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Strategies for the Neutralization of the Carbon Footprint at the University of the State of Mexico

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Abstract. Climate Change, driven by greenhouse gas emissions (GHG), demands concrete responses from all sectors, including the higher education institutions. This research aimed to calculate the carbon footprint (CF) generated by the core activities of the Autonomous University of the State of Mexico (Universidad Autónoma del Estado de México, UAEMEX) from 2021 to 2024, and to propose strategies for its neutralization. A hybrid methodology was adopted, based on international standards such as ISO 14064-1:2019, PAS 2050, PAS 2060 and the Greenhouse Gas Protocol, adapted to the characteristics of Higher Education Institutions (HEIs). This approach classified emissions into three scopes: direct emissions from fossil fuels (Scope 1), indirect emissions from electricity consumption (Scope 2) and other indirect emissions associated with waste management, paper consumption and infrastructure (Scope 3). The results indicate a 99% increase in the institutional carbon footprint between 2021 and 2022, linked to the resumption of face-to-face activities caused by COVID-19, subsequently by stabilization in the generation of HC in the subsequent years. Effective mitigation actions were identified, avoiding nearly 10 million kg CO_2e, with emphasis on sustainable university transport, process digitalization and carbon absorption through green areas. The study proposes a comprehensive neutralization plan and a replicable methodology, positioning UAEMEX as a national benchmark in university sustainability and contributing to global climate commitments through institutional management.

Keywords:
Climate Change, carbon footprint, greenhouse gases, neutralization, sustainability, higher education.

1. Introduction

Climate Change (CC) represents a global environmental threat whose consequences, such as rising average temperatures, extreme weather events and biodiversity loss, are closely linked to anthropogenic greenhouse gas emissions (GHG) [1]. The carbon footprint (CF) has been established as an essential tool to quantify these emissions, supporting the design of mitigation strategies at an organizational level.

Higher Education Institutions (HEIs), play a strategic role in the transition towards environmental sustainability, since they are both generators and disseminators of knowledge. The Autonomous University of the State of Mexico (UAEMEX) has a community of more than 100,000 members across multiple campuses, and on a daily basis the institution generates a significant amount of GHG due to multiple activities requiring energy use for essential services, comprising mobility, waste generation, paper consumption and infrastructure development.

Despite the relevance on the matter, to date there are no systematic studies on the carbon footprint of this institution. This research is therefore justified by the need to establish an emissions baseline, by means of applying a methodology adapted to the university context, and to develop an action plan for emission neutralization aligned with national and international climate commitments.

The aim of the study is to design an institutional strategy for neutralizing the carbon footprint generated by the core activities of the Autonomous University of the State of Mexico (UAEMEX) during 2021 to 2024 period. Three specific objectives were pursued as follows: (i) to identify the main activities that generate GHG emissions at the institution; (ii) to calculate the institution's CF using an adapted hybrid methodology; (iii) to design a comprehensive mitigation plan aimed at emission neutralization within the institution.

2. Methodology

To provide conceptual support for this research, the first section presents the main theoretical foundations related to CF, thus covering general notions of CC and the greenhouse effect, and addressing concepts such as GHG, global warming and mechanisms for quantifying and neutralizing emissions. The thematic organization follows a progressive and deductive logic (from general to specific), aimed at establishing a clear and coherent reference framework to support the interpretation of results.

This conceptual approach places the CF phenomenon within a broader framework that includes CC, highlighting the interrelationships among the physical, chemical and social processes that influence the generation and accumulation of GHG in the atmosphere. Likewise, the use of an indicator as a key tool for institutional environmental management is justified, particularly in university contexts, where emissions derived from core activities can be quantified, evaluated and mitigated.

The theoretical development presented here provides a solid terminological and methodological foundation, while also linking normative and technical approaches with emerging practices in environmental sustainability and climate governance.

2.1. Climate Change and Greenhouse Gases

CC is one of the most pressing environmental challenges of the twenty-first century, characterized by persistent changes in global weather patterns. It is the main driver of increases in atmospheric concentrations of GHGs derived from anthropogenic activities [2]. This phenomenon not only alters the average temperature of the planet but also affects the frequency and intensity of extreme weather events such as prolonged droughts, floods, hurricanes, and heat waves [3, 4].

The main GHG responsible for global warming include carbon dioxide (CO_2), methane (CF_4), and nitrous oxide (N_2O), along with fluorinated compounds such as hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6), all of which have significantly higher global warming potentials than CO_2 [5]. The emission of these compounds originates mainly from fossil fuels combustion, deforestation, intensive agriculture, transportation, and various industrial activities [5, 6].

