Assessing the Carbon Footprint of a Colombian University Campus Using the UNE-ISO 14064-1 Standard

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Abstract

Higher Education Institutions (HEIs) transfer skills and knowledge between industries, the government, and the public, playing a vital role in the education system for a globally sustainable future as "future leaders." Therein, evaluating greenhouse gas emissions from an educational institute is the first step towards the proposed reduction targets at the local, national and international levels. In this research, we report the first approximate carbon footprint calculation of emissions corresponding to scope 1, scope 2, and scope 3 emissions for the main urban campuses of Universidad Nacional de Colombia, Medellín, using the UNE-ISO 14064-1 standard. The carbon footprint in 2019 was approximately 7250.52 tons $CO_{2\ eq}$, and 0.432 tons $CO_{2\ eq}$ per person. Scope 1 emissions accounted for about 2.84% of the carbon footprint, while Scope 2 and 3 emissions each contributed nearly 14% and 83%, respectively. The largest sources of greenhouse gas emissions were the wastewater process (20.46%), followed by electricity consumption (14.03%) and sent emails (7.83%). We suggested some proposals and strategies for mitigating and reducing emissions. Colombian HEIs exhibit the lowest ton of $CO_{2\ eq}$. per person compared to the other HEIs. The reason may be income conditioned by the GDP of each country. Literature reviews do not exhibit a clear contribution to the carbon footprint of Colombian HEIs. This research is the first carbon footprint calculation used as a methodological contribution to HEIs in the country because the method's implementation is not extrapolated for socioecological, political and geographic conditions

Highlights

- This paper estimated the CF of public HEIs in Colombia based on the UNE-ISO 14064-1 standard.
- HEIs from developed countries appropriate the Carbon Footprint report as a strategic line of sustainability.
- The Carbon Footprints of HEIs are highly variable and demonstrate different behaviors due to several external factors.

1. Introduction

Climate change is one of the most serious global environmental problems caused by anthropogenic actions (Lima et al., 2020). It has a significant negative impact on natural resources, terrestrial and aquatic ecosystems, human health, and human systems (García-Leoz et al., 2018; Guemene Dountio et al., 2016). Greenhouse gas (GHG) emissions are a consequence of human activities and play an important role in climate change (Clabeaux et al., 2020; Ridhosari and Rahman, 2020). Therefore, decreasing GHG emissions in the atmosphere through mitigation, adaptation, and resilience is a priority to avoid irreversible effects on the planet (Guemene Dountio et al., 2016).

The Paris Agreement emerged from a need to address this issue. It was signed by 195 countries in 2015 with the goal of limiting the global average temperature increase to 2°C at a maximum (United Nations, 2015). Colombia has engaged in reducing GHG and has established several circular economy strategies that allow its economic model to transition towards a green economy (Álvarez-Espinosa et al., 2017; IPCC, 2021; UNDP, 2019). Colombia's revised Nationally Determined Contribution (NDC) aims to reduce greenhouse gases by 51% and black carbon emissions by 40% by 2030 compared to 2014 levels. The black carbon target ensures Colombia's NDC will improve air quality in Colombian cities, with significant health benefits, alongside climate mitigation (Colombia's government, 2020).

Evaluating GHG emissions in educational institutes is the first step towards the proposed reduction targets at the local, national and international levels. Several studies have reported the carbon footprint (CF) for university campuses under a life cycle assessment approach, aiming to reduce GHG emissions (Clabeaux et al., 2020). Studying GHG emissions is also expected to strengthen plans and programs currently being developed in environmental management and recognize HEIs as entities that generate atmospheric emissions. For this reason, they must reduce their CF, comply with regulations, and contribute to improving environmental quality.

In this paper, we calculate the carbon footprint of the main urban campuses of Universidad Nacional de Colombia, Medellín, which recently has declared the climate crisis as a priority for our actions (UNAL Agencia, 2021).For this analysis, we used the

UNE-ISO 14064-1 standard and its specific objectives: (i) to identify the different sources of direct and indirect greenhouse gas emissions generated by the university, (ii) calculate the carbon footprint, using the scopes established in the 2018 UNE-ISO 14064-1 standard as a reference, and (iii) define proposals and strategies for mitigating and reducing emissions. The main contribution of this paper is to generate an estimate of emissions for public HEIs with a standard methodology. It can then be used as a baseline for monitoring, evaluating, and establishing objectives for programs to reduce greenhouse gas emissions at points with the highest generation. Literature reviews do not exhibit a clear contribution to the carbon footprint of Colombian HEIs based on scientific methods. This research is the first carbon footprint calculation that is a methodological contribution for HEIs in the country. This is because the method's implementation is not extrapolated for socioecological, policy and geographic conditions.

The paper is organized as follows: in section two, a comparative analysis of the Carbon Footprint (CF) of different HEIs is performed to better understand their major GHG emissions and provide reduction strategies. Section three presents the description of the case study and the detailed methodology used for the calculation. Then, CF results are shown in section four, discriminated by scope, source of emission, per capita carbon footprint, and, in some cases, type of greenhouse gas. Finally, we discuss the results and conclude that this study motivated us to formulate and implement carbon sequestration strategies, which are being studied. Future research can use these results to create policy suggestions for a sustainable campus.

2. The Carbon Footprint (Cf) Of Heis: Case Studies

Organizations contribute significantly to GHG emissions (Robinson et al., 2018), of particular importance are the HEIs because of the population of the university community, its physical size and infrastructure, and the complex combination of activites, such as education, laboratories, catering, retail, medical, and recreational facilities (Gu et al., 2019). It is estimated that there are more than 17,000 HEIs worldwide (Altbach et al., 2009), and the number of students attending university has grown exponentially since 2000 (Goddard, 2011), especially in developing countries with more prominent environmental problems (Gu et al., 2018). The HEIs are key components of education systems worldwide, as they transcend international borders, socio-political regimes, and economic systems (Robinson et al., 2018), and HEIs are highly responsible for the production, continuation, and dissemination of knowledge (Otara, 2014). They play an important role in increasing awareness for contributing to sustainable development goals (Tan et al., 2014; Velazquez et al., 2006). CFs have been used for programs to mitigate climate change (Ridhosari and Rahman, 2020), which represent inputs for environmental, social, and economic decision-making processes that reduce GHGs, especially in critical activities, by implementing eco-efficiency and circular economy strategies. In particular, CF enable different organizations to:

(i) Identify hotspots for high-emission activities (Minx et al., 2009),

(ii) Streamline supply chains (Sundarakani et al., 2010),
(iii) Develop legitimate low-carbon products (Scipioni et al., 2012),
(iv) Define and prioritize climate policies for HEIs operation.
Comparisons among CF in universities campuses studies are difficult given the heterogeneity across HEIs, in terms of population sizes, sources of GHG emissions, and variations in their carbon footprint methodology, particularly regarding scope 3 emissions. Some university campuses have higher $CO_{2 \ eq}$ contribution from scope 3 and scope 2, followed by scope 1. However, the contribution from scope 3 is seldom the priority in carbon management policies (Ozawa-Meida et al., 2011). The carbon footprint from raw materials generally comes from steam generation and consumption for heating in countries with winter months, as well as fuels for the universities' transportation system. Some studies have chosen only activities, areas, or consumed or generated resources, regardless of the scope, as Pertamina University. In this work, we show the importance of reporting the CF by scope, as we developed Table 1, which allows a cross-comparison across HEIs.

Table 1
Report of CF emissions in different HEIs worldwide.

