Revista de Ciencias Tecnológicas (RECIT). Universidad Autónoma de Baja California ISSN 2594-1925
Volumen 9 (4): e511. Octubre-Diciembre, 2026. https://doi.org/10.37636/recit.v9n4e511

Estudios de casos

Carbon Footprint Estimation of a Higher Education Institution as a Baseline for Sustainable Technological Management: The FIMAZ-UAS Case

Estimación de la Huella de Carbono de una Institución Universitaria como Línea base para la Gestión Tecnológica Sostenible: Caso FIMAZ-UAS

Lucio Guadalupe Quirino Rodríguez, Héctor Luis López López

Universidad Autónoma de Sinaloa, Facultad de Informática Mazatlán, Av. Universidad y Leonismo Internacional S/N, Antiguo Aeropuerto C.P. 82146, Mazatlán, Sinaloa, México

Corresponding author: Héctor Luis López López, Universidad Autónoma de Sinaloa, Facultad de Informática Mazatlán, Av. Universidad y Leonismo Internacional S/N, Antiguo Aeropuerto C.P. 82146, Mazatlán, Sinaloa, México, email: hector.lopezlopez@uas.edu.mx ORCID: https://orcid.org/0000-0002-9401-9807.

Received: August 12, 2026 **Accepted:** October 23, 2026 **Published**: November 1, 2026

Abstract. - *The carbon footprint has become a fundamental tool for evaluating and managing greenhouse gas (GHG) emissions in higher education institutions, whose patterns of energy consumption, resource use, and mobility are comparable to those of small urban areas. The objective of this study was to estimate the carbon footprint of the Faculty of Computer Science Mazatlán (FIMAZ) of the Autonomous University of Sinaloa, considering electricity, drinking water, solid waste, and the mobility of students and teachers from January to December 2024, as a baseline for the sustainable technological management of its infrastructure. The study used a quantitative, non-experimental, descriptive, longitudinal case study design based on the GHG Protocol and ISO 14064-1:2018, combining institutional records and mobility surveys with national and international emission factors. Electricity was the main emission source (220,887.24 kg of CO_2), associated with the use of computing equipment and air conditioning, followed by mobility (24,705.09 kg of CO_2), with private vehicles as the main emitter; water and waste contributed 1,422.36 and 362.75 kg of CO_2, respectively. The results establish a technical baseline to guide mitigation strategies and strengthen university environmental management.*

Keywords: Carbon footprint; Higher education institutions; Greenhouse gases; Environmental management; University mobility.

Resumen. - *La huella de carbono se ha consolidado como una herramienta fundamental para evaluar y gestionar las emisiones de gases de efecto invernadero (GEI) en las instituciones de educación superior, cuyos patrones de consumo de energía, uso de recursos y movilidad son comparables a los de pequeñas áreas urbanas. El objetivo de este estudio fue estimar la huella de carbono de la Facultad de Informática Mazatlán (FIMAZ) de la Universidad Autónoma de Sinaloa, considerando electricidad, agua potable, residuos sólidos y movilidad de estudiantes y docentes de enero a diciembre de 2024, como línea base para la gestión tecnológica sostenible de su infraestructura. Se realizó un estudio de caso cuantitativo, no experimental, descriptivo y longitudinal, con base en el GHG Protocol y la norma ISO 14064-1:2018, combinando datos de registros institucionales y encuestas de movilidad con factores de emisión nacionales e internacionales. La electricidad fue la principal fuente de emisiones (220,887.24 kg de CO_2), asociada al uso de equipos de cómputo y climatización, seguida de la movilidad (24,705.09 kg de CO_2), con el vehículo particular como principal emisor; el agua y los residuos aportaron 1,422.36 y 362.75 kg de CO_2, respectivamente. Los resultados establecen una línea base técnica para orientar estrategias de mitigación y fortalecer la gestión ambiental universitaria.*

Palabras clave: Huella de carbono; Instituciones de educación superior; Gases de efecto invernadero; Gestión ambiental; Movilidad universitaria.

ISSN: 2594-1925

1 Introduction

Climate change is recognized as one of the most serious and urgent environmental challenges worldwide and is closely associated with the increase in greenhouse gas emissions from anthropogenic activities [1]. In this scenario, higher education institutions play a strategic role as centers of education, research, and knowledge management and therefore have a social responsibility to assess, manage, and reduce their environmental impacts. To achieve this, scientific and methodological tools are essential for generating reliable information and supporting decisions aimed at institutional sustainability [2], [3].

In the international literature, estimating the carbon footprint of higher education institutions (HEIs) has become an active but still underexplored line of research. The systematic review by Valls-Val and Bovea [4], which covered studies published up to March 2021, found clear differences in normalized results, with an average of 2.67 t of CO_2e per student and values ranging from 0.06 to 10.94 t of CO_2e, reflecting the variability of methodologies, inventory boundaries, and contexts. In Latin America, Cano et al. [5] reported a footprint of 0.432 t of CO_2e per person for the campuses of the National University of Colombia in Medellín. In Mexico, documented cases include the Cuajimalpa campus of the Metropolitan Autonomous University (UAM), with about 3,000 t of CO_2e in 2016 for a population of about 2,750 people (≈ 1.1 t of CO_2e per person) [6], and the Autonomous University of the State of Mexico, with 28,019.6 t of CO_2e in 2022 (261.30 kg of CO_2e per person per year) for a community of 107,231 members [7].

At the faculty level, Üstün Odabaşı [8] estimated 0.52 t of CO_2e per person per year for an engineering faculty. However, most of these studies analyze entire campuses or universities, and studies at the scale of a single faculty are less common in the Mexican context, particularly for faculties oriented to information technologies, where the relationship between the carbon footprint and the management of technological infrastructure has not been explicitly addressed.

