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An Approach for Water and Energy Savings in Public Buildings: A Case Study of Brazilian Rail Company

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Abstract: Water scarcity is a current problem in many parts of the planet and there is a worldwide concern about water availability to meet future water demand. In countries like Brazil, where most of the electricity is produced by hydroelectric power plants, water scarcity directly impacts energy production. The water–energy nexus is directly related and impacted by CO_2 emissions and its climate consequences, which calls to a broader approach: energy–carbon–water nexus. In this context, the Sustainable Water and Energy Consumption (SWEC) Program was developed to mitigate water and energy supply problems in a railway company in Brazil. The actions took place in four main areas: (a) users conscientization, (b) consumption diagnosis, (c) indicators for evaluating water and energy consumption, and (d) evaluation of implementing alternative cleaner water and energy sources. The per capita consumption of water and energy were reduced by 10% and 19%, respectively. Permanent results were achieved by the SWEC Program, such as the acquisition of two photovoltaic systems with a total capacity of 96.5 kWp. The investment made provided an average monthly reduction in energy consumption of 56% in 2022. This work contributed to the UN Agenda 2030 and the findings may help companies and industries, and other institutions, such as universities and schools, to improve their water and electricity consumption.

Keywords: energy conservation; sustainable water consumption; photovoltaic system; railway system; greenhouse gas emissions; footprint carbon

1. Introduction

Humans are using more natural resources every day, which raises questions about how their actions may directly contribute to climate change and how their consumption may affect the emissions of harmful gases into the environment. As the population increases, the demand for goods and services in major urban centers increases. This is due to the possibility that a lack of infrastructure development, timely delivery, or storage could limit the availability of water [1–3].

Water scarcity is a current problem in many parts of the planet and there is a worldwide concern about water availability to meet future water demand. Overall, from 2016 to 2050, the global urban water shortage is expected to worsen significantly. Moreover, nearly half of the world's urban population (1.693–2.373 billion people) is expected to reside in a water-scarce region by 2050 [4]. Engineering and infrastructure have traditionally been used to alleviate urban water shortages, however, water infrastructure is expensive and has the potential to cause environmental consequences [4].

Given the proportion of all transport activity that rail makes up, rail infrastructure only accounts for 3% of the global demand for transport energy. Nevertheless, steps must be taken to lessen the energy requirements of the transportation sector, which is a major contributor to world energy consumption and related greenhouse gas emissions [5,6].

Water scarcity is related to energy shortage. For the safe and reliable generation of electricity, the power generation industry requires large amounts of water, from moving turbines in the case of hydroelectric or to condensing steam in the case of thermoelectric [7]. In countries like Brazil, where most of the electricity is produced by hydroelectric power plants, water scarcity directly impacts energy production.

The implementation of actions for sustainable use of water and energy is critical for mitigating water and energy supply problems. Demand-side management (DSM) is one of these efforts and consists of planning and conducting water or energy consumption activities to encourage consumers to change their use levels and patterns [8]. Furthermore, DSM programs are designed to minimize consumption by supporting high-efficiency technology and building design [9–15]. Technological tools have been reported to achieve a 35–50% reduction in water consumption in household appliances [16].

Most literature reports the application of DSM programs to reduce water and energy consumption in schools [17–20], universities [21,22], hotels [23], households [24], and railway [6]. The lack of knowledge has been considered a hindrance in implementing sustainable specifications for public buildings [8].

Another effort is the development of regulations, which are being created and updated in both developed and developing nations to obtain optimum energy savings in buildings. Building certification is a key technique for making these laws and regulations effective [25], such as LEED, BREEAM, VERDE, and LiderA [26]. In Brazil, the MPOG Normative Instruction of 19 January 2010 established environmental sustainability criteria in the acquisition of goods, contracting of services, or works by the Federal Public Administration [27]; and, later, Decree No. 7746, of 5 June 2012 [28], established sustainable criteria, practices, and guidelines for hiring carried out by the federal public administration as legal frameworks for the adoption of criteria to reduce energy consumption and water consumption.

Strategies to promote water and energy savings may reflect in the reduction of carbon dioxide emissions [25]. The water–energy nexus is directly related and impacted by CO_2 emissions and its climate consequences, which calls to a broader approach: energy–carbon–water nexus [29].