University/Institution	Country	Year	Emission (TM CO_2 eq)		Scope			
			Total	Per capita TM CO_2 eq/person	SP1 %	SP2 %	SP3 %	Reference
University of Leuven	Belgium	2010	7085	0.35	13.5	11.5	75	Lambrechts and Van Liedekerke (2014)
Clemson University	USA	2013–2014	95418	4.3	19	40.6	40.4	Clabeaux et al., (2020)
Universitas Pertamina	Indonesia	2018–2019	1351,98	0.52	––	98.96	1.04	Ridhosari and Rahman, (2020)
Keele University	UK	2015–2016	14272	1.3	46.7	41.5	11.8	Gu et al., (2018)
Autonomous Metropolitan University (UAM)	Mexico	2016	3000	1.07	4	24	72	Mendoza-Flores et al., (2019)
Bournemouth University	UK	2018	2119,6	1.43	10	31	59	Filimonau et al., (2021)
		2019	2139,6	1.41	9	27	64	
University of Medellin	Colombia	2016	1624	––	––	––	––	1
Saint Thomas University	Colombia	2018	2415,8	0.069	18	34	48	Sebastián and Parra, (2019)
University of Santiago de Compostela	Spain	2007	32407,8	1.01	33	30.6	36.4	Hermosilla, (2014)
De Montfort University	UK	2008–2009	51080	1.99	6	15	79	Ozawa-Meida et al., (2013)
University of Valencia	Spain	2010	58517,8	0.88	6.3	20	73.6	Hermosilla, (2014)
National Autonomous University of Mexico, Engineering Institute	Mexico	2010	1577	1.47	5	42	53	Güereca et al., (2013)
University of Madrid School of Forestry Engineering	Spain	2010	2147	1.87	8.3	32.7	59	Alvarez et al., (2014)
Pontifical Catholic University of Rio de Janeiro, Gavea Campus	Brazil	2011	5782	0.29	1.5	0.2	98.3	de Carvalho et al., (2017)
University of Talca, Curico Campus	Chile	2012	1568,6	1	16	16	68	Vásquez et al., (2015)
University of Alberta	Canada	2012–2013	325351	6.51	52	40	8	Hyshka, (2014)
Polytechnic University of Cartagena	Spain	2013	9008,4	1.07	3.6	16.9	79.4	Hermosilla, (2014)

University/Institution	Country	Year	Emission (TM CO$_2$ eq)		Scope			
			Total	Per capita TM CO$_2$ eq/person	SP1 %	SP2 %	SP3 %	Reference
University of Valladolid	Spain	2014	22080,5	1.1	24.6	30.2	45.2	Hernandéz and Cano, (2014)
Edith Cowan University	Australia	2015	24797,6	1.73	4	69	27	Favacho, (2016)
University of Cambridge	UK	2016	102049,9	3.5	20	52	28	Cambridge, (2017)
University of California, Berkeley	USA	2016	151650	2.9	44.2	28.1	27.7	California-Berkeley, (2016)
University of Malaga	Spain	2017	24831,6	0.66	2	57	41	Malaga, (2017)
Autonomous Metropolitan University, Cuajimalpa Campus	Mexico	2016	2956,3	1.07	4	24	72	Mendoza-Flores et al., (2019)
National Autonomous University of Mexico, Engineering Institute	Mexico	2010	1,577	2.7	—	—	—	Güereca et al., (2013)
Tongji University	China	2009–2010	NA	3.8	—	—	—	Li et al., (2015)
The University of Cape Town, Africa	Cape Town	2007	84,926	4.0	—	—	—	Letete et al., (2011)
University of Illinois at Chicago	USA	2008	275,000	10.9	—	—	—	Klein-Banai et al., (2010)
University of Sydney	Australia	2008	20,000	—	—	—	—	Baboulet and Lenzen, (2010)
University of Maribor	Slovenia	–	974	—	—	—	—	Lukman et al., (2009)
De Montfort University	England	2008–2009	51,080	2.4	—	—	—	Ozawa-Meida et al., (2013)
Rowan University	USA	2007	38,000	4.0	—	—	—	Riddell et al., (2009)
Clemson University	USA	2014–2017	95,418	4.4	—	—	—	Clabeaux et al., (2020)
University of Castilla-La Mancha	Spain	2013	23,000	2.13	—	—	—	Gómez et al., (2016)

University/Institution	Country	Year	Emission (TM $CO_{2\ eq}$)		Scope				
			Total	Per capita TM CO_2 $_{eq}$/person	SP1 %	SP2 %	SP3 %	Reference
Yale University	USA	2003–2008	874,000	—	—	—	—	Thurston and Eckelman, (2011)
Norwegian University of Technology & Science	Norway	2009	92,000	4.6	—	—	—	Larsen et al., (2013).
University of Leeds	England	2010–2001	161,819	5.3	—	—	—	Townsend and Barrett, (2015)

In the Table 1, we observe that this is an exercise made worldwide, which has started about 2 decades ago and most of them in the last decade. The HEIs have started to perform this accounting to optimize the resource utilization and to take environmental decision on the GHG emissions reductions. From Table 1, shown different carbon footprint of HEIs. For example, Clemson University's GHG emissions are 19% for scope 1 and 41% for scope 2 and 3, respectively (Clabeaux et al., 2020). The energy-water-carbon emission nexus analysis was evaluated at Keele University, demonstrating that improving energy efficiency shows great potential for optimizing the reduction of integrated energy, water, and carbon emission footprints (Gu et al., 2019). Keele University predominantly monitors carbon emissions from natural gas (scope 1) and electricity consumption (scope 2) (Gu et al., 2018). Other carbon footprint results are: University of Alberta in Canada (Scope 1: 52%, Scope 2: 40%, and Scope 3: 8%) (Alberta, 2014), California (Berkeley) (Scope 1: 44.2%, Scope 2: 28.1%, and Scope 3: 27.7%) (California-Berkeley, 2016), and Autonomous Metropolitan University (UAM) in Mexico City (Scope 1: 4%, Scope 2: 24%, and Scope 3: 72%) (Mendoza-Flores et al., 2019). According to the consolidated information in Table 1, it is observed that the per capita emissions of some HEI register low values of 0.069 MT CO2 eq/person and high values of up to 10.9 MT CO2 eq/person, with average values of generation emissions of 2.28 MT CO2 eq/person and a standard deviation of 2.22 MT CO2 eq/person. This last result indicates the high degree of variability of the results and, therefore, their dependence on particularities that must be taken into account when performing the analyses.

On the other hand is the carbon footprint of Shikshana Prasarak Mandali's Sir Parashurambhau, located in Western India, where scope 1, scope 2, and scope 3 contributed 28%, 48%, and 25%, respectively, to total emission. In this case, electricity, biodegradable and non-biodegradable waste, laboratory chemicals, paper, LPG, and transportation were the main contributors. Wageningen in the Netherlands (Scope 1: 55%, Scope 2: 20%, and Scope 3: 25%) (Research, 2018), Cornell (Scope 1: 76.4%, Scope 2: 22.2%, and Scope 3: 1.4%) (University, 2018), Colgate in the United States (Scope 1: 63.2%, Scope 2: 3.7%, and Scope 3: 33.1%) (Colgate University, 2019),. Bekaroo et al., in 2019, did not calculate the CF of university campuses. Instead, they researched personal CF contributions in HEIs (Bekaroo et al., 2019). Finally, typical research in a UK University calculated the CF during the COVID-19 lockdown. The main conclusion was that fully closing university campuses does not result in low GHG emissions (CF decreased by almost 30% during the lockdown). This is because the carbon benefits of online education are less significant than anticipated (Filimonau et al., 2021). Regarding the scope, the contribution was 6%, 21%, and 73% for scope 1, scope 2, and remote work/study, respectively.

In the Colombian context, the CF reports from HEIs have been used for greenwashing, implementing environmentally unfriendly strategies in the name of environmental protection to achieve competitiveness compared to other HEIs. Similar to international studies, the CF assessment in Colombian HEIs has been performed with different details, scope, aims, and estimation methods (Varón-Hoyos et al., 2021); however, the majority of the reports have been used as undergraduate work and internal communication reports but not as scientist research. Some examples are the Sergio Arboleda University

(Universidad Sergio Arboleda, 2018), Jorge Tadeo Lozano University of Bogotá (Manso et al., 2017), Nueva Granada Military University (Barragan, 2014), University of La Salle (Reyes Salazar and Panche Cano, 2019), Industrial University of Santander (Rojas and Chacón, 2011), University of Applied and Environmental Sciences (Aponte, 2017) and University of Medellin[1]. University of Medellin reports its emissions according to activities, with transportation (52%) and electric energy consumption (43%) as the most representative. One of the most recent CF research studies in a university campus in Colombia explains how Scope 3 includes 98% of total GHGs (Varón-Hoyos et al., 2021). Colombian HEIs exhibit the lowest ton of $CO_{2\ eq.}$ per person compared to HEIs in the rest of the world, because of a number of reasons, such as the low use of heating/cooling given the local climate conditions, and the lack of dormitories for international students.