In this context, assessing the carbon footprint of the Faculty of Computer Science Mazatlán (FIMAZ) of the Autonomous University of Sinaloa (UAS), in Mexico, is of strategic relevance because it identifies and quantifies the total greenhouse gas (GHG) emissions from the academic, administrative, energy-related, and mobility activities carried out at the institution [2]. Such an analysis provides a detailed diagnosis of the current environmental impact and technical support for designing actions to reduce emissions, improve energy efficiency, and adopt sustainable practices on the university campus [3].

FIMAZ is a particularly suitable case study for several reasons. It is a faculty whose academic work relies on information and communication technologies, with computer laboratories, computing equipment, and 59 air-conditioning units distributed across classrooms, the library, administrative offices, and laboratories. It is located in a very hot climate zone of northwestern Mexico, which implies a considerable electricity demand. In addition, it serves a community of 836 people (783 students, 41 teachers, and 12 administrative and trust staff members), many of whom commute from distant localities. Despite this, the faculty has no baseline of its GHG emissions, and its technological innovation projects have not been explicitly oriented toward the sustainability of its infrastructure [9]. This lack of information limits the planning of data-driven energy efficiency and technological improvement actions.

In this research, technological management is understood as the planning, use, and renewal of the institution's technological infrastructure and equipment (computing equipment, laboratories, and air-

ISSN: 2594-1925

conditioning systems, among others), as well as the incorporation of technological tools into institutional decision-making. From this perspective, the carbon footprint estimate is an input for technological management: it shows the extent to which infrastructure and technology-use habits contribute to the faculty's emissions and guides decisions such as modernizing air-conditioning systems and improving the energy efficiency of laboratories.

The main objective of this study is to quantify the carbon footprint generated by electricity consumption, water use, solid waste generation, and the mobility of the teaching, administrative, and student population of FIMAZ of the Autonomous University of Sinaloa, applying standardized methodologies in order to identify the main emission sources and propose appropriate mitigation strategies [10], [11].

The main research questions concern the identification of the direct and indirect sources of greenhouse gas emissions; the characterization of FIMAZ's energy consumption, mobility, waste, and other relevant activities; the analysis of international standards such as ISO 14064-1 and the Greenhouse Gas Protocol (GHG Protocol); the determination of the sectors or activities that contribute most to total emissions; and the formulation of strategies and recommendations to reduce the institutional carbon footprint and strengthen environmental management in the university community.

This work differs from similar studies in three respects. It establishes a carbon footprint baseline at the faculty scale, rather than for an entire university campus as in other studies, in an academic unit oriented to information technologies; it integrates four emission sources (electricity, water, solid waste, and mobility) using monthly data for a full year (January to December 2024); and it links the results to the management of technological infrastructure, which helps guide concrete measures for energy efficiency and sustainable mobility.

2 Background (Theoretical Framework and State of the Art)

First, it is important to note that the emissions generated by an organization's activities can be classified as direct or indirect greenhouse gas (GHG) emissions. Direct emissions come from sources owned or operationally controlled by the organization. They are generally released at the place where the activities are carried out, such as those from heating systems or processes that burn fossil fuels within institutional facilities [10], [11].

Indirect GHG emissions, in turn, result from the organization's activities but originate from sources owned or controlled by external entities. A representative example is the consumption of purchased electricity, whose emissions are generated during the production of that energy at external plants [11].

To facilitate the identification, quantification, and reporting of direct and indirect emissions, international standards classify them into three scopes. Scope 1 includes direct GHG emissions from sources owned or controlled by the organization, such as combustion in boilers, furnaces, and institutional vehicles, as well as fugitive emissions, including refrigerant leaks in air-conditioning systems or methane leaks in pipelines [10].

Scope 2 includes indirect emissions associated with the generation of electricity, steam, heat, or cooling that the organization purchases and consumes; although these emissions are not produced within its facilities, they are a direct consequence of its energy requirements [11]. Finally, Scope 3 includes other

ISSN: 2594-1925

relevant indirect emissions that occur along the value chain, such as the extraction and production of purchased materials, business travel by external services, the transport of inputs and products by third parties, and the use of goods and services provided by other organizations [10], [11].

GHGs are linked to the greenhouse effect, an essential natural phenomenon that has made life on Earth possible by maintaining a mean temperature suitable for ecosystems. Since the Industrial Revolution, however, human activities have significantly increased the release of these gases into the atmosphere. This anthropogenic intensification has altered the natural balance of the climate system and, according to the Intergovernmental Panel on Climate Change, is the main driver of current global warming and climate change [1].

Understanding the nature, sources, and effects of GHGs is therefore essential to address the contemporary climate crisis. GHGs are gaseous compounds in the atmosphere that absorb and emit long-wave infrared radiation, which the Earth's surface releases as heat. This physical mechanism retains part of the thermal energy in the atmosphere and contributes to the increase in air temperature near the surface.

The efficiency of this process is explained by the molecular structure of GHGs. Molecules composed of three or more atoms, such as carbon dioxide (CO_2), which has three atoms, or methane (CH_4), which has five, exhibit specific vibrational modes that facilitate interaction with infrared radiation. By absorbing and re-emitting this energy, these gases limit heat loss to space and intensify the warming of the Earth's atmosphere [12].

Anthropogenic greenhouse gases (GHGs) consist mainly of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a group of compounds known as fluorinated gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These gases differ in origin, atmospheric lifetime, and global warming potential; together, however, they play a decisive role in intensifying the greenhouse effect and advancing climate change worldwide [1], [13].

