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RESEARCH ARTICLE

Carbon footprint assessment of GKVK campus: A comprehensive GHG inventory based on IPCC and GHG protocol guidelines

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Abstract

The study conducted a detailed carbon footprint assessment of the Gandhi Krishi Vignana Kendra (GKVK) campus, University of Agricultural Sciences, Bangalore, using internationally recognised standards such as the Intergovernmental Panel on Climate Change (IPCC) Guidelines and the greenhouse gas (GHG) Protocol. As institutions are increasingly recognised for their contribution to GHG emissions through energy use, transport, waste and food services, this research quantified emissions across scope 1 (direct), scope 2 (indirect from purchased electricity) and scope 3 (other indirect emissions). Activity data were collected from institutional records, surveys and field assessments, while emission factors were sourced from IPCC (6th assessment report) AR6, the united nations framework convention on climate change (UNFCCC) GHG calculator v2.6 and Central Electricity Authority (CEA) guidelines. The total GHG emissions from the GKVK campus were estimated at 7606.545 tonnes CO_2e/yr, with scope 1 contributing 42.08 %, scope 2 contributing 20.46 % and scope 3 contributing 37.46 %. Major sources included liquefied petroleum gas (LPG) usage (1334884 kg CO_2e), grid electricity (1556180 kg CO_2e), food waste (1622855 kg CO_2e), refrigerant leakage (982430 kg CO_2e) and student commuting (879466 kg CO_2e). While the study provides a comprehensive institutional GHG baseline, it is limited to one academic year and excludes embodied emissions from infrastructure. The findings establish a replicable framework for Indian educational institutions to measure, manage and mitigate emissions. Future research should extend this model to multi-campus assessments and long-term carbon management planning, strengthening the roadmap toward carbon-neutral academic ecosystems and supporting India's broader net-zero commitments.

Keywords: carbon footprint; GHG inventory; IPCC guidelines; scope emissions; sustainable campus

Introduction

Global climate change, largely driven by the accumulation of greenhouse gases (GHGs) in the atmosphere, is one of the most pressing environmental challenges of the 21st century (1-3). According to the Intergovernmental Panel on Climate Change (IPCC), anthropogenic GHG emissions have been responsible for approximately 1.1 °C of global warming above pre-industrial levels (4). The dominant contributors to these emissions include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), primarily originating from energy use, agriculture, industry and waste management sectors (5). CO_2 alone accounts for nearly 74 % of total global GHG emissions (6). In response, international frameworks like the United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol and Paris Agreement have been established, urging member nations to quantify and reduce their emissions through scientifically grounded mechanisms.

Carbon footprint refers to the total emissions of GHGs, expressed in carbon dioxide equivalents (CO_2e), associated directly or indirectly with a person, organisation, event or product (7). Institutions, particularly universities, have emerged as microcosms for studying carbon emissions due to their multifaceted operations involving transportation, energy use, food consumption and waste generation (8, 9). With global transitions toward Net Zero goals, carbon auditing and GHG inventories based on standardised protocols such as the GHG Protocol and IPCC Guidelines have become essential tools for informed policy and operational decisions (4, 10, 11).

India is currently the third-largest emitter of carbon dioxide globally, contributing approximately 7 % of the world's CO_2 emissions in 2022, following China and the United States (12). The country's emissions were estimated at 2.7 billion tonnes of CO_2e in 2022. However, India's per capita emissions remain significantly lower (1.9 tonnes) compared to the global average of 4.7 tonnes. This disparity underscores the country's developmental constraints and the need for equitable climate responsibility (13). The Government of India has initiated numerous programs such as the National Action

Plan on Climate Change (NAPCC), Perform Achieve Trade (PAT) scheme and ambitious targets to achieve 500 GW of non-fossil energy capacity by 2030 (14). Post-COVID recovery policies have also emphasised green infrastructure and circular economy models (15). Universities and public institutions are increasingly being mandated to undertake carbon audits to align with India's Intended Nationally Determined Contributions (INDCs) (12).

As a progressive state, Karnataka has implemented various climate resilience and emission reduction initiatives, including the Karnataka State Action Plan on Climate Change (SAPCC). The state boasts a strong renewable energy base with over 15 GW of installed capacity as of 2023, making it a leader in solar and wind energy. Bangalore, the state capital, houses premier educational institutions, making it a focal point for academic contributions to climate change mitigation. The University of Agricultural Sciences (UAS), Bangalore, located in the GKVK campus, is a critical stakeholder in environmental sustainability due to its dual roles in education and land-based operations. Assessing its carbon footprint becomes essential to establish a baseline for emission mitigation and to promote carbon-neutral campus models.

