SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I6P115

Volume 12 Issue 6, 190-200, June 2025

Original Article

Carbon Emission Benchmarking in University Campus: Strategic Development Toward Net Zero Transition

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Received: 12 April 2025 Revised: 16 May 2025 Accepted: 15 June 2025 Published: 28 June 2025

Abstract *- With the increase in population, resource limitation will be the upcoming major challenge. To cope with the same ground-level awareness and sensitization, the utmost need is to fulfil Net Zero's nationally determined commitment and vision. Universities have a key role in preparing youth with Net Zero-capable competencies in the wake of climate change and the imperative for transition innovation. This paper provides a benchmarking strategy to measure and contextualize academic institutions' carbon dioxide (CO_2) emissions, providing information from a real-time case study of finding per capita footprint analysis during campus operations. The study combines spatial factors—latitude, longitude, and climatic profiles—to determine regionally relevant standards. It provides institutions with a comparative frame of reference to analyze their emissions against environmental and location variables. Referred from the Intergovernmental Panel on Climate Change (IPCC), the data collection, analytics, methodology framing as well as literature collation, scoping emissions by scope and determining sectoral hotspots in infrastructure, utilities, mobility, and resource consumption, process is illustrated as short Greenhouse gas campus study. The research also examines how strategic policy-making would have a decisive impact on emission patterns. The most important mitigating pathways are advanced, such as using carbon sinks, campus-level auditing systems, and electronic inventory models. By emphasising integrating geospatial intelligence with institutional planning for sustainability, the research suggests a transparent and accurate working guide for universities to benchmark, track, and minimize their carbon footprint. The benchmarking model promotes informed decision-making and facilitates long-term harmonization with national and international Net Zero ambitions.*

Keywords *- Benchmarking of Net Zero Campus, baseline data identification, greenhouse gas emission, Sustainable campus.*

1. Introduction

In the age of climate exigency and international commitment to global sustainability, education's contribution towards realising a low-carbon, resilient future has perhaps never been more imperative. In 2024, India's higher education sector is one of the largest and most widespread globally, with about 1,213 universities and more than 58,000 Higher Education Institutions (HEIs), enrolling nearly 43.3 million students. This broad academic community is a strong lever for promoting national sustainability action and speeding up the shift to a low-carbon economy. Incorporating net zero and sustainability values into the very activities of HEIs—curriculum, research, operations, and community outreach—can catalyze the transformation of society at large by developing students with the understanding, competencies, and values needed for climate leadership. Universally, institutions are increasingly embracing Environmental, Social and Governance (ESG) principles and pledging Net Zero goals in the face of growing climate demands. Still, a decisive gap remains in India: the intellectual environment is still not well enough integrated with the changing needs of the green economy. *The governance* part also lacks policies relating to net zero committed targets, and even the basic awareness of mindset is still a lagging factor.

Despite the increasing need for experts in renewable energy, carbon accounting, sustainable finance, and supply chain decarbonization, few graduates possess the skills necessary for employers, creating much scope per India's demographic dividend [1]. This research fills this gap by reverse-engineering the job functions across the ESG and Net Zero industries to determine primary skills and competencies and inform strategic curriculum reform would be directly abridged by implementing such type of real case studies carried out in this paper. By linking the outputs of academics with actual needs for sustainability in the real world, this study seeks to increase employability among graduates, enable institutional climate action, and make Indian HEIs central drivers of the international net zero drive [2].

Progression towards carbon-neutral campuses is actively facilitated through institutional initiatives, ranking frameworks, and national policies integrating sustainability into higher education systems. The Smart Campus Cloud Network (SCCN), involving over 450 universities, is a collaborative digital platform for tracking and managing Greenhouse Gas (GHG) emissions. By leveraging real-time data monitoring, universities can implement energy efficiency measures, promote renewable energy adoption, and introduce behavioral change programs for students and faculty. Additionally, SCCN allows universities to analyze government policies on plastics, electronic waste, and energy consumption, linking their sustainability efforts with broader environmental governance trends through digital media engagement [3].

2. Rising Focus on Sustainability

The National Institutional Ranking Framework (NIRF) and the National Assessment and Accreditation Council (NAAC) have reinforced sustainability integration by incorporating carbon neutrality, resource efficiency, and energy conservation into institutional assessment criteria. These metrics influence university rankings domestically and internationally, encouraging organizations to introduce this concept into their academic research initiatives, campus operations, etc. [4]. India has mapped out important milestones like phasing out coal in 2060 and having 1,700 GW of solar power, 557 GW of wind, and 68 GW of nuclear power by 2050. Transport-wise, the aim is to have electric vehicles comprise 84% of car sales and 79% of truck sales by 2070, while 84% of transport will be running on biofuels. However, achieving net zero will demand a whopping $12.4 trillion in investments from both local and international investors. The greatest challenge in the current times is to connect the given problem with our day-to-day needs, which means neglecting any problem until it comes into your house is not a better way, especially when climate change is the goal and net zero is the aim great transformations and incentives from all the sides must be set on the complex problems emerging due to industrialization age.