The shift to a more carbon-efficient global energy system could help us achieve such goals. Buildings, in particular, account for 40% of energy usage, and there is significant room for reduction [30]. In order to understand the true impacts of these emissions, it is necessary to know how goods and services are consumed by society and to measure the impacts they cause. Moreover, the current energy crises observed in Europe reinforces the need for a solution on improving energy consumption efficiency and expanding the energy matrix.

Recently, it was observed that the sustainability field is understudied in railway research [31]. In this context, to fill the gap of more action in the railway sector to reduce water and energy consumption, and consequently GHG emissions, the Sustainable Water and Energy Consumption (SWEC) Program was developed. This paper presents the SWEC validation in the buildings of a public railway company in Brazil. The work is divided into three sections: (i) Methodology, (ii) Results, (iii) Limitation and future work, and finally, (iv) Conclusions.

2. Materials and Methods

2.1. SWEC Validation—Case Study

The SWEC validation was carried out at a public company of light railway operation and maintenance. The company buildings were distributed in four different municipalities of northeastern Brazil, as shown in Figure 1: João Pessoa, Cabedelo, Santa Rita, and Bayeux. The system is composed of 12 train stations distributed throughout 30 km of the railway. The main office, where most of the employee's works, is in the João Pessoa Rail Station (7°06′54″ S, 34°53′26″ W), while the workshop where the train maintenance is performed is located in the Cabedelo Rail Station. The company possess a total of 17 hydrometers and 22 electricity meters distributed throughout the buildings. The main office consumes most of the energy and water in the company (>90%), followed by the train workshop and train station.

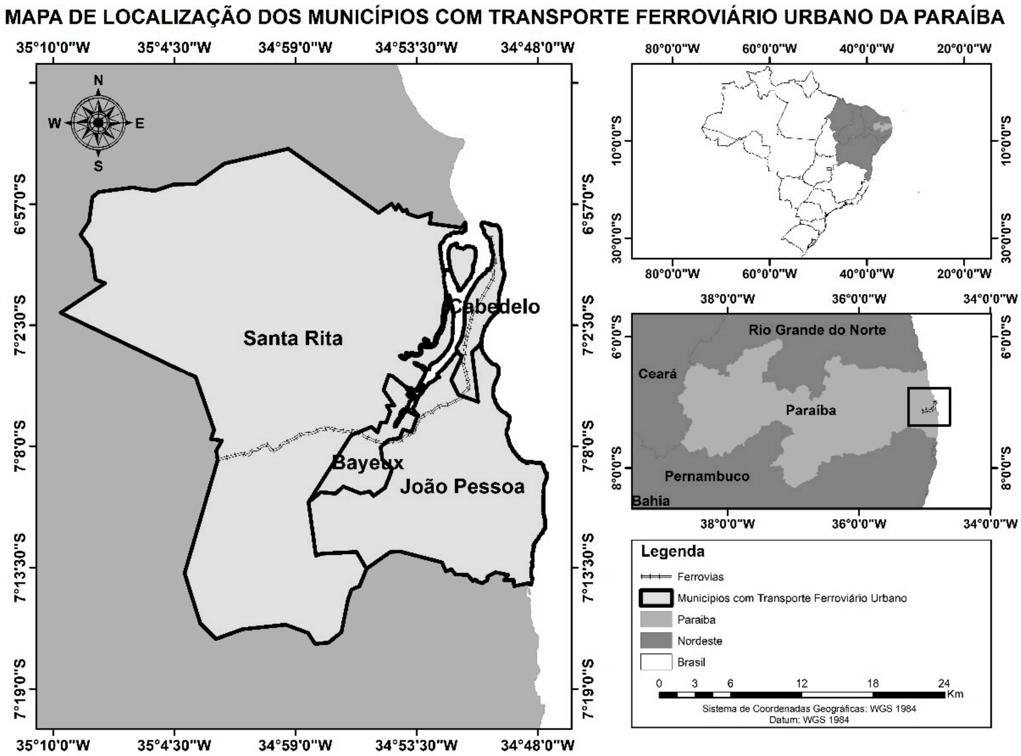

Figure 1. Location map of the Paraiba Railway System, Brazil (adapted from [32]).

