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Applied Research for the Construction of a Sustainable Campus at the University of São Paulo

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Abstract. The University of São Paulo (USP), through its Environmental Policy and under the coordination of the Superintendence of Environmental Management (SGA), has been promoting sustainability initiatives across its campuses. One of the most recent efforts is the USP Sustainability Program (USPSusten), which supports teaching, research, outreach, and shared management activities focused on socio-environmental sustainability, carried out by faculty and postdoctoral researchers. Highlighted projects include: (a) the Bioenergy and Biofertilizer Production Plant (BBPP), which uses organic waste from campus dining halls and green areas at the main *campus* (CUASO) to produce biogas and fertilizers; (b) a pilot plant for fueling hydrogen-powered buses, with a range of 240 km; (c) photovoltaic energy generation, with the potential to meet up to 27% of contracted electricity demand; and (d) greenhouse gas inventories, based on the GHG Protocol methodology. The BBPP, in operation since May 2021, processes organic waste to generate an average of 2,800 kWh/month, with an average output of 136 kWh per ton of waste. The hydrogen fuel project uses ethanol as a renewable energy source and aims to reduce CO_2eq emissions per capita by up to 72% compared to conventional combustion vehicles. Solar generation has shown economic feasibility for units consuming over 100 MWh/month. The emission inventory, structured through an action-research approach, involves pilot units within USP and highlights the need for improvements in the use of refrigerant gases in buildings and anesthetic gases in hospitals. These integrated efforts demonstrate the University's commitment to conserving natural resources and enhancing quality of life.

Keywords:
USPsusten, bioenergy, hydrogen, photovoltaib, GHG inventory

1. Introduction

The University of São Paulo (USP) has been part of the GreenMetric World University Ranking (UI) since 2010. Great efforts to build a sustainable environmental management at USP were under the scope with the creation of the Environmental Management Superintendency (SGA) in 2012. Since then, policies and programs have been implemented, resulting in prominent rankings, such as 5th place in the 2024 UI ranking among 1,477 universities worldwide.

Among all notable initiatives is USP's Environmental Policy (EP) [1], established in 2018 to guide and legitimize sustainable actions across all USP campuses concerning the preservation, conservation, and rational use of natural resources. As a sequel of EP/USP, Ordinance N^{o}. 7750 was issued in June 2022, establishing the USP Sustainability Program (USPSusten). This program offers Postdoctoral fellowships funded by USP and is coordinated by the SGA.

USPSusten is a key instrument of EP/USP for acknowledging the growing need for investment in sustainability and environmental management, as well as in the training of professionals specialized in these areas. The main objectives of the program are to encourage, promote, and support socio-environmental sustainability through teaching, research, outreach, and shared governance activities. These initiatives have led to postdoctoral research that contributes to USP's strategic actions and the development of public policies both within and beyond the university context.

The first edition of USPSusten was in August 2022 with a one-year term, extendable to two years. A total of 32 fellows were selected to work on 22 themes across five major areas: (i) water, sanitation, and oceans; (ii) biodiversity; (iii) renewable energy and sustainable construction; (iv) environment, environmental management, waste, human resources, and food security; and (v) emissions, climate change, and carbon markets. The 2022/2023 edition involved 17 USP units and professionals from several academic backgrounds, such as environmental, chemical, and electrical engineering; journalism; economics, atmospheric and biological sciences; and management. Participants were from USP and other Brazilian institutions (CEFET/RJ, UNICAMP, UFBA, UFPR, UFRGS, UFRJ), as well as from other countries (Ireland - IT Sligo).

Among all research projects developed by USPSusten, this article presents those with direct impact on USP sustainability campuses, especially in terms of infrastructure and transportation. These include: (a) a bioenergy and biofertilizer production plant using organic waste; (b) a pilot-plant for operating buses powered by hydrogen fuel cells technology; (c) self-generation through photovoltaic energy; and (d) greenhouse gas emissions inventories.