At the policy level, regulatory bodies such as the University Grants Commission (UGC) and the All-India Council for Technical Education (AICTE) have introduced guidelines to increase energy-efficient infrastructure, sustainable waste management systems, and renewable energy integration on campuses [5]. However, to be effectively implemented, these policies must be blended with practical education models that encourage students to engage in hands-on sustainability projects, behavioural studies, and real-world applications of net-zero concepts. Without experiential learning and psychological reinforcement, sustainability education remains theoretical rather than transformative [6]. The case study included in this paper provides empirical data demonstrating how practical exposure to carbon neutrality initiatives enhances student engagement, environmental responsibility, and institutional sustainability impact.

3. Literature Survey & Problem Statement

Several studies have focused on assessing the carbon emissions of institutional areas to assess their sustainability efforts and identify areas for improvement. Analyzed by Nigeria's Federal University of Agriculture in Abeokuta to establish a baseline for future mitigation efforts. Developed a process to identify the average carbon footprint of a Shanghai University student, emphasizing the effects of daily living, travel, and educational pursuits. Similarly, [7] assessed the GHG emissions of the University of Cape Town to judge its sustainability level with other academic institutions. [8] proposed a framework called CaNSEC to assess carbon neutrality and sustainability in educational campuses, aiming to facilitate comparisons between institutions and encourage mutual learning. [9] illustrated the trajectory for determining the carbon footprint on university campuses and identified stressors, particularly focusing on emissions related to Scopes 1 through 3. [10] utilized a downstream-cradle to-grave assessment approach to assess the emission of campus, considering sources such as steam generation, electricity, transportation, and paper usage. Furthermore, [11] created carbon footprint and mitigation plans for the USP Marine Campus, highlighting the significance of greenhouse gas and environmental control on campus. [12] examined carbon dioxide emissions from spectators' transportation in collegiate sporting events, comparing on-campus and off-campus stadium locations. Last but not least, [13] used machine learning and ecological footprint assessment to assess students' carbon emissions and campus sustainability, emphasizing the role of colleges in spearheading low-carbon transitions and ecological civilization. These studies collectively contribute to understanding carbon footprint identification per capita in university campuses, emphasizing the importance of assessing and reducing emissions to promote environmental sustainability within educational institutions [14, 15].

Considering the process of carbon emission identification, scope-wise distribution is carried out, and initial boundaries are set up after recognizing the identified areas and components to measure. This research aims to establish a framework that can assist universities in aligning themselves with Net Zero targets through focused emissions assessment and strategic planning. The particular research aims are:

- To determine universities' baseline carbon dioxide (CO_2) emissions by measuring per capita footprints and scoping emissions in infrastructure, mobility, utilities, and resource use.
- To incorporate spatial elements such as latitude, longitude, and climate profiles into measuring

institutional emissions, setting regionally contextualized standards.

- To determine vertical-based emission hotspots in campus operations through empirical pilot studies to facilitate strategic mitigation via carbon sinks, energy optimization, and electronic inventory systems.

In order to assess the role of institutional policy and governance on emission trends, especially in infrastructure development, management of operations, and sustainability planning. To set an example for universities to monitor, audit, and benchmark their carbon footprint, enabling conformity with national and international Net Zero policies and informing well-informed decisions. The study aims to calculate the total CO2 emissions and determine the per capita value by addressing this work [16].

4. University Campus Detailing

The current research focuses on K. R. Mangalam University, a multidisciplinary higher educational university situated along Sohna Road in the Haryana district of Gurugram, India, geographically located at 28.16° N latitude and 77.04° E longitude. The university campus is strategically placed along the industrial corridor, joining Manesar with the National Capital Territory of Delhi, marking a familiar backdrop of rising academic centres throughout India. As a fast-expanding university with growing trends in admissions, KRMU is representative of the broader issue learning institutions face regarding balancing ecological balance with infrastructure expansion.

Concerning the 2022–2023 academic year, the research collected and examined environmental data for a constant population group of 3,623 residents to evaluate the university's ecological impact and carbon footprint. The objective was to explore how a university campus, generally low on the sustainability agenda, might shift towards a net-zero carbon approach.

The building has a 521,435.682 sq. m built-up area and major sustainable infrastructure in the form of a 100 KLD STP for sewage treatment, 17 rainwater harvesting pits with a capacity of 54,672 liters, and 52,000 sq. m of area suitable for green cover. It was found through biodiversity surveys that 120 bird and 40 butterfly species are in the campus ecosystem. A 310-kW solar power facility allows an offset of about 730 metric tons of CO_2 per annum by producing 912,489 kWh/year. Four sets of Diesel Generators (DG) are kept under tight emission standards, with the creation of waste oil limited to 275 liters per year. The campus is also moving towards green mobility by adopting electric vehicles. All environmental clearances, including fire protection and air-water consents, are effective until 2026 and are under compliance reporting under national guidelines (EIA Notification, 2006).