[1] Medellin University – Campus Vivo. URL: https://www.udem.edu.co/index.php/gestion-de-la-sostenibilidad/cambio-climatico-y-resiliencia-campus-vivo#:~:text=La%20Universidad%20de%20Medell%C3%ADn%2C%20lleva,con%20una%20reducci%C3%B3n%20del%2020%25.

3. Materials And Methods

3.1 Study area - Universidad Nacional de Colombia (UNAL)

Universidad Nacional de Colombia (UNAL) is the largest public HEI in Colombia. It has nine campuses throughout the country. UNAL Medellín is the second-largest UNAL campus, divided into eight main areas: three are main urban campuses, where it carries out most academic activities, a primary school, three agricultural stations, and one forestry station. For this research, only the three main urban campuses were considered: El Volador, El Río, and Robledo, as presented in Fig. 1.

The three main campuses in the city have a total area of 405,700 m^2. These campuses largely focus on carrying out the university's mission, such as training competent and socially responsible professionals. This is for 12610 students (under and post-graduate) within 116 offered academic programs, research (142 laboratories), artistic creation, and innovation activities. Staff comprises 822 faculties, 555 administrative offices, and 923 technical and professional service contractors. When it comes to physical areas, the main campus of UNAL Medellín (El Volador Campus) has a health services unit, a variety of cafeterias (10), commercial premises, and 34 buildings. The Robledo Campus has 14 buildings and five (5) cafeterias, while the Rio Campus has ten (10) buildings and one cafeteria. The institution has 36,000 m^2 of sports venues and 260,934 m^2 of green areas, such as the "*León Morales Soto*" Arboretum and Palmetum, which is a biological collection with over 522 living species of trees and palms[2].

3.2 Carbon footprint methodology

There are several methodologies to quantify CFs, such as the PAS:2050, BSI British Standard, Green House Gas Protocol, World Resources Institute, Green Metrics, and UNE-ISO 14064-1. All these methods suffer a common limitation of over or underestimation of GHG emission. The UNE-ISO 14064-1 methodology was chosen to calculate the CF because it was created by a standard organization (ISO) and adopted by Colombia as NTC-ISO 14064-1. It is standardized, technically validated, and can be applied to any organization regardless of its economic activity, becoming a benchmark in terms of international standards. The IPCC implements this method to formulate public policies around the world. In addition, the United Nations Development Program evaluates the fulfillment of some SDG targets under this methodology (IPCC, 2021; Sachs et al., 2021).

We implemented the methodology through the following phases: *i*) the organization's limits, which included facilities the organization considers (voluntarily) involved in the scope of calculating the CF (working boundaries); *ii*) data collection; *iii*) the identification of sources of emission through the following scopes: scope 1 - direct emissions (sources owned or controlled by the organization), scope 2 - indirect emissions (from generating heat, steam, or electricity from an external origin), scope 3 - other indirect emissions than those already included in scope 2; and *iv*) calculations and reports (NTC-ISO, 2006).

The boundaries for calculating the CF of UNAL Medellín in this study include the admrative and academic activities performed in the three urban campuses (El Volador, Robledo, and El Río) by employees (administrative staff and professors),

contractors, and visitors in the 2018–2019 academic year. The research included foodservice and food consumption in cafeterias and restaurants.

3.3 Carbon footprint data inventory of UNAL Medellín

Primary data was locally collected and categorized according to scopes 1, 2, and 3. Table 2lists the data obtained for the Office of Information and Communications Technology, Transportation Section, Inventory Office, Environmental Management Office of Robledo Campus, El Volador Campus, and El Rio Campus.

Table 2
Carbon footprint data inventory of UNAL Medellín

Scope	Source	Activity		Value	Units
Scope 1	Gaseous Fuel	Propane gas	Used in cafeterias	426	m^3
		LPG	Used in boilers of dairy and wood laboratories	5146	m^3
	Liquid Fuel	Gasoline	Used for UNAL Medellín´s vehicles	8780.75	gal
		Diesel		9463	gal
Scope 2		Electrical network supply	Electricity consumption in physical units (e.g., offices, buildings, classroom)	5072.03	MWh
Scope 3	Transportation	Vehicle	Transportation by the university community to travel between the institution and their places of residence	20805450	km
		Motorcycle		6523920	km
		Bus		171790	Passengers
		Subway		20	km
	Waste treatment/valorization /landfills	Incinerated waste	Hazardous waste produced at laboratories and other areas	5.08	tons
		Post-consumer waste	WEEE, lamps, toner, used oils	1.71	tons
		Deactivation	Biological waste, Chemical wastes	1.74	tons
		Depressurization	Pressurized container waste	0.09	tons
		Recycled waste	Recovered usable materials (paper, cardboard, glass, metals, etc.)	150.73	tons
		Composting	Using organic waste (green waste and waste from cafeterias and/or restaurants. Composting is used for self-consumption.	85.02	tons
		Landfill	Ordinary and inert waste	134.16	tons
		Wastewater	Dumping domestic wastewater into the sewage system	140166	m^3
	Internet network	E-mails	E-mails sent	18020050	e-mails

3.3.1 Scope 1

This scope includes liquid fuel (gasoline and diesel) used by the institution's vehicles (buses and cars) to transport students, teachers, and employees on routes between the campuses, agricultural stations, or other journeys. Gasoline consumption in the reference year is estimated to be 8780.8 gallons, while it was 9,463 gallons for diesel.

Cafeterias and restaurants also consumed 426 m^3 of propane gas to prepare and sell food for the university community. Finally, some teaching, research, and extension laboratories have boilers for dairy production and wood processing, which consumed about 5,146 m^3 of LPG.

3.3.2 Scope 2

The electrical network supply was obtained from the grid operator's bills. This consumption is for all the university's urban campuses. Therefore, obtaining data discriminated by dependencies or buildings was not possible.

3.3.3 Scope 3

In this scope, we estimated the distances traveled by the university community from their places of residence to the university, and vice versa. The following considerations were made, according to the report on the sustainable business mobility plan of UNAL Medellín:

- Vehicle: 3,383 cars enter the university daily, with an average travel time of 30 minutes per trip. The average speed is 30km/h. It is assumed there are two trips per vehicle (round trip) every day and 205 work days.
- Motorcycles: 936 motorcycles enter the university daily, travelling an average of 25 minutes each way. Their average speed is 40km/h. We assumed motorcycle users made two trips per vehicle (round trip) per day, with 205 work days.
- Bus: 15% of the university community use the bus and spend an average of 40 minutes of transportation per trip. The average speed is 25 km/h. Therefore, we assumed 5% of a bus' emissions are attributable to the University for Personnel Transportation, with 205 work days.
- Subway: 5% of the university community uses the metro, with 40 min per journey. We considered both ways to include a return trip. The commercial speed of the metro is 40km/h.

Hazardous waste is normally generated in research laboratories. Chemical and biological waste is collected and treated (incinerated, deactivated, or depressurized) by an external manager with environmental permits from the competent authority due to their dangerous characteristics. During the reference year, there were 5.08 tons of this waste. Biohazard waste generated in healthcare services within the campus corresponded to 1.74 tons. It was deactivated through moist heat or chemical neutralization. Depressurized containers corresponded to 0.9 tons. Post-consumer waste was about 1.74 tons, which were returned to producers through the Ministry of the Environment's post-consumer programs for its recovery and treatment.

Recyclable waste corresponded to what was collected internally by the company RECIMED (150.73 tons). Ordinary and inert waste (134,16 tons) is taken to landfills by the public cleaning service company (EEVVM), and organic waste from cafeterias and restaurants is composted in the campus. In addition, aerobic composting is carried out with 185.02 tons of waste. Domestic wastewater is approximately 140,166 m^3. It is discharged through the sewage networks to be treated by the city's public utility company.

This study did not include saved e-mails and stored files, since they are stored on the university's servers and their energy consumption is already accounted for in the energy bill. E-mails sent were 18,020,050 for the 2019. The number of emails sent is high since it is the main means of communication for the university community. In addition, the institution has had a zero-paper policy since mid-2016, which implies that a large part of the procedures were transferred to digital media. E-mails received were not counted because many of these are generated by and for the university community, causing double counting. The remaining e-mails received are assumed to be footprints produced by other institutions, entities, or people outside the institution.