In Mexico, the analysis and management of the carbon footprint (CF) in higher education institutions (HEIs) is a relatively recent field of study, although its relevance is growing. This background is part of international and national efforts to promote university sustainability and contribute to climate change mitigation. This approach responds to the need for universities to systematically assess and manage their environmental impact.

The concept of the carbon footprint began to consolidate in the early twenty-first century as a fundamental indicator for estimating the total amount of greenhouse gases (GHGs) emitted directly or indirectly by an organization. Internationally, universities adopted explicit sustainability commitments through various declarations and agreements, including the Talloires Declaration, and through the integration of the Sustainable Development Goals of the United Nations 2030 Agenda [14].

In this context, Mexican HEIs have recognized their dual role in the climate crisis: they are significant consumers of energy and generators of waste, but also strategic actors responsible for generating knowledge, training professionals, and fostering greater environmental awareness in society. This vision has driven research and actions aimed at measuring the carbon footprint as a key tool for institutional environmental management [15].

ISSN: 2594-1925

The first structured attempts to measure the carbon footprint (CF) in Mexican HEIs began during the 2010s. Initially, these studies were carried out mainly as pilot projects or specific research efforts, driven by graduate programs or particular academic areas, especially those linked to environmental engineering, energy efficiency, and institutional sustainability.

Within this context, some institutions with greater academic infrastructure and research capacity, such as the National Autonomous University of Mexico (UNAM), were among the first to conduct formal studies on quantifying GHG emissions. These early experiences established methodological references that were later adopted and adapted by other higher education institutions in the country [16].

As the results of these measurements accumulated, Mexican universities began to move from an approach focused solely on quantifying emissions toward the active management of the carbon footprint. This process was characterized by the cross-cutting inclusion of the environmental component in institutional development plans and university sustainability policies. Consequently, several HEIs created or strengthened organizational units dedicated to sustainability, which are responsible for designing and implementing mitigation programs that include improving energy efficiency, incorporating renewable sources (for example, by installing solar panels), comprehensive waste management, and promoting sustainable mobility schemes [15].

A determining factor in this progress has been the consolidation of inter-institutional collaboration networks. In particular, the Network of Sustainability Indicators in Mexican Universities (RISUM), together with other academic forums, has facilitated the exchange of methodologies, experiences, and best practices for measuring and reducing the carbon footprint among federal and state universities [17].

However, one of the main challenges identified has been adapting international guidelines and protocols, such as the GHG Protocol, to the specific operating conditions of Mexican HEIs. In many cases, these institutions lack integrated information systems that allow the detailed recording of energy consumption and other inputs relevant to emissions estimation. Although national GHG inventory guidelines have been used as a methodological reference, the internal standardization of measurement processes remains a challenge. Various case studies agree that electricity consumption and the emissions associated with the mobility of the university community tend to be the main sources of the carbon footprint in Mexican HEIs, a pattern consistent with those observed internationally [16].

Overall, the background of the carbon footprint in HEIs in Mexico shows significant progress, characterized by the transition from isolated initiatives to the incorporation of emissions management as a strategic component of university sustainability, which is fundamental for advancing national and international climate commitments.

Currently, FIMAZ includes in its mission the training of professionals capable of integrating information and communication technologies into contexts that promote sustainable human development. However, this commitment is manifested mainly in teaching and research rather than in the operational management of the faculty's physical infrastructure. In the area of academic research, FIMAZ has established academic groups, such as the Academic Group “Educational Technology and Informatics” (UAS-CA-182), whose work focuses on applying digital technologies to the instructional process. To date, however, its projects have no explicit orientation toward the sustainability of university infrastructure or the direct reduction of the environmental impact of its facilities [9].

ISSN: 2594-1925

In the field of technological innovation, the faculty has developed relevant projects, such as educational platforms in virtual and metaverse environments for academic purposes. Although these initiatives represent significant advances in educational and technological innovation, their scope is limited mainly to improving teaching and learning processes, without a direct link to environmental management strategies or to the sustainability of institutional infrastructure. This represents an opportunity to strengthen the integration of technological innovation and university sustainability [14].

3 Methodology

The research follows a quantitative approach, under a non-experimental design that integrates cross-sectional, descriptive, and longitudinal characteristics, and covers the study period from January to December 2024. The work is developed as a case study, based on the application of international guidelines and standards for the preparation of greenhouse gas (GHG) inventories, which allows a systematic and comparable quantification of the emissions generated, without deliberate manipulation of the variables analyzed [10], [11], [18].

For data collection, surveys were administered to a total of 400 participants, representing 51% of the study population, which comprises 783 students, 41 teachers, and 12 administrative and trust staff members, with 100% coverage of the latter two groups. The research follows a quantitative approach, with a non-experimental, cross-sectional, descriptive, and longitudinal design, covering the period from January to December 2024. It is considered non-experimental because the variables associated with the generation of greenhouse gas emissions are not deliberately manipulated, but are observed and recorded as they occur in the natural environment of FIMAZ [18].

Currently, FIMAZ has 59 air-conditioning units with capacities ranging from 1.5 to 2.5 tons of refrigeration, distributed across eight classrooms, the library, administrative offices, and various academic laboratories. Considering this inventory of cooling systems is pertinent, since the electricity consumption associated with cooling equipment is one of the main sources of indirect emissions in higher education institutions, particularly in warm-climate areas such as northwestern Mexico [19].

To estimate the carbon footprint, the Greenhouse Gas Protocol (GHG Protocol) and the ISO 14064-1:2018 standard are applied, which establish the conceptual, methodological, and calculation framework needed to quantify and report greenhouse gas (GHG) emissions. The implementation of these standards requires the precise definition of the organizational and operational boundaries of the study, in order to ensure the consistency, transparency, and comparability of the results obtained [10], [11].

