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Artificial Intelligence in the Development of Greenhouse Gas Emission Inventories for Commuting: A Case Study at the University of Sao Paulo's Butantan Campus

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ABSTRACT

Higher Education Institutions (HEIs) play a crucial role in mitigating climate change, as centres of research and sustainable practices. This article addresses USP's Butantan Campus, using generative Artificial Intelligence (AI) tools An Origin-Destination survey (6,700 responses), calculated distances, transport modes, and associated emissions. Commuting accounts for a GHG emissions, exceeding Scope 1 and 2 emissions under certain contexts. Including Scope 3 in HEIs' GHG inventories is critical and proposes strategies to reduce emissions, such as prioritising sustainable public transport, creating cross-sectoral committees, and adopting a "green curriculum" within HEIs. AI innovates GHG inventories and public policies. HEIs must lead by example

Keywords:

GHG Emissions, Commuting, Artificial Intelligence, HEIs, Butantan Campus, Sustainability, Urban Mobility.

1. INTRODUCTION

Global GHG emissions rose staidly in the 21st century, declining briefly in 2009 (financial crisis) and 2020 (pandemic), (Emissions Database for Global Atmospheric Research, EDGAR - 2025). As a result, the atmospheric GHG concentrations intensifying climate impacts. In 2023, emissions hit 53 Gt CO2eq, excluding Land Use, land Use Change and Forestry (LULUCF), Fossil CO_2 dominated (73.7%), followed by CH_4 (18.9%), N_2O (4.7%) and F-gases (2.7%) (EDGAR - 2025).

In 2023, six regions (China, US, India, EU27, Russia, Brazil) contributed 62.7% of global emissions. BRICS nations accounted for 42% in 2018 (Koilakou *et al.* - 2024). Brazil's emissions grew faster than global averages (1990-2023), driven by energy use, even without considering LULUCF, (World Population Review, 2024). Table I compares Brazil's emissions to global totals (EDGAR - 2025).

GHG total emision Gt CO_{2eq} (EDGAR - European Comission)*								
	1990	2000	2005	2015	2020	2022	2023	% 2023/1990
world	32.726	36.175	41.297	48.809	49.328	51.968	52.963	162%
Brazil	672	899	1.025	1.252	1.216	1.298	1.300	194%
* LULUCF (Land Use, Land-Use Change, and Forestry) is not included								

Table I: Brazilian Emissions Compared to the Rest of the World (Excluding LULUCF)

According to the Copernicus Climate Change Service, January 2025 was the warmest January globally, 1.75°C above pre-industrial levels, and the 18th month in the last nineteen months where the global average surface air temperature exceeded 1.5°C above pre-industrial levels (Copernicus - 2025).

Climate change affects the environment in numerous ways, including rising temperatures, sea levels, droughts, flooding, impact essential resources and values such as water, energy, transportation, wildlife, agriculture, ecosystems, and human health. Droughts can harm food production and human health, while flooding can lead to the spread of disease, fatalities, and damage to ecosystems and infrastructure, increase mortality rates, alter food availability, limit worker productivity, and ultimately affect economic output (NOAA - 2025).

In Brazil, impacts of the climate crisis include prolonged heatwaves across nearly the entire country; heavy rainfall over short periods (e.g., in southern Brazil in 2024 – CNN Brasil - 2024a); prolonged droughts and consequent water scarcity (INFOAmazonia - 2024); unseasonably severe cold and frost in areas where such phenomena are uncommon (CNN Brasil - 2024b). Projections by Kotz *et al.* - 2024 estimate that global warming could reduce per capita income by up to 30% for approximately 60% of Brazil's population by 2050, threatening the survival of a significant portion of the population. Such scenarios can only be avoided if society eliminates GHG emission sources and engages in mitigation/adaptation through the development of research and appropriate public policies.

To date, the global population's response to the climate and nature crises has treated them as independent and non-urgent challenges, as stated in an editorial at the end of 2023 in the Indian Journal of Medical Research, (Indian J. Med. Res. - 2023). Climate change and environmental degradation must be addressed with greater urgency and realism, reducing greenhouse gas emissions, promote sustainable energy practices, and support communities in adapting to climate change and, perhaps demonstrating that HEIs, by failing to act decisively, are also responsible for perpetuating the inequalities these crises generate.

The rise in global emissions necessitates local and institutional actions, such as those discussed in this article, particularly in the context of HEIs.

