A Comprehensive Carbon Footprint Assessment Using Integration of GHG Protocol and LCA: A Case Study of an Engineering Institute in India

Prasad, Yukti
Department of Civil Engineering, National Institute of Technology Kurukshetra

Deswal, Surinder
Department of Civil Engineering, National Institute of Technology Kurukshetra

https://doi.org/10.5109/7172251

出版情報：Evergreen. 11 (1), pp.143-155, 2024-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

A Comprehensive Carbon Footprint Assessment Using Integration of GHG Protocol and LCA: A Case Study of an Engineering Institute in India

Yukti Prasad[1], Surinder Deswal[2,*]
[1,2]Department of Civil Engineering, National Institute of Technology Kurukshetra, Haryana, India

*Author to whom correspondence should be addressed:
E-mail: sdeswal@nitkkr.ac.in

(Received December 20, 2023; Revised February 18, 2024; Accepted March 16, 2024).

Abstract: The concentration of greenhouse gases (GHG) released in the atmosphere has increased to an extent that it is posing significant threats to global environment, economy, and society. It's, therefore, crucial for organizations, including academic institutions, to contribute to mitigation efforts ensuring transparency in sustainability efforts. In the present study, the carbon footprint (CF) of an engineering institute in India has been assessed using the GHG Protocol developed by World Resources Institute and World Business Council for Sustainable Development, and the Life Cycle Assessment (LCA) methodology. *OpenLCA 2.0* software, and *Ecoinvent v 3.9.1* database have been used for comprehensive analysis of environmental impacts across various products, processes, or systems. The study found that the Institute's CF was 11,254.08 metric tons of CO_2-equivalent during the fiscal year 2022-23 (from April 2022 to March 2023) accounting for 2.24 tCO_2eq per student. The CF in Scope 1, Scope 2 and Scope 3 accounting for 0.83%, 87.00% and 12.17% respectively. The indirect emissions resulting from electricity consumption (Scope 2) accounted for the highest contribution of 9,791.16 tCO_2eq of all the emissions associated with Institute activities. Scope wise comparison of Institute's carbon footprint with other academic institutions has also been presented. The findings emphasized on efforts to reduce the CF of the Institute by increasing green energy supply, teleconferencing and other AI tools to reduce visitors' transportation carbon emissions.

Keywords: Carbon footprint; Greenhouse Gas Protocol; Life Cycle Assessment; OpenLCA 2.0; Ecoinvent v 3.9.1

1. Introduction

In climate change dynamics, the role of greenhouse gases (*GHGs*) is crucial, as these possess the ability to trap heat and contribute significantly to global warming. It is estimated that global warming will cause the average earth temperature to rise to 1.5°C each year between 2032-2052[1)]. Increasing GHG emissions, particularly that of CO_2, has emerged as a serious global environmental concern that demands immediate distinctive and practical actions to overcome it[2)]. The gases that contribute to climate change have been identified in Intergovernmental Panel on Climate Change (IPCC) assessment reports[3)]. IPCC has identified 18 greenhouse gases, each with a different potential for global warming[4)]. In response to the pressing need to address climate change, the United Nations Framework Convention on Climate Change (UNFCCC)[5)] adopted the Kyoto Protocol in 1997 and this agreement established mandatory targets for emission reductions specifically for developed nations. The Kyoto Protocol specifically identified six greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), for regulation and carbon accounting purposes[6)]. The practice of quantifying and reporting greenhouse gas (GHG) emissions is of utmost importance in comprehending and addressing climate change. Accurate quantification and reporting of GHG emissions play a vital role in establishing effective strategies for mitigation, monitoring progress, and ensuring transparency in sustainability efforts.

Various standards, including the Greenhouse Gas Protocol (GHGP) developed by the World Resource Institute (WRI) and World Business Council on Sustainable Development (WBCSD), ISO 14064 (parts 1 and 2), PAS 2050 of the British Standard Institution (BSI), the 2006 IPCC guidelines for National Greenhouse Gas inventories, ISO 14025, and ISO 14067 (under development), offer the frameworks and methodologies for calculating carbon footprints (CFs) and assessing GHG emissions across sectors and products[7)]. Both, the GHG Protocol and ISO 14064 provide requirements for quantifying the GHG impact of an organization. Both the standards have sought harmonization on all qualification methodologies during their development, though with some minor differences[8].

The concept of carbon footprint (CF) pertains to the measurement of the intensity of greenhouse gas emissions associated with various goods, entities, and processes, expressed as their respective carbon footprints. Several researchers have developed various models with other carbon management considerations as well, such as carbon limits, carbon business, carbon penalties and carbon offsets[9]. However, there exists a dearth of coherence in the definitions and computations of CFs across various investigations. The CF is the measure of the exclusive total amount of CO_2 emissions that is directly or indirectly caused by an activity or is accumulated over the life stage of a product[10]. The CF assessment, a fundamental aspect of sustainability studies, involves quantifying the total greenhouse gas emissions associated with an organization, activity, or process. Global CO_2 suppression is necessary, particularly with regard to emissions from the energy and transportation sectors[11, 12]. Despite numerous CF assessment studies, very few academic institutes – universities and colleges report their carbon emissions in standard global report[13] But in recent few years, academic institutes worldwide recognized the importance of reducing their ecological footprint, and are increasingly engaged in their carbon footprint assessment and mitigation efforts[14]. The CF is conventionally presented in terms of CO_2 equivalent mass, which serves as a metric for the total quantity of carbon dioxide emissions directly and indirectly attributed to an undertaking or accumulated over the life cycles of a product. Some of the reported studies of academic institutions or universities regarding carbon footprints are summarized in Table 1[14-27] along with the computation methods being adopted.

The carbon footprint of NED University's main campus was computed by using Clean Air Cool Planet (CA-CP) Carbon Calculator, originally developed by the non-profit organization Clean Air-Cool Planet and the Sustainability Institute at the University of New Hampshire (USA), and reported as 21,500 tCO_2eq for the year 2017[28]. However, to enhances the credibility and simplicity of calculating the CF, the CO_2 emissions caused by products must be assessed throughout their life cycle; for this a product carbon footprint can be determined by using a Life Cycle Assessment (LCA) method[8]. In fact, the adoption of LCA studies has significantly increased since 2007, with particular attention given to the hybrid methodology since 2014[29]. A carbon footprint study of Ege University (EU), Turkey conducted in 2016, utilizing the LCA methodology in accordance with the ISO 14064/1, revealed total carbon emissions of 40,608 tCO_2eq with 37% attributed to constant and mobile combustion[30]. Some universities have adopted hybrid models[29], combining LCA and Environmentally Extended Input-Output Analysis (EEIOA) elements for different emission scopes. NTNU Norway adopted a hybrid methodology to assess Scopes 1 and 2, and EEIOA for Scope 3 emissions that also included commuting and waste[31]. NTNU Norway reported a total CF of 92 kilotons of CO_2eq for the year 2009, combining direct emissions from internal sources and indirect emissions from purchased electricity so as to ensure a comprehensive examination of the Institution's greenhouse gas footprint[31]. The GHGP of WRI and WBCSD is now being widely recognized as the standard for GHG accounting, providing a comprehensive framework for measuring and managing GHG emissions[32, 33].

