




Carbon footprint of higher education institutions

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Abstract

Higher education institutions (HEIs) play a fundamental role in sustainability, promoters of innovation, science, and technology. Therefore, every day more institutions are joining the fight against global warming. One of the contributions of HEIs is the carbon footprint (CF) report, to implement policies and management systems to establish strategies to reduce polluting gas emissions from their campuses. In the present study, a systematic review was carried out for 50 reports of CF, where 94% of the studies were published from 2018 to 2022. This research compiles methodologies, scope, results, and trends in Carbon Footprint calculations and provides a procedure to evaluate CF on college campuses. This research shows that the most evaluated emission sources were the consumption of electrical energy (78%), transportation (74%), and the use of fuels (64%). In addition, the HEIs with the lowest emission factors for electricity consumption are Finland, England, and Colombia. Furthermore, establishing a specific carbon footprint guideline for universities would improve reports and allow better comparisons between HEIs.

Keywords Carbon footprint · Higher education · Buildings · Scopes · Sustainable development

1 Introduction

Anthropogenic emissions of Greenhouses Gases (GHG) cause the increase in global average temperature and climate change (Wang et al., 2021; Zandalinas et al., 2021), representing an unprecedented crisis for humanity (Hausfather et al., 2022). According to the latest GHG emissions report published in 2021 by the United Nations Environment Program (UNEP), global anthropogenic emissions doubled compared to 1970 (from 28.7 to 58.5 GtCO₂e) (UNEP, 2021). In this framework, with the main objective of limiting the increase in global average temperature to below 2 °C by 2050, 195 countries signed the "Paris

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Agreement" in 2015 (United Nations, 2015). However, the policies established and the contributions determined at the international level are insufficient to achieve this objective. (UNEP, 2021). In addition, recent studies warn that some effects of climate change will be irreversible (Hughes et al., 2018; Kim et al., 2022; Li et al., 2021; Masson-Delmotte et al., 2021) and will not be avoided entirely, despite the efforts made to reduce emissions (Rogelj et al., 2016). However, it is still a global challenge that requires solutions from all sectors of society (Lee et al., 2016; Zandalinas et al., 2021).

Global GHG can be classified across five sectors: energy, industry, buildings, transportation, and AFOLU (Agriculture, Forestry, and other Land Use) (Lamb et al., 2021). In the buildings sector, the "Global Alliance for Buildings and Construction" announced in its latest global status report that 37% of global CO₂e emissions are attributed to this sector. In addition, 36% of the world's energy is consumed in construction activities, use, and demolition of buildings (GABC, 2021; IEA, 2021). In this sector are the Higher Education Institutions (IES). It is estimated that there are more than 20,000 HEIs in the world (International Association of Universities & United Nations Educational, 2019), which are made up of buildings for classrooms, laboratories, offices, dining rooms, and residences. These areas represent high energy consumption levels (Khoshbakht et al., 2018). For this reason, they are considered significant direct and indirect GHG generators. (Klein-Banai & Theis, 2013) Within their academic work, in addition to energy consumption, there are other daily GHG-generating activities such as student and staff transportation, fuel consumption within the campus, and waste generation, among others (Genta et al., 2022). As promoters of science, technology, and innovation, HEIs have a fundamental role in contributing to reduce GHG emissions as part of sustainability achievement (Bozkurt, 2022; Lozano et al., 2019; Robinson et al., 2018; Valls-Val & Bovea, 2022). Furthermore, HEIs have shown their commitment through accounting and reporting carbon emissions (Yañez et al., 2019). Leaders of HEIs signed in 2012 the "Commitment to Sustainable Practices in Higher Education" in Rio de Janeiro, Brazil, at the United Nations Conference on Sustainable Development, taking responsibility for a series of actions. Among these were greening campuses by reducing the environmental footprint and promoting more sustainable lifestyles (United Nations Conference on Sustainable Development, 2012). Also, some HEIs have participated in declarations of environmental sustainability, such as Talloires, Halifax, and Kyoto (Evangelinos et al., 2009). Some countries have enacted Environmental policies (Åkerman, 2019; Barrett & Therivel, 2019; Wysokińska, 2016) and management systems (Jiang et al., 2018; Merabtine et al., 2018; Roos & Guenther, 2020) to reduce the impacts of educational facilities. For example, initiatives such as the Higher Education Financing Council of England, which is required to establish the objective of GHG reduction, among other projects such as the Euronet 50/50 (Intelligent Energy Europe, 2013) or the Program "Eco-schools of the United Nations" (Institutional Partners—Eco-Schools, 2021).

Higher Education Institutions can be named "Small Cities" due to their size and the different impacts achieved through the community toward society and the environment (Abdullah et al., 2019). Something that HEI is already discovering by incorporating education focused on sustainability in the curriculum (Findler et al., 2018; Robinson et al., 2018). However, this commitment should not only be based on educating students in sustainable practices but also on the report of sustainability indicators, such as the carbon footprint (CF). A recent study shows how more than 400 HEIs have signed a Climate Leadership Commitment, many reporting their GHG emissions inventory. However, the number of HEIs committed to Sustainable Development (SD) and CF reporting still needs to be bigger than the total number of HEIs worldwide (Yan et al., 2019). Many higher education institutions analyze and report their campuses' carbon footprint in the literature.

Likewise, a diversity of review studies examine methodological aspects in calculating the CF of different institutions and their results. However, from our knowledge, no review makes bibliometric research focused only on the literature on evaluating and estimating the CF at the higher education level. Additionally, it analyzes the primary methodologies of the CF study and the results of the studies; in this sense, in this study, we pretend to fill this information gap by giving the concept of "Carbon Footprint" greater importance in higher education. In the same way, we encourage international organizations to establish specific guidelines for these institutions.

Our study is divided into one initial section before the methods applied for this research, called zero carbon buildings, to introduce this transitorily model of facilities in higher education. The objectives of this study were: (1) analyze the co-occurrence of keywords of literature; (2) evaluate the contribution of countries to CF of HEIs; (3) analyze and discuss the selected studies' principal methodologies and results of CF; The results of this study provide information on the level of HEIs concerning the carbon footprint. This review is developed in the framework of the research project to implement an energy management system and calculate the carbon footprint on the university campus of the Universidad Autónoma de Occidente, Colombia.

1.1 Zero carbon buildings

Zero Carbon Buildings (ZCB) has appeared as an innovative and sustainable approach to the energy efficiency of worldwide buildings (Zhao & Pan, 2015). These are considered a response to the objective of reducing GHG emissions generated by using energy and their construction (Jones et al., 2015). The ZCB correspond to the group of buildings with high Energy Efficiency (EE), which generate energy on site, in addition to providing a comfortable and healthy work environment for users, since various studies have shown some secondary effects on health due to conditions of air inside buildings (Arundel et al., 1986; Bell & Baldwin, 2013; Sliwinska-Kowalska, 2009; Wah et al., 2010). In addition, ZCB uses carbon-free and renewable energy sources, capable of meeting the demand from their operation over time (Trofimova et al., 2021). The World Green Building mentions them as Green Buildings, allowing them to increase the positive impacts and reduce the negative effects of buildings (WGBC, 2016), as their design and construction possess intelligent components for their facades, ventilation, cooling, and heating systems. The above, with the objective of achieve a significant reduction of energy consumption (Jones et al., 2015). To achieve the Paris Agreement, emissions from buildings must be reduced by 50% by 2030 to put the sector on track for neutrality by 2050 (Kober et al., 2020). Thus, governments must steer the building sector towards low-carbon buildings and update their climate commitments (ONU, 2020). This is why in governments such as in New Zealand, the Ministry of Business, Innovation and Employment (MBIE) has launched the "Building for Climate Change" program, which suggested two ways to reduce emissions from new buildings: (1) setting minimum levels of operational efficiency, and (2) setting limits for the amount of embodied carbon in new buildings (Bui et al., 2021). On the other hand, in the UK to achieve the legal obligation to reduce carbon emissions from buildings by 80% by 2050, the government's former chief construction advisor suggested providing infrastructure to enable clean energy supply and sustainable practices (Pan, 2015).