2.2. Sustainable Water and Energy Consumption Program Overview

The SWEC Program aims to promote (i) the sustainable usage of energy and water; (ii) the reduction of resource waste; (iii) optimization of water and energy expenses; and (iv) user conscientization. The specific goals are shown in Table 1.

Table 1. Specific goals of the Sustainable Water and Energy Consumption Program.

Water	Energy
Reduce water loss and waste	Reduce energy consumption and consequently expenses with electricity
Reduce consumption, and consequently, expenses on drinking water supply Keep a reduced consumption profile over time	Replace inefficient equipment
Implement a structured water use management system	
Make users aware of the sustainable use of water to reduce waste from misuse	
Apply new tools and technologies for intelligent and efficient use of water	

The following sections will detail the SWEC Program framework, which consists of actions divided into four sections: (a) users conscientization, (b) consumption diagnosis, (c) indicators for evaluating water and energy consumption, and (d) evaluation of implementing alternative cleaner water and energy sources.

2.3. Sustainable Water and Energy Consumption (SWEC) Program Framework

2.3.1. Users' Conscientization and Consumption Diagnosis

Previous research and other studies [33–35] have reported on the impact of water usage behaviors on water savings. Interventions such as workshops, e-mails, signs on washrooms, posters, and hand-delivered booklet have been shown to reduce water consumption by up to 35% [36]. A marketing campaign was developed to raise users' awareness. The initiative had four major components: (i) reminder signs, (ii) an educational booklet, (iii) periodic reports, and (iv) informative talks.

The reminder signs were placed on all faucets to encourage water conservation, and on all light switches to remind users to turn off the lights before leaving the room. Furthermore, signs were placed around the buildings requesting that water leaks and other maintenance issues regarding water and energy use be reported.

A printed educational booklet containing information on smarter water and energy-saving practices was delivered to all employees. Following the program's launching, bi-monthly updates on water and energy consumption and expenses were sent by institutional e-mail to supervisors and managers. The informative talks were placed during key events, such as "Safety and Environmental Week" which included contests and the distribution of gifts and prizes.

For the consumption diagnosis, a database was created to gather information on water and energy use, costs, and consuming items. Table 2 lists the sources for each kind of information.

Table 2. Sources of information for water and energy consumption diagnosis.

Category	Source
Consumption	24 months water and energy bills, hydrometer, and electricity meter
Expenses	24 months of water and energy bills
Consuming components	Inventory of goods and on-site inspections

2.3.2. Indicators for Evaluating Water and Energy Consumption

Indicators were set to monitor the SWEC Program results. The indicators for water and energy are displayed in Table 3.

Table 3. Indicators for water and energy consumption.

Indicator	Description
W_1—Global consumption of water (m^3)	Volume of piped water consumed by all buildings
W_2—Local consumption (m^3)	Volume of piped water consumed by each building
W_3—Self-closing faucet (%)	Number of self-closing faucets divided by the total number of faucets
W_4—Leaking hydraulic components (%)	Number of leaking items divided by the total number of hydraulic items
W_5—Per capita water consumption (m^3/employee)	Water consumed per employee
E_1—Global consumption of electricity (kWh)	Electricity consumed by all buildings
E_2—Local consumption of electricity (kWh)	Electricity consumed by each building
E_3—LED lighting (%)	Number of LED lightning divided by the total number of lightning
E_4—Per capita electricity consumption (kWh/employee)	Electricity consumed divided by the number of employees

The indicators W_5 and E_4 were included in the Program after observing an increment in the number of employees in the company of 15% in the first year. The addition of W_3 was justified by the findings by other studies that more than 50% of the water saving is possible by changing the type of faucet [37]. In addition, a study conducted in a hotel in Spain showed that installing water-saving devices in the taps is highly profitable [38].

The frequency of data collection for each indicator was defined as follows: monthly for W_1, W_2, W_5, E_1, E_2, and E_4, which the primary source of information is the monthly bills of the concessionaires; biannual for W_3, W_4 and E_3, whose main source of information is on-site inspections of all buildings. The frequency of data collection can be flexible depending upon the needs and resources available for implementing the Program.

On-site inspections were carried out to identify, count, and examine the state of all water and energy consumption items. The surveys were conducted with peers every 6 months, although a higher frequency can improve the results by fast detecting issues.