The GKVK campus spans an area of 1320 acres (5.34 million m^2) and includes academic buildings, laboratories, research farms, hostels and green zones. The campus supports 4524 students, 281 faculty members and over 300 administrative and technical staff. It operates 52 laboratories, 43 institutional buildings and multiple transportation and energy-dependent facilities. The institutional carbon footprint assessment of GKVK is a novel attempt to map its GHG emissions using internationally recognised protocols such as the GHG Protocol Corporate Standard and IPCC 2006 and AR6 guidelines.

The objective of this study is to assess the carbon footprint of GKVK campus using a comprehensive greenhouse gas inventory based on IPCC and GHG protocol guidelines. This objective involves accounting for direct (scope 1), indirect (scope 2) and other indirect (scope 3) emissions from various institutional activities such as fuel consumption, electricity use, commuting, food wastage, paper usage and waste treatment. Emission factors are adopted from IPCC AR6, UNFCCC GHG Calculator v2.6, Central Electricity Authority (CAE) and other relevant sources (16).

The GKVK campus represents a mini ecosystem with diverse land use patterns, ranging from forested patches and green belts to academic infrastructure and experimental agricultural fields. This complexity offers a fertile ground for studying both emissions and sequestration. Key areas of investigation in this study include: quantifying emissions from energy use, transportation, water pumping and waste management; mapping and inventorying vegetation to assess sequestration potential using both literature based and IPCC derived factors; evaluating current eco-friendly practices such as organic farming, composting, water recycling and solar energy adoption; performing a cost-based assessment of emissions and sequestration using standard carbon pricing frameworks.

In light of the global climate crisis, Universities must transform into sustainability leaders through evidence-based action. This research on the GKVK campus aims to establish a robust framework for institutional carbon accounting by integrating ecological, operational and economic dimensions. The outcomes of this study will not only contribute to the scientific community but also guide campus administrators, policy makers and students in adopting strategies that are environmentally sustainable and economically viable.

In the face of escalating global environmental challenges, climate change remains one of the most pressing issues affecting not only natural ecosystems but also human systems globally. The increase in GHGs like CO_2, CH_4 and N_2O is the primary driver of this change, leading to global warming, rising sea levels, extreme weather patterns and disruption of agricultural cycles.

India, as one of the world's largest emitters of GHGs, has been implementing initiatives to reduce its carbon footprint in line with the Paris Agreement. The role of higher education institutions (HEIs) in mitigating climate change is emerging as critical, particularly through sustainable campus practices. However, universities, especially in India, have not been extensively studied in terms of their carbon footprint and sequestration capabilities, despite their potential to become frontrunners in sustainability efforts.

The GKVK campus with its vast land use, vegetation and diverse research activities, provides an ideal setting to assess carbon emissions and sequestration. The campus can potentially become a model for other universities in India by evaluating and reducing its carbon footprint while enhancing its carbon sequestration capabilities. This study aims to fill this gap by evaluating the carbon emissions of the GKVK campus, its potential for sequestration and exploring pathways to carbon neutrality.

Materials and Methods

Methodological framework

The study was conducted within the premises of the Gandhi Krishi Vignana Kendra (GKVK) campus, which is part of the University of Agricultural Sciences (UAS), Bangalore, Karnataka (Fig. 1). Geographically, the campus is situated at 13.07° N latitude and 77.57° E longitude and lies at an altitude of approximately 930 m (3050 feet) above mean sea level. It falls within the eastern dry agro climatic zone of Karnataka (Zone 5), which is characterised by moderate rainfall and a semi-arid environment.

The carbon footprint assessment of GKVK Campus was carried out by adopting an organisational-level GHG inventory approach, consistent with the GHG Protocol Corporate Standard (17) and the IPCC 2006 Guidelines, incorporating the updated emission factors from IPCC AR6 by collecting both primary and secondary data. This framework divides emissions into three scopes:

Scope 1 (Direct Emissions): Emissions from on-site fossil fuel consumption (diesel, petrol, LPG), fugitive emissions from refrigerant leaks (HFC-134a, R-410A) and combustion from generators and laboratory burners (18).

Scope 2 (Indirect Emissions): Emissions from the consumption of purchased electricity supplied by Bangalore Electricity Supply Company (BESCOM). Emissions were calculated using the national grid emission factor of 0.199 kg CO_2e/kWh as published by the CEA (16).

Scope 3 (Other Indirect Emissions): Emissions from student and staff commuting, food wastage, paper usage, wastewater treatment, solid waste disposal and water supply. Each category was calculated based on specific activity data and corresponding emission factors.