In the literature, research has been carried out in ZCB compared to conventional buildings in terms of thermal comfort, air quality, lighting, health, and other factors (Trofimova et al., 2021). Speaking of the first factor respectively, it is observed that people's perception

of thermal comfort is subjective, since it depends on various personal factors. However, different governmental bodies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Chartered Institution of Building Services Engineers (CIBSE) have conducted research studies on issues such as the physical parameters that affect the comfort zone of users (Schweiker et al., 2018), in order to establish standards and benchmarks for them and that these are appropriate for a given environment (Trofimova et al., 2021).

The ZCB infrastructure has low carbon materials (Zhao et al., 2018) manufactured by technologies that imply the reduction of the Carbon Footprint, allowing it structurally to be equivalent to other materials such as concrete and steel (Markewitz et al., 2019). Companies such as Carboncure, Thomas Concrete apply block manufacturing technologies introducing recycled CO₂ to reduce up to 15 kg CO_{2e}/m³ of concrete without affecting its performance, supporting up to 35.9 MPa for each block (Grover, 2020). Blue Planet company has adopted a technology to form Calcium Carbonate (CaCO₃) rocks thus replacing conventional aggregate materials to generate concrete (Blue Planet Systems, 2020). A recent study found an 85% reduction in CF and a 101% reduction in energy consumption for buildings using alternative building materials and implementing renewable sources of energy generation. The comparison was performed by simulation between 3 buildings: a conventional building, an alternative building, and a net carbon building (NZCB). The data inventory for these models included conventional and alternative building materials, geographical and climatic parameters, NZCB guidelines, and active and passive design strategies (Fouly & Abdin, 2022).

2 Data and methods

This research follows a systematic structure, with “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) (Knobloch et al., 2011), following the three steps: (1) Planning and preparing a review; (2) Performing the review; (3) Disseminating and reporting the results of the review. Figure 1 presents the scheme of the review methodology.

2.1 Planning and preparing a review

This stage clarifies or develops the study topics. The reviewers identified the following research questions to be addressed:

- What is the current research trend of CF on HEIs based on bibliometric analysis?
- What is the current state of the art of carbon footprint on HEIs?
- What are the main carbon footprint methodologies adopted by HEIs?

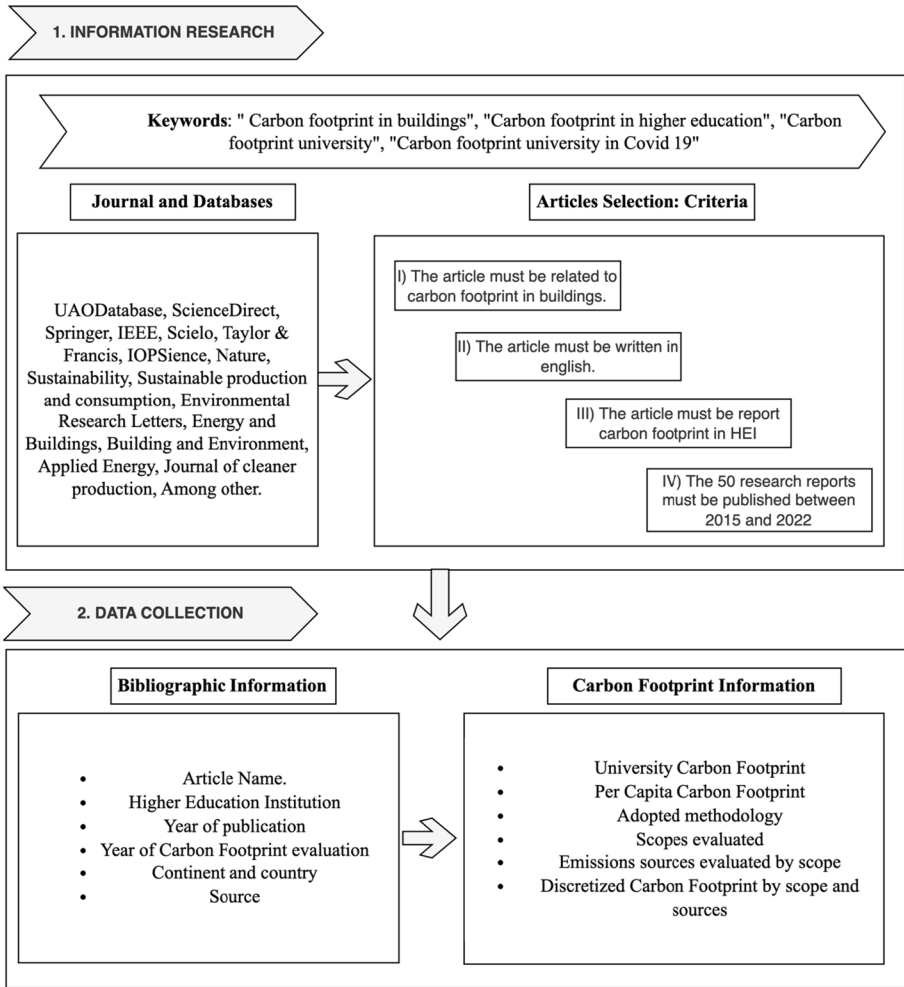


Fig. 1 Scheme of the review methodology

2.2 Performing the review

This section was divided into three stages: literature search, data collection, and bibliometric analysis. For each stage, a set of criteria is established to select from the literature the most significant studies and data for this review.

2.3 Literature search

The selection of the articles was carried out in the following way. Initially, they passed through the first filter, which consisted of the following criteria: (I) to be related to carbon footprint in buildings; (II) to be presented in English. The criteria for the second filter consisted of (III) related to carbon footprint in higher education institutions or university

campuses and (IV) Studies or research from 2015 onwards. The following keywords were used to search for articles: “Carbon footprint in buildings”, “Carbon footprint in Higher Education”, “Carbon Footprint University”, and “Carbon Footprint University COVID-19”.

For data extraction on carbon footprint evaluations in HEIs, the articles had to meet the criteria established in the second filter presented above, in addition to item (II) of the first filter. The databases and journals consulted for the extraction of articles were: UAO database, ScienceDirect, Springer, IEEE, Scielo, Taylor & Francis Online, IOPscience, Nature, Sustainability, Sustainable Production and Consumption, Environmental Research Letters, Energy and Buildings, Building and Environment, Applied Energy, among others.

2.3.1 Data collection

The data collection was made in 2 sub-stages. In the first stage, data was collected from the global context of Carbon Footprint, Environment, and Higher Education Institutions. The studies selected in this substage had to match the criteria of filter 1 (I, II). These data were collected in a Word format database.

For the second sub-stage, numerical results and some textual data were collected from carbon footprint assessments conducted in different HEI studies around the world. The extracted data were compiled in an Excel file with the following categories: Name of the HEIs, Country, Continent, Carbon footprint in TonCO_{2e} (metric tons), year of assessment (criterion V), methodology used, Scopes, description of scopes, carbon footprint per capita, additional data, and search link.

2.3.2 Bibliometric analysis

Using the keywords "carbon footprint" and "university", we found 531 articles, 205 conference papers, 9 book chapters, 32 reviews, 10 notes, 7 short surveys, 6 conference reviews, 3 letters, 3 books, and 2 errata. In total, 838 documents, of which 816 were written in English. The information extracted for the bibliometric analysis was: (1) Title of the document; (2) Abstract; (3) Address of correspondence; (4) Author keywords; (5) Indexed keywords. The analysis was performed for the co-occurrence of keywords using full counting and was programmed to visualize words with a minimum number of concurrences of 5. The total number of keywords extracted (838 documents) was 6991.