2.3.3. Clean Alternative Energy and Alternative Water Supplies

The SWEC Program's technological efforts also included the installation of greener sources of water and energy. Given the local characteristics of the 5.82 kWh m^{-2} average global radiation [39] and an annual average precipitation of 1914 mm, the acquisition of a photovoltaic system for alternative energy and rainwater harvesting for non-contact uses water supply was suitable to meet the goal of reducing water and the energy cost, particularly through more sustainable sources.

3. Results and Discussion

3.1. First 24-Months Results

Table 4 shows the results of a SWOT analysis conducted to evaluate the SWEC Program´s implementation in the company.

Table 4. SWOT analysis of SWEC Program implementation in the building of a public railway company in northeastern Brazil.

S—Strengths	**W—Weakness**
High potential of cost reduction with water and energy	Manpower shortage for the company´s buildings maintenance
Demands are concentrated in a few key buildings of the company, facilitating the monitoring of the Program	Absence of scheduled maintenance of the hydraulic and electrical networks
Alignment of the program with the company´s strategic planning	Risk of low adherence to the Program by the staff
Increase the quality of life at work through the application of modern devices and technologies	
O—Opportunities	**T—Threats**
Change of conventional tariff modality in the Workshop facility for the horo-seasonal model	Tariff adjustment of water and energy concessionaires
The public impression of rational water and energy use	Energy and water deviation
Brazilian government cost-cutting measures	Vandalism in water and energy consuming items (e.g., lightings, faucets, flushing, etc.)
Environmental legislative changes and sustainable bidding demand for the Public Administration	

Table 5 presents the summary of the indicator's performance after the first 24-months of Sustainable Water and Energy Consumption Program in the public company of light railway in northeastern Brazil.

Table 5. Summary of the results for each indicator after 24-months of implementation.

Indicator	Main Results
W_1—Global consumption of water (m^3)	Increased 37%, from 562.5 to 771.5 m^3.
W_2—Local consumption (m^3)	-
W_3—Self-closing faucet (%)	Did not suffer any variation.
W_4—Leaking hydraulic components (%)	Increased from 7% to 9%.
W_5—Per capita water consumption (m^3 /employee)	Reduced 10%.
E_1—Global consumption of electricity (kWh)	Reduced 11.2%.
E_2—Local consumption of electricity (kWh)	-
E_3—LED lighting (%)	Increased from 20% to 27%.
E_4—Per capita electricity consumption (kWh/employee)	Reduced 19%, from 184 kWh to 150 kWh.

The global water consumption, W_1, increased significantly while the global energy consumption, E_1, decreased. The increase in water consumption may be justified by the following reasons: the company had an increase in manpower of 15% during the period, the maintenance and replacement of hydrometers which were broken or not properly reading the real water consumption, and the water theft from the company in remote areas considering the economic crises and the unemployment number in Brazil in the last years [40].

As seen in Table 5, the reduction per capita energy consumption, E_4, was greater than per capita water consumption, W_5. This may be justified by the fact that, in addition to the user´s conscientization actions, more efficient electrical items, such as air-conditioning with inverter technology and LED lightings, were substituted (E_3). In Israel, some green schools were defined in research and as having particularly low usage in buildings that had a very efficient air conditioning system (VRF) installed [19]. It was observed that this strategy consumed approximately 41% less energy per year than the educational systems.

Only via the user´s education and corrective maintenance of hydraulic items it was possible to reduce per capita water consumption by 10%. Unfortunately, it was not possible to acquire more efficient hydraulic equipment, such as self-closing faucet (W_3) or dual flushing toilets kits. For W_2 the Poco station highlighted with an observed reduction of 77%, attributed to a leaking fixture in the toilet flush.

After 18 months, employees were given a questionnaire, and the following results were obtained: 97% agree totally or partially with the importance of acquiring more efficient equipment, 88.7% declare, wherever feasible, act to reduce water consumption, and 93% care about sustainable water consumption.