3.4 Carbon footprint calculation

CF is calculated for each scope according to carbon inventory data. For that, two steps must be performed, which are described below:

a) GHG emissions (in tons of GHG) from activity data that produces the emission, through the following Eq. (1).

GHG emission (t GHG) =Activity data x Emission factor (1)
This equation applies to the following emissions:

- Combustion in fixed sources is usually expressed in energy units (TJ) and is calculated as the product of fuel consumption (in mass or volume) and the Lower Calorific Value (PCI).
- Mobile combustion sources: activity data related to distance traveled (km) can be used. It can also be calculated based on the number of passengers transported.
- Process emissions: production (mass or volume) or consumption of a certain raw material (mass or volume).
- Electricity: the facility's electrical consumption (expressed in kWh).

With respect to lower calorific value, Table 3 presents information about it for Colombian fuels. This information is necessary for direct fuel emission estimates and $CO_{2\ eq}$ emissions for scope 1.

Table 3
Lower Calorific Power of Colombian fuels

Fuels	Lower calorific power (MJ/kg o MJ/m^3)	Source
LPG	45.4	UPME, (2019)
Gasoline	45.3	
Diesel	42.4	
Propane gas	46.2	

In the event of a quantitative measurement of the produced emission (either in mass or volume of generated GHG), it would move directly to the second step. Moreover, the Emission Factor is normally expressed in tons of GHG/unit and depends on the type and characteristics of the transformation process and type of fuel.

b) Converting emission data from tons of GHG to tons of $CO_{2\ eq}$ through Eq. (2).

Emissions (t CO_2 equivalent) = emission data x potential global warming (2)
Global warming potential (at 100 years) is a factor that describes the impact of a unit's radiation force based on the mass of a GHG to the equivalent unit of CO_2 in 100 years. It is expressed in tons of $CO_{2\ eq}$ / t GHG, and there is a factor for each type of GHG. Although The Intergovernmental Panel on Climate Change (IPCC) identifies that many gases have global warming potential (GWP) (Wiedmann and Minx, 2008), there is not a unanimous consensus on the GHGs that should be included in a CF calculation. Therefore, this study only considered the six GHGs reported in the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (UNFCCC, 2008), as shown in Table 4. Although Table 4 lists the most common greenhouse gases, only gases such as CH_4, N_2O, and CO_2 were included in this study.

Table 4. Potential global warming

Greenhouse Gas	Potential global warming	Source
CH_4	25	IPCC – AR 4 – WG2 – Chapter 2[1]
N_2O	298	
CO_2	1	
PFC_S	9300	
HFC_S	23900	
SF_6	22800	

[1] Intergovernmental Panel on Climate Change (IPCC). URL:

https://www.ipcc.ch/site/assets/uploads/2018/05/ar4-wg1-ts-sp.pdf

Once the unit calculation of the emissions from each source in units of tons of $CO_{2\ eq}$ was available, all emissions of the same category (direct emissions, indirect emissions for energy, and other indirect emissions) were added.

Finally, CO_2 removal was estimated through Eq. (3). The absorption rate depends on each tree species. Removal will only be relevant when the organization has an agroforestry component or owns a significant area of land. For the case of the urban campuses of UNAL Medellín, this is a component to consider because it has green areas and a biological collection in the "*León Morales Soto*" Arboretum and Palmetum.

$$CO_2 removal\left(tCO_2 equivalent\right) = feet X absorption rate (3)$$

Where:

Number of feet: the number of trees per species and per foot size (two kinds of trees are considered: those with larger feet, with a diameter greater than 5 cm, and smaller feet, with a diameter less than 5 cm). In addition, absorption rate is expressed in tons of $CO_{2\ eq}$ /units per foot and year. Each species has an absorption rate.

With respect to the emission factors of Eq. 1, Table 5lists the emission factors considered to estimate the CF.

Table 5. GHG emission factors

Source	Value	Units	Reference	Source	Value	Units	Reference
Scope 1				**Scope 3**			
LPG[1]	67185.12	kg CO_2/TJ	UPME, (2019)	Vehicle[2]	172	gCO_{2eq}/km	AMVA and UPB, (2018)
	1	kg CH_4/TJ		Motorcycle[3]	62.6	gCO_{2eq}/km	AMVA and UPB, (2018)
	0,1	kg N_2O/TJ		Metro	28.27	gCO_{2eq}/fare*km	Ríos et al., (2016)
Propane gas 1	55539.09	kg CO_2/TJ	IPCC (2006)	Bus[4]	291	gCO_{2eq}/km	AMVA and UPB, (2018)
	1	kg CH_4/TJ					
	0.1	kg N_2O/TJ		Landfill	587	$kgCO_{2eq}$/tons	IPCC (2013)
Gasoline1	69323.69	kg CO_2/TJ	UPME, (2019)	Incinerated waste	21.36	$kgCO_{2eq}$/tons	IPCC (2013)
	3	kg CH_4/TJ		Post-consumer waste	8.99	$kgCO_{2eq}$/tons	IPCC (2013)
	0.6	kg N_2O/TJ		Deactivation	21.36	$kgCO_{2eq}$/tons	IPCC (2013)
Diesel1	74193.48	kg CO_2/TJ	UPME, (2019)	Depressurization	99.76	$kgCO_{2eq}$/tons	IPCC (2013)
	1	kg CH_4/TJ		Recycled waste	8.28	$kgCO_{2eq}$/tons	IPCC (2013)
	0.26	kg N_2O/TJ		Composting	10.20	$kgCO_{2eq}$/tons	IPCC (2013)
				Wastewater	73	$kgCO_{2eq}$/person	IPCC (2007)
Scope 2							
Electricity1	0.199	$kgCO_{2eq}$/kWh	UPME, (2019)	E-mails	2.6	gCO_{2eq}/ e-mails sent	——

[1] Information taken from the UPME's calculator for the emission factors of Colombian fuels (FECOC). This information is specific for liquid, gas, and solid fuel in Colombia. Revised September 21, 2020.

[2] The average value of the emission factor of vehicles measured for the Aburrá Valley of 1000cm^3 and 1600cm^3 is estimated because the type of vehicles that enter the institution daily has not been characterized.

[3] The average value of the emission factor of motorcycles measured for the Aburrá Valley,at 100cm^3, 110cm^3, 125cm^3, 150cm^3, and 200cm^3, is estimated because the motorcycles that enter the institution daily has not been characterized.

[4]The average value of the emission factor of diesel-powered vehicles with bus operation measured for the Aburrá Valley is estimated according to different cylinder capacities and models.

[2] Arboretum and Palmetum at the Universidad Nacional de Colombia, Medellín. First Edition – December (2011)

4. Results And Discussion

This section presents the CF by Scope 1, 2, and 3, followed by the CF removal strategies. A comparative analysis is then approached, using UNAL-Medellin as a reference to other international HEIs.

4.1. *University campuses' carbon footprint by scope.*

After collecting the data for 2019, we estimated the CF considering the basis of calculation established in the previous section. The results are then discriminated by scope, source of emission, and type of GHG in some cases.

When it comes to scope 1, direct emissions from the liquid fuel consumption of the institution's fleet of vehicles (mobile sources) and the consumption of gaseous fuels used in restaurants (fixed sources) operating in urban campuses generated a total of 418.63 tons of $CO_{2\,eq}$, as shown in Table 6. Liquid fuels represent the largest contribution, with 85.0%. These emissions are equal to 2.84% of the total percentage of emissions generated in UNAL. Of this percentage, 1.41% corresponds to mobile sources and the rest correspond to fixed sources.

Table 6
Quantification of direct emissions (scope 1) from UNAL urban campuses.