Regarding organizational boundaries, FIMAZ is defined as the unit of analysis, focusing the assessment on the academic, administrative, and operational activities carried out within its institutional scope.

Emissions are quantified using the standard formula that relates activity data to the corresponding emission factors. Activity data include information on electricity consumption (kWh), fuels (liters or cubic meters), waste generation (tons), and distances traveled in mobility activities (kilometers), collected for an annual reference period. To obtain this information, techniques such as the review of invoices and institutional records are used for Scopes 1 and 2, as well as mobility surveys administered to the university community for Scope 3 [11].

ISSN: 2594-1925

The emission factors used correspond primarily to values specific to Mexico and to the regional electricity sector where available. In their absence, the factors provided by international organizations such as the Intergovernmental Panel on Climate Change (IPCC) or the International Energy Agency (IEA) are adopted. In particular, for Scope 2, it is recommended to use the emission factor of the National Transmission Grid or the Federal Electricity Commission, published by government agencies such as the Ministry of Environment and Natural Resources (SEMARNAT) [20], [22].

For the normalization and analysis of results, the total carbon footprint is expressed in standardized units, such as tons of CO_2 equivalent per student and per square meter of built area, which allows comparisons with other higher education institutions. Finally, a contribution analysis is performed to identify the main emission sources or "hotspots" within each scope, in order to prioritize the most effective mitigation actions and strategies [10], [11].

Emission factors (EFs) indicate the amount of greenhouse gases generated per kilometer traveled, according to the type of transport used. The private car has the highest value (0.21 kg CO_2e/km), while the scooter has the lowest emission level (0.007 kg CO_2e/km). The analysis of these data is presented below, considering their efficiency and environmental impact in order to calculate Scope 1, Scope 2, and Scope 3.

Private car (0.21 kg CO_2e/km): This is the transport mode with the poorest performance from a climate perspective. This is explained by its low occupancy rate, which is commonly a single person, significantly increasing emissions per passenger [20], [23], [24].

Motorcycle (0.06 kg CO_2e/km): Although it runs on fossil fuels, its lower weight and smaller engine allow better performance per kilometer traveled compared with a car, generating approximately 70% fewer emissions [20], [24]. Buses or trucks (0.03 kg CO_2e/km): Although they are large vehicles, their efficiency comes from their high capacity to carry cargo or passengers. By distributing total emissions among users, the individual carbon footprint becomes significantly lower [20]. Electric scooter (0.007 kg CO_2e/km): This is the most sustainable alternative. Its emissions are not direct, but depend exclusively on the production of the electricity used to recharge its battery, according to the available energy mix [24], [25].

Quantification of kilometers traveled and classification of motor vehicles. The kilometers traveled were obtained from mobility surveys administered to the university community (400 participants among students, teachers, and administrative staff), in which the means of transport used to reach the faculty and the distance of the trip were recorded. The distance was considered round trip, and the days of attendance from Monday to Friday of each month were counted, since it is an in-person program. Monthly kilometers were aggregated by type of transport from the responses of the sample of 400 participants, yielding the monthly and annual kilometers presented in Table 4. The means of transport were classified into four categories: buses/trucks (public transport), private vehicles (cars), motorcycles, and scooters, according to the emission factors available for each category [20], [23], [25]. Mobility emissions (Table 5) were calculated by multiplying the kilometers traveled in each category by its emission factor (kg CO_2e/km), that is: Emissions (kg CO_2e) = Σ (km traveled by type of transport × EF of the type of transport). These emissions are classified under Scope 3.

ISSN: 2594-1925

4 Analysis of Results

4.1. Electricity consumption

The monthly electricity consumption of the Faculty of Computer Science Mazatlán shows significant variations throughout the year, which suggests a direct relationship with factors such as academic activity, the school calendar, and the climatic conditions of the region (Table 1).

Table 1. Monthly electricity consumption (kWh) at FIMAZ.

Month	Consumption (kWh)	Carbon footprint (kg CO_2)
January	41,200	18,086.80
February	38,950	17,099.05
March	42,780	18,780.42
April	40,600	17,823.40
May	45,120	19,807.68
June	47,980	21,063.22
July	39,850	17,494.15
August	36,700	16,111.30
September	43,500	19,096.50
October	46,200	20,281.80
November	41,880	18,385.32
December	38,400	16,857.60
Total	**503,160**	**220,887.24**

Table 1 shows the monthly variation in electricity consumption—expressed as a carbon footprint in kg of CO_2—from January to December. These values make it possible to identify consumption patterns, peaks, and months of higher or lower energy efficiency. Variable behavior is observed, but in general the values remain between 16,000 and 21,000 kg of CO_2, which indicates a relatively constant energy demand, with fluctuations that are to be expected owing to academic activities. The months with a significant environmental impact, that is, with the highest carbon footprint, are: June (21,063.22 kg of CO_2), October

ISSN: 2594-1925

(20,281.80 kg of CO_2), May (19,807.68 kg of CO_2), and September (19,096.50 kg of CO_2); these months coincide with periods of greater academic activity, owing to the use of computer laboratories, air conditioning, etc.

4.2. **Water consumption**

Table 2 shows the monthly consumption of drinking water (m^3) at FIMAZ, as well as the associated electrical energy (kWh) and the carbon footprint generated (kg of CO_2) over an annual period. Together, these data make it possible to understand the indirect environmental impact of water use, since its supply, distribution, and treatment involve energy consumption and greenhouse gas emissions.

Table 2. Monthly water consumption (m^3) at FIMAZ.