2. Methodology

2.1. From Organic Waste to Bioenergy and Biofertilizers: Waste Management and Nutrient Recycling at the University

With approximately 100,000 people circulating daily, the Armando Salles de Oliveira University City (CUASO) features urban-level infrastructure and services, including banks, restaurants, and housing [2]. Because of this city-like structure, the management of Municipal Solid Waste (MSW) also represents a high cost for the university, and its energy and material recovery remain below its potential. Despite increased awareness and improvements in recycling and reuse services, the organic fraction still appears as a special stage of the entire process due to the lack of source segregation and the limited availability of proven viable treatment technologies, contributing to disposal inefficiencies and environmental burdens in large institutional context such as universities [16, 17].

In response to the high demand for technological alternatives and business models to better use the organic fraction of urban waste, the Bioenergy and Biofertilizer Production Plant (BBPP) which uses organic waste was designed and installed at the Institute of Energy and Environment (IEE/USP). The plant aims to develop MSW management alternatives based on biodigestion. It aims to consolidate scope economies and integrate industries involved in the waste collection, treatment, and disposal chain, as well as those that could benefit from the expanded use of potential products and services, such as the agriculture and energy sectors. These new models seek to convert harmful material flows into socially beneficial outputs, lower costs, generate financial and social returns, and potentially mitigate environmental liabilities associated with current landfill-based waste management systems.

Biogas plants may be conceptualized as environmental compliance and energy production complexes, processing waste with polluting potential into electricity, fuel, and biofertilizers. The implementation of this project allows for the study and evaluation of a technological package aimed at providing environmental compliance and energy services through anaerobic waste decomposition and biogas production. It is a clean, renewable, and storable energy source with the flexibility to be used as either electricity or biomethane. Another key product of this process is digestate, the nutrient-rich residue of organic decomposition, which can be treated and applied as a biofertilizer [18].

The project examines the waste management and biogas production value chains, addressing both gaps in the current waste valorization industry and the organization and regulation of the biogas sector and its by-products. The Bioenergy and Biofertilizer Production Plant thus functions as a research and development laboratory, encompassing both technological dimensions and industrial organization through economic and regulatory analyses of the various biogas utilization pathways [16].

The project's design was based on the quantification and characterization of organic waste generated on *campus*, along with the assessment of biomethane production potential as measured in [3]. The plant is structured into four main units: (i) the reception unit and biogas/biofertilizer production; (ii) the bioelectricity and heat generation unit; (iii) the biomethane production unit; and (iv) the monitoring, operation, and control unit.

2.2. Pilot Station for Renewable Hydrogen Fuel from Ethanol

Due to the global and national need to reduce carbon emissions, a variety of solutions aimed at advancing the energy transition in the transport sector are already underway, ranging from the deployment of battery electric vehicles (BEVs) to the adoption of hydrogen-based technologies (H_2) [19].

Battery electric vehicles, while requiring a renewable electricity source, also necessitate complex energy planning to mitigate their direct impact on the power grid — for instance, by addressing potential spikes in electricity demand caused by simultaneous use of charging stations, or by managing the temporal mismatch between renewable energy generation and consumption.

Conversely, the H_2 pathway also presents its challenges, such as the need for renewable sources for its production — for instance, electricity for the water electrolysis process. This energy conversion method typically requires about 40 kWh per kilogram of H_2 produced at a storage pressure of 450 bar, as well as approximately 10 liters of water.

While some approaches rely on water electrolysis, USP, through the RCGI (Research Centre for Greenhouse Gas Innovation), intends to adopt the ethanol reforming route, which is also a renewable alternative. The system will use a steam reformer to chemically convert ethanol into hydrogen in a process known as “steam reforming,” where ethanol reacts with water inside a reactor under specific temperatures and pressures [20].