As a recognized educational establishment on a national scale, National Institute of Technology (NIT) Kurukshetra, India exhibits a dedicated commitment towards the preservation of the environment and the promotion of sustainable development. Consequently, the principal objective of this study entailed the production of a comprehensive inventory of GHG emissions and to identify the major sources of greenhouse gas emissions associated with the Institute's operations, including energy consumption, transportation, and waste management. The current literature on GHG emissions from Indian universities has revealed significant gaps, particularly in terms of empirical research on the carbon footprints of these institutions. Moreover, the lack of comparative analysis between universities makes benchmarking and improvement efforts challenging. The understanding of specific emission sources and the development of effective mitigation policies is also limited. Further, research is needed to explore the role of technical education institutions in climate change mitigation in the Indian context. Bridging this gap is crucial for the development of tailored mitigation strategies and the promotion of sustainability initiatives in Indian universities. The Institute's CF for fiscal year 2022-23 was established as a first step toward becoming carbon neutral, taking into consideration a wide variety of Institute activities.

The novelty of this study lies in its significant departure from previous research endeavors in the field of GHG accounting and environmental assessment. Its unique approach lies in the integration of the GHGP with LCA principles, blending accounting frameworks with environmental impact assessment methodologies that are internationally recognized for a more comprehensive analysis of the academic institute located in a region that is vulnerable to climate change. This inventory would subsequently serve as a foundational cornerstone for the formulation of a comprehensive plan aimed at mitigating the adverse effects of climate change. Moreover, this study endeavor would also significantly contribute towards fulfilling the Institution's social and environmental responsibility. Its role in encouraging sustainable practices and serving as an example for the academic community and the larger society is equally important. As a result, computing, tracking, and reporting of one's own CF is a preliminary step from which it can aspire to become a sustainable organizations[34]. The comparison of Institute's carbon footprint with other academic institutes has also been presented in this study.

Table 1. Summary of reported carbon footprint (CF) of academic institutes.

Institute[Citation)]	**CF (tCO_2eq)**	**Method**	**Specific Remarks / Limitations**
Louisiana State University, USA[15)]	162,742.00	CACP campus carbon calculator, founded on IPCC workbooks and methodologies outlined by the GHGP.	The CACP calculator does not encompass the energy cost accounting and resultant emissions of materials produced elsewhere and consumed on campus. Further, materials consumption (including paper, food, and merchandise from the bookstore) was not accounted for in this study.
Federal University of Agriculture Abeokuta, Nigeria[16)]	5,935.00	GHG emission factors for the combustion of common fossil fuels, and DEFRA guidelines for electricity emission sources, carbon footprint calculator.	The analysis focuses only on specific sources of emissions such as transportation, campus energy consumption, and farm machineries; but other sources of emissions (including material consumption) were not considered.
Public University Campus, Mexico [17)]	3,000.00	Greenhouse Gas Protocol (GHGP).	Lacks a clear description of the precise procedures utilized in the research. Suggested no need of any action to reduce the emissions from cleaning products because they are so little and minimal.
ITS, Indonesia[18)]	2,846.54	GHGP and UI Greenmetric Guidelines.	Lacks discussion on the accuracy or reliability of the UI Greenmetric Guideline 2018.
BITS, Pilani, India. *et al.*[14)]	16,500.00	LCA and ISO 14064 standards.	-
University of Talca, Chile[19)]	5,472.89	GHGP.	-
Diponegoro University, Indonesia[20)]	16,345.83	IPCC method, and mapping the carbon footprint using ArcGIS.	Accuracy of the data inputs or the assumptions made during the mapping process lacks detailed analysis of the potential uncertainties.
TUP, Colombia. Hayos[21)]	8,969.00	GHGP and ISO 14064-1:2018 guidelines.	-
Univ. of Oulu, Finland[22)]	19,072.00	Hybrid model, GHGP Corporate Standard.	Data availabilty, including inaccurate/out-of-date emission factors and missing/incomplete information, missing structures and methods, has slowed down the process.
Delft University of Technology, Netherlands[23)]	106,000.00	Physical and monetary activity data, applying a process and economic input-output analysis.	Using economic input-output models to calculate universities' CF is a questionable practice, as it can provide only an initial estimation. So, better-suited methodologies are required.
AUS, UAE[24)]	94,553.30	GHGP	-
Colombian University Campus, New York, USA[25)]	7,250.52	UNE-ISO 14064-1 and WRI/WBCSD GHGP Corporate standard.	The study has not incorporated the entire spectrum of emissions, as well as the measures taken to reduce them. So, the CF of the institute can deviate significantly and exhibit distinct patterns due to external factors including socio-political and geographical circumstances.
Clemson Univ. S. Carolina, USA[26)]	93,000.00	LCA, Hybrid LCA (HLCA) approach, GWP.	Study encompasses parameter uncertainty associated with inadequate understanding of inputs, scenario uncertainty originating from system boundaries, and model uncertainties.
Rio Campus of Univ. of Patras, Greece[27)]	32,882.50	Carbon Footprint Calculator	The data collection process was challenging and time-consuming due to the lack of a central administrative office managing the required information.

2. Study area

National Institute of Technology (NIT) Kurukshetra is a technical and research Institute of national importance administered by Government of India[35]. The Institute is located in Kurukshetra city in the state of Haryana in the northern part of India having geographic location of 76.82° eastern longitude and 29.95° northern latitude, at an altitude of 260 m above mean sea level. The campus spreads over an estimated area of 292 acres (1.2 sq. km.).

The Institute offers B.Tech., M.Tech. and M.Sc. courses, and research facilities for the Ph.D. degree in the engineering faculties (namely, civil, mechanical, electrical, computer, electronics and communication, and information technology), applied science faculties, business administration and computer applications, along with facilities of sports complex, market complex, health center, etc. and forest area with lake. The Institute is having a total student strength of 5,027 during the academic year 2022-23. On-campus accommodation has been provided to students – 11 hostels for male and 04 for female students.

3. Methodology

The need for a comprehensive and standardized approach to measuring and reporting greenhouse gas emissions has become increasingly important in today's globalized world. In response to this need, an integrated life-cycle GHG Protocol accounting framework has been developed. This framework aims to harmonize the Corporate Standard and the Product Standard with the phases of LCA. The integration process begins with a detailed comparison of the inventory steps of the Corporate and Product Standards with the phases of LCA. Overall, the integrated life-cycle GHGP accounting framework is a more sustainable and transparent approach for measuring and reporting GHG emissions.

The GHGP is well-suited for both organizations and as well as universities as it provides the most extensively used standards for accounting for GHG emissions worldwide. The following standards have been developed to establish a framework for businesses, governments, and other entities to measure and disclose their greenhouse gas emissions in a manner that aligns with their missions and objectives. To clarify direct and indirect sources of emissions, enhance transparency, and cater to different types of organizations, sectors and climate policies, three scopes (Scope 1, Scope 2, and Scope 3) have been defined for GHG accounting as well as for reporting purposes. These scopes have been precisely defined in the standard to ensure that emissions are not double-counted by multiple companies, making them suitable for greenhouse gas programs where double-counting is a concern. To calculate the CF of academic institutes or universities, corporate standards are being used.