CO_2 is the dominant contributor, accounting for approximately 75% of global GHG emissions, primarily from power generation, land and air transport, as well as manufacturing processes [8]. Methane and nitrous oxide, although released in smaller volumes, have a high heat retention capacity, up to 28 and 273 times greater than CO_2 over, respectively, over a 100-year horizon [9].

The cumulative impact of these emissions has intensified the natural greenhouse effect, generating an imbalance in the Earth's climate system with large-scale ecological, social, and economic consequences, including biodiversity loss, ocean acidification, and the vulnerability of human communities to climate disasters [10, 11].

2.2. The Carbon Footprint: Concept and Application

The CF is a methodological tool used to quantify the total GHG emissions generated directly or indirectly by a person, organization, product or event, expressed in units of carbon dioxide equivalent (CO_2e) [12]. Its main purpose is to assess climate impact and support decision-making aimed at mitigating emissions.

CF has become highly relevant as an instrument for environmental management and climate accountability. In organizational contexts, such as universities, it enables the identification of key emission sources, the evaluation of temporal trends, and the design of reduction or compensating strategies [13], [14].

2.3. Methodologies for Calculating the Carbon Footprint

Several internationally recognized methodologies exist for calculating the CF, among which the following stand out:

ISO 14064-1:2019, a standard that establishes the principles and requirements for quantifying and reporting GHG emissions at the organizational level, including boundary setting, source classification, and selection of appropriate emission factors [15].

The Greenhouse Gas Protocol (GHG Protocol), developed by the World Resources Institute (WRI) along with the World Business Council for Sustainable Development (WBCSD), provides a framework that classifies emissions into three scopes: direct (scope 1), indirect energy (scope 2), and other indirect emissions (scope 3) [16].

PAS 2050 and PAS 2060, British standards aimed at calculating the footprint of products and organizations, respectively, incorporate the principles of the life cycle analysis [17].

Across all the methodologies, the basic calculation for CF follows the formula:

$$\text{Emissions } (CO_2e) = \text{Activity} \times \text{Emission Factor} \quad (1)$$

where the emission factor is a standardized coefficient indicating the amount of CO_2e generated per unit of activity [18].

2.4. Life Cycle Analysis and Emission Sources

Life Cycle Assessment (LCA) is an approach that evaluates the environmental impacts associated with all stages of a product or service's life cycle, including extraction of raw materials, production, use, and final disposal [19]. Although LCA is not mandatory in all CF calculation models, it is a valuable tool for estimating scope 3 emissions and promoting comprehensive sustainability improvements [20]. Emission sources can be classified as follows: (i) fixed sources: static installations that generate emissions, such as power plants or buildings; (ii) mobile sources: vehicles used for land, air or sea transportation; (iii) indirect sources: those not directly controlled by the organization, such as electricity generated by third parties or inputs [21].

2.5. The Environmental Role of Higher Education Institutions

Higher Education Institutions (HEIs) play a strategic role in the fight against CC, not only as natural generators of knowledge but also as entities that must minimize their own environmental impacts. According to Cifuentes-Tapia et al. (2020), integrating sustainability criteria in institutional operations, such as the measurement of the CF, effectively promotes both structural and educational improvements [22].

Universities such as the National University of Costa Rica, the Pontificia Universidad Católica de Chile, and the University of Valencia have implemented programs to calculate and neutralize their CF, applying methodologies adapted to each university context [23–25]. These experiences have shown that systematic monitoring of emissions enables the implementation of effective strategies, including sustainable mobility, efficient energy use, waste management and urban reforestation.

In Mexico, although some HEIs have begun to adopt sustainable practices, institutional CF measurements remain incipient. Therefore, studies such as the one presented here, focused on methodology developed at UAEMEX, represent significant progress toward fostering an environmentally responsible organizational culture.

To ensure comparability, transparency and scientific rigor, CF measurement of HEIs must rely on internationally recognized methodologies. In this study, a hybrid methodological approach was applied expressly designed for higher education institutions. This methodology is based on ISO 14064-1:2019 standard, the GHG Protocol and the PAS 2050 and PAS 2060 guides, developed by the British Standards Institute (BSI) in collaboration with the Carbon Trust and the UK Department for Environment, Food and Rural Affairs (DEFRA). A central principle underlying these documents is the pursuit net zero balance, meaning the achievement of equilibrium between the carbon emitted into the atmosphere and the carbon removed from it.

