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Carbon Footprint Estimation at the Salesian Continuous Training Center - San Bartolo Using System Dynamics

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Abstract. The Carbon Footprint measures greenhouse gas emissions, which are harmful to the environment and contribute to climate change, and is a solution to evaluate the production of GHGs, thus implementing mitigation actions to counteract their environmental impacts. This study focused on evaluating GHG emissions mitigation strategies at the Salesian Center for Continuing Education in San Bartolo. Data, obtained through interviews and utility bills, covered electricity, water and fuel consumption, as well as paper, plastic and organic waste. A system dynamics model was applied to identify the major contributors to greenhouse gas emissions, using Vensim PLE software, and the carbon footprint was simulated for one year. The results revealed annual emissions of 88.28 tons of CO_2 equivalent, mainly from solid waste production (73.92 tons). A mitigation scenario was simulated representing the use of LED lighting, flow control pumps, waste sorting containers, and the adoption of clean energy for transportation. The results suggest a potential reduction of 27.78 tons of CO_2 equivalent, representing a significant decrease in greenhouse gases.

Keywords: System Dynamics · carbon footprint · modeling

1 Introduction

The Carbon Footprint (CF) is defined as the amount of greenhouse gases (GHG) produced, which are considered pollutants to the environment and contribute to climate change [1]. The CF arises as a solution to evaluate the production of GHG, thus implementing mitigation actions to counteract their environmental impacts [2].

There are several methodologies that allow estimating the CF in an institution among them is the Bilan Carbone methodology [3] designed by the French Agency for Environment and Energy (ADEME) in 2012. This tool quickly converts data related to production activities into emissions using emission factors such as different types of energy and water consumption, etc. [4]; once the sources of greenhouse gas emissions are known,

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the area that emits the largest number of pollutants during the year of study can be identified [5]. In addition, strategies can be proposed for the reduction of emissions produced in an institution [6].

System Dynamics (SD) is based on analyzing evolution of the state variables of a system and allows the generation of models based on observations and experiences; therefore, it is an adequate methodology to analyze the behavior of main factors that contribute to the CF. The research conducted by [7], presented a System Dynamics model where the Box Counting method was implemented to determine the CF of several types of asphalt mixtures. System dynamics is an approach developed for the evaluation of variables that allows obtaining reliable results. The study of CF using SD relay on an optimal selection of state variables affecting GHG emissions where quantitative regression methods could be used [8]. Arroyo Lopez developed a SD model following two stages: qualitative and quantitative. In the qualitative phase, relevant variables associated with the system under analysis were identified. In the quantitative phase, these variables were expressed explicitly through equations or tabular functions supported by empirical data [9].

This article aims to develop a System Dynamics model to assess greenhouse gas emissions resulting from electricity, water, paper, plastic, and transportation consumption [10]. The Salesian Continuous Training Center - San Bartolo serves as the case study, with data collected from interviews and utility bills being utilized for model generation. Once the Carbon Footprint (CF) is estimated, proposed strategies for reducing greenhouse gas (GHG) emissions are formulated based on scenario comparisons [11].

2 Methodology

2.1 Case Study

The Salesian Continuous Training Center - San Bartolo is located at UTM 17S, Longitude 775380 and Latitude 9970938 and covers 8534.70 m^2. There three educational programs are managed, these are: Talleres Escuela San Patricio (TESPA) for technical training, the Escuela de Educación Básica Fiscomisional San Patricio (UESPA) for educational support to vulnerable children, and Start Labs with laboratories specialized in design and 3D printing for research projects (Fig. 1).

2.2 Carbon Footprint Estimation

To estimate the CF in the Salesian Continuous Training Center - San Bartolo, the same methodology applied in the Salesian Project Foundation Zona Norte in 2023 will be used. This study focused directly on the operation of the institution, collecting accurate data provided by the establishment. In addition, interviews were conducted with administrative staff and teachers, focusing on the consumption of electrical energy (EEQ electricity bills), drinking water (EPMAPS water bills), paper (reams of A4 bond paper, fomix, etc.) and fuel (diesel). The latter was recorded through previous use in the van used for visits or transfers planned by the institution. In this way, a complete collection of data provided by all personnel was obtained. Subsequently, key greenhouse gases were identified for

Fig. 1. Location Salesian Work - San Bartolo

the calculation of the carbon footprint, such as CO_2, CH_4 and N_2O [12]. In addition, the research managed three scopes: Scope 1, direct water and transport emissions from the institution's own sources such as fuel consumption; Scope 2, indirect emissions from energy consumption; and Scope 3, indirect emissions from waste generation [4] (Fig. 2).