2. THE ROLE OF HEIs

HEIs are part of the solution to climate change, leading research, education, public policy formulation, and policymaker training. They are well-positioned to drive the transitions needed to address climate change due to their broad range of expertise. This includes STEM (Science, Technology, Engineering, and Mathematics) and technical expertise, enabling collaboration with governments to drive these transitions by:

- Educating students: HEIs can teach students about climate change, including its science, economics, and social aspects, disseminating methodologies and performance indicators for energy monitoring and carbon emission tracking; fostering interdisciplinary research focused on solutions to the climate crisis, etc.
- Researching and developing new technologies: HEIs can research and develop renewable energy technologies, such as new electric batteries, energy management systems, and the genetic development of more productive and/or climate-resilient crops.
- Promoting sustainability: HEIs can promote through campus initiatives, implementing internal actions for the management, conservation, and efficient use of natural resources, and reducing the Carbon Footprint (CF), passing on this vision to future generations of professionals.
- Building resilience: HEIs can build resilience to climate change by training and educating the workforce and broader society.

- Identifying climate impacts: HEIs can identify the most critical climate impacts and ways to address them.
- Enhancing knowledge of climate risks: HEIs can enhance knowledge of local and regional and planetary climate risks.
- Sustainable practices: HEIs serve as living laboratories for sustainable practices.
- Modelling good practices: They perform a symbolic function, serving as models of good practices where students and researchers experiment with and then disseminate efficient practices to their communities.
- Techniques developed to GHG inventories in HEIs can be as detailed and robust as desired and can be adapted and replicated in other contexts, (companies, municipalities, or state and national levels).

2.1 GHG PROTOCOL

The GHG Protocol (WRI/WBCSD - 2004) is a set of standardised frameworks for measuring and managing greenhouse gas emissions. It is used to help government agencies create emissions reduction targets and monitor progress; assess the effectiveness of policies and actions; and help companies assess emissions throughout a product's life cycle and quantify and report their emissions. It is divided into three scopes (WRI/WBCSD - 2004, and EPA - 2025):

- Scope 1: Covers emissions from sources that an organisation owns or controls directly – for example, from burning fuel in its fleet of vehicles (if they are not electrically powered).
- Scope 2: Includes emissions that a company causes indirectly, arising from the generation of purchased energy. For example, emissions from generating the electricity used in buildings.
- Scope 3: Encompasses emissions that are not produced by the company itself nor result from activities from assets owned or controlled by it, but by those it is indirectly responsible for, up and down its value chain. Examples include emissions from purchased goods, commuting, and business travel.

The development of GHG inventories involves the collection and analysis of large volumes of data (energy consumption, waste, transportation, commuting, etc.) making it a complex and time-consuming task. In this context, Artificial Intelligence (AI) emerges as a tool capable of optimising processes, improving the accuracy of estimates, and providing valuable insights. To date, no GHG inventories conducted by AI in HEIs are known.

Through techniques such as machine learning (Zeng *et al.* - 2021) and natural language processing, AI can automate repetitive tasks, integrate real-time data, and identify patterns that would be difficult to detect manually. The adoption of these technologies not only increases efficiency in inventory development but also serves as a model for society, demonstrating how AI can contribute to global sustainability.

Daily commuting is a significant source of Scope 3 emissions under the GHG Protocol, particularly in the trade and services sector, and this is the focus of this article, aiming to fill the gap caused by the lack of updated and efficient methodologies for calculating GHG emissions in HEIs.

3. LITERATURE REVIEW

Various HEIs worldwide participate in efforts to control their emissions and disseminate methods for reducing CF, many of which are part of associations or networks to standardize emissions tracking, such as (apud Valls-Val and Bovea - 2021): CRUE; AASHE; ISCN and GreenMetric.