Table 1. Emission formulas

Emissions to Air	Emissions to Water	Emissions to Land
E_air_stationary = ∑(FC_i × EF_i) FC_i: Fuel consumption (litres or kg), EF_i: Emission factor (kg CO_2e/unit fuel) *Purchased Electricity (Scope 2)* E_air_electricity = (EC_grid − EC_renewable) × EF_grid EC_grid: Electricity from grid (kWh), EC_renewable: Solar/wind generation on site (kWh), EF_grid: Grid emission factor (kg CO_2e/kWh) *Air Travel (Scope 3)* E_air_travel = ∑(D_i × EF_flight,i) D_i: Distance flown (km), EF_flight,i: Emission factor per km by flight type	*Wastewater Treatment* E_water_WWT = V_wastewater × (EF_CH_4 + EF_N_2O) V_wastewater: Volume treated (m^3), EF_CH_4 ≈ 0.6 kg CO_2e/m^3, EF_N_2O ≈ 0.2 kg CO_2e/m^3 *Chemical Discharge* E_water_chemical = ∑(M_i × EF_i) M_i: Mass of chemical i (kg), EF_i: Emission factor (kg CO_2e/kg chemical)	*Solid Waste Disposal* E_land_waste = ∑(WQ_i × EF_waste,i) WQ_i: Quantity of waste (kg), EF_waste,i: Emission factor (e.g., landfill ≈ 1.9, incineration ≈ 2.9, compost ≈ 0.2 kg CO_2e/kg) *Fertilizer/Manure Use (Soil Emissions)* E_land_soil = ∑(N_i × EF_N_2O,i × GWP_N_2O) N_i: Nitrogen applied (kg), EF_N_2O,i: Emission factor for N_2O ≈ 0.01 kg N_2O/kg N GWP_N_2O: Global warming potential for nitrous oxide (typically 273–298)
Total Emission Baseline: Overall, Campus Emissions E_total = E_air_stationary + E_air_electricity + E_air_HVAC + E_air_travel + E_water_WWT + E_water_chemical + E_land_waste + E_land_soil		

As per the World Economic Forum, the sector potential will unlock a $15 trillion economic opportunity by 2070, creating over 50 million net new jobs in India. With concerted action, up to $1 trillion of this opportunity could materialize within the next decade.

India has a demographic dividend in this context, as Indian youth is projected to make up about 76% of the global population by 2030. Thus, such activities will strive hard to fill such gaps.

4.1. Climate Profile Building

Climate change directly impacts air quality, an important consideration in developing baseline Greenhouse Gas (GHG) emission studies at the university level. Universities wishing to benchmark and reduce emissions need to consider climate-driven changes to air quality since they have immediate implications on operational energy use and public health. Outdoor air pollution, for example, is heightened by temperature and precipitation variability, which amplify ground-level ozone (O_3) and particulate matter (PM2.5), resulting in compromised air quality that frequently carries over indoors via HVAC systems [6]. This variability amplifies indoor pollutant exposure and energy requirements for ventilation and filtration. The increasing number of wildfires—a byproduct of extended dry seasons and increasing temperatures—has worsened smoke-caused air pollution events, compromising visibility and respiratory function throughout campus settings. This adds to transient emission peaks with more use of mechanical air recirculation and backup systems. Climate change also changes the cycles of airborne allergens, lengthening pollen seasons as a result of increased CO_2 and increased temperature, thus enhancing allergic responses among campus communities and boosting HVAC consumption for comfort and air purification. These effects on indoor air quality are paramount to the well-being of students and staff and directly influence the university's carbon footprint, which requires them to be included as parameters in emissions benchmarking. Thus, including API (Air Pollution Index) data, seasonally trending pollutants, and HVAC-related energy profiles in GHG baseline studies enables institutions to contextualize emissions more precisely, predict peak loads, and design mitigation approaches accordingly. This air quality-based assessment serves as a working checklist, connecting environmental health metrics with operational emissions and finally enhancing institutional alignment with national and international Net Zero objectives [19].

5. Scope-Based University Campus Emission Assessment

Based upon scope-wise categorization, the checklist can be prepared based on the data recorded, and annual emissions can be carried out based on consumption patterns.

5.1. Liquefied Petroleum Gas Cylinder CO_2 Emission

Using LPG cylinders on campus significantly adds to the university's general carbon footprint, especially with year-round usage over summer and winter semesters. About 58 LPG cylinders are used annually, each holding about 14 kilograms of gas. This means the general yearly consumption stands at 728 kilograms. Applying the average emission factor of 2.983 kg CO_2 per kilogram of LPG—taken from the GHG Protocol Calculation Tools—the corresponding carbon emissions amount to about 2,174.98 kg CO_2, or about 2.42 metric tonnes annually. Although appearing relatively small, this figure for emissions becomes important within the realm of institutional sustainability analysis. It highlights the importance of tracking and managing such indirect emissions through improved fuel efficiency, alternative power, and specific mitigation measures to align with wider Net Zero targets [17, 18].