2.5.1. Methodological Foundation

PAS 2050 focuses on the life cycle of products and services, establishing procedures for the calculation of emissions of gases such as CO_2, CF_4, N_2O, HFCs, PFCs and SF_6. This methodology is grounded in key principles, including the definition of system boundaries, the identification of emission sources, and the quantification and offsetting of emissions, including emission factors based on international inventories [26, 27].

Launched in 2010 by the British Standards Institute (BSI), PAS 2060 specifies requirements for the demonstration of carbon neutrality. This standard extends a methodological scope to the organizational level, enabling the calculation and reporting of emissions generated by an entire institution, accounting for both direct and indirect activities.

It also stablishes a framework for achieving carbon neutrality by integrating requirements for the validation and verification of climate commitments [28].

ISO 14064-1:2019, a widely accepted international standard, provides a structured system for the quantification and reporting of GHG emissions also at an organizational level. It classifies emissions into three categories, which were Scope 1: Direct emissions from sources owned or controlled by the institution (e.g., institutional vehicles, boilers); Scope 2: Indirect emissions derived from the consumption of purchased electricity; and Scope 3: Other indirect emissions related to activities not directly controlled, such as waste generation, paper consumption, or construction activities [29].

The GHG Protocol, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), complements these methodologies by providing practical tools for accounting and managing corporate emissions. This protocol, adopted by thousands of organizations worldwide and is fully compatible with ISO regulations [16].

2.5.2. Methodological Adaptation for HEIs

Since the aforementioned methodologies were originally designed for companies or government agencies, they required some adaptation for application in HEIs. To address this, in this study, a hybrid methodology tailored to the context of the UAEMEX was developed, integrating the strengths of international approaches while considering the particular characteristics of HEIs, such as the heterogeneity of substantive activities, the high mobility of the student community, and the environmental impact associated with teaching and learning processes.

This methodological framework comprises eleven main stages: (i) Definition of the study period: 2021 – 2024; (ii) Determination of organizational and operational boundaries; (iii) Identification and classification of emission sources; (iv) Selection of appropriate emission factors, based on IPCC guidelines (2006, 2019) and national sources [21]; (v) Quantification of emissions by each source and scope; (vi) Year-on-year comparative analysis; (vii) Evaluation of reduction strategies currently implemented; and (viii) Proposal of new neutralization strategies based on mitigation scenarios.

The calculation of the UAEMEX's carbon footprint (CF) covered the period 2021 - 2024, accounting for emissions from six main sources: electricity consumption, fossil fuel use, waste generation, paper consumption, construction activities, and mobility. The approach was structured in accordance with the three scopes defined by ISO 14064-1:2019 and the GHG Protocol (direct, energy-related indirect, and other indirect emissions). It also enabled the assessment of total per capita CF, as well as avoided emissions and mitigation actions.

2.5.3. Data Sources and Emissions Calculation

Primary data sources were employed, including internal records of energy consumption, waste inventories, mobility statistics, and construction reports. The calculation of emissions was conducted using the standard formula (Equation 1):

$$\text{Emissions} = \text{Activity} \times \text{Emission Factor} \qquad (1)$$

where activity refers to the magnitude of an emitting action (e.g., kWh consumed, liters of fuel, tons of waste) and emission factor: it is a coefficient that represents the amount of CO_2e

emitted per unit of activity. The emission factors were selected from authoritative and widely recognized sources, such as the Intergovernmental Panel on Climate Change (IPCC), the Environmental Protection Agency (EPA) and the National Institute of Ecology and Climate Change (INECC).

2.5.4. Limitations

The study presents inherent limitations related to the availability and quality of data, particularly with regard to Scope 3. Relevant aspects such as academic travel, supply chain of goods and services, and remote activities were not included in the analysis. In addition, data was conducted internally, which restricts the possibility of obtaining external certification.

3. Results and Discussions

3.1. Total and Per Capita Carbon Footprint

In 2021, the total institution's CF was 14,077,139.90 kg CO_2e, while in 2022 the figure nearly doubled, reaching 28,019,621.33 kg CO_2e (representing a 99% increase). This sharp rise is explained by the return to full-time, in-person activities after the COVID-19 pandemic, during which distance learning and teleworking has temporarily reduced emissions. By 2023, UAEMEX achieved a reduction of almost 10,000 tons of CO_2e. However, due to construction works, emissions rose again in 2024, reaching 22,350.57 tons of CO_2e, as shown in Table 1.