The project, developed by Hytron in partnership with Shell Brazil, Raízen, EMTU, and the National Service for Industrial Learning (SENAI), plans to deliver a pilot station in 2025 to operate two hydrogen fuel cell buses using PEMFC (Proton-Exchange Membrane Fuel Cell) technology. Operating conditions will be similar to those of the TAC, with 30 kg of hydrogen stored in each bus at 350 bar, and refueling performed via a hydrogen dispenser at up to 450 bar. This would allow the buses to reach a driving range of 240 km.

2.3. Photovoltaic Generation at USP

In recent years, the utilization of renewable energy sources, particularly solar energy, has become the main driver of the global expansion in electricity generation capacity across many countries. This expansion is primarily motivated by the need to reduce greenhouse gas emissions, as well as by advances in technology, economies of scale, and fiscal, financial, and tariff incentives that promote the adoption of these resources. In this context, solar energy has emerged as a highly scalable and technologically mature resource, capable of meeting the growing global demand for electricity generation in the coming decades. Among the various solar energy technologies, photovoltaic generation has experienced rapid growth and is expected to continue playing a fundamental role in shaping a sustainable energy future [4].

Brazil presents a strong potential for solar energy generation due to its higher levels of solar irradiation compared to most European countries. The average daily annual photovoltaic potential ranges between 3.8 and 4.8 kWh/kWp, placing Brazil among the global leaders in solar energy potential [5].

In light of this, and in alignment with its multidimensional mission, the University of São Paulo has increasingly incorporated environmental education to better understand and address its energy system. It has also promoted initiatives such as the self-generation of renewable energy, aiming to decarbonize its campuses, with the capital campus serving as a model.

Most of USP's teaching, research, outreach, and administrative units are at CUASO, which is located at latitude -23.5° with an average annual photovoltaic potential of about 4.4

kWh/kWp [6]. The *campus* covers approximately 3.65 km², of which 0.92 km² are green common areas. It includes 23 teaching units, nearly 7,000 lighting points, 102 primary substations, and a 13.8 kV distribution network covering 30 km, all connected to five feeders from a substation with a capacity of 27.5 MVA, supplying power to the 80,000 – 100,000 people on *campus* daily. The monthly electricity consumption is around 6.5 GWh, with a similar demand profile of large metropolitan commercial consumers. The contracted demand is 22 MW [2].

Although the campus features extensive, horizontal, and relatively unshaded areas suitable for PV system installation, the EP/USP ensures the preservation and conservation of areas designated as ecological reserves, thus limiting their potential use. Consequently, areas available for photovoltaic generation are largely restricted to building rooftops and parking lots (carports). Despite the numerous benefits that distributed generation offers to the power distribution system, the widespread, uncoordinated installation of PV systems can create more challenges than solutions and may also be economically less viable.

Studies show that a significant number of universities worldwide use less than 20% of self-generated electricity from alternative sources [7][8]. At USP *campus* São Paulo, research carried out under the USPSusten Program using simulation software has shown that it is technically and economically feasible to self-generate photovoltaic energy to meet 20% of the demand of academic units with high consumption, defined as those using more than 100 MWh/month. The average monthly consumption of these units is approximately 2.9 GWh. Thus, the theoretical photovoltaic potential of this campus is about 586 MWh/month, which represents 9% of total electricity consumption.

2.4. Greenhouse Gas Inventory

Universities emit greenhouse gases (GHGs) directly or indirectly through their activities and operations. Many of these emissions stem from infrastructure, such as electricity, heating, cooling, and air conditioning systems, as well as wastewater and waste management, and the transportation of materials and people, including students and staff commuting to campus.

The identification and quantification of these emissions, known as a greenhouse gas emissions inventory, is one of the most important tools for climate action. It serves as the foundation for monitoring institutional performance, setting priorities, transparently communicating results to society, and leveraging economic instruments such as carbon pricing, investment decisions aimed at emissions reduction, and the generation of carbon credits in regulated or voluntary markets. It also provides the basis for potentially establishing an internal carbon market, founded on institutional GHG emissions caps at the University of São Paulo.