Scope 1 (Direct GHG emissions): These arise from the sources owned by the organization. These includes emissions from combustion in owned or controlled vehicles, boilers and furnaces.

Scope 2 (Indirect GHG emissions from electricity consumption): Emissions resulting as a result of generation of purchased electricity that is being consumed by the organization are included in this scope.

Scope 3 (Other Indirect GHG emissions): It is an optional reporting category that encompasses all other indirect emissions. These emissions are a result of the organization's activities, but they originate from sources which are not owned or controlled by it, such as the extraction and production of purchased materials, business travel, and waste generation.

3.1 OpenLCA 2.0 and Ecoinvent database

OpenLCA 2.0 in conjunction with the *Ecoinvent 3.9.1* database, was utilized as the primary tool for conducting calculations and assessments in this study. The greenhouse gas accounting scopes were determined based on the Greenhouse Gas Protocol (GHGP) standards across various categories, ensuring consistency and comparability in emissions accounting practices. To carry out these calculations, process datasets were generated for each category using the comprehensive dataset provided by *Ecoinvent*. These datasets contain detailed information on inputs and outputs for each product, forming the foundation for subsequent inventory creation. Almost all process datasets are thoroughly documented, detailing the inputs and outputs at the unit process level, and the existence of the *Ecoinvent* database proves that it is possible and feasible to build up a large interlinked system of LCI unit processes[36]. The inventory was further developed by incorporating available data (input) from the Institute, with markets linked to each input and output so as to accurately represent material flows. In cases where specific Indian market data was not available, global market data was utilized so as to maintain the integrity of the analysis. Once the inventory data was established, processes were systematically followed, tracing flows and flow properties to outline the sequence of activities and material exchanges within each product system. Subsequently, product systems were created and validated for each process to ensure accuracy and reliability. Thereafter, an impact assessment method was applied to these validated product systems, quantifying and evaluating the environmental impacts associated with each scenario. Finally, the project resulted in the development of a platform to compare different product systems.

OpenLCA 2.0 is life cycle assessment software that facilitates comprehensive analysis of environmental impacts across various products, processes, or systems[37]. LCA is an established methodology by International Standardization Organization (ISO) of evaluating a product, process, or service's environmental impact over the course of its entire life cycle[38]. During the extraction, production, use, and disposal of raw materials, the environmental implications are evaluated by analyzing the resources used, the energy expended, and the emissions released.

1. *Goal and scope definition:* The first step in an LCA is defining the purpose as well as the boundaries of the assessment. This includes specifying the goals, the functional unit (what the assessment is based on), and the system boundaries, encompassing all life cycle stages to be evaluated. This stage entails defining the objectives and goals of the LCA and determining the scope of the desired study. This encompasses identifying which product or service to be analyzed, as well as the time frame and geographic region that needs to be covered. The research pertains to the GHG protocol.

2. *Life Cycle Inventory (LCI):* LCA involves the compilation and quantification of inputs (e.g., materials, energy) and outputs (emissions, waste) for each stage of the product or process life cycle. This stage comprises of gathering data on the inputs and outputs associated with each stage of the product's life cycle, including information on emissions, energy usage, raw materials, water usage, and waste generation. The *Ecoinvent v 3.9.1* database was utilized for this study[39].

3. *Impact assessment and method*: After gathering the LCI data, an impact assessment is conducted. The calculation is done using the GHG protocol impact assessment method, that is by an *OpenLCA* Life Cycle Impact Analysis (LCIA). This method was developed for the WRI/WBCSD road test process to test the feasibility of the GHG Protocol's draft carbon emissions standard. The characterization factors for each substance in this method are same as in the IPCC 2013 GWP method (100a). The only difference is that this method incorporates carbon sequestration and biogenic carbon emissions, and distinguishes between – fossil carbon (carbon from fossil fuels), biogenic carbon (carbon from biological sources such as, plants and trees), carbon from land conversion (direct impacts), and carbon uptake (accumulated by plants and trees as they grow). This stage encompasses the assessing the environmental impacts of the product's life cycle. It may entail evaluating the effects on GHG emissions as well as air and water resources.

4. *Interpretation:* The final step involves interpreting the results to draw conclusions and make recommendations. In this phase, the impact assessment's findings are analyzed to find areas where the product's sustainability might be enhanced.

3.2 Emission factors

An emission factor is a representative value that aims to correlate the quantity of a pollutant released into the atmosphere with an activity linked to its release. Typically, emission factors are expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant[40]. By quantifying environmental impacts, *OpenLCA 2.0* enables robust life cycle assessments. Through the software's extensive set of emission factors incorporated into its architecture, various processes can be performed using the inbuilt emission factors. In *Open LCA's* GHG impact assessment method, emissions factors are derived from IPCC guidelines. For instance, CO_2 (fossil) is rated at 1 kg $CO_2\,eq/kg$ and CH_4 (fossil) at 30.5 kg CO_2 eq/kg, and similar characterization emission factors being provided for each gas so to assist in impact assessment.

4. Scope emissions

The major source of data for the present study includes the records from the concerned sections or departments, except the commuting data – average distance travelled by

Table 2. Sources of the data used for their relevant scopes.

Activity	Unit	Department
Scope 1 emissions		
Institute's vehicle fleet	*Liters* of fuel consumed, and types of vehicles	Central Workshop
Generator	*Liters* of fuel consumed	Estate Section
Scope 2 emissions		
Outside purchased electricity	*kWh* of electricity purchased	Estate Section
Scope 3 emissions		
Water supply	m^3 of water purchased	Estate Section
Sewage Treatment Plant (STP)	Amount of chemicals used, and m^3 of water influent and treated	CPWD
Waste generation and disposal	*kg* of waste generated	Estate Section
Commuting	Vehicle in–out records, parked vehicles record, staff and student record to calculate *km* of vehicle traveled	Security Dept. (Offline survey)
Paper procurement	Total Stationary purchased, quantity, number, name of assets to calculate *kg* of paper purchased	Store Dept.

students and staff by different means of transport, which was collected by an offline survey (Table 2).

4.1 Scope 1 emissions

This study concerns itself with the direct emissions of greenhouse gases from facilities owned by the Institute. There are eight vehicles on campus, two of which are buses, and one is an ambulance. The total fuel consumption of all vehicles summed to 10,742 *liters*. Based on the parameters provided in the dataset, the ambulance is categorized as a large vehicle. The calculation of the distance traveled per vehicle is based on the mileage of the various vehicles. The fuel consumption of each vehicle was multiplied to its mileage for the distance travelled by them. The total distance covered by cars was calculated as 95,148 *km* and by buses was 18,091 *km*. For the dataset of car, the activity provides an average transport in a passenger car with internal combustion engine. This is a linking activity, linking specific "transport, passenger car" in the EURO classes 3, 4 and 5 into a generic product. For the calculations, the EURO 5 was used in the study because it was observed that most vehicles are considered new and EURO 5 compliance. For buses, “transport, regular bus” inventory was considered as most suitable for India among all the existing inventories because the buses are diesel-powered transportation in urban and suburban areas that is close to regular buses inventory. This product includes all LCA submissions. The allocation of vehicle contribution to transport performance is being predicated on the assumption of a vehicle's lifetime performance being 2.39E05 passenger kilometers per vehicle. The data for the gas leakage of annual refrigerants revealed no recorded leakage in the year. For the CF of direct burning of fuel (generators), the diesel consumption of total of 27,382 liters was recorded. The duration of generator operation throughout the entire year (2022–23) is taken into account, and the fuel consumption is utilized to calculate the number of hours of operation. Details of the Scope 1 emissions computations are presented in Table 3.

