivity that aligns with sustainability goals and real-world policies. The allocation of credits is based on the total emissions, which includes CO□, CO, NOx, PM and HC emissions.

$$\text{Total emissions (kg)} = CO_2 + CO_2\text{ equiv }(CO) + CO_2\text{equiv }(NO_x) + HC + PM_x$$

The total carbon credits are calculated as follows:

$$C_{total} = C_{base} + C_{factor}$$

where,

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C_{base} = Carbon credits from the emission **range**
C_{factor}= Modification based on the factor

The credit allocation follows a two-step process:

1. Base Credits – Vehicles are assigned credits based on their total emissions, following a predefined emission range, ensuring consistency across test cases.This is the default credit allocation for every test case.

Table 1. Base Credits Allocation as Per the Emissions Range

Total Emissions (kg)	0 - 0.96 kg (Very Low)	0.96 - 1.92 kg (Low)	1.92 - 2.88 kg (Moderate)	2.88 - 3.48 kg (High)	>3.48 kg (Very High)
Base Carbon Credits	+5	+4	+3	+2	+1

2. Factor-Specific Credits – Additional adjustments are made for specific test cases, rewarding sustainable choices such as EVs over petrol vehicles, eco-friendly driving over aggressive driving, and optimal routes over longer routes.Only modify credits based on the test factor under consideration

Table 2. Factor-Specific Credits Allocation

Sr. No.	Factor	Credit Modification Rule
1.	Fuel Type	EV (+2) Diesel (+1) Petrol (-1)
2.	Speed	Optimal Speed(16.66 m/s-25 m/s) (+2) High Speed (otherwise) (-2)
3.	Driving Behaviour	Eco-Friendly (+2) Aggressive (-2)
4.	Vehicle Type	Bus (+2) Car (-2) Moped (+1) Motorcycle (-1)
5.	Route	Optimal / Short Route (+2) Long Route(-2)

IV. RESULTS AND ANALYSIS

1. <u>Fuel Type Comparison</u>

- Objective**:** To compare emissions across different fuel types in identical conditions.
- Setup: 3 vehicles were monitored that have the same route (distance), maximum speed, and vehicle type (car). Fuel types are different : Petrol, Diesel and Electric Vehicle (EV).

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Table 3. Predefined Parameters for Fuel Type Comparison

Vehicle id	vClass	emissionClass	maxSpeed	accel	decel	depart	Route Distance (approx)
veh1	passenger	HBEFA3/PC_G_EU6	33.30	2.60	4.50	0.00	5439
veh2	passenger	HBEFA3/PC_D_EU6	33.30	2.60	4.50	0.00	5439
veh3	evehicle	HBEFA4/PC_BEV	33.30	2.60	4.50	0.00	5439

Table 4. Credits Allotted

Vehicle id	Total emission (kg)	Base Credits	Factor-Specific Credits	Total Credits
veh1	2.4985	3	-1	+2
veh2	2.2951	3	+1	+4
veh3	0.7958	5	+2	+7

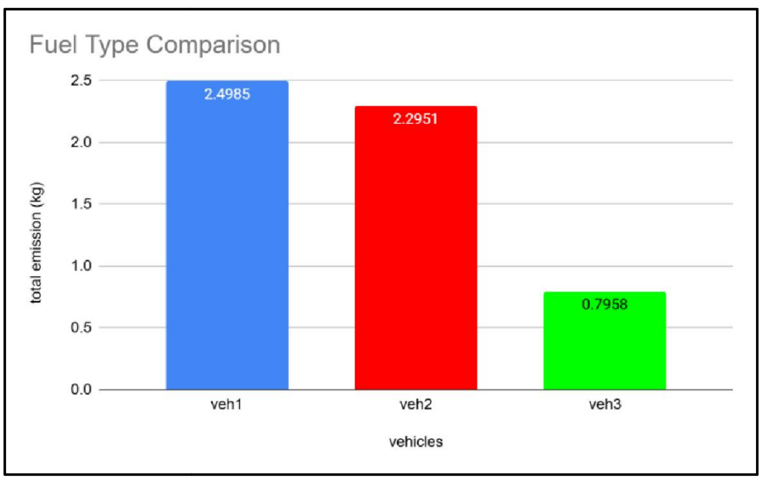

Fig.4. Total emission based on fuel type

2. Speed Variation Impact

- Objective: Toanalyze how speed influences emissions for the same trip
- Setup: 2 vehicles were monitored that have the same route (distance), fuel type (Petrol), and vehicle type (Car) . They have different speed categories: one fast-moving and one slow-moving.