2.4 Disseminating and reporting the results of the review.

The results of this review were grouped and presented in the following categories: (1) Bibliometric analysis; (2) Contribution by continents; (3) Carbon footprint in HEIs; (4) Scopes for carbon footprint assessment in HEIs; (5) Carbon footprint by HEIs electric energy consumption; (6) Methodologies for carbon footprint assessment in HEIs; (7) Carbon footprint of HEIs in COVID-19 pandemic.

3 Results

3.1 Bibliometric analysis

The bibliometric analysis of keyword co-occurrence plotted 4 clusters. The keyword with the highest co-occurrence for the red cluster was "climate change," with 133 co-occurrences. In the green color, we have the keyword "greenhouse gases" with 129. For the blue color, we have the keyword "carbon footprint" with 551 co-occurrences. Finally, we have the keyword "sustainable development" in yellow, totaling 124 (Fig. 2).

3.2 Contribution by countries

Figure 3 shows the country of the corresponding authors, taking into account single-country publications (SCP), where all authors belong to the same country or intra-country, and multi-country publications (MCP), where authors belong to different countries or inter-country. On the other hand, the corresponding author is the author who sends the article to the journal editor and channels all correspondence to him/her.

In the top 3 most published documents related to carbon footprint in Higher Education institutions, we have the United States, United Kingdom, and China with 125, 50, and 48 publications, respectively. For SCP publications, we have the United States (110), the United Kingdom (39), and China (32). However, we have China with the first place for MCP publications, followed by the United States and the United Kingdom with 16, 15, and 11 publications, respectively. Our analysis reported that of the 838 documents, 280 did not identify the country of correspondence. Analyzing the remaining 558, we found that 60% of the published documents were concentrated in 16% of the countries (United States, United Kingdom, China, Spain, Germany, Italy, Australia, and Canada).

3.3 Carbon footprint in HEIs

The results of this research are in Table 1, reporting the carbon footprint of 43 HEIs worldwide, highlighting that 7 HEIs didn't report the carbon footprint cumulative data.

The studies in Table 1 show that the quantities are not comparable between HEIs, since the campuses have different characteristics such as the type of infrastructure, study and work modalities, number of students and staff, campus area, and vegetation, among others. In addition, the studies establish different scopes and limits in their research.

3.4 Scopes for carbon footprint assessment in HEIs

For the evaluation of CF in HEIs most studies adopt three scopes from the literature. The first, in which GHG generating activities are identified directly on campus; the second, in which GHG generation is identified indirectly and in situ; for this scope, most studies associate it with the purchase or consumption of electricity to meet the needs of the institution; the third, activities in which GHG are generated indirectly by educational work are contemplated. The last scope, respectively, is the most extensive. Table 2 shows the 50 reports included in this carbon footprint study for 2014–2020, as well as the scopes and activities evaluated for each study.

Table 1 Carbon footprint in HEI

HEI	Year Evaluated	CF TCO _{2e} /Year	Source
Punjab	2019	18,324.1	(Haseeb et al., 2022)
	2020	7802.4	
Negeri Semarang	2019	10,679.25	(Rahayuningsih et al., 2021a, b)
	2020	4312.27	
Sunway	2018	10,369	(Devandran & Dewika, 2021)
	2019	10,005	
	2020	7523	
“Unknown”	2020	922.5	(Shah et al., 2021)
Oulu	2020	745.83	(Javid, 2022)
Autónoma de México	2020	7199.29	(Alanis et al., 2021)
Maiêutica	2019	2937	(Veludo et al., 2021)
UNAL (Medellin)	2019	7238.91	(Cano et al., 2022)
Bournemouth	2019	2140	(Filimonau et al., 2020)
Afe caballa	2019	12,837.037	(Folorunso et al., 2020)
Oulu	2019	15,827	(Kiehle et al., 2021)
ESNE Madrid	2019	255,546	(Filippone et al., 2021)
Rijeka	2019	1039	(Žiković et al., 2020)
Hassanuddin	2019	2203.035	(Zakaria et al., n.d.)
Malaysia Teremgganu	2018	1,209,743.2	(Abdullah et al., 2019)
Jaume I	2018	11,083	(Valls-Val & Bovea, 2022)
Sharjah	2018	94,553.3	(Samara et al., 2022)
EAN	2018	2.08	(García-Alaminos et al., 2022)
Diponegoro	2018	16,345.83	(Ivanova et al., 2020)
“Unknown”	2018	644,137	(El Geneidy et al., 2021)
Jyväskylä	2018	5293.6	(Ernesto et al., 2021)
HTWG Konstanz	2018	52,156.5	(Sippel et al., 2018)
Federal University of Technology – Paraná	2018	10.34 (Monthly)	(Barros et al., 2018)
Michael Okpara	2017 (7 months)	705.5	(Obi et al., 2021)
Pertamina	2017	1351.98	(Ridhosari & Rahman, 2020)
Technology of Pereira	2017	8969	(Varón-Hoyos et al., 2021)
Mahidol	2017	1784.32	(Kulsuwan et al., 2019)
Batman	2017	3,162,855.4	(Serkan & Hakan, 2019)
Western Norway	2017	1700	(Zeiss & Slaymark, 2018)
Metropolitan Technological Institute	2016	999.3	(Aristizábal-Alzate et al., 2021)
Talca	2016	5472.89	(Yañez et al., 2019)
Metropolitan Autonomous	2016	3000	(Mendoza-Flores et al., 2019)
Haripur	2016	0.579	(Hussain, 2020)
Kelaniya	2016	42,383.8	(Bandara et al., 2018)
Da Coruña	2016	10,188	(Perez-Lopez et al., 2021)
Keele	2015	66,784.9	(Gu et al., 2018)
Sir Parashurambhau College	2015	3630.57	(Kulkarni, 2019)
Sakarya	2015	12,330.73	(Sreng & Gümrukçuoğlu Yiğit, 2017)

Table 1 (continued)

HEI	Year Evaluated	CF TCO _{2e} /Year	Source
Uttaradit Rajabhat	2015	138.47	(Saphanthong et al., 2020)
British Columbia	2015	960	(Dolf & Teehan, 2015)
Patras	2015	32,882.5	(Vrachni et al., 2022)
Clemson	2014	95,000	(Clabeaux et al., 2020)
BITS pilani	2014	16,500	(Sangwan et al., 2018)

The research identified 49 HEIs, 23 GHG generating activities or sources, where 66% evaluated at least one activity in scope 1, 70% in scope 2, and 80% in scope 3. However, in the studies, some activities were identified in different scopes as in the case of Jaume I, which introduces energy generation in scope 2; for this case, we consider that as energy generation is produced on site and also is part of the use of fossil fuel, it should be part of the direct emissions of scope 1.

Studies such as Sakarya University (Sreng & Gümrukçuoğlu Yiğit, 2017) and Qasim University (Al-Mufadi et al., 2016) mention wastewater as an emission source. In this case, it should be analyzed from two perspectives. First, if there is wastewater treatment on campus (scope 1), considering the emissions generated in the drying bed process. Secondly, if the water is discharged without prior treatment (scope 3). It is evident that the CF of wastewater without pretreatment is higher, and more significant environmental impacts are attributed to it (Schneider et al., 2015). Furthermore, if the emissions occur on-site, as is the case for wastewater treatment, they should be considered in scope 1. If this is not the case and the wastewater is discharged without any treatment, the contribution to the CF should be included in scope 3 because the GHG emissions result from an HEIs action outside of campus.

Siliwangi University (Busaeri et al., 2021) and Malaysia Terengganu (Abdullah et al., 2019) adopted the UI GreenMetric methodology. This guideline does not consider the same 3 scopes proposed by the GHG Protocol. However, for the analysis objective, these studies were established under the 3 scopes mentioned above.