5.2. Printing Carbon Emission

Paper usage in university operations is a major contributor to carbon dioxide (CO_2) emissions, mainly caused by academic and administrative work. The major contributors are examinations, circulars, and general paperwork, contributing to an estimated monthly usage of 150 to 200 reams of paper. Yearly, this amounts to an approximate CO_2 emission of 7.2 tonnes (7,200,000 grams). Aside from scholarly printing, non-academic materials—like disposable cups made of paper, plates, cardboard items, and paper waste pertinent to projects—contribute an estimated 4 kilograms of CO_2 per day. Yearly, this is around 1.68 tonnes (1,680,000 grams) of CO_2. Together, the paper-based emissions stand at around 8.88 tonnes of CO_2 per year, which highlights the carbon footprint of the campus' dependence on paper. To reduce these emissions, the university may implement digital document management to limit dependency on paper. Changing to electronic media for examinations, notices, and submission of projects would help reduce paper usage substantially. By embedding green IT practices and advocating a paperless environment, institutions can progress toward a lower-carbon working model that enables more general sustainability and Net Zero goals [20].

5.3. Solar Generation, Diesel Utilization & Electricity Consumption Emission Contribution

Carbon accounting is the present-day term used to obtain the actual status of emission and absorption. The data highlights monthly solar generation, electricity usage, and the corresponding CO2 emissions. It is essential to accurately adjust solar CO2 emissions to reflect the real reductions achieved from using electricity, ensuring a precise understanding of environmental impact mitigation. Solar generation data for each month indicates varying levels of electricity generated, alongside consumption figures and corresponding bills. For instance, in June 2023, solar generation amounted to 37,307 units, offsetting a part of the total consumed units of 2,733,033. Similarly, May 2023 provided solar generating 36,168 units against a consumption of 1,869,414 units. This data highlights the potential for solar to mitigate conventional electricity use and consequent CO2 emissions. To accurately reflect the environmental impact, adjustments are necessary to account for the reduction in CO2 emissions attributable to solar generation. The annual total solar generation stands at 1,130,153 units, resulting in a calculated CO2 emission of approximately 956,109.6072 grams, or 433.60 tonnes annually. This underscores the environmental benefit of solar energy in reducing carbon footprints [21].

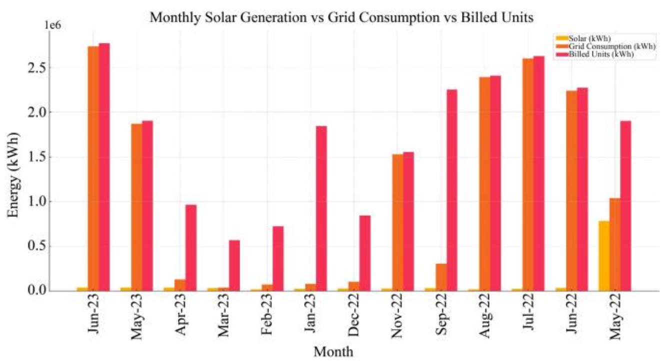

Fig. 1 Solar consumption and electricity bill recordings of KRMU campus

As per figure 1, the graphical overview points to a crucial reliance of the institution on grid power even as it has a functional solar energy system. Throughout the months, solar output is persistently lower—less than 10% in most instances—than grid-sourced power, which is the predominant component of the total energy mix. In May 2022, a uniquely high solar generation value was recorded, which seems to either be cumulative or an outlier. The charged units closely follow the grid usage, reflecting a high correlation between use and cost. This movement highlights a greater necessity for expanded solar facilities, better net metering systems, and possible integration of energy storage devices to minimize fossil-fuel-based emissions. Strategically improving solar coverage can significantly reduce the carbon footprint of campus activities and help towards Net Zero goals [23].

5.4. Transport Fleet CO_2 Emission

The university transport fleet encompasses various vehicle types and fuel sources, mirroring diverse commuting patterns by hostel residents, faculty and staff, private cars, and intercity government transport services. Obtaining accurate data across this range of transport modes is a formidable challenge, which was overcome through organized Google Forms for recording vehicle types, frequency of use, and commuting distances. The fleet comprises petrol-driven two-wheelers (2W) and four-wheelers (4W), as well as diesel and Compressed Natural Gas (CNG) vehicles. Petrol-driven 2W and 4W vehicles have daily fuel use between 0.88 and 6.25 litres, corresponding to a yearly usage between 78.95 and 562.50 litres per vehicle. Diesel-driven 4W automobiles, such as larger utility and SUV cars, have larger fuel requirements—usually 4.17 to 6.25 litres per day, with a yearly consumption of 100.00 to 562.50 litres per car. CNG-fuelled buses and local transport services contribute the most to the fleet emissions, with a daily consumption of between 5.00 and 7.50 litres per vehicle and an annual consumption of 700.00 to 900.00 litres [22, 24].