Table 3. Details of Scope 1 emissions.

Category	**Fuel used**	**Dataset used**	**Flow property**	**Unit**
Large vehicles				
Ambulance	Diesel	*Ecoinvent* dataset for IC engine	Length	*km*
Bus	Diesel	*Ecoinvent* dataset for transport regular bus	Person transport	*P*km*
Medium vehicles				
Car	Diesel	*Ecoinvent* dataset for IC engine	Length	*km*
Car	Petrol			
Generators				
Generator	Diesel	*Ecoinvent* dataset for machine operated diesel >= 74.57 kw generators	Time duration	*h*

4.2 Scope 2 emissions

Details of the Scope 2 emissions, comprising of outside purchase of electricity from national grid mix electricity, are shown in Table 4.

Table 4. Details of Scope 2 emissions.

Dataset used	*Ecoinvent* dataset for electricity, high voltage, production mix | electricity, high voltage, Northern Region, India.
Flow and unit	Energy and *kWh*

4.2.1 Grid mix electricity

Grid mix electricity for India's northern region was determined by utilizing the *Ecoinvent* dataset for electricity production mix in India for the northern region. As the manufacturing phase in electricity generation is the required input, so the dataset focuses on the production grid mix of electricity in the northern region of India, covering the states of Rajasthan, Punjab, Uttar Pradesh, Uttarakhand, Delhi, Haryana, and Himachal Pradesh. This dataset is being categorized by different sources of electricity generation, including hard coal, oil, lignite, wood chips, natural gas conventional, and natural gas combined for each state. Approximately 8.5% of the total electricity in the northern region of India is being consumed in Haryana.

The monthly electricity consumption data of the Institute for the fiscal year 2022-23 was meticulously recorded from the Estate Section. Consequently, it was determined that the Institute’s annual electricity consumption amounted to 6,971,465 *kWh*. The month-wise electricity consumption of the Institute during April 2022–March 2023 is shown in Fig. 1.

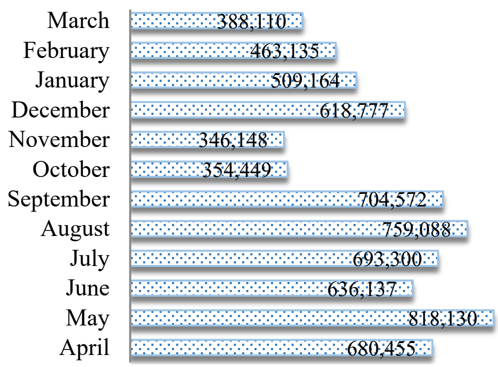

Fig. 1: Monthly electricity consumption (in kWh) during April 2022 to March 2023.

In order to ascertain the proportions of different energy sources of electricity for the Institute, the percentages were computed based on the 8.5% electricity consumption by Haryana state from the grid mix electricity within the northern region of India. The estimated percentages of the various sources in the purchased electricity by the Institute are presented in Fig. 2. A Proportional Allocation Method was used to find the percent of sources in purchased electricity consumption of the Institute. The computation revealed that the major source of purchased electricity was hard coal (89.12%) that is the main source of CO_2 emissions responsible to the green house effects or global warming[41].

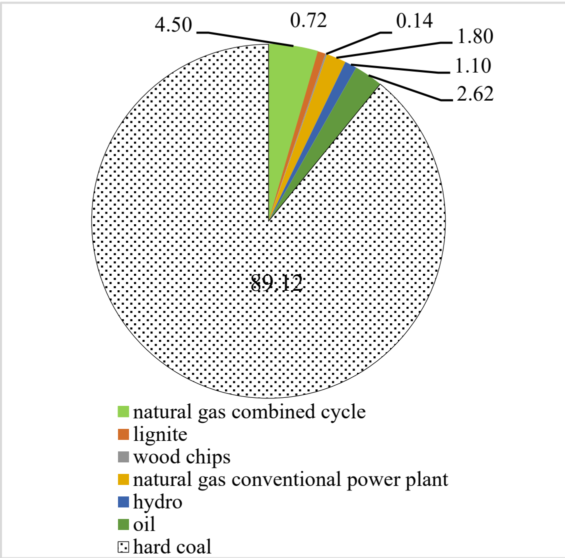

Fig. 2: Sources and proportion (%) of the purchased electricity.

4.3 Scope 3 emissions

These emissions result from activities conducted by the Institution at locations or through non-institutional means. Efforts may be made to reduce emissions from sources with negligible effect (below the establishment's threshold of importance) or where the calculation is impracticable due to technical limitations or economic impotence.

The data sources utilized for Scope 3 emissions are summarized and presented in Table 5 and discussed subsequently.

4.3.1 Paper procurement

The stationary data was collected from the Store section of the Institute, and the quantity of paper was used to calculate the total mass of paper purchased in fiscal year 2022–23. The stationary data included total items purchased and their quantity, number, name of assets such as paper rims, envelopes, registers, sheets, etc. The standard sizes of each item was used to compute the overall weight of the papers used which considers the entire life cycle of printing paper. The total annual weight of the purchased/used paper accounted to be 5,327*kg*.

Table 5. Details of Scope 3 emissions.

Type	*Ecoinvent* dataset used for	Reference flow	Unit
Paper procurement	paper production	mass	*kg*
Wastewater treatment	wastewater treatment, average	volume	*m*^{3}
Waste generation	waste disposal, sanitary landfill	mass	*kg*
Water supply	tap water production, underground water	volume	*m*^{3}
Commuting - Students - Staff - Visitors	 Not applicable passenger car with IC engine passenger car with IC engine for cars, for motorbike (using activity data *(km)* and emission factor)	 length length length	 *km* *km* *km*

4.3.2 Water supply

The main source of potable water supply for bathing, washing, drinking & cooking, gardening, and other purposes in the Institute is ground water (tube-well) that is being stored in an overhead water tank after disinfection. Records from the Estate Section of NIT Kurukshetra were utilized to determine the overall and monthly water consumption volume during the fiscal year 2022-23 in the campus. The total annual water consumption accounted to be 650,000 *m*^{3} (1.78 *MLD)* during the study period.