The most evaluated emission sources in the CF studies were electricity consumption with 78% of the studies (Scope 2), community transportation (employees and students) with 74% of the studies (Scope 3), and finally, the use of fuels with 64% (Scope 1) (Table 3).

The results show that energy consumption and transportation are among the most evaluated activities contributing to an increase in the carbon footprint. In this framework, many researchers have proposed strategies and approaches to decrease university campuses' CF values. The implementation of energy management systems oriented towards efficient and conscious use of electricity, water and waste management (Yañez et al., 2019), the adaptation of fleets of electric or natural gas vehicles to transport students and university staff (Valls-Val et al., 2021), photovoltaic power generation, recycling, and organic waste valorization (Maciej Serda et al., 2021) are some activities to reduce campus emissions.

This research shows a greater relevance in scope 2 (Fig. 4). There is a huge gap in the GHG emission report in scope 3. This scope (indirect emissions) represents for the industrial sector the largest proportion of the organizational carbon footprint (Hertwich & Wood, 2018; Robinson et al., 2018). Some activities from this scope tend to be excluded, and they are rarely prioritized in carbon management policies (Talbot & Boiral, 2018).

Table 2 Scopes and emission sources evaluated by HEIs

HEI	Scope 2										Source								
	Scope 1	Scope 2	Scope 3	Fuel Refrig- use erant or fuel leaks	Ferti- lizer use	Human Com- breath- ing	Waste- post water treat- ment	Electricity Agri- consump- tion forestry and fish- ing	Elec- tricity life cycle	Transporta- tion, public and private vehicles, university fleet		Paper consump- tion	Build-Fur- ing consump- tion	Cof-Fur- nitrate fee and tea	Food consump- tion waste gen- eration (food and other)	Waste- water dis- charge	Water consump- tion	Chemicals Elec- consump- tion equip- ment	Inter- net net- work
Sunway			X																(Devandran & Dewika, 2021)
ITM	X	X	X	X						X						X			(Aristizábal-Alzate et al., 2021)
Mateúica										X									(Veludo et al., 2021)
Talca	X	X							X	X			X						(Yañez et al., 2019)
Siliwangi									X	X									(Busaeri et al., n.d.)
UNAL (Medellín)	X								X	X			X					X	(Cano et al., 2022)
Clemson	X	X		X					X	X									(Cibaieux et al., 2020)
Pertamina									X	X									(Ridhosari & Rahman, 2020)
Malaysia Terengganu									X									X	(Abdullah et al., 2019)
Keele	X								X									X	(Gu et al., 2018)
Bournemouth	X								X									X	(Filimonau et al., 2021)
Jaume I	X	X		X					X	X								X	(Valls-Yal & Bovea, 2022)
Arlington	X	X							X	X								X	(Maclej Serda et al., 2021)

Table 2 (continued)

HEI	Scope 1			Scope 2			Scope 3			Source											
	Fuel use or fuel leaks	Refrigerant use	Fertilizer use	Human breathing	Compost treatment	Waste water	Electricity consumption	Agri-culture, forestry and fishing	Life cycle		Transportation, public and private vehicles, university fleet	Paper consumption	Building	Furniture and fixtures	Co-located facilities	Food and other	Waste-discharge	Water consumption	Chemicals consumption	Electronics equipment	Inter-net-work
Sharjah	X				X		X			X						X					(Samara et al., 2022)
Michael Okpara	X				X		X														(Obi et al., 2021)
Ibadan	X				X		X			X											(Adeyeye et al., 2022)
EAN	X				X		X			X											(García-Alaminos et al., 2022)
Diponegoro	X				X		X			X											(Ivanova et al., 2020)
BITS pilani	X				X		X			X											(Sangwan et al., 2018)
"Unknown I"												X									(Shah et al., 2021)
Technology of Pereira	X				X		X			X											(Varón-Hoyos et al., 2021)
Autonomous metropolitan	X				X		X			X											(Mendoza-Flores et al., 2019)
Montreal										X											(Arsenaull et al., 2019)
Sir Parashurambhau College										X											(Kulkarni, 2019)

Table 2 (continued)

HEI	Scope 1			Scope 2			Scope 3			Source													
	Fuel use or leaks	Refrigerant use	Fertilizer use	Human breathing	Compost treatment	Waste-water	Electricity consumption	Agri-culture, forestry and fishing	Life cycle		Transportation, public and private vehicles, university fleet	Paper consumption	Building consumption	Furniture and fixtures	Co-firing	Textiles and other	Food generation (food and other)	Waste-water discharge	Water consumption	Chemicals consumption	Electronics equipment	Inter-net work	
Sakarya	X				X	X	X			X	X				X		X						(Steng & Gümrtükçüoğlu Yığıt, 2017)
"Unknown"	X				X		X			X	X		X									X	(El Geneidy et al., 2021)
Jyväskylä										X													(Ernesto et al., 2021)
Afe Babalola	X					X																	(Folorunso et al., 2020)
Mahidol						X																	(Kulsuwan et al., 2019)
Haripur	X			X			X			X								X				X	(Hussain, 2020)
Nadu Agricultural	X			X			X			X								X					(Arunachalam & Kannan, 2021)
Oulu							X			X								X					(Kiehle et al., 2021)
Qassim	X	X		X	X	X	X			X								X					(Al-Mufadi et al., 2016)
Kelaniya	X						X			X								X					(Bandara et al., 2018)
ESNE	X	X					X			X	X	X	X	X	X	X	X	X				X	(Filippone et al., 2021)
Rijeka	X						X			X													(Žiković et al., 2020)

Table 2 (continued)

HEI	Scope 1			Scope 2			Scope 3			Source							
	Fuel Refrig- use erant or fuel leaks	Ferti- breath- ing use	Human Com- post water treat- ment	Electricity consump- tion forestry and fish- ing	Agri- culture, and fish- ing	Elec- tricity life cycle	Transporta- tion, public and private vehicles, university fleet	Paper consump- tion	Build-Fur- ing consump- tion		Cof- fee and tea	Tex- gen- eration (food and other)	Food consump- tion	Waste- water dis- charge	Water consump- tion	Chemicals consump- tion	Elec- tronics equip- ment
Punjab				X		X					X						(Haseeb et al., 2022)
Federal de Sao Carlos	X	X		X			X					X					(Silva et al., 2021)
Oulu				X													(Javid, 2022)
Negeri Sembawang				X		X					X						(Rahayuningsih et al., 2021a, b)
Batman	X			X													(Serkan & Hakan, 2019)
Autonomia del estado de Mexico																	(Alanis et al., 2021)
Da Coruña										X							(Perez-Lopez et al., 2021)
Uttarakhand	X	X	X	X						X							(Saphanthong et al., 2020)
Western Norway	X	X		X						X							(Zeiss & Slaymark, 2018)
British Columbia										X							(Dolf & Teehan, 2015)
Hochschule Konstanz	X		X	X						X							(Sippel et al., 2018)

Table 2 (continued)

HEI	Scope 2										Source							
	Scope 1	Fuel Refrig- use erant or fuel use leaks	Human Com- breath- post treat- ment	Waste- water Agri- culture, forestry and fish- ing	Electricity consump- tion	Elec- tricity life cycle	Transporta- tion, public vehicles, university fleet	Paper consump- tion	Build- ing consump- tion	Fur- niture and tea		Cof- fee and tea	Food waste gen- eration (food and other)	Waste- water dis- charge	Water consump- tion	Chemicals consump- tion	Elec- tronics equip- ment	Inter- net work
Technology – Paraná							X											(Barros et al., 2018)
Ponta Grossa																		
Patras	X	X			X					X								(Vrachni et al., 2022)
Hassanuddin	X				X					X								(Zakaria et al., n.d.)