The emission profiles of HEIs depend on various factors, such as the level of social development (e.g., transport options); societal infrastructure (often reliant on fossil fuels for electricity and heating/cooling); household income of campus users; location and distance between home and campus; local geography; areas of study available on campus (STEM fields typically require more equipment and energy consumption than humanities), etc. Due to these distinct characteristics, literature shows cases where Scope 1 and 2 dominate in some HEIs (>80%) while Scope 3 prevails in others (up to 90%):

- Socioeconomic factors: wealthier nations show higher per capita emissions. For example the University of Illinois at Chicago (USA) emitted 10.9 tons CO_{2eq}/person in 2008) vs 0.52 tons CO_{2eq}/person at Universitas Petamina (Indonesia) in 2018/19 (Cano *et al.* - 2023).
- Different academic fields: Natural Science, Engineering, and Medicine fields, which require large amounts of equipment and consumables, have a higher CF than Social Sciences and Humanities (Larsen *et al.* - 2013).
- Energy infrastructure: Universities served by fossil fuel-based electricity have more significant GHG emissions from energy than those with renewable energy matrices, (Cano *et al.* – 2023)
- Geography and location; home-campus distance: Delft University of Technology (Netherlands) is located on flat terrain, with 44% of employees cycling to campus and 32% using cars. Among students, 77% use bicycles or trains, while the remaining 23% use cars (Hert and Blok - 2022). Despite Scope 3 accounting for approximately 83% of emissions, commuting is the smallest component of this scope. Huazhong University of Science and Technology, also known as the "University in the Forest," has strict traffic control, with students mainly walking or cycling to school, making the ecological footprint of transportation negligible (Zheng *et al.* - 2021).
- Transport infrastructure: Availability of transport modes near (or within) campuses; transport quality; accessibility; convenience (Crotti *et al.* - 2022); and TDM, or Travel Demand Management (Logan *et al.* - 2020; Gurrutxaga *et al.* - 2017) can directly influence commuting emissions and CF reduction. Given the importance of this variable in most HEIs, the absence of commuting data can hinder inter - and intra - HEI comparisons, such as temporal evolution (Helmers *et al.* - 2021).
- Behaviour and culture: Variables that are predominant in one HEI may be less significant in others, such as the level of education/awareness within HEIs (Ma *et al.* - 2023); community engagement (Hansen and Agger - 2023); accounting for intangibles (Loyarte-Lopez *et al.* - 2020); procurement emissions (Ozawa-Meida *et al.* - 2013); and standardisation plans (Papantoniou *et al.* - 2020; Valls-Val and Bovea - 2021).
- Difficulty in calculating Scope 3: Some researchers report challenges due to the complexity of data collection for Scope 3 (Kant *et al.* - 2024).

Finally, the components listed above are not independent, with overlaps and influences between them. One such component is electrical infrastructure, which in Brazil is almost entirely renewable.

4. BRAZILIAN ENERGY MATRIX AND HEIs EMISSION

According to the Brazilian Energy Research Company (EPE - 2024), Brazil's energy matrix, although predominantly fossil-based, is among the cleanest in the world, with 47,4% renewable energy while the world has only 14.3%. The electricity matrix comprises approximately 86% renewable sources, with a significant share from hydroelectric, wind, and solar power (59% hydraulic; 13% wind; 7% solar). The predominance of renewable sources in Brazil's electricity matrix significantly reduces Scope 2 emissions for HEIs, making commuting and other Scope 3 sources more relevant in calculating the carbon footprint of educational and research institutions, particularly due to fossil fuel consumption.

4.1. EMISSIONS FROM BRAZILIAN HEIs

Universities from various regions of Brazil have published their GHG emission inventories. For ranking purposes, such as in GreenMetrics (UI GreenMetrics - 2025), most focus on accounting for Scope 1 and 2 emissions, giving little importance to Scope 3 emissions.

Although still preliminary, the only complete publication available in Brazil, including commuting, was produced by Carvalho *et al.*- 2017, focusing on PUC-Rio. The study indicates that 20,000 campus users emit approximately 6,000 tons of CO_{2eq}, 98% of which comes from commuting.

The University of Sao Paulo, ranked in the top 5 of GreenMetrics (GreenMetrics - 2024), began publishing its GHG inventories in 2007, with annual regularity until 2012, as stated on its environmental management page (USP - 2025), placing it among universities accounting only for Scope 1 and 2 emissions.

With the consequences of GHG emissions becoming increasingly evident, there is a growing global initiative to reduce the consumption of products that generate greenhouse gases. As shown in Table 1, these changes have not been sufficient to alter the trend of increasing emissions, with energy consumption being the primary source. In particular, in the state and city of Sao Paulo, the largest share of emissions comes from fossil fuel consumption (SMA-CETESB - 2011; Ekos-Geoclock - 2013; SVMA - 2022).