One of the most widely used methods for preparing GHG inventories is the GHG Protocol, created through a partnership between the World Resources Institute and the World Business Council for Sustainable Development in 2008 [9], for North America use only, although the method has been adapted for its use in other countries. It outlines principles and guidelines for inventory preparation, general and sometimes sector-specific criteria, and provides Microsoft Excel-based calculation tools to streamline and automate mathematical work.

Under the GHG Protocol, an organization’s emissions are classified into “Scope 1” (direct emissions that occur within the organization’s boundaries), “Scope 2” (indirect emissions from purchased energy, usually electricity), and "Scope 3" (all other indirect emissions) [9].

The preparation of GHG inventories involves two critical dimensions: technical and managerial. The technical aspect includes knowledge of the organization's activities, emissions sources and sinks, required physical data, expected data quality, and the use of calculation tools. The managerial aspect includes the institutional structure for implementing the inventory: team organization, administrative records as data sources, leadership commitment and support, and resource allocation. Perhaps the most crucial success factor is the establishment of a bridge between these two dimensions, ensuring an administrative structure capable of collecting the data required for the calculation tools, and translating the outputs into climate strategies and actions.

USP has been implementing a project to study the university's main sources of emissions, the associated barriers and opportunities, and proposals for bridging technical and administrative dimensions in order to make GHG inventories a daily practice. These projects are being carried out in seven USP units using the action-research methodology [10]. Each participating unit serves as a pilot site and an internal coordinator to oversee the project is designated.

3. Results and Discussions

3.1. From Organic Waste to Bioenergy and Biofertilizers: Waste Management and Nutrient Recycling at the University

According to data published in [11], an average of 92 tons of organic waste is generated monthly at the Armando Salles de Oliveira University City (CUASO), with approximately 30% of this volume concentrated in the four restaurants managed by USP's Superintendence of Social Assistance. This amount varies significantly each month, reaching up to 113 tons in March, which is the month of highest *campus* occupancy, therefore corresponding to a daily 5.1 tons of food waste managed by the University itself. Another major type of waste generated on *campus* consists of prunings and foliage from shrubs and trees. A survey conducted within the University revealed that approximately 22,774 m^3 of pruning waste are collected annually on campus.

The biodigestion and biogas production processes are carried out in CSTR-type reactors (Continuous Stirred Tank Reactors), comprising three tanks with a volume of 430 m^3 each (Figure 1). The plant has a processing capacity of 25 tons per day. The biogas is used in a cogeneration system that produces both electricity and thermal energy, with a 75 kW power unit and an additional generator with an installed capacity of 240 kW. Currently, the system injects an average of 2,800 kWh/month into the CUASO electrical grid, with an average production capacity of 136 kWh per ton of waste.

After anaerobic digestion and stabilization, the liquid effluent, known as digestate, is being evaluated for its potential use as fertilizer for various crops. The project aims to recycle nutrients within urban areas through application in vegetable cultivation. Studies are being conducted on digestate treatment and its use in hydroponic systems and soil-based agriculture to assess technical and economic feasibility.

The implementation of this industrial-scale facility not only reinforces sustainability and decarbonization efforts on campus but also addresses scientific and technological challenges across the waste-to-energy chain. These challenges include: (1) Integrated Waste Management with a focus on energy recovery from organic fractions in biogas plants; (2) Development and demonstration of innovations and optimization of replicable technical arrangements; and (3) Support for the development of economic, regulatory, and institutional models for organic waste valorization.

(a) (b)

Figure 1. Images of the bioenergy and fertilizer production plant installed at IEE-USP
(a) CSTR biodigesters and (b) Electric power generation units.

3.2. Pilot Station for Renewable Hydrogen Fuel from Ethanol

In 2016, USP spent approximately one million Brazilian reais per month to operate two bus lines between the Butantã subway station and Armando Salles de Oliveira University City (CUASO), and vice versa. According to São Paulo Transporte (SPTrans), these two lines account for a total of 256 trips per day, requiring 12 buses to operate for 22 hours daily. This results in approximately 66,560 trips per year, considering only weekdays. In terms of distance traveled, these trips are equivalent to three times the distance between the Earth and the Moon.