Together, the official fleet of the institution—especially its four-wheeler buses—is mainly responsible for the campus's carbon footprint, with an estimated annual output of about 21,668.91 tonnes of CO_2. Transport has become the largest emitter across all categories, and as such, it is a vital intervention area through targeted interventions like optimized routes, fuel-efficient scheduling, vehicle electrification, and encouraging sustainable commuting options.

Advancements in technology are profoundly reshaping the transport sector, ushering in solutions that enhance efficiency, safety, and sustainability. Technologies like GPS for real-time vehicle tracking and route optimization, alongside advanced traffic monitoring systems with sensors and analytics, are revolutionizing how transportation networks are managed. Commuters benefit from smartphone apps that provide live traffic updates and alternative routes, while predictive analytics leverages data to forecast demand and refine transport services [25]. Telematics systems in vehicles optimize efficiency by monitoring performance metrics and fuel consumption.

Table 2. Comparison of framework for data collection

Parameters Covered	Total CO2 Emission (Tonnes/Annum) - Manual	Present Manual Way Utilized for data collection	Technology-Based Mapping Approach
LPG Consumption	116.41	Bills from the Agency, km records of office from a university campus	Real-time IoT monitoring for accurate tracking
Transport Fleet	21668.91	Petrol bills, maintenance bills, kilometer-based route charts	GPS-enabled transport tracking to optimize routes and reduce emissions
Printing Emission	9.79	Ink packet consumption and bills, paper count, sent for waste	Digital printing logs for precise paper usage calculations
Electricity Emission	12854.01	Electricity bills, and metering records for solar, diesel log book, waste part for DG set	Smart energy meters for continuous energy use assessment
AY-2022-23 Total Emissions	34649.12	IPCC, ISO 14064, and excel based calculations	Dynamic, real-time emission tracking system
Per Capita Emission	8.66 Tonnes CO2 Per Person	The scope of improvisation exists for traceability measures and emission factors.	Automated dashboard with individual footprint tracking

Environmental sensors and AI-driven algorithms are pivotal in managing emissions and improving environmental impact, fostering a greener, more sustainable transportation ecosystem. These integrated technologies empower transport authorities and commuters, driving a smarter and eco-conscious era of mobility. The total emissions of the university calculated are provided hereby in Table 2.

These factors combine to produce 34,649.12 tonnes of CO_2 emissions annually for the academic year 2022-23. This translates to an average contribution of 8.66 tonnes of CO_2 per person, emphasizing the collective obligation to lower carbon emissions and adopt sustainable practices in all university operations [26].

6. Role of Data Collection and Methodology

Creating meticulous data sets and emission calculation methods undertaken for campus align closely with the rigorous standards set by Verra and the Clean Development Mechanism (CDM) under the Kyoto Protocol. These practices meet the current emission reporting requirements and lay a strong foundation for future certification or validation processes under Verra or CDM, demonstrating a commitment to transparent and verifiable greenhouse gas accounting practices essential for carbon offset projects and climate change mitigation initiatives. Data inconsistencies are swiftly identified and rectified using advanced machine learning and automation tools. Being a cradle of knowledge, special courses must be designed to mitigate the technology transition challenges of industries. Net zero practices and solutions can bridge that gap. The quantification of CO_2 emissions has been the subject of various studies. As provided by, Jain et al. (2013) explored carbon footprinting in Indian higher education institutions, emphasizing the need for precise data collection and analysis. Similarly, the work of Röder et al. (2019) on CO_2 emissions from universities in Europe highlights the variability in emissions due to different operational practices and energy sources. The study by Bonini and Banchi (2018) emphasized the significance of sustainable practices and offered insights into how renewable energy can lower campus emissions. Together, these studies highlight how crucial thorough data collection and adopting sustainable practices are to lowering CO_2 emissions. The challenges in obtaining accurate data and the variability in emissions due to different institutional practices were studied [27-29].

Data placement for app building can be carried out to quantify and improve the GHG emission inventory building and multiple access [35-37]. Transportation, particularly diesel and petrol engines, is a major contributor to emissions; the second is energy consumption. Despite the use of solar power, the utilization of diesel generators and higher dependency on coal-based generation will introduce higher emissions with high electricity demand. As per location, some considered weather conditions, including temperature and wind speed, influence energy consumption patterns. For instance, higher temperatures with higher moisture seasons may lead to increased use of air conditioning, thus raising electricity consumption and associated emissions. Hence, in-house moisture control and temperature-holding assets must be maintained, especially during monsoon and dry summers.