Therefore, the inclusion of commuting in institutional inventories, including HEIs, is necessary for defining public policies to reduce CF. The absence of commuting limits comparisons between HEIs (e.g., the impact of new mobility policies on emissions over time) and with other HEIs.

4.2 COMMUTING

Urban mobility in Brazil is directly linked to the rapid urbanisation of cities since the 1930s (IBGE - 2024), with accelerated migration from rural to urban areas—from 35% in cities in 1930 to over 80% today. Public transport systems in large Brazilian cities have not kept pace with rapid urban growth, leading to declining quality and encouraging wealthier classes to acquire private vehicles, increasing the number of individual transport vehicles on the roads.

In addition to failing to meet demand, mass public transport in large Brazilian cities is predominantly fossil-fuel-powered buses, highlighting the clear disconnect between sustainability demands and reality (Habitability - 2024). Thus, the deficiency in mobility infrastructure, combined with low CF in electricity consumption, makes commuting a significant source of emissions and a necessary inclusion in inventories.

4.3 HEIs AND COMMUTING

Given that the commuting profile of HEIs is subject to the factors mentioned earlier, the decarbonisation of university campuses should be executed after a preliminary survey of their characteristics, ranking the most important factors, and adopting appropriate tools for this purpose.

Most campuses are located in urban areas - or near them - with a significant number of users residing off-campus. In these cases, since HEIs are not isolated islands, the policies governing their operations must be connected to the urban agglomeration. This implies that, for campus decarbonisation, HEIs managers must involve public authorities in developing policies aimed at reducing emissions, including high-quality, low-CF public transport, such as prioritizing the entry of electric public transport vehicles into the campus.

The case study on commuting emissions will focus on the University of Sao Paulo's Butantan Campus.

4.4 THE UNIVERSITY OF SAO PAULO BUTANTAN CAMPUS

Campus Characteristics:

- 70,000 users per day
- Located in an urban agglomeration of 39 municipalities and 21.5 million inhabitants
- Ranked among the top 100 universities globally (QSWUR - 2025)
- A leader in training the country's leaders (Factory of Leaders - 2025)
- Subway and train stations located outside the campus
- Strong culture of individual motorised transport, favouring this mode
- Low-quality public transport (Boisjoly *et al.*, 2020), leading to user dissatisfaction and a gradual shift to individual transport
- Public transport predominantly fossil-fuel-powered buses
- 1,257 international business trips by faculty in 2023 (AUCANI - 2025)

To understand the impact of commuting on the Butantan Campus's GHG emissions and develop future public policies to reduce institutional carbon, a survey conducted by the campus administration on the Origin-Destination of campus users was used.

4.5 DATA FROM THE ORIGIN-DESTINATION SURVEY OF BUTANTAN CAMPUS USERS

A 2023 survey (6.700 responses) captured origin, transport modes and ZIP Codes (latter unused due to errors - many users incorrectly indicated the campus ZIP Code), adjustments were made to the spreadsheets to make use of the survey data for appropriate data collection (fossil fuels, biofuels, and electricity) and ultimately the associated emissions. The neighbourhood and/or city of origin and the transport modes used for commuting were identified, but not the exact starting point of the journey.

4.6 AI IN THE DEVELOPMENT OF GHG INVENTORIES FOR COMMUTING

To address this issue, it was assumed that campus users depart from a midpoint in their neighbourhood or city, considered the "Population Density Centre" (PDC), which is the geographical point where the entire population of that area would be concentrated. This PDC was calculated by IA.

Tools used included:

- Navigation and mobility tools (Google Maps and Waze) to map routes and calculate distances.
- Generative AI tools (Meta AI, ChatGPT, and DeepSeek) to calculate PDCs, determine routes by transport mode, and optimise calculations.

From the survey responses, users from 94 neighbourhoods in Sao Paulo and 37 cities in the metropolitan region were identified. Each user was subjected to the described procedures, identifying the route taken, the modes and associated fuel consumption, and subsequently applying emission factors obtained from official data. Additionally, a series of conditions for calculation benchmarking were established, described in **Appendix A**.