Table 1. Carbon Footprint as Measured in the UAMEX from 2021 to 2024

Year	CF Total (Ton CO_2e)	UAEMEX Community	CF per capita(kg CO_2e/person)
2021	14,077.13	105,249	133,75
2022	28,019.62	107,231	261,30
2023	18,885.63	108,283	174.41
2024	22,350.57	110,450	202.35

At the individual level, the average per capita CF across the four years was 192.95 kg CO_2e/person.

3.2. Avoided Emissions and Mitigation Actions

Due to various institutional initiatives aimed at sustainability, a total of 9,769.42 tons of CO_2e were avoided in 2024. These actions included: (i) the acquisition of university transportation vehicles "*Potrobus*", which avoided 5,766.10 tons of CO_2e per year; (ii) the expansion of university green areas, which enabled the absorption of 3,380.46 tons of CO_2e annually; (iii) the implementation of the institutional mailing system "*SICOINS*" for digital information management processes, which avoided 622,87 tons of CO_2e; (iv) together, these strategies helped offset a significant portion of the emissions generated by institutional operations.

3.3. Discussion

The quantitative results obtained allow us to reflect on the magnitude of the environmental impact derived from UAEMEX's substantive activities and highlight the need to implement more effective measures to achieve carbon neutrality in the medium term. On an average, the institution is giving away 192.95 kg CO_2e/person/year.

3.3.1. Interpretation of Results

The sharp increase in emissions in 2022, as compared to the previous year, can be explained by the return to face-to-face work after the COVID-19 pandemic, which resulted in an increase in the use of facilities, mobility and consumption of resources. Of particular interest are the emissions related to new construction works, which accounted for more than 39% of the total CF in 2022. A similar pattern is observed in subsequent years, where construction activities significantly contributed to the overall CF. These findings underscore the urgency of adopting sustainable construction criteria in the future university developments, as emphasized by other authors [30, 31].

At the same time, the emissions avoided through collective transportation, the digitalization of academic procedures, and CO_2 absorption by green areas demonstrate that it is possible to implement effective mitigation mechanisms at the institutional level. These results establish a pathway for scaling up sustainable actions in the future.

3.3.2. Comparison with Previous Studies

The emission levels per student at UAEMEX (192.95 kg CO_2e/person, on average over the four years) are comparable to those reported by Latin American institutions such, such as the National University of Costa Rica (UNA), which recorded 242 kg CO_2e/person in 2019 [26]. These levels are notably lower than those reported by some European universities, such as the University of Valencia, which documented 372 kg CO_2e/person [24].

In contrast, studies carried out at universities in the United States report per capita CF of more than 1,000 kg CO_2e, particularly in contexts with high energy dependency and intensive vehicular mobility [32]. These contrasts highlight not only regional differences in infrastructure, energy policies, and institutional practices, but also reflect the influence of national economic scale.

3.3.3. Environmental, Social, and Economic Implications

From an environmental perspective, the present findings underscore the urgency of advancing towards low-emission institutional models, particularly in sectors such as construction and transportation. Socially, the engagement of the university community in mitigation strategies –such as the promotion of sustainable transportation and the rational use of resources– can foster collective awareness and encourage sustainable practices beyond the university setting [33].

Economically, emission reduction implies direct benefits through energy savings and enhances operational efficiency, while also opening opportunities for access to climate finance mechanisms and environmental certifications [34]. Strengthening such measures could also improve the university's positioning in sustainability rankings such as the *UI GreenMetric World University Rankings.*

3.3.4. Carbon Footprint Neutralization at UAEMEX

Drawing on the findings of this research, a comprehensive strategy for the progressive neutralization of UAEMEX’s CF is proposed. This strategy is grounded in multidimensional approaches that integrate technological, infrastructural, operational, and institutional environmental management actions, aligned with international guidelines for CC mitigation [35, 31].

One of the priority axes is the transition to low-carbon institutional mobility. To this end, it is recommended that the official vehicle fleet of "Potrobuses" is to be progressively replaced by electric or hybrid units, aligned with the guidelines of the National Electric Mobility Program [36]. This action will significantly reduce Scope 1 emissions, particularly those derived from fossil fuel consumption.

Likewise, expanding the Potrobus system to areas with high student density and elevated GHG emissions could further reduce reliance on individual motorized transport and mitigate urban mobility-related emissions.

In terms of infrastructure, the need to incorporate energy efficiency and sustainable design standards in all new university buildings is underscored. Certifications such as LEED (Leadership in Energy and Environmental Design) and EDGE (Excellence in Design for Greater Efficiencies), have demonstrated effectiveness in reducing energy, water, and material consumption, and are widely recognized benchmark for sustainable construction in the higher education sector [37].