Scope	Sources	Type of fuel	CO_2 Emissions (tons $CO_{2\,eq}$/yr)	CH_4 Emissions (tons $CO_{2\,eq}$/yr)	N_2O Emissions (tons $CO_{2\,eq}$/yr)	Carbon footprint (tons $CO_{2\,eq}$/yr)	% of scope 1	% of the total carbon footprint
1	Liquid fuel	Gasoline	77.23	0.0011	0.00011	77.30	37.86%	1.07%
		Diesel	95.90	0.0012	0.00031	96.29	47.17%	1.34%
	Gaseous fuel	LPG	15.70	0.00023	8.85734E-08	15.70	7.69%	0.22%
		Propane	14.86	0.000098	0.0000002	14.86	7.28%	0.21%
	SUBTOTAL		203.69	0.00263	0.0004	204.15	100.00%	2.84%
In terms of scope 2, the network operator in different contracts bills the energy consumption								

In terms of scope 2, the network operator in different contracts bills the energy consumption of UNAL's urban campuses. However, the value of annual consumption is totaled to calculate the carbon footprint. Therefore, a consumption of 5,072.03 MWh is demonstrated for 2019, which translates into generating 1,099.33 tons of CO_2eq, as seen in Table 7. This is equivalent to 14.03% of the total emissions generated by the institution. Although energy consumption is considerable, the CF does not represent a high contribution to the total CF because the Colombian energy matrix is one of the most renewable systems worldwide. The energy matrix is highly dependent on water sources and natural gas, which represent 82% and 11%, respectively, of energy consumption in 2018 (UPME, 2019). On the other hand, thermal plant power generation has a participation of 6%, while contributions from other renewable energies do not exceed 0.1% (UPME, 2019).

Table 7
Quantification of indirect (scope 2) emissions from UNAL urban campuses.

Scope	Source	Carbon footprint (tons $CO_{2\,eq}$/yr)	Unit	% of the total carbon footprint
2	Energy gained	1009.33	ton $CO_{2\,eq}$/yr	14.03%

Finally, sources of emissions not controlled by the entity are reported for scope 3. This scope includes (i) transportation by the university community to and from their places of residence, (ii) waste generation from the various activities carried out in the institution that is handled by third parties for its management and treatment, and (iii) sent e-mails. For this reason, generation is estimated at 5981.067 tons of CO_{2eq}, as presented in Table 8, which is equal to 83.13% of the total emissions generated by UNAL's urban campuses and university community. Approximately 70% of these emissions come from transportation. Of this percentage, vehicle transportation was the main contributing factor. However, indirect emissions from transportation, such as commuting and university-related travel are more difficult to control, reason why additional projects are necessary for the university to reach carbon neutrality.

Table 8
Quantification of other indirect emissions from UNAL urban campuses (scope 3)

Scope	Sources	Type	Carbon footprint (tons $CO_{2\,eq}$/yr)	% of the scope	% of the total
3	Transportation	Vehicle	3.58	59.83%	49.74%
		Motorcycle	0.408	6.83%	5.68%
		Subway	0.097	1.62%	1.35%
		Bus	0.125	2.09%	1.74%
	Waste treatment/valorization /landfills	Landfill	78.75	1.32%	1.09%
		Incinerated waste	0.109	0.0018%	0.0015%
		Post-consumer waste	0.0154	0.0003%	0.0002%
		Deactivation	0.0372	0.0006%	0.0005%
		Depressurization	0.00898	0.0002%	0.0001%
		Recycled waste	1.25	0.021%	0.017%
		Composting	0.00087	0.00001%	0.00001%
		Wastewater	1223.772	20.46%	17.01%
	Internet network	E-mails	468.52	7.83%	6.51%
		SUBTOTAL	5981.067	100.00%	83.13%

In summary, total GHG emissions in the urban campuses of UNAL -Medellín for each scope are listed in Table 9.

Table 9
Total emissions by scope on UNAL urban campuses.

Scope	Subtotal (tons $CO_{2\,eq}$/yr)	% of the total
1	204.148	2.84%
2	1009.333	14.03%
3	6037.039	83.13%
TOTAL	7250.52	100.00%

In addition, taking into account that there was a university population of 16,764 people during the study period, the institution's per capita carbon footprint is estimated to be 0.432 tons $CO_{2\,eq}$/person.

4.2. Carbon footprint removal

UNAL- Medellín has extensive natural areas - about 260.934 km^2. These areas are important because they generate multiple ecological services and are an important brick of the ecological structure of the city of Medellín and the Aburra Valley. The fact that these natural areas include the *Arboretum and Palmetum* collection, which hosts a sanctuary of fauna and flora inside the Metropolitan Area, is particularly relevant.

The *León Morales Soto* Arboretum and Palmetum collection is a botanical garden with approximately 445 species and about five thousand individual trees, palms, and bushes. It is a patch of urban forest matrix, making it one of the city's green lungs.

This collection provides multiple ecosystem services for the city, such as thermal regulation, pollution protection, wildlife habitat, CO_2 sequestration, and water regulation[3].

The forest inventory carried out in December 2016 was used to estimate GHG removal. In this inventory, 5,351 individuals were registered in the three main campuses. For this study, it was impossible to consider the absorption factors reported by the IPCC because of the species listed, which almost entirely differed from those reported in the collection. For this reason, the average absorption factor was considered to be 0.02352 tons of $CO_{2\ eq}$/year per individual, according to absorption rates raised by Ihobe (2006) in different regions of Asia. Therefore, it is estimated that CO_2 removal by the institution's biological collection is approximately 125.86 tons CO_{2eq}/year and represents 1.74% of the greenhouse gases emitted in the institution.

4.3. Comparative analysis of the carbon footprint of HEIs

UNAL Medellín is committed to reducing and mitigating GHG emissions. For this reason, it has calculated the institution's CF in 2019. This study found that its CF was 7250.52 tons CO_{2eq}, distributed as follows: scope 1 2.84%, scope 2 14.03%, and scope 3 83.13%. According to the Greenhouse Gas Protocol, the operational boundaries have to consider scope 1 and scope 2, while scope 3 is optional. Some elements from scope 3 were considered in this research. Consequently, the CF per person could have higher values than those of other international HEIs.

Figure 2 shows that the percentage distribution differs when comparing these values to those reported by institutions such as the University of Keele in the United Kingdom (Gu et al., 2019) and Clemson University in Southern California - United States (Clabeaux et al., 2020). The differences may be associated with the specific characteristics of each institution since the students of UNAL, as a public institution, have different economic conditions than students from private universities. These characteristics impact consumption factors, forms of food consumption, and transportation, leading to a lower contribution to the carbon footprint. In addition, it is necessary to consider that activities and sources were included in each scope, since this can mark the difference in calculations of total and per capita emissions.

For example, Clemson University (Clabeaux et al., 2020) estimated its CF at 95,418 tons CO_2eq, where 19% corresponded to scope 1. This scope is one of the most represented in the CF, and 86% of the emissions accounted for in this range are associated with generating steam used for heating, domestic water, and dehumidification in the winter. This type of generation was also registered at the University of Keele (Gu et al., 2019) and the University of Leuven (Lambrechts and Van Liedekerke, 2014) for the same purposes. However, this component was not observed at UNAL because of its geographical location. The above implies that the institution does not generate emissions associated with this activity. Therefore, values are lower in this scope.

When it comes to scope 2, the large emission gap associated with power generation can be related to generation sources (the energy matrix) in each country. For example, as Clabeaux et al. (2020) stated in their study, the generation matrix in California is mainly composed of 53% nuclear energy and 30% thermal energy. By contrast, Colombia has the sixth cleanest matrix globally, with 82% of installed capacity coming from renewable sources[4]. This implies variations in the emission factor, which is greater for Clemson University. Therefore, this represents a greater share of emissions in the total CF estimate for that university.

It is noteworthy that is not possible to compare the GHG emissions from activities linked to scope 3, due to the protocol lacks of the a standardization. UNAL Medellín had the greatest participation in scope 3 (83.13%), followed by the University of Leuven (74.95%). Although these values are relatively close, the sources and activities accounted for in this scope differ. For this reason, it is necessary to review the considerations made in each of the studies in detail, because it can demonstrate the differences in results regarding the rest of the universities. The above may be the case for the mobility/transportation and waste component. In Figure 3, the results obtained by UNAL Medellín are compared with those of the universities mentioned above, in addition to Pertamina University in Jakarta-Indonesia (Ridhosari and Rahman, 2020) and the University of Medellín[5] in Colombia, according to the waste, mobility, and electricity consumption components.

The differences in the transportation component occur due to various reasons. The methodology used at the University of Pertamina (Ridhosari and Rahman, 2020) included bicycles and public transportation, reducing the contribution of $CO_{2\ eq}$. The above may also be related to different geographical regions and the type of transportation. These conditions allow using private or public bicycles as more affordable means of transportation for all. This results in their carbon footprint being much smaller than UNAL's for this component.