The population density centre is calculated as the weighted average of the coordinates of a predefined region, where the weights are the populations of each point, calculated using equations. 1 and 2:

$$\text{Latitude of centroid} = \frac{\sum_{i=1}^{n} Latitude(i) \times Population(i)}{\sum_{i=1}^{n} Population(i)} \quad (1)$$

$$\text{Longitude do centroid} = \frac{\sum_{i=1}^{n} Longitude(i) \times Population(i)}{\sum_{i=1}^{n} Population(i)} \quad (2)$$

Where:

- Latitude (i) and Longitude (i) are the coordinates of point i.
- Population (i) is the population associated with point i.
- n is the total number of points.

The results of the total distance travelled by the set of users who participated in the survey, broken down by transport mode, are presented in Table II, with the meaning of abbreviations in **Appendix B**[1]:

TOTAL DISTANCE travelled by campus users, in km SP (ROUND TRIP)							
		car	shuttle	sub	bus	train	moto
6,700 questionaires	N (daily)	43,264	10,105	32,390	48,451	2,823	1,136
	M (daily)	27,863	2,776	18,196	30,011	6,613	994
extrapolations to 70,000	N+M (250 days)	187,202,888	33,903,519	133,142,390	206,510,002	24,835,050	5,607,685

Table II total distance travelled by users: firstly the 6,700 questionnaires (neighbourhoods (N) and Metropolitan cities (M)) and then, extrapolating to the 70,000 users

Total annual distance shown in Table 2 follows the conditions:

- Over the year, there were 213 academic days at the university.
- For the rest of the year, operation & maintenance and research activities (including undergraduate research, postgraduate, and postdoctoral studies) continue, albeit with fewer students. To include these activities, an additional 37 days were arbitrarily added, totalling 250 campus days with 100% user presence, of which 81% of users are from Sao Paulo and 19% from neighbouring cities.

In total, approximately 5.9×10^8 user-km/year are travelled, with an average of 8.4×10^3 km/user-year. Considering that the expected intensity of car use in Sao Paulo is 1.5×10^4 km/year (CETESB - 2013), on average, commuting to/from campus accounts for about 56% of total trips for car users, confirming the expected distribution of trips between work, leisure, and other purposes.

Total emissions calculations were performed using equation 3:

$$GHG\ Emission\ (tCO2e) = \sum_{i=1}^{n} x(i) \times ef(i) \quad (3)$$

Where:

x (i) = annual distance of specific mode and

[1] Since emissions are not counted in active mobility, it will not be considered here.

ef (i) = emission factor (GHG emissions per physical unit of the specific mode)

Table III presents the emission factors by energy source/transport mode used (Carvalho - 2011; Metro - 2024; IPCC - 2019; Climatiq - 2025), total emissions by mode, and total annual emissions from commuting for the entire Butantan Campus user community.

mode	fuel	emission factor $g_{CO2eq/passenger.km}$	emission factor $t_{CO2eq/passenger.km}$	annual emissions by mode of transport - 70,000 users $t_{CO2eq/year}$	
car	gasoline/ethanol	100	1.0E-04	18,720	
shuttle	diesel	85	8.5E-05	2,882	
sub	electric	6	6.0E-06	799	
bus	diesel	85	8.5E-05	17,553	
train	electric	6	6.0E-06	149.0	
moto	gasoline/ethanol	71	7.1E-05	398	
total emissions from commuting in 1 year			=	40,501	$tCO_{2eq/year}$

Table III: Emission Factors by Transport Mode and Fuel Used, and Total CO_{2eq} Emissions from Commuting at the Butantan Campus, USP

5. DISCUSSION

Although not used in this study, ZIP Codes are a powerful source of information for calculating commuting and developing inventories of energy consumption and GHG emissions from mobility. Depending on the volume of data, calculations can require significant manpower, which can be mitigated using virtual tools such as AI.

In this study, the failure to collect ZIP Code data led to its replacement with PDC calculations for the considered region, taken as the starting point of the outbound journey and the endpoint of the return journey. This substitution introduces intrinsic uncertainty, independent of the sophistication of AI calculations, as it assumes that all trips from that region will start from a PDC point. The comparison with users starting from the farthest and closest points to the final destination may not be accurately represented by the PDC. Additionally, the central point may differ from the midpoint.

During the journey, many campus users utilised more than one transport mode. The lack of information on intermediate transfer points-imposed constraints required a large volume of calculations, reinforcing the need for AI (**Appendix A**). The optimisation of calculations via AI brings innovation potential to a field that remains largely manual and reliant on outdated methodologies.