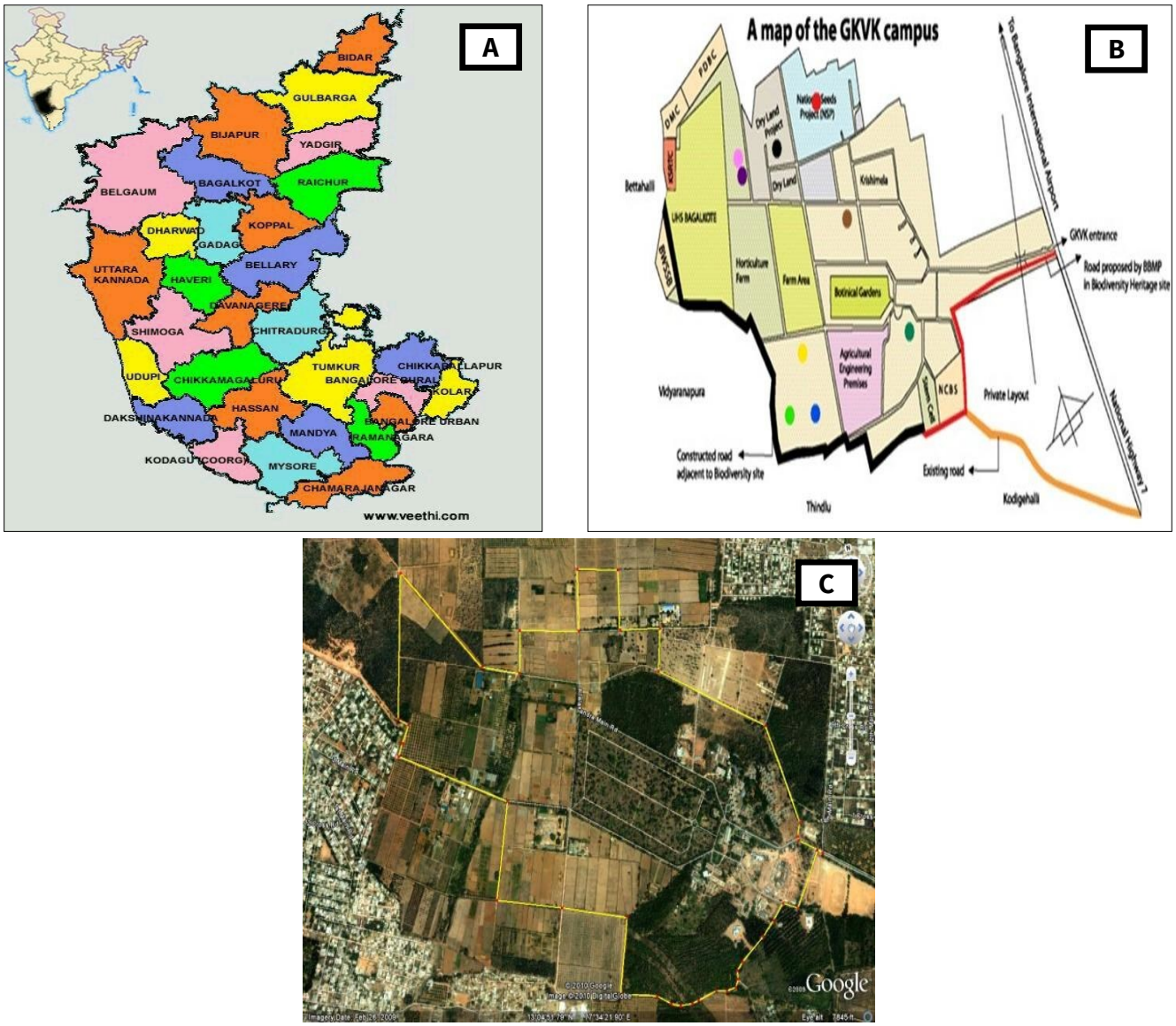

Fig.1: Map depicting the location of the study area.

Source : A - www.veethi.com, B - (19), C - Google Earth

Data Collection was both primary and secondary. Primary data was gathered through field measurements, stakeholder surveys (for commuting patterns) and institutional logs (for utilities and procurement). Secondary data included academic calendars, vehicle logs, electricity bills, canteen supply records and waste management reports and these categories are depicted in Table 1.

Activity Data and Emission Factors

Emissions were computed using the formula:

$$\text{Emissions (kg } Co_2e) = \text{Activity Data} \times \text{Emission Factor} \quad \text{(Eqn. 1)}$$

The Emission factors were sourced from the IPCC AR6 (GWP100 values for CH_4, N_2O, HFCs), the UNFCCC GHG Calculator v2.6, the Central Public Health and Environmental Engineering Organisation (CPHEEO) for water and wastewater and The Energy and Research Institute (TERI) and International Council on Clean Transportation (ICCT) for commuting emissions. Electricity transmission and distribution losses were considered at 8 % as per BESCOM standards. Food waste was estimated from the number of meals served, average meal weight (400 g) and average wastage rate (17 %) and multiplied by an emission factor of 0.91 kg CO_2e/kg (20).