Month	Consumption (m^3)	Energy (kWh)	Carbon footprint (kg CO_2)
January	210	252	110.63
February	190	228	100.09
March	225	270	118.53
April	230	276	121.16
May	260	312	136.97
June	270	324	142.24
July	185	222	97.46
August	205	246	107.99
September	240	288	126.43
October	255	306	134.33
November	230	276	121.16
December	200	240	105.36
Total	**2,700**	**3,240**	**1,422.36**

The results show a direct relationship between the volume of water consumed, the associated electrical energy, and the carbon footprint generated. The total energy consumption linked to water use reaches 3,240 kWh per year, resulting in an accumulated carbon footprint of 1,422.36 kg of CO_2. The months with the highest water consumption also show higher energy consumption (for example, June with 324 kWh) and higher CO_2 emissions, with June (142.24 kg of CO_2), May (136.97 kg of CO_2), and October (134.33 kg of CO_2) standing out.

ISSN: 2594-1925

This is explained by the fact that drinking water supply involves energy-intensive processes, such as extraction, pumping, distribution, and, subsequently, wastewater treatment. Consequently, greater use of water resources translates into indirect GHG emissions, generally classified under Scope 3 in institutional carbon footprint inventories.

4.3.**Implications for the environmental management of FIMAZ**

It can be established that water consumption represents not only an impact on the water resource but also a significant indirect source of carbon emissions. Therefore, this information is essential to:

- Identify the critical months with the greatest environmental impact.
- Integrate water use into carbon footprint mitigation strategies.
- Promote water efficiency measures, such as water-saving devices, leak detection, and awareness campaigns.
- Assess the potential impact of technologies that reduce the energy consumption associated with water use.

4.4.**Waste generated**

The waste generated at FIMAZ (white paper, printers, toner, cartridges, etc.) is presented in Table 3, which shows the monthly volume of solid waste (kg/month) and the carbon footprint associated with its management, expressed in kilograms of carbon dioxide (kg of CO_2). Together, the results make it possible to assess the indirect environmental impact derived from the generation and disposal of waste within the faculty.

ISSN: 2594-1925

Table 3. Waste generated at FIMAZ.

Month	Waste (kg/month)	Carbon footprint (kg CO_2)
January	90.00	22.50
February	110.00	27.50
March	120.00	30.00
April	100.00	25.00
May	150.00	37.50
June	100.00	25.00
July	160.00	40.00
August	120.00	30.00
September	200.00	50.00
October	110.00	27.50
November	95.00	23.75
December	96.00	24.00
Total	**1,451.00**	**362.75**

During the study period, FIMAZ generated a total of 1,451 kg of solid waste per year, with an accumulated carbon footprint of 362.75 kg of CO_2. This shows that, although waste accounts for a smaller volume than other emission sources such as electricity, its contribution to the institutional carbon footprint is significant and should not be underestimated. The monthly average of waste is approximately 121 kg, although significant variations are observed between months, which suggests a direct influence of the academic calendar and the intensity of in-person activities.

4.5. **Monthly variability and observed patterns**

The months with the highest waste generation are September (200 kg), July (160 kg), and May (150 kg). These values coincide with periods of high academic activity, return to classes, and greater influx of students and staff, which increases the consumption of food, office supplies, and disposable products. In particular, September shows the highest value in both waste generation and carbon footprint, reaching 50 kg of CO_2, which makes it a critical month from an environmental perspective. Conversely, the lowest waste volumes are recorded in January (90 kg), November (95 kg), and December (96 kg). These months coincide with vacation periods or periods of lower academic activity, which is reflected in reduced use of the facilities and, consequently, in waste generation.

ISSN: 2594-1925

4.6. **Mobility**

Table 4 shows the kilometers traveled monthly by the FIMAZ university community, broken down by type of transport: buses/trucks, private vehicles, motorcycles, and scooters, as well as the monthly and annual totals. This indicator makes it possible to assess the real magnitude of mobility and its direct relationship with the greenhouse gas emissions associated with transport, classified under Scope 3 of the GHG inventory. It is worth mentioning that FIMAZ serves a large number of students who come from small rural communities and other distant municipalities, generally with travel times of 1 to 2 hours, such as Rosario, Escuinapa, Concordia, and Villa Unión, as well as very remote communities and neighborhoods.

During the period analyzed, a total of 330,661 kilometers per year was recorded, which indicates a considerable volume of daily trips to and from the faculty. The kilometers traveled and the vehicle types were quantified according to the procedure described in the Methodology section (mobility surveys administered to the university community and classification into four transport categories). The distribution by type of transport shows a marked dependence on motorized means, particularly public transport and private vehicles: buses/trucks, 218,480 km (≈ 66% of the total); private vehicles, 76,500 km (≈ 23% of the total); motorcycles, 34,640 km (≈ 10% of the total); and scooters, 1,041 km (≈ 0.3% of the total).

This distribution indicates that, although private vehicles have a significant presence, public transport accounts for most of the total mobility, which has relevant implications in terms of efficiency and emissions per passenger-kilometer.

Table 4. Mobility of FIMAZ students and teachers in kilometers traveled.

Month	Buses / Trucks	Private vehicle	Motorcycles	Scooter	Total km traveled
January	17,370	6,100	3,050	80	26,600
February	14,000	6,800	3,700	78	24,578
March	18,000	7,100	2,900	86	28,086
April	18,450	8,700	3,550	99	30,799
May	19,850	10,400	2,600	110	32,960
June	18,800	9,300	3,540	78	31,718
July	16,500	3,000	1,200	66	20,766
August	18,410	2,900	2,300	90	23,700
September	21,000	3,600	4,700	111	29,411
October	20,700	7,500	3,700	99	31,999
November	19,200	6,500	2,200	78	27,978
December	16,200	4,600	1,200	66	22,066
Total	218,480	76,500	**34,640**	**1,041**	**330,661**

ISSN: 2594-1925

The comparison between the distance traveled by type of transport (see Table 4) and the carbon footprint generated (see Table 5) makes it possible to understand not only how much the university community travels, but also which means of transport have the greatest environmental impact.