The standard diesel bus engines have an average fuel efficiency of 1.5 km per liter. This means the operation of these trips requires at least 754.3 m^3 of diesel fuel annually. Based on the carbon intensity per energy unit, as reported by the RenovaBio program, diesel combustion emits 3,073 grams of CO_2 equivalent (gCO_2eq) per liter. Consequently, the bus lines 8012 and 8022 operating at CUASO are responsible for direct emissions of approximately 2,318 metric tons of CO_2eq per year, or 2.05 $kgCO_2eq$ per kilometer. Given that over 3.4 million users per route used the university buses in 2016, the per capita emission is approximately 0.166 kgCO2eq per km, or 166 gCO2eq per kilometer traveled by each passenger. While this value is relatively low compared to individual car use, potentially 100 times higher, it still represents a significant environmental burden.

If a fleet powered by hydrogen fuel cell technology were to be implemented, the annual operation would require at least 141.4 metric tons of hydrogen. This corresponds to the consumption of approximately 683.5 m^3 of ethanol, assuming the hydrogen is produced through ethanol steam reforming. According to average emissions data from certified RenovaBio facilities, ethanol production emits 578 gCO_2eq per liter when considering life cycle emissions.

Under this scenario, the transportation services provided by the CUASO bus lines could reduce emissions to 654 metric tons of CO_2eq per year, representing a reduction of 1,664 tons annually or 0.58 $kgCO_2eq$ per kilometer. The per capita CO_2eq emission could reach as low as 47 gCO_2eq per kilometer, which corresponds to an approximate 72% reduction when compared to conventional internal combustion engine operation. However, emissions must be evaluated on a case-by-case basis, as outcomes depend not only on the performance of each bus but also on other factors, such as the national electricity mix. Different hydrogen production pathways have different energy requirements: for example, ethanol reforming requires relatively little electrical energy, whereas green hydrogen production depends entirely on electricity.

As this case illustrates, the energy transition demands not only academic research to address technical challenges, such as decarbonizing transport, but also strategic partnerships with the private sector to advance high-level research and applied solutions. These innovations can be scaled up to meet broader needs, such as the University of São Paulo bus project. Additionally, public sector engagement is essential to shape policies and regulations that govern hydrogen use in various applications, overcoming the traditional lag between technological innovation and regulatory development.

Figure 2. Photo of the hydrogen station

3.3. Photovoltaic Generation at USP

Studies using simulation software carried out under the USPSusten Program have shown that the self-generation of photovoltaic energy is technically and economically viable to meet 20% of the demand of academic units with significant electricity consumption, defined as those consuming more than 100 MWh per month. The average monthly consumption of these academic units is approximately 2.9 GWh. Therefore, the theoretical photovoltaic potential of this *campus* is estimated to be around 586 MWh per month, which corresponds to 9% of the total electricity consumption of the entire *campus*. Figure 3 presents typical values of photovoltaic system losses, obtained through computer simulations under the specific climatic conditions of USP *campus* in São Paulo, for two different deployment configurations: rooftops and parking lots.

The simulation results indicate that the typical total energy loss in photovoltaic systems installed on rooftops and in parking lot structures is 28.1% and 19.6%, respectively. Due to the local climate, the greatest losses are associated with decreased solar cell efficiency caused by higher operating temperatures of the photovoltaic modules, especially when installed on rooftops, where typical thermal losses reach about 9.5%. In contrast, due to better air circulation and heat dissipation, losses are around 4.2% in the parking lots.