7. Regression Analysis with Used Cases Comparison

Traditional parametric modeling approaches have been common in analyzing these factors but are limited by their predefined parameters and lack of flexibility. With the advent of algorithms, the solutions to various problems are obtained by taking the help of artificial integration and machine learning. Similar cases are discussed here, and two similar modeling practices will be detailed afterwards. Machine learning’s Bayesian nonparametric kernel prediction algorithm forecasts CO_2 emissions in a particular case study. Relevant independent variables were found with the help of an extensive literature review. Gaussian Process Regression (GPR) algorithms, robust least squares, and classical least squares are used to summarize their evaluation criteria and prediction performance. The suggested algorithms' dependability and effectiveness are shown by comparisons between actual data and predicted outcomes, with GPR emerging as the most accurate CO_2 emission predictor [30]. Similar approaches to predicting CO_2 emissions are provided in references [31, 32]. The initial paper utilizes Multiple Linear Regression (MLR) for estimation but with different objectives. It employs a multiparameter linear regression model, highlighting the thorough examination of various predictors. On the other hand, the second paper [32] delves into CO_2 emissions prediction separately for the UK and Malaysia, showcasing distinct predictors for each country, including agriculture and transportation. Another work in [33] introduces a multivariate grey prediction model. It integrates feature selection and residual modification to boost accuracy. This methodology reflects a nuanced comprehension of refining prediction models and their impact on emissions forecasting. work also integrated various machine learning techniques like MLR, SVM, RF, and CNN models, allowing for a comprehensive exploration of diverse prediction methods to analyse their effectiveness in CO_2 emissions prediction. Additionally, the occasional absence of data points in CO_2 emissions forecasting can be addressed through regression techniques in machine learning, exemplified in this study by a meticulous approach to data management and statistical analysis. Employing Ordinary Least Square and Weighted Least Square methods ensures the reliability and consistency of predictions, bolstering the robustness of predictive modeling techniques in environmental research. The studies keep multiplying with changes in constraints, techniques, etc., even from the traditional regression approaches to advanced machine learning techniques, each offering unique insights and contributions to the field. Each research approach [34, 35] can contribute valuable insights in shaping strategies for CO2 emissions inside a university campus. Multiple benefits can be stated. Technological mapping can be directly used to improve logistics operations involved in transport operations, as provided in Table 3.

Table 1. Technology required to map emissions

Service Facility	Relevant Technologies
Precise Emission Prediction	IoT Sensors, Building Management Systems (BMS), GIS Tools
Forecasting Emission Trends	Predictive Analytics (ARIMA, Prophet), Digital Twins, Data Visualization Tools (Tableau, Power BI)
Improved Sustainability Rankings	Carbon Accounting Tools (Carbon Trust), Accreditation Software (LEED, ISO 14001)
Comprehensive Analysis	Machine Learning Frameworks (SVM, RF, CNN with TensorFlow), Big Data Platforms (Apache Spark)
Addressing Data Gaps	Data Imputation (AI techniques), Cloud Warehousing (AWS Redshift, Google BigQuery), Blockchain for Integrity

8. Sequential Inferences and Study Conclusions

The work started by importing libraries like (pandas, numpy,matplotlib, and sklearn) for data manipulation, numerical operations, visualization and machine learning implementation. The database, which we called "fuel consumption", is loaded. It is then divided into training and testing sets using the 'Stratified random sampling' method, in which 80% of the data and 20% are used for the training and testing. Modeling features, such as engine size, number of cylinders, and fuel consumption features, are chosen and retained. The target variable is specified, and a linear regression model is instantiated and trained using the training data and selected features.

The model's performance is evaluated using the R-squared score on the test data, with the result printed to the console. Users input the characteristics of a vehicle, and the trained model predicts its CO2 emissions. A scatter plot is used to visualize the actual versus predicted CO2 emissions for the test data, with the x-axis representing actual emissions and the y-axis representing anticipated emissions. The R-squared score reflects the model's fit to the test data, with higher scores indicating better predictive ability. Visualizing actual versus predicted emissions enables a qualitative assessment of the model's accuracy.

This code demonstrates the practical application of linear regression for predicting CO2 emissions in cars, with potential uses in environmental impact assessment and regulatory compliance—dependency over direct and indirect parameters required for modeling the co2 emission AI model. Direct parameters are fuel type and consumption, vehicle or equipment type, and distance travelled, while indirect parameters are population density, economic indicators, land use patterns, energy sources, climate and weather conditions, maintenance intervals, and issues solvency level.