During the on-site inspection, it was detected that some water-consuming items such as flushes and faucets were broken or showed some defect that limited their use. As a result of the SWEC Program´s application, these items were repaired or substituted by maintenance staff, and consequently, the number of water consuming items increased. The slightly increase in the leaking hydraulic components, W_4, can be justified by the fact that past defective items, which have since been repaired, were susceptible to leaking from misusage or minimal maintenance. The W_4 results clearly indicate that greater attention should be spent towards maintenance of consuming items, as their leakage might represent a large amount of water wasted daily, reducing the overall Program efficiency for water saving. Water waste in public buildings has been identified as a serious issue in public buildings as a result of faulty plumbing fixtures [41].

Water conservation education and awareness initiatives, as well as the marketing of water-saving devices, have a significant influence on water use [34]. To improve the user's conscientization, it would be highly recommended to create a social media campaign, which is proven to make marketing campaigns much more powerful [42].

Given that rainwater acceptability is higher for non-contact and non-intake uses [43], the SWEC Program proposed rainwater usage for gardening, trains washing, and toilet flushing. It was found that for the mentioned usage, the economic viability of the system would be met [44]. However, it was not possible to be executed due to administration restrictions. Moreover, a study conducted in Recife (a city nearby Joao Pessoa) showed that green roofs also have a great potential for non-potable uses and should be considered in buildings to reduce consumption of public supply water [45].

3.2. Recent Results

One of the main results of the SWEC Program was achieved some years after two years, by the installation of two on-grid photovoltaic (PV) systems: (a) a PV system of 67 kWp in João Pessoa office, and (b) a PV system of 29.5 kWp in Cabedelo train workshop. Figure 2 shows the PV system installed in the Joao Pessoa office. The simple payback period was expected to be four years. This estimate was based on the PV system prices in the region, insulation hours in the area, and the electricity prices.

Figure 2. Photovoltaic systems from Joao Pessoa office during (**top**) and after (**down**) installation.

Figure 3 and Table 6 show the results of energy consumption for the period before and after PV system installation. The period of 2019 was compared to that from 2022 (until September), because 2020 and 2021 were atypical years affected by pandemic lockdowns. An average monthly reduction of 56% was observed in 2022. Other programs have achieved a 42.4% reduction on net-energy demand with a program to implement PV systems, a total replacement of actual lighting by LED, and the implementation of a battery system using lithium-ion batteries with a capacity of 100 kWh [22].

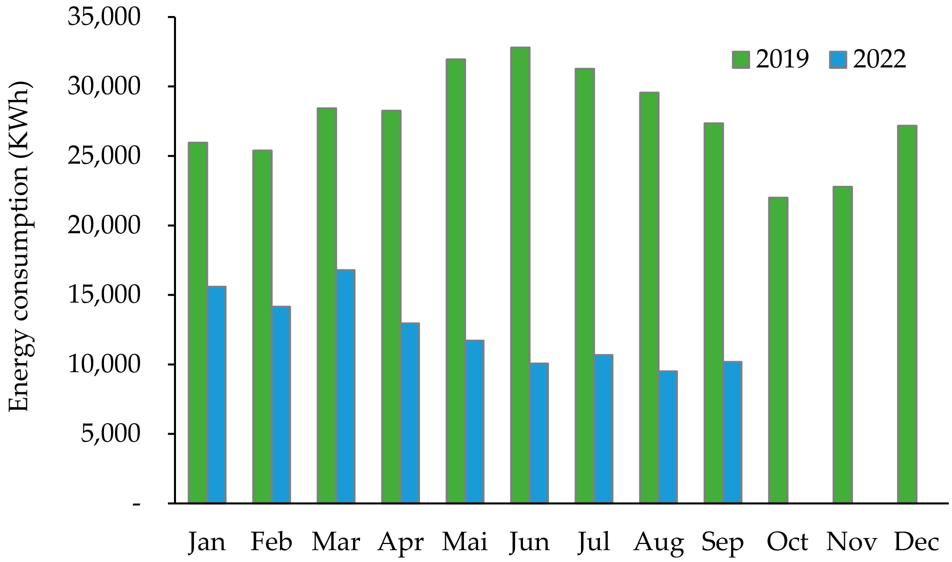

Figure 3. Comparison of energy consumption in Paraiba rail company before (2019) and after (2022) photovoltaic system installation.

Table 6. Energy consumption in the Paraiba rail system in 2019 and 2022.