On the other hand, the topography and building density of USP *campus* in São Paulo are favorable for photovoltaic generation, as shading losses are relatively low (ranging from 3.1% to 4.5%) even around areas designated as USP Ecological Reserves. Based on these results, and considering an average annual daily photovoltaic potential of approximately 4.4 kWh/kWp, it is estimated that an installed photovoltaic capacity of about 6 MWp is needed to generate 586 MWh/month, which would cover 9% of the campus's total electricity consumption. This installed capacity would represent 27% of the campus's contracted demand.

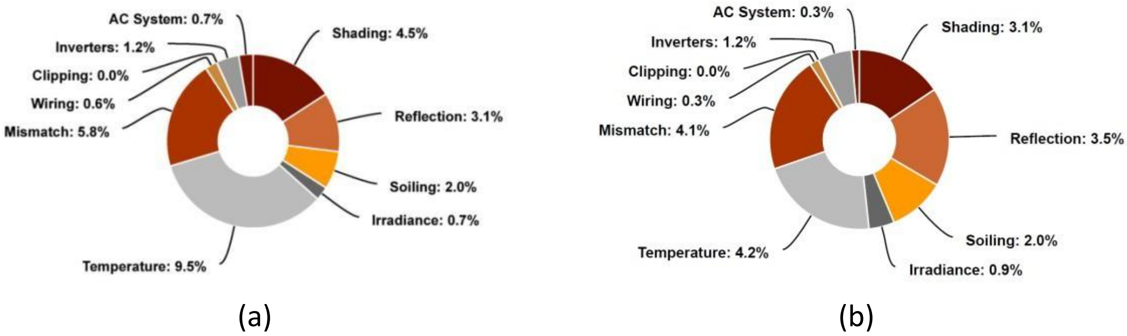

Figure 3. Typical loss values of photovoltaic generation at USP Capital campus
(a) Installation on the roof and (b) Installation in a parking lot

3.4. Greenhouse Gas Inventory

The GHG Inventory pilot projects were launched in three phases to give researchers insight into USP's administrative structures and to enable different levels of support. In the first phase, the researcher conducted most of the work; in the second, a more collaborative, “joint effort” model was used with both the unit's team and the researcher sharing responsibilities; and in the third phase, the researcher played a support role, encouraging the unit's own team to perform data collection and use the calculation tools independently.

As expected, there were challenges in obtaining some data. Since 2022, the year most units inventoried, these data were not routinely collected, as highlighted in [12]. In some cases, such as fuel and electricity consumption, data were available through existing systems. Similarly, information about fuel use for fixed equipment such as generators and boilers were relatively easy to find, as purchases are usually not frequent and well documented. However, data on fugitive emissions from refrigeration equipment proved particularly difficult to obtain. This may explain why such emissions are not reported in at least 40% of greenhouse gas inventories from higher education institutions analyzed in [13].

At the School of Arts, Sciences and Humanities, where electricity was the primary emissions source, fugitive emissions from refrigeration systems were estimated to account for approximately 90% of Scope 1 and 15% of total Scope 1 + Scope 2 emissions when considering only Kyoto Protocol-regulated gases, as required by the GHG Protocol. However, when including R-22 (a potent greenhouse gas also on the list of regulated substances but reported separately under GHG Protocol rules), fugitive emissions accounted for around 30% of total Scope 1 + 2 emissions.

A surprising finding was the impact of anesthetic gases, which were the primary emission source at the University Hospital. These gases accounted for more than 70% of Scope 1 emissions, far surpassing fixed combustion sources, which made up just over 20% of Scope 1, and were more than 15 times higher than emissions from electricity consumption (Scope 2).

As for indirect emissions from daily commuting by staff and students, this remains an area to be inventoried. Typically, data collection is done by sampling, as seen in studies by

[14] and [15]. However, several methodological challenges remain. Published studies often do not provide the questionnaires used and lack clarity on key assumptions tied to local contexts, making replication difficult and limiting the ability to assess uncertainty and confidence intervals in the results. In Brazil, where private cars, taxis, and ride-share services can operate on either ethanol or gasoline (a detail usually unrecorded), this adds further complexity.