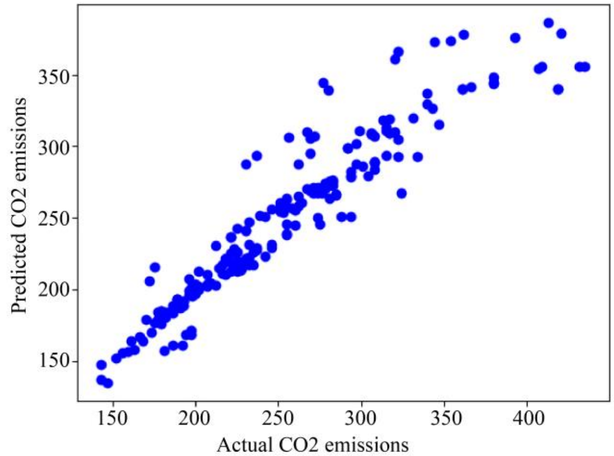

Fig. 2 CO_2 estimation with regression model

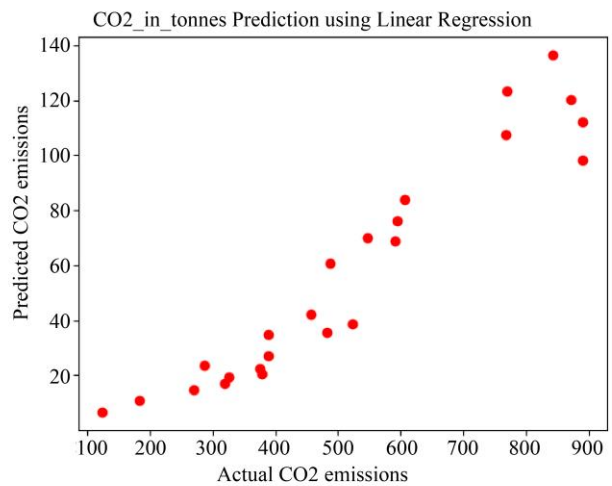

Fig. 3 CO^2 estimation of K R Mangalam University busses

As the simulation part is considered, the output of the first case provided 260.91 MT of emission as per the dataset, as shown in Figure 2 [36-38]. The second case represents the university database of buses: it comes out to be 47.41 MT. as plotted in Figure 3 and summarized in Table 4.

Table 4. Case wise result comparison

First case (case of vehicles database)	Second case (case of University Buses database)
R2 score: 0.884 = 88.4%	Mean squared error: 34.599
Predicted CO2 emissions: 260.91MT	R-squared score: 0.964 = 96.4%
Enter the fuel consumption: 15	Predicted CO2_in_tonnes: 47.41 MT

The model explains roughly 88.4% of the variance in the CO2 emissions data, according to the first process's R-squared (R2) score of 0.884. When predicting CO2 emissions for a new car with an engine size of 2 or 4 cylinders and fuel consumption values provided by the user, the model predicts a CO2 emission of approximately 260.91 metric tonnes. On the other hand, in the second process, the Mean Squared Error (MSE) is 34.599, and the R2 score is 0.964.

The R2 score indicates that the model explains approximately 96.4% of the variance in the CO2 emissions data. When predicting CO2 emissions for a new car with the provided features, the model predicts a CO2 emission of approximately 47.41 metric tonnes. Comparing the two processes, the second process has a higher R2 score and lower MSE, suggesting that it provides a better fit to the data and more accurate predictions than the first. Additionally, the predicted CO2 emission in the second process (47.41 metric tonnes) is substantially lower than in the first process (260.91 metric tonnes).

Both approaches aim to predict CO2 emissions using linear regression models and visualize the results through scatter plots. However, they differ in their methods of data splitting and evaluation. The first method divides the data into training and testing sets using the train_test_split function, computes the Mean Squared Error (MSE) and R-squared (R2) score for evaluating the model, and directly defines new data for prediction. On the other hand, the second method manually separates the data into training and testing sets, computes just the R-squared score for assessment and asks the user to predict CO2 emissions for fresh data. Despite these differences, both approaches effectively predict CO2 emissions and provide insights into the relationship between actual and predicted values.

9. Strategies for Emission Reduction

The Transport Fleet is the largest contributor to CO2 emissions, accounting for 21,668.91 tonnes per annum, significantly outpacing other sources. Electricity Emission follows next at 12,854.01 tonnes per annum. LPG Consumption, though much smaller at 116.41 tonnes per annum, still contributes to the overall emissions, while Printing Emission, at just 9.79 tonnes per annum, has the least impact. Overall, the total CO2 emissions for AY-2022-23 amount to 34,649.12 tonnes per annum, with an average of 8.66 tonnes of CO2 per person. Encouraging students to innovate and develop intellectual property can significantly integrate green credit systems, ecolabeling, and eco-friendly products into university initiatives. Students can lead small projects that optimise resource usage and precisely manage consumption by employing technology to assess and establish a baseline for the university’s Environmental, Social, and Governance (ESG) metrics. This approach not only aids in reducing emissions across various operations but also instils a strong sense of environmental stewardship within the campus community. These student-led efforts have the potential to generate new technologies and sustainable practices, which align with the university's broader sustainability objectives while providing valuable experiential learning opportunities [39, 40].