Table 3 Discretized percentages in carbon footprint scopes

HIE	Scope 1 (%)	Scope 2 (%)	Scope 3 (%)	Source
Siliwangi		1.4	98.6	(Busaeri et al., n.d.)
Punjab	4.9	59.6	35.6	(Haseeb et al., 2022)
	1.1	98.2	0.6	
Federal de Sao Carlos	65% Reduction between 2019–2020			(Silva et al., 2021)
Negeri Semarang	11.6	1.8	86.5	(Rahayuningsih et al., 2021a, b)
Sunway		100		(Devandran & Dewika, 2021)
		100		
		100		
Maiêutica			100	(Veludo et al., 2021)
UNAL (Medellin)	2.84	14.02	83.14	(Cano et al., 2022)
Bournemouth	9	27	21	(Filimonau et al., 2021)
Arlington	51	27	21	(Maciej Serda et al., 2021)
Afe Babalao		100		(Folorunso et al., 2020)
Nadu Agricultural	3	69	28	(Arunachalam & Kannan, 2021)
Oulu	0.03	49.2	50.77	(Kiehle et al., 2021)
ESNE—Madrid	16	28	56	(Filippone et al., 2021)
Rijeka	5	5	90	(Žiković et al., 2020)
Jaume I	14.2	54.2	31.6	(Valls-Val & Bovea, 2022)
Sharjah		61	39	(Samara et al., 2022)
EAN	0.20	6	93.80	(García-Alaminos et al., 2022)
Diponegoro	5.8	85.4	8.9	(Ivanova et al., 2020)
“Unknown”		13	87	(El Geneidy et al., 2021)
Jyväskylä			100	(Ernesto et al., 2021)
Technology Paraná Ponta Grossa			100	(Barros et al., 2018)
Michael Okpara	88.06	11.94		(Obi et al., 2021)
Pertamina	1	92.3	6.7	(Ridhosari & Rahman, 2020)
Technology of Pereira	0.8	2.5	96.7	(Varón-Hoyos et al., 2021)
Mahidol		100		(Kulsuwan et al., 2019)
ITM	82.7	17.3		(Aristizábal-Alzate et al., 2021)
Talca	4.8	36.2	59	(Yañez et al., 2019)
Metropolitan Autonomous	4	24	72	(Mendoza-Flores et al., 2019)
Haripur	37.1	37.4	25	(Hussain, 2020)
Da Coruña			100	(Perez-Lopez et al., 2021)
Keele	47.6	40.3	12.1	(Gu et al., 2018)
Sir Parashurambhau College	28	48	25	(Kulkarni, 2019)
Sakarya	16	65	18	(Sreng & Gümrükçioğlu Yiğit, 2017)
Uttaradit Rajabhat	40.3	56.9	2.8	(Saphanthong et al., 2020)
British Columbia			100	(Dolf & Teehan, 2015)
Patras	1.27	27.55	71.18	(Vrachni et al., 2022)
Clemson	19	40.5	40.5	(Clabeaux et al., 2020)
BITS pilani	1.1	50	48.9	(Sangwan et al., 2018)

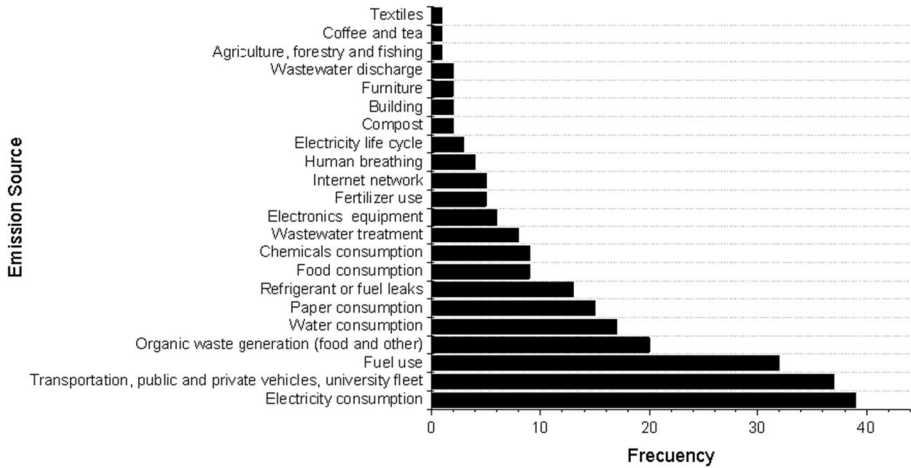


Fig. 4 Emission sources. Research results by frequency

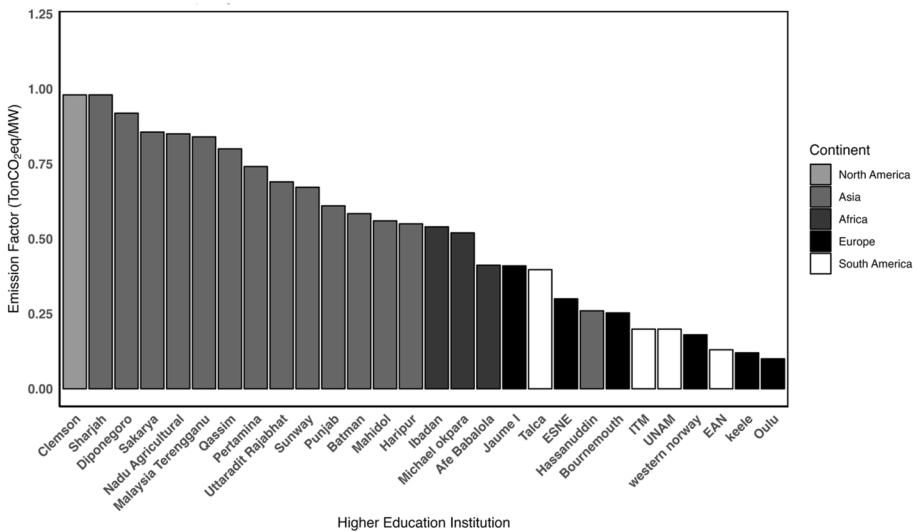


Fig. 5 Emission factors for energy consumption found in this study

However, HEIs are interested in managing emissions of this scope under a methodology that is consistent and comparable with other HEIs (Versteijlen et al., 2017).

3.5 Carbon footprint by HEIs electric energy consumption

The amount of GHG coming from electric energy consumption depends not only on the amount of energy in kWh demanded by the campuses but also on the Emission Factor adopted by each study and established by organizations for each country’s grid or

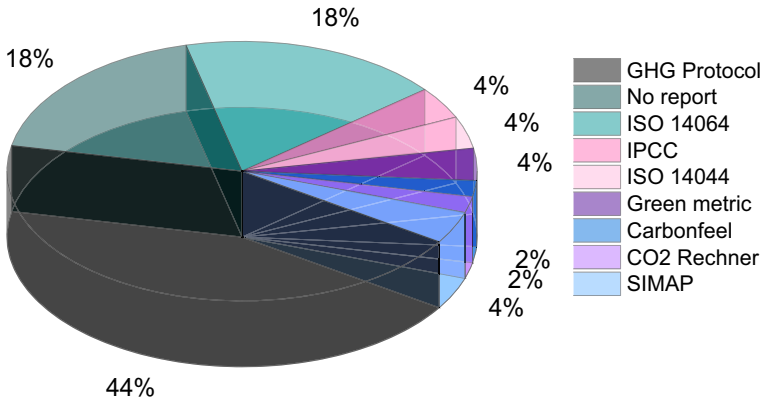


Fig. 6 Standards, methodologies, and calculators adopted by the studies

interconnected system. Figure 5 compiles some of the Emission Factors collected in this study.