In the study conducted by Gu et al. (2019) for Keele University, only the contributions of emissions generated by the institution's vehicles were considered. In contrast, Clemson University (Clabeaux et al., 2020) and University of Leuven (Lambrechts and Van Liedekerke, 2014) included emissions generated by the university community with their vehicles and public transportation. Therefore, these sources were also included in this study. In the case of the University of Clemson, total emission values in this component were higher than UNAL Medellín's because of the number of vehicles. For the first case, there were 16,521 vehicles, compared to 3,383 in this study. The University of Medellín had values similar to those found for UNAL. The differences can be related to the population that manages each institution, type of academic offer (some programs involve several field trips), and fuel consumption for transportation to rural campuses.

The waste component had an 18.12% share in the CF of UNAL Medellín, with higher values compared to the University of Pertamina (1.04%), University of Leuven (0.1%), and Clemson University (0.19%). This estimate is related to the generation of hazardous waste that requires special management through incineration. This situation was not considered when calculating the waste component at the University of Pertamina (Ridhosari and Rahman, 2020). In addition, in the research carried out by Lambrechts and Van Liedekerke (2014) for the University of Leuven, emissions generated due to wastewater treatment were not included. The University of Medellin does not record emissions associated with this component. It was found that the per capita CF is similar, between the range of 0.52 and 0.93 tons CO_{2eq}. The University of Pertamina, University of Leuven and UNAL Medellín had values of 0.52 tons $CO_{2\ eq}$, 0.93 tons $CO_{2\ eq}$, and 0.432 tons CO_2, respectively. Clemson University had a CF of 4.4 tons $CO_{2\ eq}$, with the biggest difference between the mentioned institutions.

Figure 4 shows the main sources that contribute to the CF by sources. The greatest contribution was from vehicle transportation (49.74%), followed by wastewater processes (17.01%), energy consumption (14.03%) and sent e-mails (6.51%). With that in mind, UNAL Medellín needs to implement actions to reduce and mitigate the large GHG emissions from these sources. The institution has implemented various strategies to incentivize changing transportation methods. Some of them included educational persuasion and teleworking. The university recently installed electric charging stations in the Robledo and El Volador Campuses for cars, motorcycles and bicycles. Additionally, UNAL Medellín has implemented a photovoltaic energy system, that generates approximately 112 MWh, providing 2.16% of the energy consumption from the Colombian electrical grid in 2020. This represents a 2.2% reduction in $CO_{2\ eq}$ emissions. Our institution expects to self-generate an additional 1140 MWh of energy by installing more panels in different buildings by the end of 2021. In addition, UNAL has worked on campaigns to reduce the digital CF by taking into account the use of computers, internet browsers, and sending e-mails.

Regarding the contribution of wastewater to the carbon footprint, it has already been mentioned that the institution does not have a domestic or industrial wastewater treatment plant. The wastewater generated in various activities is discharged through the sewage network to be treated at the municipal treatment plant later. However, the wastewater generated in laboratories is deactivated or neutralized before discharging it to reduce its potential danger. In terms of the consumption of water, which becomes domestic wastewater, some taps that regulate the flow have been changed to avoid the loss of water. In addition, the Environmental Management Office of UNAL Medellín will implement the water footprint methodology to calculate the direct and indirect green, blue, and gray water footprint and the sustainable water footprint index to implement optimization strategies. Educational campaigns have also been carried out for all university personnel to reduce water consumption and avoid waste. Similarly, obsolete sanitary batteries and those in bad conditions have been replaced to reduce water consumption and, therefore, wastewater generation. The institution has also carried out two planting days and sown a total of 150 individual trees. Some of the species planted include *Andira Inermis*, *Koelreuteria Bipinnata*, and *Swartzia Robiniifolia*, which are typical of the geographic location.

Finally, when comparing $CO_{2\ eq}$ emissions/person, Fig. 5 shows a large variability. The reason can be the income conditioned by the GDP of each country, as is the case of Clemson and Cambridge University compared to Pertamina and UNAL Medellín.

[3] Universidad Nacional de Colombia – Noticias. URL: //medellin.unal.edu.co/noticias/514-la-coleccion-de-arboles-y-palmas-de-la-u-n-fue-designada-como-arboretum-y-palmetum-leon-morales-soto.html
[4] Asociación Colombiana de Generadores de Energía Eléctrica -ACOLGEN-. URL: https://www.acolgen.org.co/.
[5] Medellin University – Campus Vivo. URL: https://www.udem.edu.co/index.php/gestion-de-la-sostenibilidad/cambio-climatico-y-resiliencia-campus-vivo#:~:text=La%20Universidad%20de%20Medell%C3%ADn%2C%20lleva,con%20una%20reducci%C3%B3n%20del%2020%25.

5. Conclusions

Knowing our GHG emissions is crucial for formulating sustainability strategies and public policies, which will make it possible to correct local and regional environmental problems associated with the CF. The main estimate is the University's CF, which was 7250.52 tons $CO_{2\ eq}$, and 0.432 tons $CO_{2\ eq}$ /person in 2019. According to the Greenhouse Gas Protocol, the operational boundaries must consider scope 1 and scope 2, while scope 3 is optional. In this research, some elements from scope 3 were considered, for which reason the CF per person could be higher compared to other international HEIs. Scope 1 emissions accounted for about 2.84% of the carbon footprint, while Scope 2 and 3 emissions each contributed nearly 14% and 83%, respectively. Electricity consumption, waste generation, and sent e-mails were the main contributors to the generations of GHG emissions, with contributions of 14.03%, 20.46%, and 7.83%, respectively. This work is particularly relevant considering that the University Council has declared as a priority all actions towards improving the climate crisis.

We have also compared the CF between different HEIs, despite the limitations due to the dependence on multiple determining factors, such as geographic location (climate and topography), cultural factors (consumption patterns and types of transportation), population size, typology (public or private), and methodology selection. GDP plays an important role in the HEIs´ GHG emissions because more income means more consumption and more GHG emissions. However, comparisons between studies that have reported the CF of university campuses are difficult because the HEIs have ranging population sizes, GHG emission sources, and variations in their carbon footprint methodologies, particularly regarding scope three emissions. Uncertainties from characterization factors should be into account in future works due to could present change both the results and mitigation strategies.

Determining the CF is an important step in transforming a Campus into a Sustainable, zero-CF Campus, because it provides inputs for formulating and implementing carbon reduction and sequestration strategies. These actions reflect the commitment of university campuses and, therefore, their endeavors to implement initiatives aimed at preventing, mitigating, and compensating for the environmental impact of their activities. It is important to clarify that the 2018–2019 period is the baseline and the gas emissions reduction strategies to be implemented in the following years will be evaluated based on it.

UNAL Medellín has a representative collection of tree species that capture 1.74% of $CO_{2\ eq}$. Nevertheless, it is evident that this percentage is low compared to the contribution of the GHG sources in the study. Therefore, planting more trees is not very effective if capturing emissions is analyzed in isolation. In this sense, generating awareness and alternative policies aimed at reducing greenhouse gas emissions is also required. This includes the conversion or transition from conventional to electric vehicles, efficient use of utilities (energy and water), use of alternative energy sources and rainwater, minimization of solid waste generation, use of bicycles, among others.

This study estimated total sequestration value based on an average value of emission factors from literature, adapted to local characteristics. Therefore, further research could study the contribution of the species located in the institution to offsetting GHG emissions. Additionally, it is recommended to include future CF information corresponding to agricultural research centers, since they contribute considerable $CO_{2\ eq}$ figures due to their livestock and agricultural activities. It is important to consider implementing the Carbon Credit Market into HEIs as verification by a third party that some organizations or

individuals removed or avoided the emission of one ton of CO2e. This is because the Paris Agreement's 2°C scenario requires adopting high-efficiency and low-carbon systems.