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Table 5. Predefined Parameters for Speed Variation Impact

Vehicle id	**vClass**	**emissionClass**	**maxSpeed**	**accel**	**decel**	**depart**	**Route Distance (approx)**
veh4	passenger	HBEFA3/PC_G_EU6	33.30	2.60	4.50	0.00	5439
veh5	passenger	HBEFA3/PC_G_EU6	16.65	2.60	4.50	0.00	5439

Table 6. Credits Allotted

Vehicle id	Total emission (kg)	Base Credits	Factor-Specific Credits	Total Credits
veh4	2.4993	3	-2	+1
veh5	1.7181	4	+2	+6

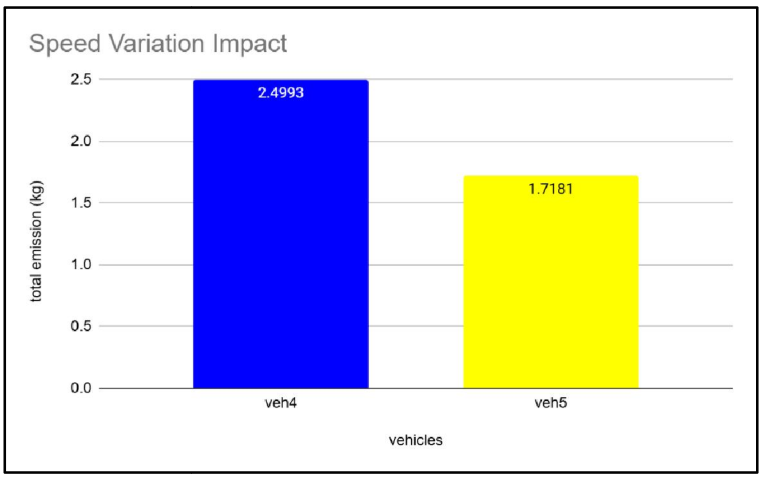

Fig.5. Total emission based on speed

3. <u>Distance-Based Emission Comparison</u>

- Objective: Toexamine the effect of route length on emissions.
- Setup: 2 vehicles were monitored that have the same source and destination,fuel type (Petrol), vehicle type (Car), and maximum speed. They have different routes with varying distances.

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Table 7. Predefined Parameters For Speed Variation Impact

Vehicle id	vClass	emissionClass	maxSpeed	accel	decel	depart	Route Distance (approx)
veh6	passenger	HBEFA3/PC_G_EU6	33.30	2.60	4.50	0.00	4840
veh7	passenger	HBEFA3/PC_G_EU6	33.30	2.60	4.50	0.00	8015.6

Table 8. Credits Allotted

Vehicle id	Total emission (kg)	Base Credits	Factor-Specific Credits	Total Credits
veh6	1.4171	4	+2	+6
veh7	2.2650	3	-2	+1

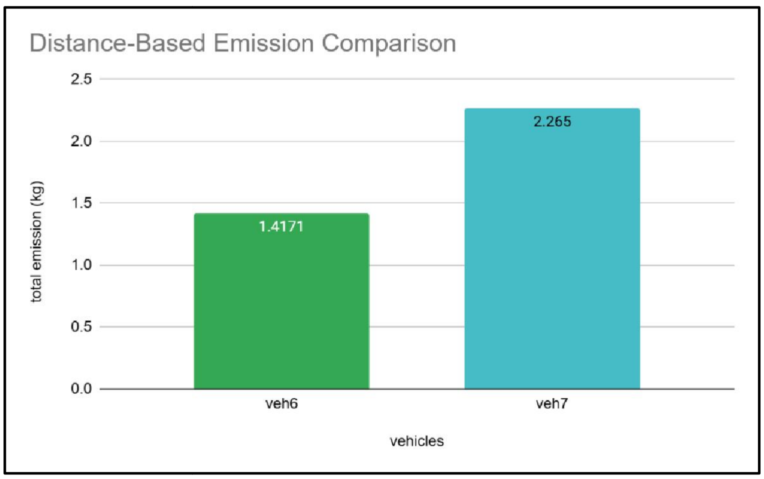

Fig.6. Total emission based on distance

4. <u>Vehicle Type Comparison</u>

- Objective: Tocompare emissions of different vehicle types
- Setup: 4 vehicles including petrol car, bus, moped, motorcycle were monitored that have the same route (distance) but different vehicle types. Parameters such as maximum speed, acceleration, deceleration and fuel type are set according to the vehicle type.