As observed in Fig. 5, the emission factors for electricity consumption used by Asian HEIs are higher compared to the other continents (0.98–0.55 $\text{TCO}_{2e}/\text{MWh}$), followed by African (0.54–0.41 $\text{TCO}_{2e}/\text{MWh}$), South American (0.39–0.19 $\text{TCO}_{2e}/\text{MWh}$) and European (0.30–0.1 $\text{TCO}_{2e}/\text{MWh}$) respectively. On the other hand, only 1 American HEI (Clemson) adopted a relatively high FE of 0.98 compared to the different studies. These behaviors are due to the conventional, renewable energy generation sources and the distribution through the national interconnected system corresponding to the country of each HEI, as mentioned above (Ji et al., 2016; Lou et al., 2022). Also, emission factors for electricity consumption can vary according to geographical factors. Due to their location on the planet, all countries do not have the same availability of resources such as water, wind, and sunlight. For this reason, their energy matrix cannot be sustained with low-carbon sources (Arús García, 2020).

The 3 HEIs with the lowest emission factors for electricity consumption in the studies are located in Finland (2020), England (2015), and Colombia (2018) with 0.1–0.12–0.13 $\text{TCO}_{2e}/\text{MWh}$, respectively. In addition, the 3 HEIs with the highest electricity consumption emission factors in their studies are located in the United States (2018), Arab Emirates (2018), and Indonesia (2015) with 0.98–0.98–0.91 $\text{TCO}_{2e}/\text{MWh}$, respectively.

3.6 Methodologies for carbon footprint assessment in HEIs

Currently, there are different methodologies for carbon footprint assessment. However, there are no universal guidelines for HEIs (Robinson et al., 2018). For this reason, institutions have adopted methodologies established for organizations and companies. Figure 6 shows the methodologies adopted in the 50 carbon footprint reports of this research (Table 4).

Eight guidelines were used, including carbon footprint calculators and organizational methodologies. Figure 6 shows that 44% of the studies used the methodology established by the GHG Protocol. This methodology, published by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), provides requirements for public reporting and for quantifying GHG emissions (Bhatia et al.,

Table 4 Authorities and initiatives promoting Carbon Management methodologies

Company or calculator	Description
Greenhouse Gas Protocol	The protocol initiative was created by an alliance of companies, ONGs, governments, and other entities convened by WRI and CED (Protocol, 1998)
Intergovernmental Panel on Climate Change	The IPCC is an intergovernmental organization constituted by a group of expert scientists on climate change (IPCC, 1988)
Carbonfeel	Carbonfeel is an initiative to calculate the carbon footprint established by an inter-university group composed of researchers from Spanish universities (Carbonfeel, 2015)
GreenMetric	GreenMetric is an Indonesian university initiative launched in 2009 which evaluates green and sustainable campus policies of universities around the world (Universitas Indonesia, 2010)
Department of Environment, Food and Rural Affairs	DEFRA is a government department responsible for protecting the environment, food products and standards, agriculture, fisheries, and rural communities in the United Kingdom
International Standardization Organization	ISO is a global federation of national standardization agencies comprising more than 160 countries

2011), as well is based on the Life Cycle Assessment (LCA) approach established by ISO standards (Garcia & Freire, 2014).

LCA approach of the ISO 14044, 14064, and 14067 standards was adopted by 22% of the HEIs in their studies. ISO 14044 is a standard for inventorying Input/output data for a system under analysis (Finkbeiner et al., 2006); ISO 14064 and 14067 are specific in requirements for design, development, management, reporting, and verification of GHG inventories. The main difference is that 14064 is focused on organizations and 14067 on specific products (Schirone & Pellitteri, 2017).

An 18% of the HEIs did not specify the methodology used for CF assessment and quantification; however, there is something particular. The 9 HEIs that didn't specify the methodology of their study adopted the 3 most relevant emission sources: fuel consumption, electricity, and transportation. Furthermore, 4% of the HEIs reviewed in this research adopted the methodology established by the Intergovernmental Panel on Climate Change (IPCC). This methodology considers the emissions generated by the energy sector, which includes transportation, heating, and electricity imports from the grid (Bastianoni et al., 2014). The studies considered energy consumption (Serkan & Hakan, 2019) and consumption of water, energy, and transport (Ivanova et al., 2020). Another 4% of HEIs adopted the UI GreenMetric methodology. This initiative of Universitas Indonesia is the first attempt to make a global ranking of sustainable behavior in HEIs (Suwartha & Sari, 2013). GreenMetric establishes 6 evaluation criteria: environment and infrastructure, energy and climate change, waste, water, transportation, and education (Universitas Indonesia, 2010). Finally, 8% of the HEIs used calculators identified as SIMAP, Carbonfeel, and CO₂ rechner.

3.7 Carbon footprint of HEIs in the COVID-19 pandemic

The COVID-19 pandemic caused a series of impacts in all sectors of the world (Filimonau et al., 2020), affecting the world economy. The tourism, commercial, and transportation sectors were the most affected (Toubes et al., 2021). However, the higher education sector was no exception because state orders were linked to the immediate closure of HEIs and educational institutions (Murphy, 2020) in the face of possible outbreaks and virus spread.

All HEIs around the world were forced to implement "eLearning" policies and protocols (Murphy, 2020), something similar to what happened with the H1N1 virus in 2009 (Allen & Seaman, 2010), bringing about a comprehensive global digital transformation (Jing et al., 2020). This change gave a complete turnaround to traditional education models, causing a major change in teaching (Yin et al., 2022). It also led to a significant reduction of negative environmental impacts in the world, especially global GHG emissions (Loh et al., 2021), which were reduced by approximately 8% [121], for a total of 2.6 Gt of CO_{2e}. This scenery had not been seen since 1900 (IEA, 2020).

HEIs were an important CF study setting in this latest pandemic for its drastic emissions reduction (Valls-Val et al., 2021), giving way to discussions about the benefits, implications, and opportunities of online education. In Wuhan City (China), in 2020, the carbon emissions caused by electricity consumption were reduced to 732,346.596 TCO_{2e} by virtual education, also decreased the transportation emissions between 503,731.04 and 727,250 TCO_{2e} (Yin et al., 2022).

Margareta for Negeri Semarang University in Indonesia reported a reduction from 10,670 to 4312.27 TCO_{2e} considering a PRE-COVID and COVID period. In this evaluation, three scopes were taken into consideration: (I) transport activities by operational vehicles and LPG use, (II) electricity use activities, (III) transport of teachers, educational staff, and students, paper use and waste generation (Rahayuningsih et al., 2021a, b). Evidently, the reduction of GHG emissions due to confinement generated a decline in carbon footprint behavior in the education sector. This demonstrates a close relationship between online education and CF. However, a study by the University of Oulu, Finland, which calculated the carbon footprint of university staff in the use of Information and Communication Technologies (ICT), showed that hybrid work might not contribute to a decrease in the carbon footprint, and might even increase it by 36% (Javid, 2022). However, the use of ICT by university staff does not represent an important fraction of the scopes that make up the CF of a HEI, but it is nevertheless an important point of research.

The reduction of CF for times of COVID-19 in HEIs should be analyzed from the different scopes proposed by the guidelines (mentioned in the previous chapter). Table 5 below compiles the reports of carbon equivalent in university campuses worldwide, published in times of pandemic.

COVID-19 generated a global impact on the reduction of the carbon footprint of HEIs, especially the emissions of Scope 3, where the transportation of educational staff and students reduced their emissions drastically (Alvarez Franco, 2021). In addition to transportation, energy consumption on the campuses decreased considerably and allowed knowing the energy consumption of HEIs with zero students. However, due to virtuality, part of the energy demanded by the campuses was transmitted to homes, increasing the carbon footprint of the residential sector.