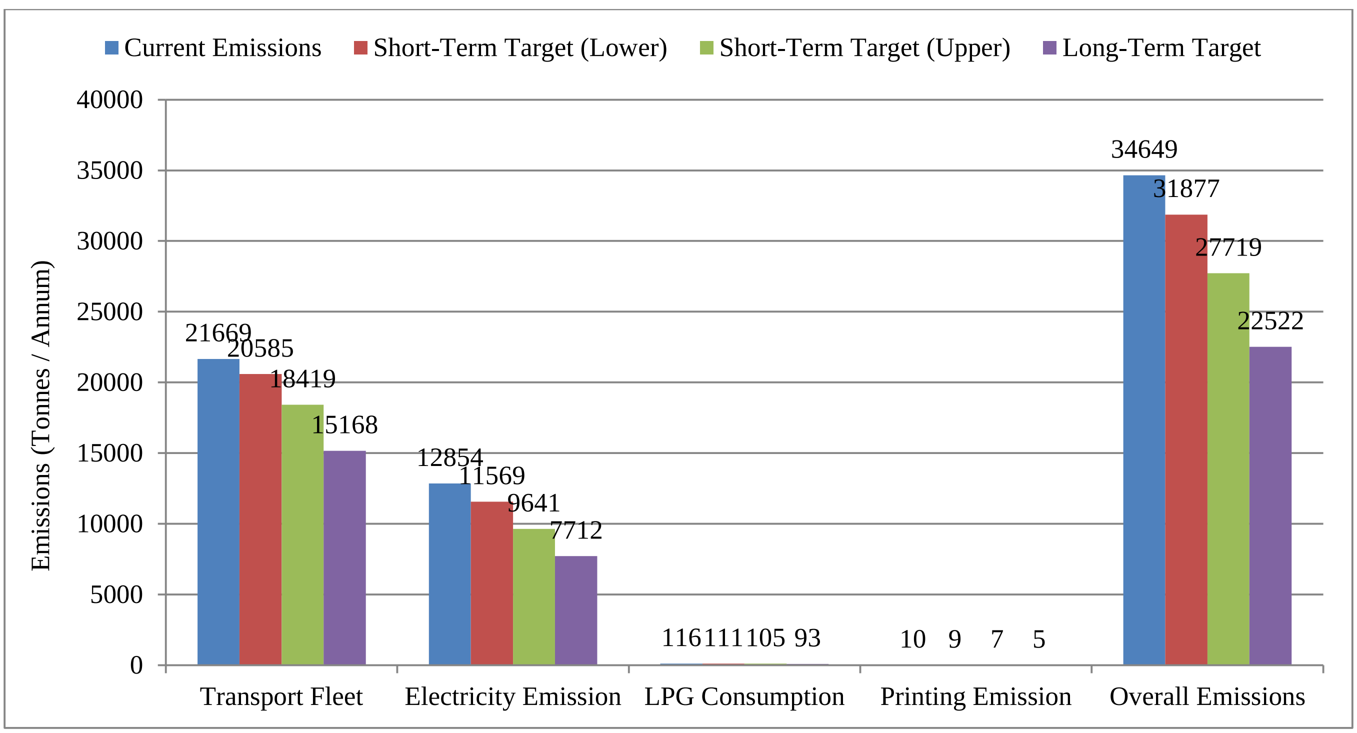

Fig. 4 Strategic process to reduce emission with targeted practices

The graphical comparison in Figure 4 highlights that Transport Fleet and Electricity Emissions are the largest contributors to annual CO_2 output, demanding immediate attention. While short-term goals aim for modest reductions, long-term targets reflect an ambitious decarbonization strategy across all sectors. Strategic interventions like EV adoption, renewable energy integration, and digitalization are key to achieving these emission benchmarks.

10. Conclusion

This study offers a spatially fixing benchmarking approach to evaluate and minimize carbon emissions in higher learning institutions that meets the pressing need for climate action in the context of increasing population pressure and decreasing resources. Having a quantified emission intensity of 8.66 tonnes CO_2 per individual, the research presents a sectoral analysis of emission hotspots—chiefly transport, electricity, LPG consumption, and printing—and identifies operating inefficiencies and behaviors contributing to a university's carbon footprint.

The research formulates region-specific baselines that facilitate comparisons and policy formulation based on evidence by combining latitude, longitude, and climate profiles in emissions analysis. The study shows how educational institutions are well-positioned to be incubators of Net Zero skills and provide students with actionable, evidence-based experience in sustainability. Students educated in GHG accounting techniques provided timely data and actionable ideas such as route optimization, intelligent parking systems, and infrastructure redesign. These solutions are now finding their way into entrepreneurial start-ups and informing policy changes at the institutional level. In addition, the research promotes the mainstreaming of sustainability by adopting institutional practices such as carbon accounting, green purchasing, and resource-conscious campus design.

The suggested strategic interventions are policy action for sustainable building, energy and water audits, and landscaping focusing on carbon sequestration. Also, optimal scheduling of academics and resources can reduce excess energy consumption, synchronizing campus operations with low-carbon objectives. This pilot study underlines the position of universities not only as energy and resource consumers but also as forward-looking drivers of transition innovation.

With the combined application of geospatial intelligence, student-initiated auditing, and institutional governance transformation, the benchmarking model outlined above provides a foundation for long-term alignment with Nationally Determined Contributions (NDCs) and global Net Zero targets. The research identifies the imperative need for universities to implement focused, data-driven measures to lower emissions in areas of high impact, such as transport and electricity. Institutions can establish realistic location-specific carbon reduction targets through a geospatial benchmarking approach and monitor progress in real-time and through audits. In the future, having a clear emissions baseline, integrating Net Zero values in learning and governance, and encouraging open reporting will make universities leaders in climate action and supporters of national Net Zero ambitions.

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