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Table 9. Predefined Parameters For Distance Based Comaprison

Vehicleid	vClass	emissionClass	maxSpeed	accel	decel	depart	Route Distance (approx)
veh8	passenger	HBEFA3/PC_G_EU6	33.30	2.60	4.50	0.00	4000
veh9	bus	HBEFA4/UBus_Std_gt15-18t_Euro-VI_D-E	22.20	2.00	4.00	0.00	4000
veh10	moped	HBEFA3/LDV_G_EU6	37.00	2.60	4.50	0.00	4000
veh11	motorcycle	HBEFA3/LDV_G_EU6	38.90	3.0	5.0	0.00	4000

Table 10. Credits Allotted

Vehicle id	Total emission (kg)	Base Credits	Factor-Specific Credits	Total Credits
veh8	1.1291	4	-2	+2
veh9	5.1616	1	+2	+3
veh10	0.9841	4	+1	+5
veh11	1.1342	4	-1	+3

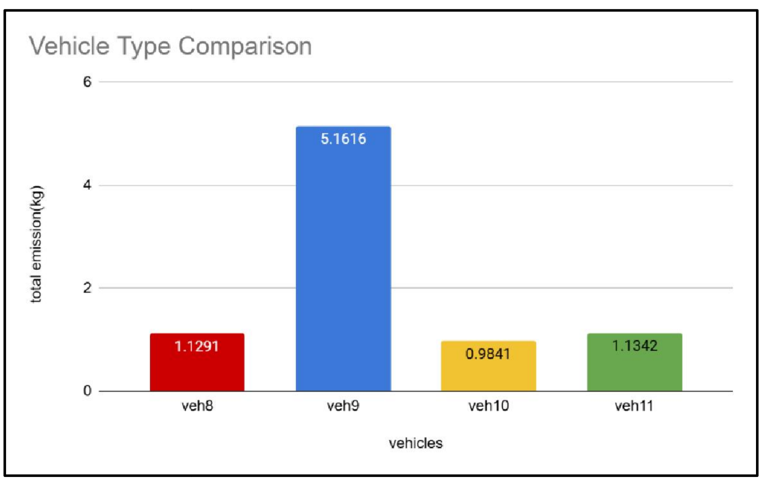

Fig.7. Total emission based on vehicle type

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5. Driving Behavior Comparison

- Objective:To analyze how driving behaviour influences emissions for the same trip
- Setup:2 vehicles were monitored that have the same route (distance), fuel type (Diesel), vehicle type (Car), and maximum speed. They have different acceleration, deceleration, sigma, lcAssertive, lcPushy, lcImpatience values (which makes the driving behaviour different for both cases).

Table 11. Predefined Parameters For Vehicle Type Comparison

Vehicle id	**vClass**	**emissionClass**	**maxSpeed**	**speedFactor**	**accel**	**decel**	**sigma**	**lcAssertive**	**lcPushy**	**lcImpatience**	**depart**	**Route Distance (approx)**
veh12	passenger	HBEFA3/PC_D_EU6	33.30	normc(0.80,1.00)	4.00	5.00	0.40	0.5	0.00	0.00	0.00	4000
veh13	passenger	HBEFA3/PC_D_EU6	33.30	normc(1.30,1.60)	7.00	8.00	0.80	1.5	1.00	1.00	0.00	4000

Table 12. Credits Allotted

Vehicle id	Total emission (kg)	Base Credits	Factor-Specific Credits	Total Credits
veh12	0.3420	5	+2	+7
veh13	0.5070	5	-2	+3

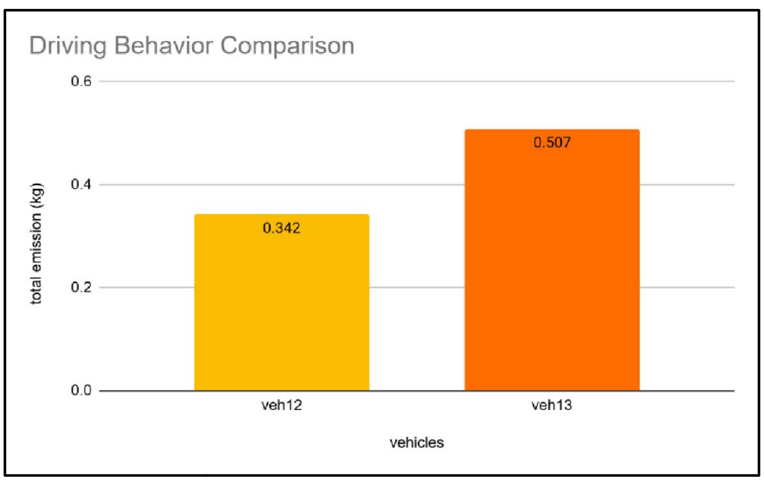

Fig.8. Total emission based on driving behaviour

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Among the emissions obtained, Co2 was the major component. Speed and driving behavior of the vehicle are the major factors which directly influence fuel consumption that is correlated with CO_2 emissions [6,18]. Hence, though the carbon credit allocation system considers total emissions, we did the CO_2-specific analysis for speed and driving behaviour.