5.1 HEIs AS TRIP GENERATION POLES

In the development of municipal GHG emission inventories, mobility plays a prominent role, both in cases of high emissions (where fossil fuel consumption is predominant) and in avoided emissions (cities undergoing decarbonisation).

The primary generators of trips are Traffic Generation Poles or Trip Generation Poles (TGP) (Lemonde *et al.* - 2001; Nogueira *et al.* - 2021; Coelho - 2008), which are essentially centres of convergence for large population masses throughout the day: hospitals, shopping centres, schools, and universities are examples of TGPs.

Summing TGPs' inventories cover most urban mobility emissions. Since the emissions inventory is the first and fundamental step in the process of defining public policies for decarbonising human activities, the importance of developing complete GHG inventories (Scopes 1, 2, and 3) as an educational/training tool within HEIs becomes evident.

In Sao Paulo, the university has four main campuses, in addition to smaller spaces with fewer fixed users. The campuses are:

- Armando de Salles Oliveira University City (Butantan Campus): Houses the central administrative structure of USP, several teaching units, the Residential Complex, and the Sports Centre. This is where the OD survey was conducted, and the data for this research were extracted.
- Largo Sao Francisco: Home to the Law School.
- East Campus: Houses the School of Arts, Sciences, and Humanities.
- Pinheiros Campus: Hosts health courses and the "Clinical Hospital".

The Butantan Campus's 2022 emissions inventory (USPSusten - 2024) totals approximately 10,500 tCO2e (Scopes 1 and 2). In this scenario, GHG emissions from electricity consumption and water/sewage treatment account for about 30% of total emissions, as calculated in **Appendix C**.

In turn, the total emissions of the entire University (campus Sao Paulo, Bauru, Lorena, Ribeirao Preto, Piracicaba, Santos, Sao Carlos, and Pirassununga, 115,000 users in total) from 2007 to 2012, scope 1 and 2 are (USP – 2024; USP - 2025):

2007 =15.000 tCO_{2eq};

2008 and 2009 = 20.000 tCO_{2eq};

2010 = 19.000 tCO_{2eq};

2011 = 15.500 tCO_{2eq};

And 2012 = 21.000 tCO_{2eq};

As the campuses of the University of Sao Paulo have different characteristics among themselves (urban population density, distance to the urban centre, road infrastructure, etc.), comparisons between them would only be possible if presented in a disaggregated manner, that is, item by item for each of the scopes. Whether in previous inventories of the Butantan campus or in inventories of all USP campuses, it is evident that the inclusion of Scope 3, and within it commuting, plays a significant role in the overall calculation of GHG emissions under the responsibility of the University of Sao Paulo. This responsibility becomes even more evident when discussing decisions regarding intra- and extra-campus mobility policies and the emissions observed/avoided. Low-impact and low-carbon footprint (CF) transport services should be prioritised. In other words, USP, like all HEIs, must create a decision-making model for universities that helps prioritise investments in sustainable transport based on emission data.

Among the various necessary strategies that HEIs—and the University of Sao Paulo in particular—must adopt to reduce the impact of commuting on GHG emissions, the following stand out:

- Changes in school curricula, with a focus on a "green curriculum" aimed at reducing CF and addressing climate change (Ma *et al.* - 2023; Gurrutxaga *et al.* - 2017).
- Community mobilisation: Engaging the community (Hansen and Agger - 2022).
- Development of Travel Demand Management programmes (cycle paths; safety; parking policies, etc.), car sharing, carpooling (Logan *et al.* - 2020); incentives to use public transport with adequate frequency and quality, such as electric bus lines, subway stations

within the campus, improved access to train stations, and river transport (via the Pinheiros River, which borders the university).
- Programmes to develop student housing within the campus—and its surroundings—as a way to migrate towards active mobility.
- Private space concession policies: Prioritising affordable tariffs for private concessions (e.g., snack bars and restaurants) to ensure product prices are accessible and prevent off-campus trips for better deals.
- Creation of cross-sectoral/inter-institutional committees to discuss sustainable mobility policies.

5.2 BUSINESS TRAVEL

Due to its high emissions per kg.km transported - but also its importance as a tool for academic workforce success (Glover *et al.* - 2019) - business travel is a particular case of GHG emissions from mobility. Reducing academic staff's air travel emissions has become a critical issue for universities committed to net-zero targets (Tseng *et al.* - 2022). Therefore, pro-environmental behaviour and sustainable consumption will not be increased simply by asking or forcing the university community to change behaviour. Transformations require the intervention of new social practices, more research, and the development of new public policies with the community, with universities already proposing net-zero emissions in the coming years (Kyle and Stockdale, -2021), mainly focusing on air travel.