During the period analyzed, FIMAZ students and teachers traveled a total of 330,661 kilometers, resulting in total emissions of 24,705.09 kg of CO_2. This result confirms that mobility is one of the main sources of indirect emissions for the institution.

Table 5. Carbon footprint from the mobility of FIMAZ students and teachers.

Month	Buses / Trucks	Private vehicle	Motorcycles	Scooter	CO_2 emissions (kg)
January	521.10	1,281.00	183.00	0.56	1,985.66
February	420.00	1,428.00	222.00	0.55	2,070.55
March	540.00	1,491.00	174.00	0.60	2,205.60
April	553.50	1,827.00	213.00	0.69	2,594.19
May	595.50	2,184.00	156.00	0.77	2,936.27
June	564.00	1,953.00	212.40	0.55	2,729.95
July	495.00	630.00	72.00	0.46	1,197.46
August	552.30	609.00	138.00	0.63	1,299.93
September	630.00	756.00	282.00	0.78	1,668.78
October	621.00	1,575.00	222.00	0.69	2,418.69
November	576.00	1,365.00	132.00	0.55	2,073.55
December	486.00	966.00	72.00	0.46	1,524.46
Total	6,554.40	16,065.00	**2,078.40**	**7.29**	**24,705.09**

4.7.**Seasonal variation: mobility and carbon footprint**

The relationship between the two tables shows a general correspondence between greater mobility and higher CO_2 emissions. The months with the greatest mobility are: May (32,960 km | 2,936.27 kg of CO_2), June (31,718 km | 2,729.95 kg of CO_2), and October (31,999 km | 2,418.69 kg of CO_2). These months coincide with high academic activity, examinations, and the end of the semester. The months with the least mobility are: July (20,766 km | 1,197.46 kg of CO_2) and December (22,066 km | 1,524.46 kg of CO_2), which correspond to vacation periods, in which in-person attendance decreases.

4.8. **Comparison with previous studies**

Integrating the four sources analyzed, the carbon footprint of FIMAZ in 2024 was 247,377.44 kg of CO_2 (≈ 247.4 t of CO_2e), of which electricity accounted for 89.3%, mobility for 10.0%, water for 0.6%, and

ISSN: 2594-1925

waste for 0.1% (Figure 1). Considering the 836 members of the community, this is equivalent to approximately 0.30 t of CO_2e per person per year (0.32 t per student).

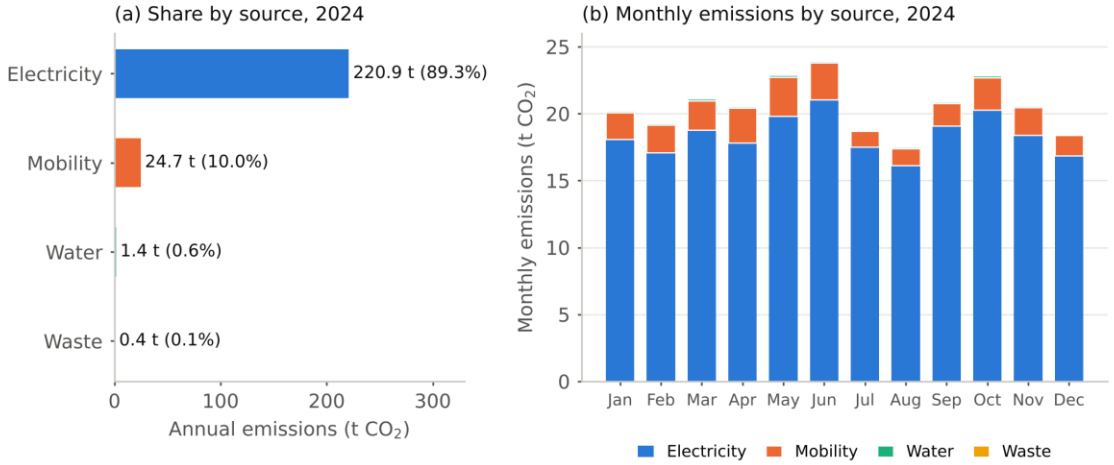


Figure 1. Carbon footprint of FIMAZ in 2024: (a) share of total emissions by source and (b) monthly emissions by source.

This value is below the average of 2.67 t of CO_2e per student (range of 0.06 to 10.94) reported in the systematic review by Valls-Val and Bovea [4], and is of the same order of magnitude, although lower, than the values reported for the National University of Colombia in Medellín (0.432 t of CO_2e per person) [5], for an engineering faculty (0.52 t of CO_2e per person per year) [8], and for the Autonomous University of the State of Mexico (261.30 kg of CO_2e per person in 2022) [7]. At the Cuajimalpa campus of UAM [6], with an approximate population of 2,750 people and about 3,000 t of CO_2e in 2016, the value is equivalent to about 1.1 t of CO_2e per person, that is, about 3.7 times that of FIMAZ (Table 6).

Table 6. Comparison of the FIMAZ carbon footprint with previous studies in higher education institutions.