Table 1: Emission categories and the required activity data for calculating CO_2 emissions in GKVK Campus

Sl. No.	Scope	Emission category
1	Scope 1	On campus stationary sources Direct transportation sources
2	Scope 2	Purchased electricity Purchased heat
3	Scope 3	Employee commuting Student commuting Employee official travel Water usage Paper consumption Waste Electricity T and D losses

Note: This structure follows GHG protocol + IPCC guidelines and is aligned with international university GHG reporting methods

Solid and sanitary waste categories were mapped with emission factors from national municipal solid waste databases and UNFCCC norms (21). The assessment also included normalisation metrics such as emissions per capita, per student, per staff and per square meter of built-up area to benchmark GKVK against other Indian and international campuses. This detailed methodological approach ensures replicability, accuracy and alignment with global best practices.

Post-COVID institutional emissions and sustainability trends

Post-COVID changes in academic calendars, hybrid learning models and reduced commuting have influenced emissions globally. In India, institutional GHG footprints saw temporary reductions during lockdowns, but resumed upward trends post-2021. This underscores the need for permanent sustainability transitions such as green energy adoption and modal shift in transport. The carbon footprint assessment of the GKVK campus holds significant academic, institutional and policy relevance. It represents one of the first comprehensive GHG inventories conducted for an Indian agricultural university, using globally recognised methodologies such as the IPCC guidelines and GHG protocol. This positions the University of Agricultural Sciences, Bangalore, as a pioneering institution in integrating environmental accountability into campus operations.

The significance of the study

The findings help establish a data-driven baseline for understanding the environmental impact of key campus activities - fuel usage, electricity consumption, food waste, commuting and waste management. These insights empower the university administration to implement targeted mitigation strategies such as adopting renewable energy, promoting low-carbon transport, reducing food and paper waste and enhancing energy efficiency. These interventions align directly with India's climate action goals and Sustainable Development Goals (SDGs). Additionally, this study enhances institutional transparency and stakeholder engagement. By quantifying its emissions, GKVK can demonstrate environmental responsibility to students, faculty, funders and accreditation bodies. The study also supports potential participation in carbon markets and grants tied to sustainability performance.

From an academic perspective, the carbon inventory serves as a living laboratory for students and researchers to explore applied climate science, carbon budgeting and sustainability policy. It fosters experiential learning and builds institutional capacity in climate governance. Finally, the methodology adopted in this study is scalable and replicable across other academic institutions in Karnataka and India. It offers a structured blueprint for universities to measure, manage and reduce emissions, thereby contributing to the broader climate resilience of India's education sector.

Results and Discussion

Scope-wise annual GHG emissions at GKVK campus

The total GHG emissions from the GKVK campus, categorized under the three internationally recognized scopes defined by the GHG protocol - scope 1 (direct emissions), scope 2 (indirect emissions from purchased electricity) and scope 3 (other indirect emissions) and are depicted in the Table 2–4 respectively and emission categories from Table 1. The total annual emissions from all scopes amount to 7606545 kg CO_2e. Each category reflects emissions arising from different institutional operations and resource usage patterns, using activity data and emission factors aligned with IPCC AR6, UNFCCC GHG Calculator v2.6 and CEA of India guidelines (16).

Scope - one annual GHG emissions at GKVK Campus

The scope 1 emissions represent direct emissions from fuel combustion and refrigerant leakage occurring within the boundaries of the campus are illustrated in Table 2. Diesel consumption for generators and university-owned vehicles amounts to 121500 liters annually, producing 305718 kg CO_2e using an emission factor of 2.516 kg CO_2e/liter. Petrol consumption by campus vehicles contributes an additional 577676 kg CO_2e from 248400 liters, using the IPCC-recommended emission factor of 2.326 kg CO_2e/liter are illustrated in table 1. Similar findings have been observed in the study (22). Liquefied Petroleum Gas (LPG), widely used in hostel kitchens, laboratories and canteen services, contributes the largest share in scope 1 - 1334884 kg CO_2e from 857600 liters, calculated at 1.557 kg CO_2e/liter. Similar results have been observed in the study (23, 24). Another significant contributor is refrigerant leakage from air conditioning units, notably HFC-134a and R-410A. Despite the low quantity of 634.47 kilograms leaked, their extremely high global warming potentials (averaging 1550 kg CO_2e/kg) result in 982430 kg CO_2e (25, 26). These four components combined make scope 1 emissions the largest category, totalling 3200708 kg CO_2e annually and indicate a substantial opportunity for emissions reduction through fuel substitution and improved refrigeration maintenance (27).