4.3.3 Wastewater treatment

The 1.5 *MLD* aerobic sewage treatment plant (STP) in the Institute's campus is being operated and maintained by an external agency supervised by the Central Public Works Department (CPWD) that effectively purifies the wastewater generated in the Institute as per national disposal standards. The total annual wastewater influent was recorded as 381,735.425 *m*^{3} (1.05 *MLD*) The activity starts with the wastewater being available at the entrance of the treatment facility, that is influent; and the activity ends with the wastewater being treated and waste specific emissions released to the environment. Emissions may include emissions from any sludge digestion, biogas generation and utilization (heeding specific wastewater composition) have also been included.

4.3.4 Waste Generation

The dataset used in this study pertains to the generation and disposal of municipal solid waste, specifically in the context of a sanitary landfill. The generated solid waste in the campus in the fiscal year 2022-23 was 1,615,027 kg that is being transported to a municipal landfill site for final disposal and treatment. Inventoried solid waste contains paper, mixed cardboard, plastics, laminated material, glass, textiles, etc., and their standard proportion percentage shown in Fig. 3.

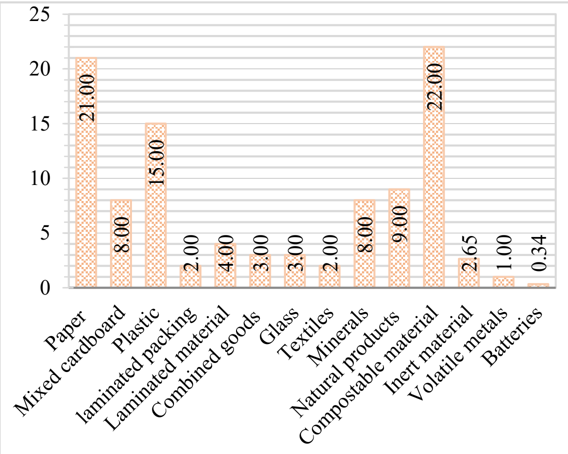

Fig. 3: Standard proportion percentage of solid waste.

4.3.5 Commuting

An offline survey was conducted to determine how often students and employees traveled to the Institute by various means of transport and their average distance. The questions of the survey included how many days in a week a student or employee traveled to the institute, including all the major activities conducted in the Institute and their modes of transportation. On an average, the working days were found to be 252 days per year. From the survey, it was found that 98.6% of students are hostellers, and only 1.36% are day-scholars who prefer two-wheelers for commuting. Due to the non-availability of the 2-wheeler dataset in *Ecoinvent*, student commuting was calculated as per the Scope 3 GHG guidance protocol[42]. According to the guidance, there are three methods of calculating commute emissions, namely *fuel based method*, *distance-based method* and *average data method*.

For the calculation of the student commuting, the *average data method* was used. The data required for this was according to Scope 3 guidance and the GHGP that include –

- average daily commuting distances of typical students/employees,
- average modes of transport of typical students/employees,
- average number of commuting days per week and average number of weeks worked per year,
- average distance travelled by an average student / employee per day,
- average breakdown of transport modes used by students/employees,
- average number working days per year, and
- emission factors needed,

and the following formula is being used:

Sum Across Each Transport Mode (*kg CO_2-eq/vehicle-km*) =
∑ [Total number of students × % of students using mode of transport × One-way commuting distance (Vehicle-*km*) × 2 × Working days per year × Emission factor of transport mode] (1)

The average one-way distance and emission factor are considered as per Indian GHG protocol, Indian specific road transport emission factor[43] presented in Table 6.

Table 6. Details of average distance and emission factor for Indian specific road transport.

Commute group	**Mode of transport**	**Average one-way distance**	**Emission factor (*kg CO_2-eq/vehicle-km*)**
Students	Motor bikes	10 *km*	0.0324

For employee commuting, the carbon footprint was calculated by calculating the total distance traveled by the average commutes of all employees using the *Ecoinvent* dataset. Other commuting calculations involve the offside commuting of vehicles, including business travel, visits, and events. Vehicle in-out records, parked-vehicles records etc. were taken into consideration for the visitors' commuting. The cars and motorcycles were taken into account as per the available data quality. For motorbikes, the CF was calculated using activity data and emission factor. While for cars, the *Ecoinvent* dataset for passenger cars with internal combustion engines was used. The computed total distance travelled by employees (car); visitors (car); and visitors (motor bike) was 451,887; 3,003,950; and 4,416,358 *kms* respectively.

5. Results and discussion

Keeping in mind the stated objectives and novelty of this study so as to provide valuable insights for sustainability efforts within the academic institutions, the results and discussion have been presented by using whole-to-part approach so that the percentage contribution of an activity/source under the relevant Scope to total emissions of the Institute can be analyzed and presented in an effective manner. Therefore, Institute's total CF is presented first followed by Scope-wise analysis, and finally the comparison with other institutions.

5.1 Institute's total carbon footprint

The CF of NIT Kurukshetra in 2022-2023 amounted to 11,254.08 tCO_2eq. The emissions generated directly by the campus (Scope 1) amounted to 93.25 tCO_2eq, the indirect emissions resulting from electricity consumption (Scope 2) 9,791.16 tCO_2eq and the remaining indirect emissions (Scope 3) 1,369.67 tCO_2eq (Fig. 4), accounting for 0.83%, 87.00% and 12.17% of total CF of the Institute respectively.

The carbon footprint per student was found to be 2.24 tCO_2eq. The results revealed that Scope 2 emissions were

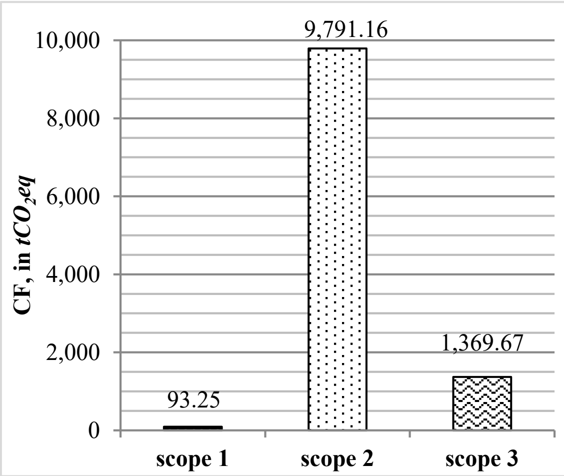

Fig. 4: Carbon emissions of NIT Kurukshetra.

the predominant contributors to the Institute's CF. Further, due to the limited number of day scholars and reduced student commuting activities, the Institute's Scope 3 emissions profile was quite lower.