Declarations

References

1. Alberta U, of (2014) Facilities and operations [WWW Document]. Univ. Alberta Greenh. gas CARBON Manag. 105 Emiss. Invent. 2005-06 baseline 2012- 13 Rep
2. Altbach P, Reisberg L, Rumbley L (2009) Trends in Global Higher Education: Tracking an Academic Revolution. in: UNESCO. Paris
3. Álvarez-Espinosa A, Ordóñez D, Nieto A, Wills W, Romero G, Calderón SL, Hernández G, Argüello R, Delgado-Cadena R (2017) Economic Evaluation of Colombia's Commitment at COP21. Desarro Soc 79. https://doi.org/. DOI
4. Alvarez S, Blanquer M, Rubio A (2014) Carbon footprint using the Compound Method based on Financial Accounts. the case of the School of Forestry Engineering, Technical University of Madrid. J Clean Prod 66:224–232. https://doi.org/10.1016/j.jclepro.2013.11.050
5. AMVA UPB (2018) Actualización inventario de emisiones atmosféricas del Valle de Aburrá - Año 2016. Medellín
6. Aponte H (2017) Proposal of mitigation strategies based on the calculation of the carbon footprint of the north and south campuses of the University of Applied and Environmental Sciences in the years 2014–2015. University of Applied and Environmental Sciences
7. Baboulet O, Lenzen M (2010) Evaluating the environmental performance of a university. J Clean Prod 18:1134–1141. https://doi.org/10.1016/j.jclepro.2010.04.006
8. Barragan J (2014) Estimacion de la huella de carbono producida durante el año 2013 en la Universidad Militar Nueva Granada. Universidad Militar Nueva Granada

9. Bekaroo G, Bokhoree C, Ramsamy P, Moedeen W (2019) Investigating personal carbon emissions of employees of higher education institutions: Insights from Mauritius. J Clean Prod 209:581–594. https://doi.org/10.1016/j.jclepro.2018.10.238

10. California-Berkeley U, of (2016) GHG inventory [WWW Document]. URL https://sustainability.berkeley.edu/carbon-neutrality/ calcap-ghg-inventory. (accessed 3.14.20)

11. Cambridge U, of (2017) Environmental Sustainability Report 2017

12. Clabeaux R, Carbajales-Dale M, Ladner D, Walker T (2020) Assessing the carbon footprint of a university campus using a life cycle assessment approach. J Clean Prod 273:122600. https://doi.org/10.1016/j.jclepro.2020.122600

13. Colgate University (2019) FY 2018 Colgate University Greenhouse Gas Inventory Report A stepby- step guide to completing the annual greenhouse gas inventory at Colgate University [WWW Document]. URL https://www.colgate.edu/ about/sustainability/sustainability-news/2018-greenhouse- gas-emissions-inventory

14. de Carvalho JPAF, van Elk AGHP, Romanel C (2017) Eng Sanit e Ambient 22:591–595. https://doi.org/10.1590/S1413-41522017155865. Inventário de emissões de gases de efeito estufa no campus gávea da PUC-Rio

15. Favacho S (2016) Organizational Greenhouse Gas Inventory (Carbon Footprint) Report

16. Filimonau V, Archer D, Bellamy L, Smith N, Wintrip R (2021) The carbon footprint of a UK University during the COVID-19 lockdown. Sci Total Environ 756:143964. https://doi.org/10.1016/j.scitotenv.2020.143964

17. García-Leoz V, Villegas JC, Suescún D, Flórez CP, Merino-Martín L, Betancur T, León JD (2018) Land cover effects on water balance partitioning in the Colombian Andes: improved water availability in early stages of natural vegetation recovery. Reg Environ Chang 18:1117–1129. https://doi.org/10.1007/s10113-017-1249-7

18. Gobierno de, Colombia (2020)Actualización Contribución Prevista Determinada a Nivel Nacional

19. Goddard B (2011) Future perspectives: horizon 2025. Making a Difference: Australian International Education. University of New South Wales Press, Sydney

20. Gómez N, Cadarso M, Monsalve F (2016) Carbon footprint of a university in a multiregional model: the case of the University of Castilla-La Mancha. J Clean Prod 138:119–130. https://doi.org/10.1016/j.jclepro.2016.06.009

21. Grindsted A (2011) Sustainable universities – from declarations on sustainability in higher education to national law. Environ Econ 2:27–34

22. Gu Y, Wang H, Robinson ZP, Wang X, Wu J, Li X, Xu J, Li F (2018) Environmental footprint assessment of green campus from a food-water-energy nexus perspective. Energy Procedia 152:240–246. https://doi.org/10.1016/j.egypro.2018.09.109

23. Gu Y, Wang H, Xu J, Wang Y, Wang X, Robinson ZP, Li F, Wu J, Tan J, Zhi X (2019) Quantification of interlinked environmental footprints on a sustainable university campus: A nexus analysis perspective. Appl Energy 246:65–76. https://doi.org/10.1016/j.apenergy.2019.04.015

24. Guemene Dountio E, Meukam P, Pahane Tchaptchet DL, Okono Ango LE, Simo A (2016) Electricity generation technology options under the greenhouse gases mitigation scenario: Case study of Cameroon. Energy Strateg Rev 13–14:191–211. https://doi.org/10.1016/j.esr.2016.10.003

25. Güereca LP, Torres N, Noyola A (2013) Carbon Footprint as a basis for a cleaner research institute in Mexico. J Clean Prod 47:396–403. https://doi.org/10.1016/j.jclepro.2013.01.030

26. Hermosilla A (2014) Huella de Carbono en la Universidad Politécnica de Cartagena: En busca de la Eco-eficiencia. Universidad Politécnica de Cartagena

27. Hernandéz E, Cano C (2014)La huella ecológica de la Universidad de Valladolid. Valladolid

28. Hyshka C (2014)University of Alberta Greenhouse Gas Inventory

29. de Ihobe SP G.A (2006) Guía metodológica para la aplicación de la norma UNE-ISO 14064-1:2006 en organizaciones. Bilbao

30. IPCC (2021) Sixth Assessment Report of the Intergovernmental Panel on Climate Change: Climate Change 2021 The Physical Science Basis

31. Klein-Banai C, Theis TL, Brecheisen TA, Banai A (2010) A Greenhouse gas inventory as a measure of sustainability for an Urban public research university. Environ Pract 12:35–47. https://doi.org/10.1017/S1466046609990524

32. Lambrechts W, Van Liedekerke L (2014) Using ecological footprint analysis in higher education: Campus operations, policy development and educational purposes. Ecol Indic 45:402–406. https://doi.org/10.1016/j.ecolind.2014.04.043

33. Larsen HN, Pettersen J, Solli C, Hertwich EG (2013) Investigating the Carbon Footprint of a University - The case of NTNU. Journal of Cleaner Production. Elsevier Ltd, pp 39–47. https://doi.org/10.1016/j.jclepro.2011.10.007

34. Letete TCM, Mungwe NW, Guma M, Marquard A (2011) Carbon footprint of the University of Cape Town. J Energy South Africa 22:2–12. https://doi.org/10.17159/2413-3051/2011/v22i2a3208

35. Li X, Tan H, Rackes A (2015) Carbon footprint analysis of student behavior for a sustainable university campus in China. Journal of Cleaner Production. Elsevier Ltd, pp 97–108. https://doi.org/10.1016/j.jclepro.2014.11.084

36. Lima MA, Mendes LFR, Mothé GA, Linhares FG, de Castro MPP, da Silva MG, Sthel MS (2020) Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil. Environ Dev 33. https://doi.org/10.1016/j.envdev.2020.100504

37. Lukman R, Tiwary A, Azapagic A (2009) Towards greening a university campus: The case of the University of Maribor. Slovenia Resour Conserv Recycl 53:639–644. https://doi.org/10.1016/j.resconrec.2009.04.014

38. de Malaga U (2017) Vicerrectorado de Campus y Sostenibilidad. Huella ecológica de la, p 510

39. Manso D, Parrado C, Aristiz abal A (2017) Inventario de gases efecto invernadero en la Universidad de Bogot_a Jorge Tadeo Lozano. Mutis 7:44–58

40. Medina MP, Villalba DC, Felipe R, Juan SQ, Carrasco B, Rodríguez WE (2016)FACTORES DE EMISIÓN CONSIDERADOS EN LA HERRAMIENTA DE CÁLCULO DE LA HUELLA DE CARBONO CORPORATIVA MVC COLOMBIA

41. Mendoza-Flores R, Quintero-Ramírez R, Ortiz I (2019) The carbon footprint of a public university campus in Mexico City. Carbon Manag 10:501–511. https://doi.org/10.1080/17583004.2019.1642042