Scope – two annual GHG emissions at GKVK Campus

The scope 2 emissions stem exclusively from purchased grid electricity provided by the Bangalore Electricity Supply Company (BESCOM) are described in table 3. The total annual electricity consumption of the campus is 7.82 million kilowatt-hours (kWh) and the associated emission factor of 0.199 kg CO_2e/kWh - reflective of India's current grid mix - yields 1556180 kg CO_2e shown in table 3. Though indirect, these emissions are significant due to the vast infrastructure including laboratories, hostels and administrative blocks dependent on electricity for lighting, cooling, heating and equipment operation. The high energy demand of the institution underscores the importance of energy efficiency upgrades and

Table 2. The scope one GHG emissions with activity data and emission factors of GKVK campus, UASB (2023 - 24)

Scope type	Emission source	Activity data	Emission factor	Total emissions (kg CO_2e/year)	Percent
Scope 1 (Direct emissions)	Diesel (vehicles, generators)	121500 L	2.516 kg CO_2e /L	305718	4.02
	Petrol (campus vehicles)	248400 L	2.326 kg CO_2e /L	577676	7.60
	LPG (labs, hostels, mess)	857600 L	1.557 kg CO_2e /L	1334884	17.55
	Refrigerants (HFC-134a, R-410A)	634.47 kg leakage	1550 kg CO_2e /kg	982430	12.91
		Sub total (A)		**3200708**	

Table 3. The scope two GHG emissions with activity data and emission factors of GKVK campus, UASB (2023 - 24)

Scope type	Emission source	Activity data	Emission factor	Total emissions (kg CO_2e/year)	Percent
Scope 2 (Indirect emissions)	Electricity (from BESCOM)	7820000 kWh	0.199 kg CO_2e/kWh (CEA 2023)	1556180	20.46
		Sub total (B)		**1556180**	

transitioning to renewable sources such as rooftop solar photovoltaic systems. Similar results were observed in the study (16, 28).

Scope – three annual GHG emissions at GKVK Campus

The scope 3 emissions encompass all other indirect sources, such as commuting, food waste (29), material usage, water supply (30) and waste treatment (31) are presented in Table 4. Student commuting contributes significantly, with 4524 students traveling an average of 6 km/day over 180 academic days (32). Using a weighted emission factor of 0.18 kg CO_2e/km similar results were found with the total emissions amounting to 879466 kg CO_2e (31, 33). Staff commuting further adds 139903 kg CO_2e, based on 381 staff members traveling 8.5 km daily for 240 days a year. Official travel - primarily for academic and extension work - accounts for 5280 kg CO_2e, assuming approximately 44000 km travelled annually with an emission factor of 0.12 kg CO_2e/km. It reflects an average based on business travel carbon calculators and it is described in Table 1. Similar findings have been found in previous studies (23).

A major hotspot within scope 3 is food wastage. The total number of meals served annually is estimated at 26.2 million, based on student and staff meal counts. Assuming a 17 per wastage rate and an average meal weight of 400 grams, the wasted food equals roughly 1.78 million kilograms. Using an emission factor of 0.91 kg CO_2e/kg of food waste, this results in 1622855 kg CO_2e - making it the single largest component within scope 3. It is based on the methane generation potential of organic food waste (25, 26). For the regional food waste factors (34).

Paper usage contributes 13875 kg CO_2e, calculated from 37500 kilograms of annual usage and an emission factor of 0.37 kg CO_2e/kg. Similar results were observed in previous studies (26). Similarly, water pumping and supply activities consume 22300 cubic meters of water, producing 61101 kg CO_2e. It is based on energy consumption for municipal and borewell pumping (30), while wastewater treatment for 80000 cubic meters results in 37600 kg CO_2e based on standard treatment-related emissions. It is due to indirect methane and nitrous oxide emissions (35).

The solid waste disposal accounts for the final component of scope 3, with an estimated 351.3 tonnes of campus-generated waste. When routed to landfills, this waste releases 195669 kg CO_2e. These emissions arise due to anaerobic decomposition of mixed and organic waste in landfills and are magnified by the presence of organic and unrecycled materials (34, 25). Collectively, scope 3 emissions total 2849657 kg CO_2e, revealing a substantial share of the university's carbon footprint that is often underestimated or ignored in typical institutional carbon audits. Scope 3 emissions illustrate the broader environmental impact of daily campus operations and behaviours, often underestimated in institutional audits. Addressing these requires cross-cutting strategies including behaviour change, sustainable procurement, waste segregation, modal shift in commuting and food management. These actions can significantly improve campus sustainability and institutional alignment with global carbon neutrality goals. The same as depicted in the Fig. 2.