Study	Unit of analysis	t of CO_2e per person per year	Predominant sources
This study (FIMAZ-UAS, 2024)	Faculty (836 people)	0.30	Electricity (89.3%); mobility (10.0%)
Valls-Val and Bovea [4]	Systematic review of HEI studies	2.67 per student (range: 0.06–10.94)	—
Cano et al. [5]	Urban campuses of the National Univ. of Colombia, Medellín (2019)	0.432	Scope 3 (≈ 83%); Scope 2 (≈ 14%)
Üstün Odabaşı [8]	Engineering faculty	0.52	Electricity (59%); transport (22%); heating (18%)
Mendoza-Flores et al. [6]	Cuajimalpa campus, UAM, Mexico City (2016)	≈ 1.1 *	Commuting (51%); electricity (24%)
Calderon Maya et al. [7]	Autonomous University of the State of Mexico (2022)	0.261	—

* Value calculated from ≈ 3,000 t of CO_2e and ≈ 2,750 people reported in the study. Inventory boundaries and methodologies differ among studies.

ISSN: 2594-1925

Regarding the composition of emissions, the predominance of electricity at FIMAZ (89.3%) contrasts with what has been reported in other studies: at the Cuajimalpa campus of UAM, electricity accounted for 24% of emissions and commuting of the university community for 51% [6]; in the engineering faculty analyzed by Üstün Odabaşı [8], electricity accounted for 59%, transport 22%, heating 18%, and waste 1%; and at the National University of Colombia, Medellín campus, Scope 2 accounted for about 14% and Scope 3 for about 83% [5].

This difference may be associated with FIMAZ's high demand for air conditioning and computing equipment in a warm climate lasting eight to nine months of the year, as well as with the scope of the inventory, which here was limited to electricity, water, waste, and the mobility of students and teachers, without including other sources (for example, refrigerant leaks, paper consumption, or food), which are considered in some of the studies cited. Therefore, comparisons should be interpreted with caution, given that inventory boundaries and methodologies differ among studies [4]. Nevertheless, the results agree with the Mexican literature reviewed in that electricity and mobility are among the main sources of the university carbon footprint [16].

5 Conclusions

The results obtained make it possible to conclude that the carbon footprint of FIMAZ is dominated by electricity consumption and mobility, which should be considered priority areas within environmental management and emission mitigation strategies. The marked dependence on air-conditioning systems and computing equipment, combined with warm climatic conditions and high academic activity, explains the significant weight of electricity consumption in total emissions.

Likewise, the mobility of students and teachers is a critical factor, not because of the total number of kilometers traveled, but because of the preference for private vehicles, which account for most of the CO_2 emissions. This finding shows that the environmental impact of university transport is determined more by the type of vehicle used than by the distance traveled, which opens a broad margin for action on sustainable mobility strategies.

Water consumption and solid waste generation, although with a smaller relative contribution to the total footprint, reflect patterns clearly associated with the academic calendar and constitute indirect sources of emissions that should not be underestimated. In particular, water consumption shows a direct relationship with electricity use, which reinforces the need for comprehensive resource management.

Overall, the findings confirm that the institutional carbon footprint of FIMAZ exhibits clear seasonal variability, influenced by academic activity and vacation periods. This makes it possible to identify the critical months with the greatest environmental impact, which are essential for planning corrective actions.

Compared with similar studies, the contribution of this work is to provide a carbon footprint baseline at the faculty scale, rather than for an entire campus, for an academic unit oriented to information technologies, with monthly data for a full year. The estimated footprint (≈ 0.30 t of CO_2e per person per year) is below the average reported in the international literature [4] and is close to that of other Latin American institutions [5], [7], although with an emissions structure more concentrated in electricity, associated with air conditioning and computing equipment. In this way, the study links carbon footprint

ISSN: 2594-1925

estimation to the technological management of the faculty's infrastructure, by indicating which equipment and systems should be prioritized in modernization and energy efficiency decisions.

Finally, the study provides a solid baseline for decision-making, which makes it possible to propose concrete measures such as:

- Energy efficiency programs and modernization of air-conditioning systems.
- Promotion of public transport, carpooling, and low-impact mobility options.
- Implementation of water-saving and waste-reduction strategies.
- Strengthening of the environmental culture in the university community.

In this way, FIMAZ has fundamental technical information to advance toward a sustainable management model, aligned with national and international commitments on climate change and sustainable development.

6. Authorship acknowledgements

Héctor Luis López López: Conceptualization; Methodology; Formal analysis; Investigation; Data curation; Visualization; Original draft; Review and editing; Project administration. *Lucio Guadalupe Quirino Rodríguez:* Investigation; Resources; Data curation; Review and editing.

References

[1] Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis*. Cambridge, U.K.: Cambridge Univ. Press, 2021. [Online]. Available: https://www.ipcc.ch/report/ar6/wg1/

[2] K. N. Paredes-Canencio, A. Lasso, R. Castrillón, J. R. Vidal-Medina, and E. C. Quispe, "Carbon footprint of higher education institutions," *Environment, Development and Sustainability*, vol. 26, pp. 30239–30272, 2024, https://doi.org/10.1007/s10668-024-04596-4

[3] UNESCO and UNESCO International Institute for Higher Education in Latin America and the Caribbean (IESALC), *General Guidelines for the Implementation of Sustainability in Higher Education Institutions*. Paris, France: UNESCO, 2023. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000387008

[4] K. Valls-Val and M. D. Bovea, "Carbon footprint in Higher Education Institutions: a literature review and prospects for future research," *Clean Technologies and Environmental Policy*, vol. 23, pp. 2523–2542, 2021, https://doi.org/10.1007/s10098-021-02180-2

[5] N. Cano, L. Berrio, E. Carvajal, and S. Arango, "Assessing the carbon footprint of a Colombian university campus using the UNE-ISO 14064–1 and WRI/WBCSD GHG Protocol Corporate Standard," *Environmental Science and Pollution Research*, vol. 30, no. 2, pp. 3980–3996, 2023, https://doi.org/10.1007/s11356-022-22119-4