42. Minx JC, Wiedmann T, Wood R, Peters GP, Lenzen M, Owen A, Scott K, Barrett J, Hubacek K, Baiocchi G, Paul A, Dawkins E, Briggs J, Guan D, Suh S, Ackerman F (2009) Input-output analysis and carbon footprinting: An overview of applications. Econ Syst Res 21:187–216. https://doi.org/10.1080/09535310903541298

43. NTC-ISO (2006) ISO 14064-1:2006. Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals

44. Otara A (2014) Rethinking university education: a navigation in the emerging knowledge economy in Africa. J Educ Humman Dev 3:449–471

45. Ozawa-Meida L, Brockway P, Letten K, Davies J, Fleming P (2013) Measuring carbon performance in a UK University through a consumption-based carbon footprint: De Montfort University case study. J Clean Prod 56:185–198. https://doi.org/10.1016/j.jclepro.2011.09.028

46. Ozawa-Meida L, Brockway P, Letten K, Davies J, Fleming P (2011) Measuring carbon performance in a UK University through a consumption-based carbon footprint: de Montfort University case study. J Clean Prod 56:185–198

47. Research WU (2018) CO2 footprint 2018 CO2-emissie inventaris volgens ISO 14064-1 [WWW Document]

48. Reyes Salazar D, Panche Cano L (2019) Determination of the carbon footprint of the University of La Salle Candelaria headquarter. University of La Salle

49. Riddell W, Bhatia KK, Parisi M, Foote J, Imperatore J (2009) Assessing carbon dioxide emissions from energy use at a university. Int J Sustain High Educ 10:266–278. https://doi.org/10.1108/14676370910972576

50. Ridhosari B, Rahman A (2020) Carbon footprint assessment at Universitas Pertamina from the scope of electricity, transportation, and waste generation: Toward a green campus and promotion of environmental sustainability. J Clean Prod 246:119172. https://doi.org/10.1016/j.jclepro.2019.119172

51. Ríos V, Marquet O, Miralles-Guasch C (2016) Estimación de las emisiones de CO2 desde la perspectiva de la demanda de transporte en Medellín.Rev. Trasp. y Territ.302–322

52. Robinson OJ, Tewkesbury A, Kemp S, Williams ID (2018) Towards a universal carbon footprint standard: A case study of carbon management at universities. J Clean Prod 172:4435–4455. https://doi.org/10.1016/j.jclepro.2017.02.147

53. Rojas M, Chacón Y (2011) General quantification of carbon dioxide emissions generated by activities at the Industrial University of Santander and mitigation proposals. ndustrial University of Santander

54. Sachs J, Kroll C, Lafortune G, Fuller G, Woelm F (2021) Sustainable Development Report 2021, Sustainable Development Report 2021. https://doi.org/10.1017/9781009106559

55. Scipioni A, Manzardo A, Mazzi A, Mastrobuono M (2012) Monitoring the carbon footprint of products: A methodological proposal. J Clean Prod 36:94–101. https://doi.org/10.1016/j.jclepro.2012.04.021

56. Sebastián J, Parra F (2019) INFORME CÁLCULO DE LA HUELLA DE CARBONO DE LA UNIVERSIDAD SANTO TOMÁS 2018

57. Sundarakani B, De Souza R, Goh M, Wagner SM, Manikandan S (2010) Modeling carbon footprints across the supply chain. International Journal of Production Economics. Elsevier, pp 43–50. https://doi.org/10.1016/j.ijpe.2010.01.018

58. Tan H, Chen S, Shi Q, Wang L (2014) Development of green campus in China. J Clean Prod 64:646–653. https://doi.org/10.1016/j.jclepro.2013.10.019

59. Thurston M, Eckelman MJ (2011) Assessing greenhouse gas emissions from university purchases. Int J Sustain High Educ 12:225–235. https://doi.org/10.1108/14676371111148018

60. Townsend J, Barrett J (2015) Exploring the applications of carbon footprinting towards sustainability at a UK university: Reporting and decision making. J Clean Prod 107:164–176. https://doi.org/10.1016/j.jclepro.2013.11.004

61. Agencia UNAL (2021) Desde el CSU, UNAL declara acciones de mitigación y adaptación al cambio climático [WWW Document]. URL http://agenciadenoticias.unal.edu.co/detalle/desde-el-csu-unal-declara-acciones-de-mitigacion-y-adaptacion-al-cambio-climatico (accessed 1.17.22)

62. UNDP (2019) The Paris Agreement

63. UNFCCC (2008) Kyoto Protocol reference manual

64. United Nations (2015) Conference of the Parties (COP21), Adoption on the Paris Agreement. Paris

65. Universidad Sergio, Arboleda (2018) Instituto de Estudios y Servicios Ambientales IDEASA [WWW Document]. emisiones gases Ef. invernadero, Inventar

66. University C (2018)Greenhouse gas inventory [WWW Document]

67. UPME (2019) Mapa Energético de Colombia 2019–2050. in: UTP-WORLD ENERGY COUNCIL

68. UPME (2015) Factor de emisión de CO2 para combustibles colombianos -FECOC- [WWW Document]

69. Varón-Hoyos M, Osorio-Tejada J, Morales-Pinzón T (2021) Carbon footprint of a university campus from Colombia. Carbon Manag 12:93–107. https://doi.org/10.1080/17583004.2021.1876531

70. Vásquez L, Iriarte A, Almeida M, Villalobos P (2015) Evaluation of greenhouse gas emissions and proposals for their reduction at a university campus in Chile. J Clean Prod 108:924–930. https://doi.org/10.1016/j.jclepro.2015.06.073

71. Velazquez L, Munguia N, Platt A, Taddei J (2006) Sustainable university: what can be the matter? J Clean Prod 14:810–819. https://doi.org/10.1016/j.jclepro.2005.12.008

72. Wiedmann T, Minx J (2008) A Definition of 'Carbon Footprint'. Nova Science Publishers, NY, USA
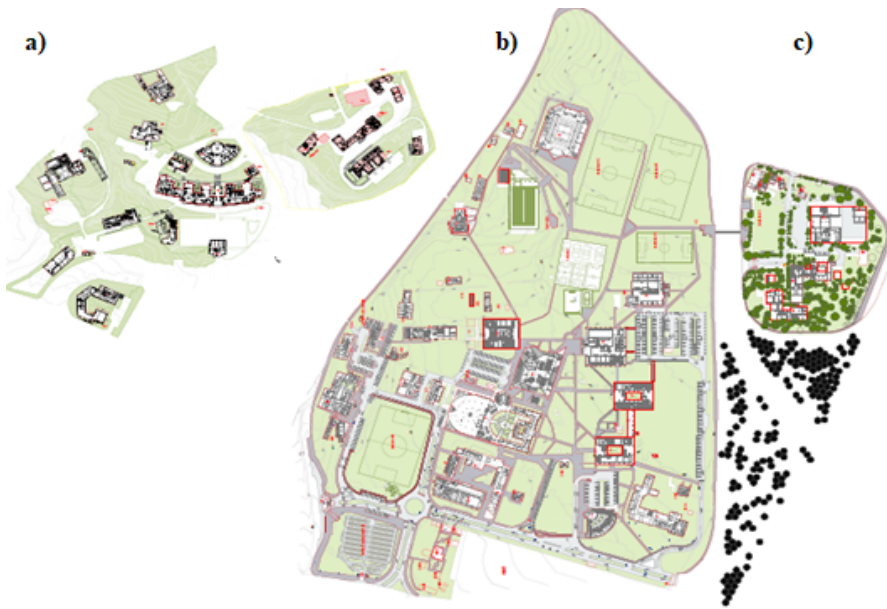
Figures

Figure 1

Map of Universidad Nacional de Colombia – Medellín. a) Robledo Campus, b) El Volador Campus, and c) El Rio Campus. Information provided by the Physical Planning Office.

Figure 2

Comparison of the percentage distribution of UNAL Medellín's scopes and those of other universities.

Figure 3

Comparison of the percentage of total emissions by components of UNAL Medellín and other HEIs.

Figure 4

UNAL Medellín's CO2eq emissions contribution analysis

Figure 5

Comparison of CO_2eq emissions per capita between UNAL Medellín and other universities