The barriers and challenges described have potentially significant implications for the reliability of GHG inventory reports. Although the GHG Protocol offers a standardized reporting framework, it appears to leave limited room for explicit and transparent discussion of such difficulties. This is a critic that can be made to a substantial number of higher education inventory studies. It applies both to data quality issues and inventory completeness. Often, the exclusion of certain emission categories is not justified [13], leaving it unclear whether the activity or source is irrelevant, was estimated and deemed negligible, or simply excluded due to lack of data. The pilot project reports have sought to address this gap by including additional information to enhance transparency.

In terms of team mobilization, both faculty-led and staff-led formats presented advantages and disadvantages, with a slight preference for staff-led projects. Leadership engagement and the commitment of project coordinators were critical, and the frequency of team meetings was often a key factor. In cases where the meeting schedule was disrupted, there were notable delays, particularly in labor-intensive tasks such as gathering data on air travel and refrigeration equipment.

It is important for higher education institutions, when publishing their indicators and inventories, to also provide information that clarifies the scope (i.e., which sources are included) and the reliability (i.e., data quality), in order to ensure greater transparency and confidence in decision-making related to climate change mitigation and sustainability performance.

4. Conclusions

Sustainability at the University of São Paulo (USP) is a strategic management priority that has been continuously refined in recent years. This evolution reflects not only an internal perspective — focused on its campuses and operational realities — but also an external one, as USP serves as a living laboratory for sustainability. Beyond its core missions of teaching, research, and outreach, the University also manages its own territories, positioning it as an important model for the analysis and development of public policy.

Since its establishment, and more recently through the USPSusten Program, the University's Environmental Management Superintendence (SGA/USP) has consistently demonstrated an innovative approach. It has fostered the application of knowledge produced within the University — grounded in empirical research — by implementing case studies within USP itself. This allows for engagement with the diverse contexts and specificities of the territories where its campuses are located.

The combination of greenhouse gas quantification and monitoring, strategic planning, and project implementation has laid the foundation for the University to lead by example in the fight against climate change. Improving operational performance in terms of emission mitigation would already constitute a significant achievement. However, beyond this, integrating practical experience into the knowledge base of technical staff and faculty enhances the training of students — making them more technically proficient and better equipped to connect strategies, policies, technical knowledge, and management practices.

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Conflict 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.

Authors Contribution
P.I.: conceptualization, methodology, validation, writing – review & editing, project administration, funding acquisition; **T.G.:** conceptualization, methodology, validation, investigation, data curation, resources, writing – original draft writing – review & editing, project administration, visualization; **A.O.A.:** conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing – original draft, writing – review &editing, visualization; **B.NR.:** conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing – original draft, writing – review &editing, visualization; **C.A.D.:** methodology, validation, formal analysis, investigation, data curation, writing – original draft; **D.P.:** methodology, validation, formal analysis, investigation, data curation, writing – original draft; **F.B.:** conceptualization, methodology, validation, writing – original draft writing – review & editing, project administration, visualization; **I.L.S:** conceptualization, methodology, validation, resources, data, curation, writing – review & editing, supervision; **J.R.M.B:** conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing – original draft, writing – review &editing, visualization; **J.R.M.:** conceptualization, methodology, validation, resources, data, curation, writing – review & editing, supervision; **P.R.C:** conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing – original draft, writing – review &Editing, visualization; **R.Z.:** conceptualization, methodology, validation, Resources, data, curation, writing – review & editing, supervision; **S.A.P.:** conceptualization, methodology, validation, Resources, data, curation, writing – review & editing, supervision; **S.T.C.:** methodology, validation, formal analysis, investigation, data curation, writing – original draft; **T.L.:** conceptualization, methodology, validation, formal analysis, investigation, data curation, writing – original draft, writing – review &editing, visualization; **C.G.C.J.:** conceptualization, writing – review & editing, project administration, funding acquisition. All authors reviewed and approved the final version of the manuscript.

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