The comprehensive digitization of administrative and academic processes represents a strategic opportunity. his measure reduces paper consumption and associated transportation logistics while enhancing institutional efficiency [38].

The transition to institutional digital platforms must be supported by training campaigns and digital adoption programs, ensuring that information and communication technologies (ICTs) serve as effective tools for environmental performance.

Another key element is the expansion of university green areas through the planting of native species with high CO_2 capture potential, such as *Quercus rugosa*, *Alnus acuminata* and *Pinus montezumae*. These species are proven sinks in Mexican highlands ecosystems [39]. Beyond their ecological function, green areas provide aesthetic and recreational benefits, while serving as natural carbon sequestration system.

In addition, the implementation of an institutional GHG emissions monitoring system is proposed to ensure accountability across academic and administrative units. Annual indicators would enable evidence-based decision-making and could be integrated into the University Environmental Management System, with potential coordination through already existing platforms such as *SICOINS* and GreenMetric. Such a system would strengthen UAEMEX's capacity to consolidate a robust climate management model.

From the research perspective particular attention should be devoted to the quantification of Scope 3 emissions, identified as a critical knowledge gap. This scope includes national and international academic travel, supply chain-related emissions, and the institutional digital footprint.

Finally, the application of these strategies must be fit in a framework of collaborative environmental governance. This requires the active involvement of the university community in the co-creation of sustainable solutions. The transition towards carbon-neutrality at UAEMEX is not only solely technical or operational, but also cultural and educational, requiring coherent, measurable, and replicable institutional processes.

4. Conclusion

This study quantified the CF derived by the substantive activities of the UAEMEX over a four-year period (2021-2024), through the application of a hybrid methodology aligned with international standards such as ISO 14064-1:2019, the Greenhouse Gas Protocol and the PAS 2050 and 2060 standards. Adapted to the context of HEIs, this approach proved effective in identifying emission sources, quantifying emissions across three scopes (direct, energy-related indirect, and other indirect) and proposing viable, replicable neutralization strategies.

Overall, the findings demonstrate that the integrated sustainability initiatives implemented by the university have delivered a substantial and measurable contribution to climate change mitigation. In total, 9,773,640.64 kg CO_2e emissions were avoided through a combination of resource efficiency, waste management, digitalization, and ecosystem-based actions. One of the most relevant findings was the sharp increase in GHG emissions between 2021 and 2022, which rose 14,000 tons of CO_2e to 28,000 tons of CO_2e. This surge, mainly attributed to the return to in-person activities following the COVID-19 teleworking model to a new construction project, highlighting that building activities, electricity consumption and institutional mobility represent the main sources of emissions.

Conversely, mitigation actions already implemented by the UAEMEX, such as the Potrobus transport system, the adoption of digital communication technologies (SICOINS platform) and the expansion of green areas, enabled the avoidance of approximately 10,000 tons of CO_2e in 2024. These initiatives demonstrate the potential for significantly reducing the institutional footprint through strategic environmental management. This research positions UAEMEX as a national benchmark in the measurement and neutralization of carbon emissions. Importantly, the methodology developed here can be transferred to other Mexican HEIs, encouraging the adoption of university policies that foster climate sustainability.

Based on the findings and limitations of the present study, the following directions are proposed: (i) Expand the analysis of Scope 3 to incorporate factors such as international academic travels, institutional procurement, and full life cycle of purchased goods; (ii) Establish a continuous GHG monitoring system within the university, including agency-specific environmental performance indicators; (iii) Explore the technical and financial feasibility of integrating renewable energy sources (e.g. solar photovoltaic and biogas) into institutional operations; (iv) Assess the impact of the university's digital footprint, including cloud storage, educational platforms, and use of information technologies; (v) Develop predictive models using artificial intelligence to simulate emission- reduction scenarios in the short, medium and long term. Ultimately, the measurement of the CF should be understood not only as a quantitative tool, but also a pedagogical, institutional and ethical instrument that can guide universities towards a comprehensive ecological transition aligned with international climate commitments.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors Contribution

M.O.R. was the leader of the project within the university, setting the main objective of this work and aiding in the confection and coordination of the force work needed to collect the data within several university areas, as well as critical revision. **J.R.C.M.** suggested the methodological framework and provided conceptual support for this research, also being responsible for writing the first draft. **N.A.C.M.** held the data collection and executed the research phase, and data analysis was performed by **Y.M.G.** All authors reviewed and approved the final version of the manuscript.

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