At the University of Sao Paulo, the negotiation and funding of travel for academic event participation is conducted with external organisations, such as research support foundations, with little to no intervention from the university administration. Thus, there is no centralised body responsible for collecting travel information, corresponding emissions, or accountability.

A potential solution for reducing CF is prioritising virtual events. In unavoidable cases, the creation of an internal collaborative platform for emission compensation could account for and subsequently control emissions, where business travel could be partially offset, with the participation and coordination of the university administration. This way, instead of avoiding responsibility or shifting it to event organisers, the university can establish clear compensation criteria, ensuring the institution shares part of the burden.

5.3 ADVANTAGES AND LIMITATIONS OF USING NAVIGATION AND AI TOOLS

- The use of location/navigation tools combined with generative AI facilitates work and reduces calculation time. Additionally, AI contributes to structuring and organising methods.
- The replacement of ZIP Codes with PDC calculations introduces uncertainty that is difficult to quantify, as without the user's residential ZIP Code, it is impossible to guarantee how close this substitution is to reality.
- Since the accuracy of information from tools like Google Maps and Waze depends on good tower coverage, in rural areas or regions with low mobile data coverage, position and route information may be compromised, increasing inherent uncertainties in calculations.
- Route, fuel consumption, and GHG emission calculations may be hindered by missing or incomplete data on public transport routes, schedules (and their adherence); traffic congestion/delays; and variations in fuel consumption.

- The combination of these uncertainties and the difficulty of assigning error margins to each condition applied in GHG emission calculations for commuting makes it impossible to assess uncertainties in the final result.

The pursuit of low uncertainty margins for commuting and GHG emission calculations using AI requires the following input data:

- ZIP Codes for the origin and destination of the trip
- Good data coverage throughout the journey
- Transport mode(s) used, transfer points, and subsequent modes
- Well-defined public transport routes, with real-time information on position, speed, traffic flow, fuel consumption per km, and the number of passengers transported
- Willingness of public transport operators to share data

6. CONCLUSION

While some HEIs neglect commuting emissions, this study demonstrates their potential dominance over Scopes 1 and 2.

This highlights the responsibility of HEI decision-making bodies and the urban agglomerations in which they are located in developing public policies aimed at using the transport network to achieve the lowest possible CF, within the conceptual triad of conservation, rational and efficient use of natural resources, and the goal of decarbonising society—or net-zero emissions—and combating climate change.

As HEIs are part of the solution to climate change, leading research, education, public policy formulation, and policymaker training, they must signal to society the paths to be taken to avoid environmental disaster. One of the most important measures, even before developing tools and actions to reduce GHG emissions, is the correct identification of emission sources and the responsibilities for policy decisions on natural resource consumption. For this reason, HEIs ranking organisations should require participants to report their emissions across all scopes (1, 2, and 3), under penalty of deficient and/or insufficient policies driven by flawed or partial surveys.

AI streamlines large-scale commuting data analysis. The use of geolocation and mobility tools combined with generative AI available online can greatly facilitate data collection, provided that input data is available in quality and format. In other words, AI can—and should—be used as a tool for institutional inventory development and to assist in combating global climate change.

Furthermore, the use of AI tools and applications combined with real-time traffic data integration can become powerful tools for traffic management and CF reduction. AI can predict behaviours and future traffic trends, energy consumption, and GHG emissions, aiding in the formulation of proactive, rather than merely reactive, policies.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

- Expansion of the Study to Other USP Campuses: Conduct similar studies at other USP campuses (e.g., Ribeirao Preto, Sao Carlos, Lorena, Bauru, and Piracicaba) to compare GHG emissions from commuting in different geographical and urban contexts.
- Integration of Real-Time Data: Develop a platform integrating real-time traffic data, such as congestion, public transport schedules, and fuel consumption, to improve the accuracy of GHG emission calculations.