Fast-speed vehicles emit 44% more CO_2 than slow-speed vehicles, according to linear regression analysis of CO_2 emissions between the two types of vehicles. This recommends that daily CO2 emissions can be considerably decreased by keeping a slow to moderate pace.

```
# Calculate reduction percentage based on total emissions
reduction_percentage = ((fast_total - slow_total) / fast_total) * 100
print(f"CO₂ Emission Reduction (Based on Total Emissions): {reduction_percentage:.2f}%")

CO₂ Emission Reduction (Based on Total Emissions): 44.44%
```

Fig. 9. Results from Linear Regression Analysis for Speed

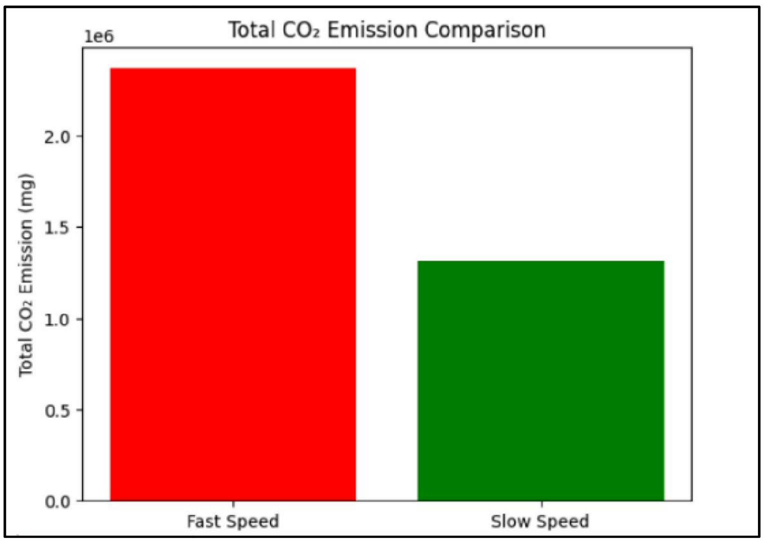

Fig. 10.Linear Regression analysis graph of Total CO2 Emission Comparison for Speed

2. The CO2 emissions from rough and moderate driving styles are compared using a Paired Sample t-test (Dependent t-test). The findings highlight the environmental advantages of smoother driving behavior by showing that cars driven with a rough driving style emit noticeably more CO_2 than those driven with a moderate style.

```
print(f"T-test p-value: {p_value}")
if p_value < 0.05:
    print("Fast acceleration produces significantly more CO₂ emissions than slow acceleration.")
else:
    print("There is no significant difference in CO₂ emissions between fast and slow acceleration.")

T-test p-value: 3.059120002846222e-06
Fast acceleration produces significantly more CO₂ emissions than slow acceleration.
```

Fig. 11.Results based on Speed from Linear Regression Analysis

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It was found that faster speeds and aggressive driving tend to higher CO emissions, making it the most relevant metric for these factors.Other pollutants like CO,NOx, HC and PM also cause air quality degradation and public health risks. Since our carbon credit system is designed to incentivize emission reductions holistically, it incorporates these pollutants as well in credit allocation.

V. CONCLUSION

The "SUMO Simulation based Total Emission Estimation for Vehicles with Carbon Credit System" is a novel and effective method for tracking and mitigating car carbon emissions. The system precisely estimates the emissions from SUMO simulation and rewards environment-friendly driving habits using a dynamic credit-based mechanism. The findings by analysis of Speed and Driving Behaviour reinforce that driving at high speeds raises CO_2 emissions by 44% over low-speed driving, while aggressive driving styles cause much higher emissions than customary driving. These outcomes emphasize the necessity of controlled and smooth driving habits for sustainable mobility.

The system not only improves transparency in emission monitoring but also provides useful insights for policymakers and individual users alike, facilitating data-driven decision-making in emission control policies. Future studies can aim at incorporating sophisticated AI-based optimizations and scaling the system's application to larger transportation networks to further enhance its effectiveness in lowering urban carbon footprints.

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