[6] R. Mendoza-Flores, R. Quintero-Ramírez, and I. Ortiz, "The carbon footprint of a public university campus in Mexico City," *Carbon Management*, vol. 10, no. 5, pp. 501–511, 2019, https://doi.org/10.1080/17583004.2019.1642042

[7] J. R. Calderon Maya, C. E. Barrera Diaz, N. A. Colin Mercado, Y. Montoya Garcia, and F. J. Rosas Ferrusca, "Towards the neutralization of the carbon footprint at the Autonomous University of the State

ISSN: 2594-1925

of Mexico," *Journal of Sustainability Perspectives*, vol. 4, no. 1, pp. 98–108, 2024, https://doi.org/10.14710/jsp.2024.24795
[8] S. Üstün Odabaşı, "Reducing carbon footprint: a sustainable and green campus case study," *International Journal of Global Warming*, vol. 31, no. 4, pp. 454–469, 2023, https://doi.org/10.1504/IJGW.2023.134913
[9] Universidad Autónoma de Sinaloa, *Plan de Desarrollo Institucional y Misión Universitaria (in Spanish)*. Sinaloa, Mexico: Universidad Autónoma de Sinaloa, 2022. [Online]. Available: http://transparencia.uasnet.mx/institucional/Documentos/PDI_con_vision_de_futuro_2025.pdf
[10] International Organization for Standardization, *ISO 14064-1:2018 Greenhouse Gases—Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals*. Geneva, Switzerland: ISO, 2018. [Online]. Available: https://www.iso.org/standard/66453.html
[11] World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, revised ed., 2015. [Online]. Available: https://ghgprotocol.org/corporate-standard
[12] D. Archer, *Global Warming: Understanding the Forecast*, 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, 2012. [Online]. Available: https://www.wiley.com/en-us/global-warming-understanding-the-forecast-2nd-edition-p-9781118213971
[13] United Nations Framework Convention on Climate Change, "GHG inventory data," 2022. [Online]. Available: https://unfccc.int/process-and-meetings/transparency-and-reporting/greenhouse-gas-data/ghg-inventory-data
[14] UNESCO, *Education for Sustainable Development Goals: Learning Objectives*. Paris, France: UNESCO Publishing, 2017. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000247444
[15] S. Mo, Y. Wang, F. Xiong, C. Ai, D. Wang, y G. Y. A. Tan, "Changes of asphalt fumes in hot-mix asphalt pavement recycling," *J. Clean. Prod.*, vol. 258, p. 120586, jun. 2020, https://doi.org/10.1016/j.jclepro.2020.120586
[16] Y. Z. Alharthi, M. K. Siddiki, and G. M. Chaudhry, "Resource Assessment and Techno-Economic Analysis of a Grid-Connected Solar PV System," *Sustainability*, vol. 10, no. 10, p. 3690, Oct. 2018, https://doi.org/10.3390/su10103690
[17] Red de Indicadores de Sustentabilidad en las Universidades Mexicanas, *Avances y Desafíos de la Sustentabilidad Universitaria en México (in Spanish)*. Mexico, 2024. [Online]. Available: https://revistaidentidad.uaemex.mx/article/view/25261
[18] R. Hernández-Sampieri, C. Fernández-Collado, and M. P. Baptista-Lucio, *Metodología de la Investigación (in Spanish)*, 6th ed. Mexico City, Mexico: McGraw-Hill Education, 2018. [Online]. Available: http://www.biblioteca.cij.gob.mx/Archivos/Materiales_de_consulta/Drogas_de_Abuso/Articulos/Sampieri6aEdicion.pdf
[19] K. Valls-Val and M. D. Bovea, "Carbon footprint assessment tool for universities: CO2UNV," *Sustainable Production and Consumption*, vol. 29, pp. 791–804, 2022, https://doi.org/10.1016/j.spc.2021.11.020
[20] IPCC, "AR6 Working Group III: Mitigation of climate change – Chapter 10: Transport," Intergovernmental Panel on Climate Change, 2022. [Online]. Available: https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-10/
[21] International Energy Agency, "Emission factors and electricity generation," 2023. [Online]. Available: https://www.iea.org

ISSN: 2594-1925

[22] Secretaría de Medio Ambiente y Recursos Naturales, *Factores de Emisión para la Estimación de GEI en México (in Spanish)*. Mexico City, Mexico: SEMARNAT, 2022. [Online]. Available: https://www.gob.mx/semarnat

[23] M. Noussan, E. Campisi, and M. Jarre, "Carbon intensity of passenger transport modes: A review of emission factors, their variability and the main drivers," *Sustainability*, vol. 14, no. 17, p. 10652, 2022, https://doi.org/10.3390/su141710652

[24] Statista, "Greenhouse gas emissions by mode of transport (grams of CO_2 equivalent per passenger kilometer)," 2024. [Online]. Available: https://www.statista.com/chart/32350/greenhouse-gas-emissions-by-mode-of-transport/

[25] European Environment Agency, *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2023: Road Transport Emission Factors*, 2023. [Online]. Available: https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023

Derechos de Autor (c) 2026 Lucio Guadalupe Quirino Rodríguez, Héctor Luis López López

Este texto está protegido por una licencia Creative Commons 4.0.

Usted es libre para compartir —copiar y redistribuir el material en cualquier medio o formato — y adaptar el documento — remezclar, transformar y crear a partir del material— para cualquier propósito, incluso para fines comerciales, siempre que cumpla la condición de:

Atribución: Usted debe dar crédito a la obra original de manera adecuada, proporcionar un enlace a la licencia, e indicar si se han realizado cambios. Puede hacerlo en cualquier forma razonable, pero no de forma tal que sugiera que tiene el apoyo del licenciante o lo recibe por el uso que hace de la obra.

Resumen de licencia - Texto completo de la licencia

ISSN: 2594-1925