Higher education during the COVID-19 pandemic has allowed a look into the future. It is giving way to alternative models of teaching and solutions that allow a reduction of emissions from education. Hybrid education would reduce the emissions of some scopes of

Table 5 Carbon footprint of HIE in times of pandemic. *Source* Authors

HEI	Country	Methodology	TCO _{2e} / Year		Scope %		
			Total	Person	1	2	3
Sunway	Malaysia		7523			100	(Devandran & Dewika, 2021)
Bournemouth	United Kingdom	GHG Protocol	1521.39	0.14	6.2	20.52	(Filimonau et al., 2021)
Punjab	Pakistan	GHG Protocol	7802.45	0.22	1.1	98.2	(Haseeb et al., 2022)
Oulu	Finland	GHG Protocol	745.83	1.278	CF information technologies		(Kiehle et al., 2021)
Negeri Semarang	Indonesia		4312.27		11.6	1.8	(Rahayuningsih et al., 2021a, b)
Federal Sao Carlos	Brazil	ACV + GHG Protocol			Reducción CF en 65% al 2020		(Silva et al., 2021)
Wuhan	China				CF for electricity decreased 732,346 TCO _{2e}		(Yin et al., 2022)
Wuhan	China				CF for transport decreased between 503,731–727,250 TCO _{2e}		

Studies reported in the literature using "Carbon footprint COVID-19" as keywords

the carbon footprint in HEIs as we experienced in the pandemic (Mateiciuc & gest., 2022; Naderipour et al., 2020). Also, implementing other strategies to reduce campus emissions for the different scopes of carbon footprint is important.

4 Discussion

This research presents a strategy for the evaluation of the Carbon Footprint for HEIs (Table 6). The following fundamental principles should be considered: (I) Establishment of limits. (II) Identification of activities. (III) Data collection. (IV) Carbon footprint reporting. (V) Carbon footprint analysis. In addition, emission factors adopted by the different studies analyzed are compiled. It should be noted that emission factors are not universal values, are dynamic, and change due to various factors. For this reason, data sources should be investigated before using the emission factors recommended in this strategy. Whenever possible, use emission factors proposed by national entities in each country. For fuels, emission factors established by the Environmental Protection Agency (EPA) can be used (Epa, 1970).

(I) Establishment of limits

Identifying the scopes to be considered for calculating and assessing the carbon footprint is necessary. The scopes will depend on the data available and the tools for its collection, for example, staff surveys, input inventories, and measurement equipment.

(II) Identification of activities

This document mentions that each scope has several activities or emission sources. In this sense, once the scopes have been established, it is necessary to identify which activities will be considered for the carbon inventories.

(III) Data collection

This strategy suggests a digital tool for data storage, processing, and analysis that is easy to use and access. Tools such as Excel and Google Sheets, among others, can be used for data collection over time.

(IV) Carbon footprint reporting

Consider the emission sources for the carbon footprint inventory and establish the emission factors for each activity to make a practical calculation. In this case, Table 6 recommends a series of emission factors obtained from this research. In addition, it is necessary to build a database and inventory of the carbon footprint for future analysis.

(V) Carbon footprint analysis

What cannot be measured cannot be analyzed, and what cannot be analyzed cannot be controlled. In this sense, and after reporting and monitoring the carbon footprint, a detailed and specific analysis is necessary for each of the scopes taken into account in the inventory and the emissions sources.

For example, on-campus energy consumption, directly proportional to the university's carbon footprint, should be analyzed hourly, identifying the reasons for energy peaks in each campus building. That means associating energy consumption patterns with the activities and tasks performed by students and administrative staff to identify buildings, areas, and equipment with significant energy use to establish operational controls over them. ISO 50001 can be a guideline on which universities can rely to improve the energy performance of their campuses and establish better control in the energy management system since the conscious use of energy resources and electricity indirectly means a reduction in the carbon footprint of energy consumption.

Table 6 Strategy for carbon footprint assessment in HEI

Activity	Description	Emission sources	EF (suggestions)*
Direct Emissions	Combustion	Combustion engines	Gasoline: 2.6 kgCO _{2e} /L (Ridhosari & Rahman, 2020)
	Electric power and heat generation	Boilers	2.19 kgCO _{2e} /L (Folorunso et al., 2020)
Processes	Transportation of university-owned vehicles	Tractors, Buses, airplanes, cars, motorcycles	0.07 kgCO _{2e} /MJ (Ivanova et al., 2020)
			0.02 kgCO _{2e} /MJ (Serkan & Hakan, 2019)
	Organic waste treatment	Compost	Diéseli: 2.2 kgCO _{2e} /L (Ridhosari & Rahman, 2020)
			2.61 kgCO _{2e} /L (Folorunso et al., 2020)
	Agriculture	Animal husbandry (aviculture, pisciculture and livestock)	2.74 kgCO _{2e} /L (Saphanthonng et al., 2020)
			Gas: 0.0693 kgCO _{2e} /MJ (Ivanova et al., 2020)
	Waste Water Treatment	Application of fertilizers and chemicals to the soil	Bus: 0.1 kgCO _{2e} /km (Personen et al., n.d.)
			0.29 kgCO _{2e} /km (Cano et al., 2022)
	Leaks	Power generation	2.74 kgCO _{2e} /Milla (Streng & Gümrükçüoğlu Yiğit, 2017)
			Cars: 0.2 kgCO _{2e} /km (Personen et al., n.d.)
	Cooling systems	Cooling systems	0.17 29 kgCO _{2e} /km (Cano et al., 2022)
			Motorcycle: 0.1 kgCO _{2e} /km (Personen et al., n.d.)
Leaks	Cooling systems	0.06 1 kgCO _{2e} /km (Perez-Lopez et al., 2021)	
		Plane: 0.129 kgCO _{2e} /km (Dolf & Teehan, 2015)	
Leaks	Cooling systems	0.11 kgCO _{2e} /km (Perez-Lopez et al., 2021)	
		0.421 kgCO _{2e} /kg (Yañez et al., 2019)	
Leaks	Cooling systems	0.427 kgCO _{2e} /kg (Ivanova et al., 2020)	
		Cows: 5 kgCO _{2e} /day (Quinton, 2019) (Fuentes, 2019)	
Leaks	Cooling systems	Fish: 0.55 kgCO _{2e} /kg production (Isabel, 2014)	
		3.39 kgCO _{2e} /kg Salmon Produced (Liu et al., 2016)	
Leaks	Cooling systems	chicken: 4.4kgCO _{2e} /kg produced (Mosley Mfiguel, 2014)	
		Urea: 3.54 kgCO _{2e} /kg (Hussain, 2020)	
Leaks	Cooling systems	Phosphate fertilizers: 33 kgCO _{2e} /kg (Hussain, 2020)	
		Pesticides: 0.11 kgCO _{2e} /kg (Hussain, 2020)	
Leaks	Cooling systems	Table 1 (Chat et al., 2015)	
		(Willis et al., 2016)	
Leaks	Cooling systems	53.06 kgCO _{2e} /mmBTU (EPA & Corporate Climate Leadership, n.d.)	
		Review EPA (EPA, n.d.)	
Leaks	Cooling systems	R-134a 103.33 kgCO _{2e} /kg (Saphanthonng et al., 2020)	

Table 6 (continued)

Activity	Description	Emission sources	EF (suggestions)*
Indirect Emissions	Power from grid	Water steam consumption	Heating
		Interconnected electric power system	Electric power
Consumption and procurement		Water consumption	Water (Drinking water)
		Food consumed in coffee shops	Water (hygienic purposes) Food
		Internet	Emails
Consumption of chemical products for water treatment, sanitation, and academic tasks		Consumption of chemical products for water treatment, sanitation, and academic tasks	Chemicals
		Stationery in printing, administrative areas, and restrooms	Paper
		Use and procurement of textile products	Textiles
Medical supplies and services	Medical kit	Medical kit	

*“Depends on the fuel used for steam generation”
 “Depend on each country”

6.6 kgCO_{2e}/m³ (Hussain, 2020)

1.46 kgCO_{2e}/m³ (Hussain, 2020)

Beef: 2 kgCO_{2e}/kg (Lewis, 2015)

Rice: 1.37 kgCO_{2e}/kg (Hussain, 2020)

Sugar: 0.241 kgCO_{2e}/kg (de Figueiredo et al., 2010)

Chicken: 0.47 kgCO_{2e}/kg (Baltierra-Trejo et al., 2017)

Eggs: 0.34 kgCO_{2e}/kg (Lewis, 2015)

0.03–26 gCO_{2e}/Email (SEDNA, 2021)

Table 1, item 7(Hussain, 2020)

Page 2 (Emission Factor (Kg CO_{2e}q per Unit), n.d.)