Overall (Scope 1,2,3) annual GHG Emissions at GKVK Campus

The annual GHG emissions at the GKVK campus, University of Agricultural Sciences, Bangalore, categorised by the three scopes defined by the GHG protocol are presented in Table 5. Scope1 (direct emissions) accounts for 3200708kg CO_2e, representing approximately 42.07 % of the total emissions; this includes onsite fuel combustion such as LPG and refrigerant leakage. Scope 2 (indirect emissions), primarily derived from purchased grid electricity consumption, contributes 1556180kg CO_2e or 20.43 % of the total. Scope3 (Other indirect emissions), encompassing emissions from activities like student commuting, food waste and outsourced services, constitutes 2849657kg CO_2e or 37.50 % of the campus's total emissions. Combined, these yield a total annual footprint of 7606545kg CO_2e, with each scope's share summing to 100 %. This scope-wise analysis highlights that scope1 is the largest source, followed by scope3 and scope2, indicating priority areas for targeted emission reduction strategies. The same has been depicted in Fig. 2.

Emission intensity metrics

The emission intensity metrics for the GKVK campus to enable comparison across different units and institutions are presented in Table 6. Per student emissions are estimated at 1681.37 kg CO_2e, reflecting the average environmental impact of a single student across the year. Per staff emissions are significantly higher at 19964.68 kg CO_2e, due to greater commuting, office energy use and operational responsibilities. Similar results were found in previous

Table 4. The scope three GHG emissions with activity data and emission factors of GKVK campus, UASB (2023 - 24)

Scope type	Emission source	Activity data	Emission factor	Total emissions (kg CO_2e/year)	Percent
Scope 3 (Other indirect emissions)	Student commuting	4524 × 6 km/day × 180 days *	0.18 kg CO_2e / km (avg. bus + car)	879466	11.57
	Staff commuting	381 × 8.5 km/day × 240 days **	0.18 kg CO_2e / km	139903	1.83
	Official travel	44000 km	avg. 0.12 kg CO_2e / km	5280	0.07
	Food Wastage	26225840 meals/year (4524*3*180 + 381*2*240) ***	0.91 kg CO_2e/kg	26225840×0.068×0.91 = 1622855 kg CO_2e (1624.61 tonnes CO_2e per year)	21.33
	Paper usage	37500 kg	0.37 kg CO_2e / kg	13875	0.18
	Water pumping and supply	226300 m^3	0.27 kg CO_2e / m^3	61101	0.80
	Wastewater treatment	80000 m^3	0.47 kg CO_2e / m^3	37600	0.50
	Solid waste disposal (landfill share)	351.3 tonnes	0.55 kg CO_2e / kg (Overall)	195669	2.57
		Sub total (C)		**2849657**	

Note:

*Active academic days (when students are present on campus).

** Annual working days in a year for staff.

***Average meal weight 400 g (0.4 kg), assumed average wastage rate 17 % and food waste per meal 68 g (0.068 kg).

Table 5. Scope-wise GHG emissions with activity data and emission factors of GKVK campus, UASB (2023 - 24)

Sl. No.	Scope type	Total emissions (kg Co_2e/year)	Percentage in Total
1	Scope 1 (Direct emissions)	3200708	42.07
2	Scope 2 (Indirect emissions)	1556180	20.43
3	Scope 3 (Other indirect emissions)	2849657	37.50
	Total (A+B+C)	**7606545**	**100.00**

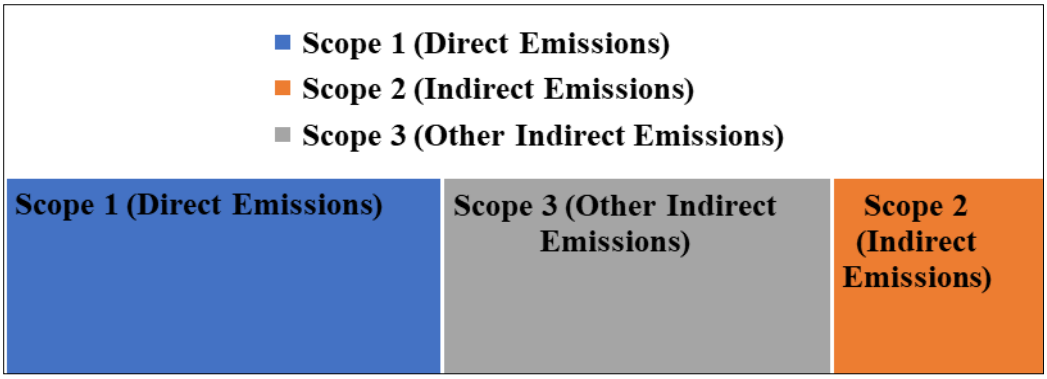

Fig. 2: The Annual scope wise GHG emissions of GKVK Campus, UASB.

studies (36). The overall per capita emissions for the campus population (students and staff combined) are calculated as 1550.77 kg CO_2e, which provides a baseline for benchmarking against other campuses.