	Year	January	February	March	April	May	June	July	August	September	October	November	December
Consumption (kWh)	2019	25,951	25,395	28,426	28,251	31,944	32,797	31,273	29,556	27,342	21,993	22,775	27,175
	2022	15,592	14,153	16,779	12,949	11,715	10,065	10,670	9506	10,178	-	-	-
	Reduction	−40%	−44%	−41%	−54%	−63%	−69%	−66%	−68%	−63%			

When comparing sustainable building research to the same energy-saving studies, most have achieved an average of 30 to 50% reduction in energy consumption by implementing sustainable projects with photovoltaic systems, replacement of inefficient lightning, and implementing new air conditioning and heating technologies [19–21].

3.3. Emission of Greenhouse Gas (GHG)

The photovoltaic system originating from solar energy, a renewable source, can also reduce the CO_2 emission. The reduction on CO_2 emissions related to the energy savings by the photovoltaic system was quantified. For the emissions of each GHG to be transformed into CO_{2e} emissions, the Global Warming Potential (GWP) was used. The GWP is an indicator of the ability of a gas to contribute to global warming and compares the heat factor in the atmosphere of a ton of a GHG for a given time interval with a ton of CO_2, showing the relative contribution of the emission to the atmosphere of 1 t of a given GHG compared to the emission of 1 t of CO_2 [46,47]. This time interval is called the time horizon, which represents the period of analysis counted from the instantaneous emission of the GHG [46].

The analysis of the carbon footprint has been done by adopting a streamlined lifecycle approach and the results are presented using a CO_2 e metric [48]. This approach is in essence a slimmed down version of a complete LCA adopting all its core processes and excluding low contributing processes that would be otherwise included in a full LCA. The methodology adopted in this work for the carbon footprint is based partially on the framework described by the World Resources Institute (WRI) [49], The Ministry of Science, Technology, and Innovation of Brazil (MCTI) [48], and the conceptual LCA framework guidelines designated by the ISO [50,51].

In this context, to perform the calculation, the parameters of The Ministry of Science, Technology, and Innovation (MCTI) [48] were used, using the Equation (1): GHG emission calculation for the purchase of electricity [49].

$$ECO_2, m, = Cm, FECO_2, m, \quad (1)$$

where ECO_2 are the emissions attributable to electricity consumption from the national grid in month m of year y, in tCO_2e; Cm,y is the electricity consumption from the national grid in month m of year y, in MWh; $FECO_2$ is the emission factor applicable to electricity from the national grid in month m of year y, in t CO_2/MWh; m is the month of consumption referring to electricity consumption; and y is the reference year.

The two-year epidemic prevented the rail system from operating at full capacity and prevented all staff from working. To better understand the true impact of The SWEC Program and the deployment of the solar system, it was decided to compare the years before and "after" the epidemic. Table 7 and Figure 4 show a comparison between the greenhouse gas emissions in 2019 and 2022.

Table 7. GHG Emission CO_2 (t).

Year	January	February	March	April	May	June	July	August	September	October	November	December
2019	1.66	1.54	1.81	1.48	1.94	3.00	3.36	3.49	3.23	1.76	0.83	0.93
2022	1.00	0.86	1.07	0.68	0.71	0.92	1.15	1.12	1.20	-	-	-
GHG emission avoided	0.66	0.68	0.74	0.80	1.23	2.08	2.22	2.37	2.03	-	-	-