5.2 Institute's Scope 1 emissions

The CF of each source in Scope 1 are shown in Fig. 5. Out of the 93.25 tCO_2eq Scope 1 emissions', cars, buses and generator contributed 32.69 tCO_2eq (35.06%), 35.91 tCO_2eq (38.52%) and 24.63 tCO_2eq (26.42%) respectively. Scope 1's major contributors are buses despite cars having higher fuel consumption. This is possibly due to the factors that influence the CF such as, vehicle type, age, and fuel efficiency. Higher CF by buses seemed to be due to lower mileage, sub-optimal route planning or under-utilization of capacity. Although, the CF of diesel fueled generators is lowest, still optimizing the generator's operation hours based on load demand and efficiency is crucial to reduce fuel consumption and carbon dioxide emissions. The refrigerant leakage was not reported during the observed year that can be attributed to meticulous maintenance. In terms of contribution to total

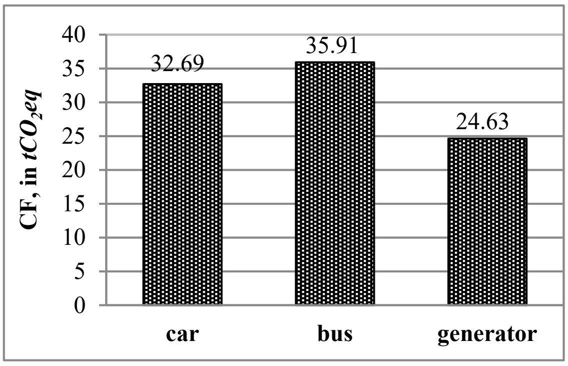

Fig. 5: Scope 1 emissions of NIT Kurukshetra.

emissions, transportation sector (cars and buses combined) contributed 0.61%, and generators contributed 0.23% to CF of the Institute.

5.3 Institute's Scope 2 emissions

Scope 2 imparts the highest CF to the tune of 9,791.16 tCO_2eq of all other scopes accounting for 87% of the total emissions of the Institute. Within Scope 2, the carbon emission from various sources is shown in Fig. 6. The highest contributor is the indirect emissions resulting from electricity produced from hard coal (9314.71 tCO_2eq) accounting for 95.10% of Scope 2 emissions. Every other source contributed less than 2% to insignificant amount (Fig. 6). The results are consistent with other reported CF studies of higher academic institution consistently highlighting electricity consumption as the primary contributor to overall energy usage. For instance, the Esentepe Campus of Sakarya University emitted 12,330.73 tCO_2eq in the year 2015, with electricity consumption accounting for 65.4% of the total emissions[44].

Considering the environmental concerns associated with coal combustion, there is a clear need for sustainable and cleaner alternatives in the energy mix. The relatively low contributions from natural gas, oil, lignite, wood chips, and hydroelectric sources indicate a potential for carbon footprint reduction through a transition to cleaner energy sources. The adoption of in-house solar energy plant could be a better and feasible option to reduce emissions from electricity consumption.

In terms of contribution to total emissions, the indirect emissions resulting from electricity produced from hard coal alone contributed 82.77% to CF of the Institute.

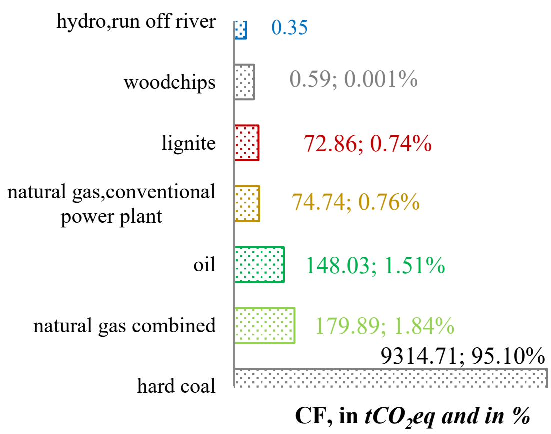

Fig. 6: Scope 2 emissions of NIT Kurukshetra

5.4 Institute's Scope 3 emissions

Indirect emissions (Scope 3) accounted for 1,369.67 tCO_2eq. The CF of the five categorized sources of Scope 3 are presented in Table 7 along with their percentage contribution within Scope 3 emissions. The contribution of commuting accounted for 97.95% of Scope 3 emissions; out of which visitor's contribution (motor bike and car) accounts for 86.69% of Scope 3 CF. The contribution of other sources is relatively negligible.

In terms of contribution to total CF of the Institute, commuting contributed 11.92% of total emissions, and visitors accounted for 10.55% to total emission.

Table 7. Scope 3 emissions of NIT Kurukshetra.

Type	CF in tCO_2eq and (%)
Paper procurement	2.57 (0.002)
Water supply	0.35 (0.0003)
Waste treatment	6.27 (0.005)
Waste generation	18.91 (0.014)
Commuting	1,341.58 (97.95)
- Motor bike (Student)	11.16
- Motor bike (Visitors)	143.09
- Car (Staff)	155.25
- Car (Visitors)	1,032.07
Total for Scope 3	1,369.67

standardization is crucial to ensure consistency and reliability in assessing sustainability efforts across academic institutions.

Despite above mentioned constraints and/or limitations, the CF of NIT Kurukshetra has been compared to the reported studies of academic institution in different parts of the world in Table 8. The CF per student in a year was lowest (less than 0.5 tCO_2eq) of Nigerian universities – University of Ibadan, and Federal University of Agriculture (FUA), and Universitas Pertamina, Indonesia. The CF of University of Cape Town (UCT), S. Africa, BITS Pilani, India, and Al Akhawayn University (AAU), Morocco was relatively in the higher range of 3.6 to 6.2 tCO_2eq per student per year. The CF per student per year of NIT Kurukshetra (2.24 tCO_2eq) is in comparable range (1.7 to 3.7 tCO_2eq) of University Teknologi Malaysia, Cambridge University, UK, and Clemson University, USA.

Table 8. Comparative carbon footprint of reported academic institution [source: [14), 45)]].

Academic Institute	Scope wise CO_2 emissions, in tCO_2eq and (%)			Total CF (tCO_2eq)	CF per student (tCO_2eq)
	Scope 1	Scope 2	Scope 3		
UCT, Cape Town, S. Africa	764.33 (0.9)	68,279.70 (80.4)	15,880.97 (18.7)	84,925.00	3.60
DeMU, Leicester, UK	3,064.80 (6.9)	7,662.00 (17.5)	40,353.20 (75.6)	51,080.00	1.13
Universitas Pertamina, Indonesia	1,243.00 (92.0)	90.00 (6.7)	18.00 (1.3)	1,351.00	0.27
FUA, Abeokuta, Nigeria	2,018.00 (34)	653.00 (11.0)	3,264.00 (55)	5,935.00	0.36
University of Ibadan, Nigeria	210.84 (4.0)	4,743.86 (90.0)	316.26 (6)	5,270.95	0.13
Clemson University, S. Carolina, USA	56,050.00 (59.0)	3,8950 (41.0)	-- -- (0)	95,000.00	3.67
Cambridge University, UK	51,077.13 (74.0)	17,393.83 (25.2)	552.18 (0.8)	69,023.15	2.97
UTM, Malaysia	48,248.69 (83.8)	7,283.36 (12.6)	2,043.95 (3.55)	57,576.00	1.78
AAU, Morocco	1,929.82 (14.7)	7,955.57 (60.6)	3,242.62 (24.7)	13,128.00	6.14
BITS Pilani, India	181.50 (1.0)	8,250 (50.1)	8,068.50 (48.9)	16,500.00	4.65
National Institute of Technology (NIT) Kurukshetra, India ***(present study)***	***93.25 (0.83)***	***9,791.16 (87.0)***	***1, 369.67 (12.17)***	***11,254.08***	***2.24***

In this study, the Scope 3 carbon footprint assessment is made less definite as there is insufficient information about computers, electronics, and lab equipment that are also part of Scope 3 emissions estimate. Even though this gap prevents offering a comprehensive analysis, but fewer data doesn't always equate to greater emissions.