- Feasibility Analysis of Sustainable Transport Modes: Study the feasibility of implementing sustainable transport modes, such as electric buses, cycling infrastructure, and river transport, around the Butantan Campus and other HEIs.
- Development of a “Green Curriculum”: Create and implement curricula, courses, and projects focused on sustainability and institutional carbon reduction, involving students, faculty, and staff in developing sustainable practices.
- Creation of an Emission Compensation Platform: Develop a collaborative platform for compensating GHG emissions related to business travel, with clear criteria and active participation from HEI administrations.
- Partnerships with Transport Operators: Establish partnerships with public transport operators to obtain detailed data on routes, schedules, and fuel consumption, aiming to improve the accuracy of GHG inventories.
- Behaviour and Trend Studies: Use AI techniques to predict behaviours and future trends in traffic, energy consumption, and GHG emissions, aiding in the formulation of proactive policies.
- Inclusion of Other Scope 3 Sources: Expand the study to include other Scope 3 emission sources, such as business travel, supply chains, and waste, providing a more comprehensive view of institutional carbon.
- Collaboration with Government: Promote collaboration between HEIs and local, state, and federal governments to develop sustainable mobility public policies, integrating HEIs’ GHG inventories into governmental emission reduction plans.
- Validation and Replication of the Methodology: Validate the proposed methodology in other Brazilian and international HEIs, adapting it to different contexts and urban realities.

8. Data Availability Statement

The datasets supporting the conclusions of this study are fully tabulated and presented within the main text and tables of the manuscript

9. Authors' Contribution:

Vilela, M.M.: Conceptualization, Methodology, formal analysis, writing (original draft, review & editing).

Grimoni, J. A. B.: Conceptualization, Methodology, formal analysis, writing (original draft, review & editing).

10. Conflicts of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX A: Calculation Conditions

- Distances were considered between the PDC of the neighbourhood/city and the PDC of the Butantan Campus.

- If a user reported using bus+subway and the bus is direct from the neighbourhood to the campus, only the bus was used in calculations (as it is cheaper to use only this mode).
- If a user lives in a distant neighbourhood and reports using A (active transport), the calculation used the bus+shuttle option.
- If a user report using only the subway, the calculation used subway+shuttle (as the shuttle is next to the subway station, connecting to the campus).
- Un reported transport modes: defaulted to bus+shuttle.
- ZIP Codes were not used due to data suspicion.
- Subway and train were considered equivalent, as both use electricity.
- If a user is from Sao Paulo neighbourhoods, the total distance travelled was equally divided between the modes used. The exception is the shuttle, as public transport users either use the bus to enter the campus or depend on the shuttle for the final leg.
- If a user is from the metropolitan region, although subway and train are equivalent, distances differ, with cases where the train is longer and others where the subway is longer.
- Traffic congestion and consequent increases in GHG emissions were not considered due to data unavailability.
- Due to the difficulty of obtaining data, “business travel” was not considered.
- Due to the lack of historical commuting data, the data extracted from the OD survey were used to extrapolate trips for a typical academic year.
- For CF calculations, “CF calculation tools” available online were not used. Instead, official government data on emissions were used.
- Average emission factors were used, without considering different vehicle models/engine sizes.
- The use of official emission factors does not necessarily reflect local emissions.
- For daily trips, no distinction was made between full-time and part-time campus presence.
- Visitor trips to the campus were not considered.
- Students and staff were not differentiated.
- Car or motorcycle trips were considered as the full distance.
- Active transport trips were considered only those reported by users around the campus.

APPENDIX B: Abbreviations Used

- **A =** active transport
- **bus =** bus
- **sub =** subway
- **shuttle =** campus shuttle, serving exclusively the campus, with a starting point near campus limits, next to a subway station
- **train =** train
- **car =** individual car
- **moto =** motorcycle
- **RM =** metropolitan region

APPENDIX C: Emission Factors

Annual GHG emissions from electricity and water/sewage consumption at the Butantan Campus:

- Annual electricity consumption: 78,000 MWh/year (PUSPCB - 2025)
- Electricity generation emission factor: 0.0385 tCO_2eq/MWh (MCTI - 2025)
- Annual emissions from electricity consumption: 3,000 tCO_2eq

- Annual water consumption: 70,000 m3/year (PUSPCB - 2025)
- Water production emission factor: 0.09 kgCO2eq/m3 (SANEPAR - 2025)
- Sewage treatment emission factor: 2.65 kgCO2eq/m3 (SANEPAR - 2025)
- Total emissions (water + sewage treatment): 192 tCO2eq

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