Emissions per hectare of built-up area (60 ha) stand at 126775.75 kg CO_2e, showing the intensity of carbon output per land use area. Similarly, per square meter emissions for the built space (approx. 600000 m^2) are 12.68 kg CO_2e, useful for space utilisation audits. Finally, emissions per unit of electricity (7.82 million kWh annually) match the CEA grid emission factor at 0.199 kg CO_2e/kWh, validating the calculations. These metrics offer a standardised way to track efficiency, identify hotspots and compare GKVK with national and global institutions.

The Comparison of annual carbon emissions from electricity use across global universities

The annual GHG emissions and per capita intensities of GKVK with other prominent national and international universities are presented in Table 7. GKVK records 1556.18 tonnes of CO_2e per year for a population of 4905, with a per capita emission of 3.17 tonnes, reflecting moderate emission levels for an Indian agricultural institution. In comparison, Indian Institute of Science, Bangalore and Tamil Nadu Agriculture University, Coimbatore report 1.15 and 1.48 tonnes per capita respectively. Previous studies indicate lower footprints likely due to more energy-efficient infrastructure or reduced commuting emissions (37).

On the international front, UC Davis (6.15 t/capita) and Oxford University (12.8 t/capita) show much higher per capita emissions, driven by larger campuses, colder climates requiring heating and intensive research operations. Interestingly, elite US

Table 6. The Emission intensity metrics of GKVK campus with formula basis

Sl. No.	Metric	Activity basis / unit	Emission factor / formula	Emissions (kg CO_2e)
1	Per student	4524 students	7606545 / 4524	~1681.37
2	Per staff	381 staff	7606545 / 381	~19964.68
3	Per capita avg.	4905	7606545 / 4905	~1550.77
4	Per hectare (built-up area)	60 ha	7606545 / 60	~126775.75
5	Per m^2 of built space	~600000 m^2	7606545 / 600000	~12.68
6	Per unit electricity	7.82 million kWh	0.199 kg CO_2e / kWh	1557180

Table 7. The Comparison of Annual Carbon Emissions from Electricity use across Global Universities

Sl. No.	Institution	Population	Electricity use (kWh/year)	Emission factor	Total emissions (t CO_2e/year)	Per capita emissions (t CO_2e)
1	GKVK, UAS Bangalore	4905	7820000	0.199 kg/kWh	1556.18	3.17
2	IISc Bangalore	12000	15500000	~0.199 kg/kWh	13800	1.15
3	TNAU Coimbatore	6200	9300000	~0.199 kg/kWh	9200	1.48
4	UC Davis	39000	120000000	0.2 kg/kWh	240000	6.15
5	Oxford University	25000	185000000	0.16 kg/kWh	320000	12.8
6	University of Cape Town	21175	69083	14855	708	279
7	University of Delaware	19359	116614	33336	2538	54
8	Univ. of Maryland	36014	224733	118466	4560	3386
9	Univ. of Pennsylvania	26537	317000	25548	5750	0
10	MIT	5909	195861	16407	2807	0

Note: University of California, Davis. (2022). UC Davis Sustainability Report: Campus Carbon Footprint. Oxford University. (2022). Oxford University Carbon Management Strategy. Massachusetts Institute of Technology (MIT). (2022). MIT Sustainability Metrics and Energy Usage Report. IISc Bangalore (2021). (TNAU Coimbatore, 2023).

institutions like the University of Maryland and the University of Delaware report extremely high per capita values, exceeding 50 tonnes, possibly due to the inclusion of extensive air travel, research facilities and fossil-fuel-based energy sources. This comparison illustrates that while GKVK has room to reduce emissions, it already performs better than several global institutions in terms of per capita emissions and aligns competitively with peer Indian universities. It reinforces the need for continued efficiency improvements and serves as a benchmarking tool for climate performance.

Mitigation Strategies and Estimated Reductions

The proposed carbon mitigation strategies for the GKVK campus, with estimated reductions in CO_2e emissions based on activity data and scientific assumptions, are described in Table 8. The most impactful intervention is promoting a modal shift in staff transport, encouraging 30 % of car users to switch to buses, which could reduce emissions by 480000 kg CO_2e per year (38). Similarly, converting 25 % of student commuting to cycling or walking is expected to reduce emissions by 650000 kg CO_2e, targeting scope 3 emissions effectively (39, 40). In the energy domain, the installation of a 1 MW rooftop solar photovoltaic system could replace grid electricity and result in a 250000 kg CO_2e annual reduction under scope 2. Research has demonstrated similar results previously (41). Additionally, improving energy efficiency to cut electricity use by 10 % could save another 155718 kg CO_2e, showing the significance of power management (42).