5.5 Comparison with other academic institutions

The CF of different academic institutions differs widely due to varying factors including, campus size and layout, geographic location and climate, and transportation practices (commuter habits and access to public transportation) that has significant impact on energy consumption. It has been observed that urban universities have lower CF due to accessible public transportation and walkable campuses. Additionally, differences in calculation methodologies further complicate direct comparisons among academic institutes. Therefore,

6. Conclusions

The total CF of National Institute of Technology Kurukshetra for the fiscal year 2022-23 were estimated at 11,254.08 metric tons of CO_2-equivalent, accounting for 2.24 tCO_2eq per student. The study showed that electricity usage is the largest contributor (87%) followed by commuting by vehicles (11.92%) to the Institute's CF. Efforts are required to reduce the CF by increasing green energy supply, teleconferencing and other AI tools to reduce visitors' transportation carbon emissions, and introducing monitoring, updating and reporting of Institute's annual carbon emissions.

Although CF assessment among academic institutions appears to be in infancy stage, particularly in reporting their emission data. However, academic institutions have the potential to substantially reduce CF per student, as has been displayed by University of Ibadan, Nigeria and Universitas Pertamina, Indonesia. Being innovative drivers in engineering and technology, engineering institutes need to accept the responsibility to augment the transformation towards a sustainable campus and, in turn sustainable world. Despite limitations/constraints of insufficient data and/or activity-gaps under Scope 3, the study provides a fair idea of the Institute's annual CF. The study can encourage academic institutions, particularly in India, to introduce and develop institute specific carbon management strategies.

Acknowledgments

The writers of this research express their gratitude to OpenLCA Nexus Ecoinvent V3.9.1 for providing the academic license and the data necessary for this study. Additionally, our appreciation is extended to the Estate Section, Store Section and Central Section of NIT Kurukshetra, and Central Public Work Department, for their invaluable inputs and support.

Nomenclature

CF	Carbon Footprint
eq	equivalent
GHG	Greenhouse gas
GHGP	Greenhouse gas protocol
h	Hour
km	kilometer
kg	kilogram
kWh	kilowatt hour
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
m^3	meter cube
MLD	Million Liters per Day
*P*km*	person kilometer
t	metric tons
tCO_2eq	metric tons CO_2-equivalent

References

1) M. H. Huzaifi, M. A. Budiyanto and S. J. Sirait, "Study on the carbon emission evaluation in a container port based on energy consumption data," *Evergreen*, **7(1)**, 97-103 (2020). https://doi.org/10.5109/2740964.
2) N. A. Lestari, "Reduction of CO2 emission by integrated biomass gasification-solid oxide fuel cell combined with heat recovery and in-situ CO2 utilization," Evergreen, 6(3) 254-261 (2019). https://doi.org/10.5109/2349302
3) IPCC, "2006 IPCC Guidelines for National Greenhouse Gas Inventories," IGES, 2008. https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf
4) J. T. Houghton, G. J. Jenhins and J. J. Ephraums, "Climate Change: The IPCC Scientific Assessment," Cambridge University Press, 1990. https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf
5) UNFCCC, "FCCC/SBI/2010/10," UN Framework Convention on Climate Change, 2010. https://climate.onep.go.th/wp-content/uploads/2019_bak/07/SBI_32.pdf
6) "COP 28 - United Nations Climate Change Conference," 2023. https://unfccc.int/. (accessed October 17, 2023).
7) D. Pandey, M. Agrawal and J. S. Pandey, "Carbon footprint: current methods of estimation," *Environmental Monitoring and Assessment*, 178 135-160 (2011). DOI 10.1007/s10661-010-1678-y
8) T. Gao, Q. Liu and J. Wang, "A comparative study of carbon footprint and assessment standards," *International Journal of Low-Carbon Technologies*, 9(3) 237-243 (2014). https://doi.org/10.1093/ijlct/ctt041
9) M. I. Sabtu, H. Hishamuddin, N. Saibani and M. N. A. Rahman, "A review of environmental assessment and carbon management for integrated supply chain models," *Evergreen*, 8(3) 628-641 (2021). https://doi.org/10.5109/4491655
10) T. Wiedmann and J. Minx, "A definition of 'carbon footprint'," In: C. C. Pertsova, Ecological Economics Research Trends, Nova Science Publishers, 1-11 (2008).https://www.researchgate.net/publication/247152314_A_Definition_of_Carbon_Footprint#fullTextFileContent
11) A. A. S. Gheidan, M. B. A. Wahid, O. A. Chukwunonso and M. F. Yasin, "Impact of internal combustion engine on energy supply and its emission reduction via sustainable fuel source," *Evergreen*, 9(3) 830-844 (2022). https://doi.org/10.5109/4843114
12) H. Koide, T. Seiichi, K. Tamura, W. Jung, H. Nakayama, S. Matsuda and K. Moroga, " Possibility of cooperration for a low carbon society: comparison of the Fukuoka and Busan metropolitan cities," *Evergreen* 2 21-35 (2010).
13) E. Helmers, C. C. Chang and J. Dauwels, "Carbon footprinting of universities worldwide: Part I-objective comparision by standardized metrics," *Environmental Sciences Europe*, 33(1) 1-25 (2021). https://doi.org/10.1186/s12302-021-00454-6
14) K. S. Sangwan, V. Bhakar, V. Arora and P. Solanki, "Measuring carbon footprint of an Indian university using life cycle assessment," *Procedia CIRP*, 69 475-480 (2018). https://doi.org/10.1016/j.procir.2017.11.111
15) M. Moerschbaecher and J. W. Day Jr, "The greenhouse gas inventory of Louisiana State University: a case study of the energy requirements of public higher education in the United States," *Sustainability*, 2(7) 2117-2134 (2010). https://doi.org/10.3390/su2072117
16) O. O. Ologu and S. W. Tita, " Carbon footprint

evaluation and reduction as a climate change mitigation tool - case study of Federal University of Agriculture Abeokuta, Ogun State, Nigeria," *International Journal of Renewable Energy Research*, 4(1) 176-181 (2014). https://www.researchgate.net/publication/281745904_Carbon_Footprint_Evaluation_and_Reduction_as_a_Climate_Change_Mitigation_Tool_-_Case_Study_of_Federal_University_of_Agriculture_Abeokuta_Ogun_State_Nigeria#fullTextFileContent