0.85 kgCO_{2e}/1000 letter size sheets (Aristizábal-Alzate et al., 2021)

7.91 KgCO_{2e}/kg textile (Filippone et al., 2021)

Emission Estimation Technique Manual for Medicinal and Pharmaceutical Product Manufacturing, 1998

Table 6 (continued)

Activity	Description	Emission sources	EF (suggestions)*
Transport	Public and private vehicles without university ownership	Bus	0.1 kgCO _{2e} /km (Personen et al., n.d.) 0.29 kgCO _{2e} /km (Cano et al., 2022) 2.74 kgCO _{2e} /Milla (Streng & Gümrükçüoğlu Yiğit, 2017)
		Cars	0.2 kgCO _{2e} /km (Personen et al., n.d.) 0.17 29 kgCO _{2e} /km (Cano et al., 2022)
		Train	0.0282 kgCO _{2e} /km (Cano et al., 2022) 0.000913 kgCO _{2e} /km (Kiehle et al., 2021)
		Motorcycles	0.1 kgCO _{2e} /km (Personen et al., n.d.) 0.06 1 kgCO _{2e} /km (Perez-Lopez et al., 2021)
	Business trips	Plane	0.129 kgCO _{2e} /km (Dolf & Teehan, 2015) 0.11 kgCO _{2e} /km (Perez-Lopez et al., 2021)
Buildings	Academic and research trips Buildings materials	Clay brick	0.20 tCO _{2e} /t (Abid et al., 2021)
		Cement	0.86 tCO _{2e} /m ³ (Abid et al., 2021)
		Steel Rod	3.15 tCO _{2e} /t (Abid et al., 2021)
		Concrete block	0.20 tCO _{2e} / m ³ (Abid et al., 2021)

*This strategy presents some suggested emission factors from the analyzed reports and some from the literature. Before using these emission factors, the source should be investigated, and it should be verified that they apply to the conditions of the study. Remember that emission factors vary in different aspects

Table 7 Carbon footprint per capita for HEIs. *Source:* Authors

HEI	Carbon footprint Per capita TCO _{2e}	Source
Hochschule Konstanz	10.9	(Sippel et al., 2018)
Kelaniya	4.7	(Bandara et al., 2018)
Clemson	4.4	(Clabeaux et al., 2020)
Montreal	2.97	(Arsenault et al., 2019)
Western Norway	1.7	(Zeiss & Slaymark, 2018)
Mahidol	1.64	(Kulsuwan et al., 2019)
Uttaradit Rajabhat	1.15	(Saphanthong et al., 2020)
Oulu	0.93	(Kiehle et al., 2021)
Sir Parashurambhau College	0.81	(Kulkarni, 2019)
ESNE	0.76	(Filippone et al., 2021)
Jaume I	0.68	(Valls-Val & Bovea, 2022)
Punjab	0.52	(Haseeb et al., 2022)
Pertamina	0.52	(Ridhosari & Rahman, 2020)
“Unknown” (Finland)	0.51	(El Geneidy et al., 2021)
British Columbia	0.33	(Dolf & Teehan, 2015)
EAN	0.25	(García-Alaminos et al., 2022)
Sakarya	0.15	(Sreng & Gümrükçüoğlu Yiğit, 2017)
Bournemouth	0.14	(Filimonau et al., 2020)

This table presents the Per Capita carbon footprint reported in the literature. However, it is not consistent to compare universities because not all studies contemplate the same scopes in their carbon footprint reports. Thus, per capita reports vary concerning the number of activities considered for each scope

Likewise, this analysis can be taken for each activity. In addition, this strategy contemplates the calculation of carbon footprint per capita. Different studies, such as those in Table 7, calculated this indicator, considering the total carbon footprint and the number of students and administrative staff of the HEIs.

The per capita footprint makes it possible to know the individual contributions of the educational community (Table 7). This indicator can be adopted for each scopes, allowing a comparison between HEIs. However, it must be considered that the per capita footprints being compared have the same scopes and emission sources. Another indicator that should be taken into account is carbon offsetting. In other words, carbon sequestration occurs within the HEIs through vegetation, like trees, bushes, and green zones. This indicator can be calculated through equations, thus allowing a decrease in the CF of HEIs. Several studies analyze carbon offsetting through their green campuses (Banuwa et al., 2019; de Villiers et al., 2014; Sayer et al., 2018; Sharma et al., 2020) and thus can be adopted as a frame of reference for counting emissions that are captured.

The per capita carbon footprint of each emission source contemplated for carbon footprint reporting and carbon sequestration is a crucial indicator to analyze from their campuses. The professionals in charge of the campus should make these analyses. The Universidad Autónoma de Occidente has an area called "Sustainable Campus," with various indicators to monitor to improve and reduce the carbon footprint and the impacts caused by academic activities.

4.1 Limitations and future research

The main limitation of this study stems from the need for a standard for evaluating and calculating the carbon footprint of higher education institutions. In this sense, the comparison between universities worldwide could not be made because all the studies contemplate different methodologies, scopes, emission sources, and emission factors. Therefore, it needs to be more consistent to compare HEIs, knowing that each study adopts information from the literature that may represent significant differences between the studies. In addition, the carbon footprint of HEIs also varies depending on the number of people in the institution and the size of the infrastructure.

Based on the findings and limitations of this study, future studies could focus on assessing the carbon footprint of specific emission sources and the specific scope of HEIs, reporting the factors that may make it difficult to compare the results of their study with results from other studies, so that consistent comparisons can be made between different institutions around the world, and inspire more institutions to report their carbon footprints while establishing a global standard. The results of upcoming carbon footprint studies may further provide the information to develop such a standard.

5 Conclusions

The first step to reducing the carbon footprint of the higher education sector is the collection of annual data that allows the report of the CF by the source of emissions. Effectively, CF reporting increases the level of awareness of the educational community and provides a framework for managing resources and consumption on their campuses. Also, for the implementation of management systems and the improvement of their performance indicators.

This research revealed a notable gap in the indirect emissions (Scope 3), which is the largest contributor to the carbon footprint of HEIs. Emissions associated with the transportation of the educational community and electricity consumption are the most significant sources of carbon emissions. However, some studies have not considered these sources. HEIs in Asia tend to have a higher CF for electricity consumption than HEIs in Europe and South America. In addition, the use of fuels is another emission source frequently evaluated in the studies.

Due to the disparity between the emission sources adopted for the carbon footprint assessment of each report, it is necessary to be more precise in comparing HEIs. However, this research manages to propose through the results found a strategic procedure, in addition to a prototype emissions inventory with a consistent approach, which allows a comparison between HEIs, avoiding double counting of emissions. Furthermore, the proposed strategy does not consider emissions from energy transmission and distribution losses since the IES cannot control these factors.

This research is part of the actions to fill the gaps in reporting greenhouse gas emissions in the education sector. In effect, it persuades the higher education community to lead in the current environmental crisis and work faster to achieve sustainability.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

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