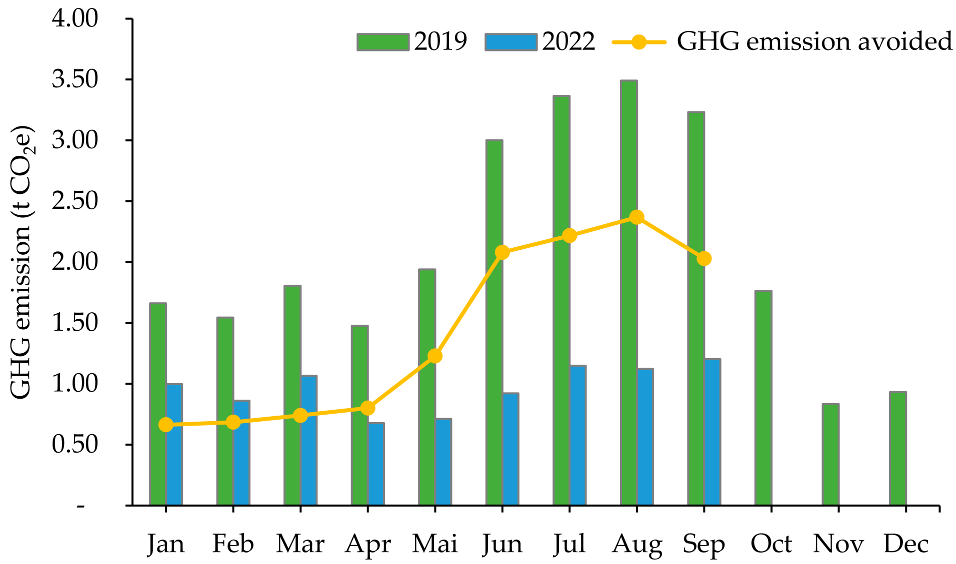

Figure 4. GHG emission in 2019 and 2022, after photovoltaic system installation.

The months with the lowest emissions of greenhouse gases were June, with 69%, August, with 67%, and July, with 65%, respectively. These months are winter in Brazil, but because to the region's proximity to the equator, the solar insulation remains constant, showing no seasonal variation reflected in the greenhouse gases emission stability in 2022.

More than 50% of GHG emissions were avoided in every month, indicating that the SWEC Program and the use of photovoltaic energy were successful to promote carbon reduction by the company.

4. Limitations and Future Work

The SWEC Program brought a radical shift in the rail company by changing the way employees thought about water and energy use, which helped to develop solutions and creative consumption habits. However, the Program´s execution was limited to the public budget and availability of personnel to carry out activities other than their regular responsibilities. The implementation of initiatives, which depends on investments, is very limited in governmental companies, particularly in emerging economies. Other technologies and devices are suggested to provide water and energy savings, such as motion sensor light switch, dual flush toilets, self-closing faucets, flow reducing devices, and faucet aerators. The potential for savings with these items is significant, as it was estimated that each unit increase of each unit of water-saving devices resulted in a 0.512 decrease in the water consumption level in households [52]. Moreover, the irrigation system and vegetation with lower water requirements can also be considered to reduce water consumption and consequently cost, after payback time [53].

The SWEC approach´s effectiveness is highly dependent on a continuous assessment of the consumption. It is wise to verify the consumption of each hydraulic and energy consuming items, as well as estimate the consumption of the railway passengers. A benchmarking study is also necessary to identify other best practices that were critical to water and energy savings at a mid-stage point.

Given that the motivational variable impacts water-saving behaviors and that basic actions may be suitable for integration into a daily routine [54], the SWEC Program should revise its strategy to effectively motivate employees on the issue while also aiming for long-term results.

5. Conclusions

The paper presented a methodology to implement a sustainable consumption approach of water and energy in the building. The methodology was validated in a public company, more specifically, a railway company in northeastern Brazil. The per capita consumption of water and energy was reduced by 10% and 19%, respectively. These results can be justified by the high education campaign, but not only considering technological efforts carried out through the implementation of the Program.

Permanent results were achieved by the SWEC Program implementation, such as the acquisition of two photovoltaic systems with a total capacity of 96.5 kWp. The investment made provided a fast return, with an average monthly reduction in energy consumption of 56% in 2022, due to the high insulation of the region.

An overall evaluation for the SWEC Program revealed that the approach must be applied and evaluated on an ongoing basis. Water use was not reduced globally, and efforts such as analyzing each water-using device, quantifying consumption for the passenger, and implementing the Program in other companies with comparable characteristics are necessary.

The SWEC Program has a strong appeal in sustainability and climate change actions. It decreased the emission of greenhouse gases by more than 50% on average per month, calculated by the reduction on energy use, leading to an average reduction of 1.4 tons of CO_2 emission per month, and minimizing the environmental effect caused by the operation of the rail system.

The findings of this paper may be useful to other companies and industries, public or private, and other public institutions, such as universities and schools with large buildings and elevated consumption of water and electricity. Finally, this work contributed to the UN Agenda 2030, mainly to the Sustainable Development Goals 11 (Sustainable Cities and Communities), 7 (Affordable and Clean Energy), and 13 (Climate Action).

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