17) R. Mendoza-Flores, R. Quintero-Ramírez, I. Ortiz, "The carbon footprint of a public university campus in Mexico City," *Carbon Management*, 10(5) 501-511 (2019). https://doi.org/10.1080/17583004.2019.1642042
18) N. K. Sari, R. Gusvita and D. J. Puradimaja, "The carbon footprint estimation based on campus aactivities in ITERA (Institut Teknologi Sumatera)," *Journal of Sustainability Perspectives*, 1 431-438 (2021). https://doi.org/10.14710/jsp.2021.12036
19) P. Yañez, A. Sinha and M. Vásquez, "Carbon footprint estimation in a university campus: evaluation and insights," *Sustainability*, 12(1) 181 (2020). https://doi.org/10.3390/su12010181
20) S. Syafrudin, B. Zaman, M. A. Budihardjo, S. Yumaroh, D. I. Gita and D. S. Lantip, "Carbon footprint of academic activities: a case study in Diponegoro University." *IOP Conference Series: Earth and Environmental Science*, 448 012008 (2020). DOI 10.1088/1755-1315/448/1/012008
21) M. Varón-Hoyos, J. Osorio-Tejada and T. Morales-Pinzón, "Carbon footprint of a university campus from Colombia," *Carbon Management*, 12(1) 93-107 (2021).https://doi.org/10.1080/17583004.2021.1876531
22) J. Kiehle, M. Kopsakangas-Savolainen, M. Hilli and E. Pongrácz, "Carbon footprint at institutions of higher education: The case of the University of Oulu," *Journal of Environmental Management*, 329 117056 (2023).https://doi.org/10.1016/j.jenvman.2022.117056
23) A. Herth and K. Blok, "Quantifying universities' direct and indirect carbon emissions–the case of Delft University of Technology," I*nternational Journal of Sustainability in Higher Education*, 24(9) 21-52. (2022). https://doi.org/10.1108/IJSHE-04-2022-0121
24) F. Samara, S. Ibrahim, M. E. Yousuf and R. Armour, "Carbon Footprint at a United Arab Emirates University: GHG protocol," *Sustainability*, 14(5) 2522 (2022). https://doi.org/10.3390/su14052522
25) N. Cano, L. Berrio, E. Carvajal and S. Arango, "Assessing the carbon footprint of a Colombian University Campus using the UNE-ISO 14064–1 and WRI/WBCSD GHG Protocol Corporate Standard," *Environmental Science and Pollution Research*, 30(2) 3980-3996 (2023). https://doi.org/10.1007/s11356-022-22119-4
26) R. Clabeaux, M. Carbajales-Dale, D. Ladner, and T. Walker, "Assessing the carbon footprint of a university campus using a life cycle assessment approach, "*Journal of Cleaner Production*, 273(12) 122600 (2020). DOI: 10.1016/j.jclepro.2020.122600
27) A. Vrachni, A. Christogerou, G. A. Thomopoulos, C. Marazioti and G. N. Angelopoulos, "Carbon footprint of the University of Patras in Greece: evaluating environmental culture and campus' energy management towards 2030," *Pollutants*, 2(3) 347-362 (2022). https://doi.org/10.3390/pollutants2030024
28) A. Mustafa, M. Kazmi, H. R. Khan, S. A. Qazi and S. H. Lodi, "Towards a carbon neutral and sustainable campus: case study of NED university of engineering and technology," *Sustainability*, 14(2) 794. (2022) https://doi.org/10.3390/su1402079
29) A. E. Fenner, C. J. Kibert, J. Woo, S. Morque, M. Razkenari, H. Hakim and X. Lu, "The carbon footprint of buildings: a review of methodologies and applications," *Renewable and Sustainable Energy Reviews*, 94 1142-1152 (2018). https://doi.org/10.1016/j.rser.2018.07.012
30) S. T. Daglioglu, "Carbon footprint analysis of Ege University within the scope of environmental sustainability," *Commagene Journal of Biology*, 5(1) 51-58. (2021). https://doi.org/10.31594/commagene.865194
31) H. N. Larsen, J. Pettersen, C. Solli and E. G. Hertwich, "Investigating the carbon footprint of a university-the case of NTNU," *Journal of Cleaner Production*, 48 39-47 (2013). https://doi.org/10.1016/j.jclepro.2011.10.007
32) WRI/WBCSD, "Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard," World Resource Institute and World Business Council for Sustainable Development, n.d. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf
33) WBCSD/WRI, "The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard," World Business Council for Sustainable Development and World Resource Institute, 2004. https://member.ghginstitute.org/ghgcourses/Course2/downloads/ghg_project_protocol.pdf
34) K. Valls-Val, M. D. Bovea, "Carbon footprint in higher education institutions: a literature review and prospects for future research," *Clean Technologies and Environmental Policy*, 23(9) 2523-2542 (2021). https://doi.org/10.1007/s10098-021-02180-2
35) "National Institute of Technology Kurukshetra," n.d. https://nitkkr.ac.in/ (accessed November 21, 2023).
36) R. Frischknecht, N. Jungbluth, H. J. Althaus, G. Doka, R. Dones, T. Heck M. Spielmann, "The ecoinvent database: overview and methodological framework

(7pp)," *The International Journal of Life Cycle Assessment*, 10 3-9 (2005) http://dx.doi.org/10.1065/lca2004.10.181.1
37) C. Rodríguez, S. Greve, "Regionalized LCIA in openLCA," GreenDelta GmbH 2016. https://www.openlca.org/wp-content/uploads/2016/08/Regionalized-LCIA-in-openLCA.pdf
38) S. Sarraf and S. Deswal, "Life cycle assessment of a water treatment plant based on non-conventional moving bed biofilm reactor process," *Evergreen*, 10(3) 1388-1397 (2023). https://doi.org/10.5109/7151687
39) "OpenLCA Nexus: Your Source of LCA and Sustainability Data" n.d. https://nexus.openlca.org/database/ecoinvent. (accessed November 21, 2023).
40) EPA,"Basic information of air emissions factors and quantifications," *US Environmental Protection Agency*, (n. d.). https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification (accessed Febuary 07, 2024).
41) S. Notosiswoy and I. Iskandar, "Contribution of coal mine and coal fired power plant to CO_2-emission in Indonesia," *Journal of Noval Carbon Resource* Sciences, 4 17-20 (2011). http://www.tj.kyushu-u.ac.jp/evergreen/ncrs/files_jncrs/JNCRS_Vol4_17-20.pdf
42) "Greenhouse Gas Protocol: Scope 3 calculation guidance," n.d. (accessed November 21, 2023). https://ghgprotocol.org/sites/default/files/2023-03/Scope3_Calculation_Guidance_0%5B1%5D.pdf.
43) "India GHG Program: Transport Emission Factors," n.d.https://indiaghgp.org/sites/default/files/Road%20Transport%20Technical%20Paper.pdf (accessed November 21, 2023)
44) R. Sreng and M. G. Yiğit, "Carbon footprint studies on Esentepe campus of Sakarya University, Turkey in 2015," *Sakarya University Journal of Science*, 21(5) 1095-1099 (2017). https://www.academia.edu/64592190/Carbon_footprint_studies_on_Esentepe_Campus_of_Sakarya_University_Turkey_in_2015
45) D. Adeyeye, A. Olusola, I. R. Orimoloye, S. K. Singh and S. Adelabu, "Carbon footprint assessment and mitigation scenarios: a benchmark model for GHG indicator in a Nigerian university," *Environment, Development and Sustainability*, 25(1) 1361-1382 (2023). DOI: 10.1007/s10668-021-02098-1