On the fuel side, replacing 50 % of LPG use in kitchens with biogas derived from canteen food waste could cut emissions by 21094 kg CO_2e, offering a circular and sustainable alternative (43). Further, adopting composting for 80 % of organic solid waste can reduce emissions by 29000 kg CO_2e, shifting waste treatment from landfilling to eco-friendly processing (44). Lastly, introducing methane capture in the sewage treatment plant (STP) is expected to mitigate an additional 18000 kg CO_2e, addressing hidden methane emissions in scope 3. Together, these strategies highlight a balanced mix of behaviour change, infrastructure upgrades and circular waste management to achieve meaningful carbon reductions across all scopes (45).

Conclusion

The carbon footprint assessment of the GKVK campus provides a detailed and scientifically validated baseline of GHG emissions arising from institutional activities. Using globally aligned methodologies under the IPCC and GHG protocol frameworks, the study comprehensively captures emissions under scope 1, 2 and 3 categories. The total annual emissions of 7.6 million kg CO_2e are significant, especially for an academic institution and underline the urgent need for integrated emission reduction strategies. Among the three scopes, scope 1 emissions were the highest, primarily due to extensive LPG use and refrigerant leakage from laboratory and hostel air conditioning systems. Scope 2 emissions from electricity consumption also represent a substantial share, reflecting the dependency on grid power for academic, residential and research infrastructure. Scope 3 emissions, though often overlooked, emerged as critical contributors - particularly student and staff commuting, food wastage and solid waste disposal.

The per capita emission of 1.55 tonnes CO_2e suggests moderate performance in comparison to global universities, but also highlights areas for improvement. Mitigation strategies such as shifting to renewable energy, reducing food and paper waste and encouraging sustainable transport could yield substantial reductions. In fact, the proposed mitigation plan could offset over 21 % of current emissions. Importantly, the carbon footprint inventory establishes a performance baseline for GKVK that can inform both short-term action plans and long-term sustainability goals. It also facilitates accountability to internal stakeholders, regulatory bodies and potential sustainability funders. As educational institutions are expected to lead by example, the results from this study can serve as a template for other campuses in Karnataka and across India. In conclusion, this assessment is more than a technical exercise - it is a strategic tool for transforming GKVK into a low-carbon, resource-efficient academic model, contributing directly to India's climate commitments and sustainable development objectives.

Future perspective

The carbon footprint assessment offers multiple avenues for future policy alignment and institutional transformation. At the institutional level, GKVK can adopt a formal Carbon Management Plan with annual reduction targets, integrated into academic and operational planning. Implementing green procurement policies, mandating energy audits and investing in low-emission infrastructure can institutionalise sustainability.

The findings from this study support the inclusion of higher educational institutions in Karnataka's SAPCC and India's NDCs. A state-level mandate for carbon audits in public universities could standardise GHG accounting and make them eligible for carbon credit trading and performance-linked green funding.

The model developed here can be scaled to the University Grants Commission (UGC) as a national-level framework for institutional carbon benchmarking. GKVK's leadership in this domain positions is to influence policy dialogues and pilot carbon neutrality programs in agricultural education.

Research-wise, this study opens the door to lifecycle assessments (LCA) of campus operations, climate literacy integration into curriculum and exploration of nature-based solutions for carbon sequestration within campus green areas.

Table 8: Mitigation strategies and estimated reductions of GKVK Campus, UASB

Sl. No.	Mitigation strategy	Estimated reduction (kg CO_2e/year)	Primary scope affected
1	Encourage 30 % modal shift from car to bus among staff	480000	Scope 3
2	Convert 25 % student commuting to cycling/walking	650000	Scope 3
3	Install 1 MW rooftop solar PV system	250000	Scope 2
4	Reduce electricity consumption by 10 % via efficiency	155718	Scope 2
5	Switch 50 % of LPG use to biogas from canteen waste	21094	Scope 1
6	Adopt composting for 80 % of organic solid waste	29000	Scope 3
7	Introduce STP methane capture for wastewater treatment	18000	Scope 3

Collectively, these steps would place GKVK at the forefront of India's academic climate leadership.

Authors' contributions

MKL conceptualized the study and carried out the complete carbon footprint assessment of the GKVK campus, including data collection, field surveys, emission calculations using IPCC, GHG Protocol and CEA guidelines, benchmarking, data interpretation and full manuscript preparation with figures and tables. MG, as the doctoral supervisor, provided overall guidance, reviewed the research design and methodology, and contributed to manuscript revision, ensuring academic rigor and clarity. DAS offered conceptual and analytical inputs, particularly on greenhouse gas accounting standards and result interpretation, strengthening the study's analytical robustness. GMR provided consistent moral and collegial support throughout the research process, helping sustain motivation. S assisted with data collection and facilitated institutional approvals and administrative coordination necessary for accessing departmental records and resources.

Compliance with ethical standards

Conflict of interest: The authors declare that there are no conflicts of interest-financial, personal, or professional, that could have influenced the outcomes or interpretation of this study.

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