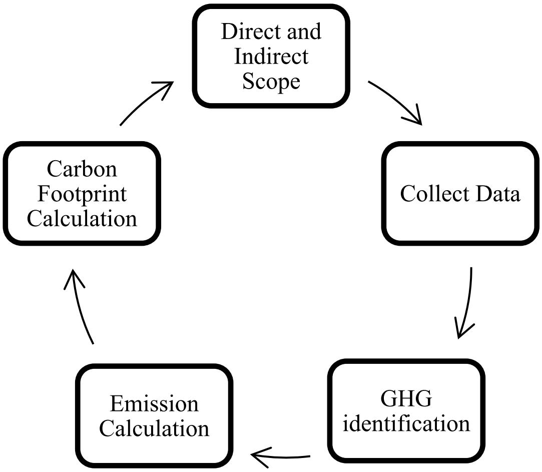

Fig. 2. Steps for estimating CF.

2.3 Modeling

To simulate the behavior of the carbon footprint, System Dynamics was applied, and a Forrester diagram was developed in the Vensim PLE program. Forrester diagrams represent the state variables of the system through Levels or Stocks elements, while its variations are represented through Flow elements. In this study, energy consumption, water consumption, fuel consumption for transportation and GHG generated by the waste produced were considered as state variables (Stocks). In addition, GHG emission factors for energy, water and fuel consumption, as well as the Global Warming Potential (GWP) of the different GHG generated (CO_2, CH_4 and N_2O) were considered as model parameters (Table 1).

Table 1. Emission factors

Parameters	Emission factor			Units
	CO_2	CH_4	N_2O	
Energy	0,000197			ton/kWh
Water	0,000272			ton/m^3
Transportation	0,00268	0,0000051	0,00000022	ton/l
Waste		0,055		ton

On the other hand, the following equation was used to calculate GHG emissions measured in tons of CO_2 equivalents (Ton CO_2eq):

$$GHG\,emissions = Activity\,data * FE * PCG \tag{1}$$

where:

- Activity data represents fuel consumption, energy consumption, water consumption or waste generated.
- EF is the emission factor for each activity
- GWP is the global warming potential of each GHG generated (CO_2, CH_4 and N_2O).

And for the calculation of the total carbon footprint the equation presented in ISO 14064:2019 was applied:

$$Carbon\,Footprint = Indirect\,Emissions + Direct\,Emissions \tag{2}$$

2.4 Mitigation Scenarios

Simulations of a mitigation scenario where strategies to reduce the carbon footprint are implemented were carried out. These were the use of LED lighting, flow control pumps, and waste sorting garbage cans, as well as the adoption of clean energy for transportation.

3 Results

The Forrester diagram obtained can be presented in several parts that represent the dynamics of each state variable, i.e. electricity consumption, water consumption, fuel consumption and GHG emissions from waste generated.

From the monthly electricity consumption data, the annual consumption was calculated and promised as 5212.37 kWh. The Forrester diagram modeling this process is shown in Fig. 3.

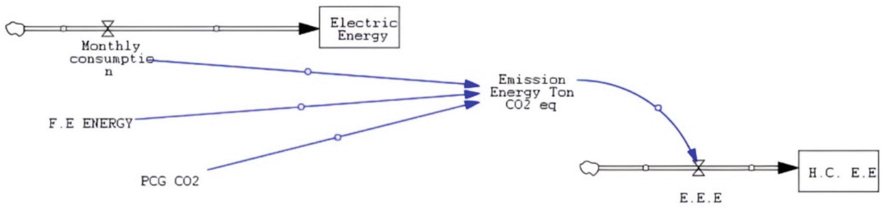

Fig. 3. Forrester diagram for electricity consumption.

Monthly potable water consumption was estimated at 148,6153 m^3 and corresponds to the average consumption from January to December 2023. The Forrester diagram modeling this process is shown in Fig. 4.

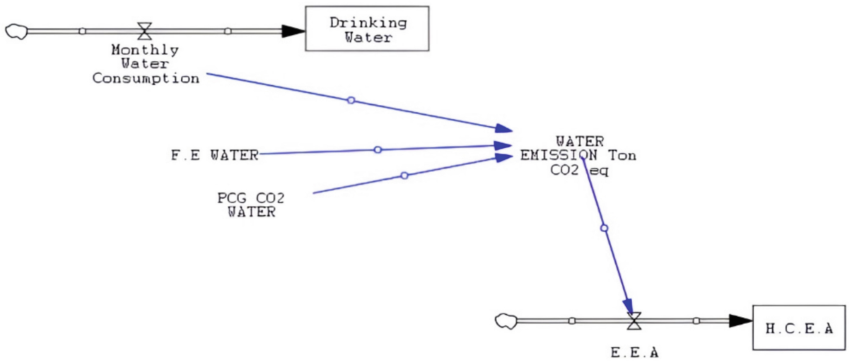

Fig. 4. Forrester diagram for water consumption.

The data on fuel consumption per transport covers the period from January to July, and a monthly consumption of 47.04 L has been estimated for the calculation of the carbon footprint. The Forrester diagram modeling this process is shown in Fig. 5.

The dynamic model representing GHG emissions due to waste generation considers the generation of organic and inorganic waste (plastic and cardboard) with their different emission factors and GWP. The Forrester diagram modeling this process is shown in Fig. 6.

Finally, the four contribution sources modeled above are summed to calculate the total carbon footprint, as shown in Fig. 7.

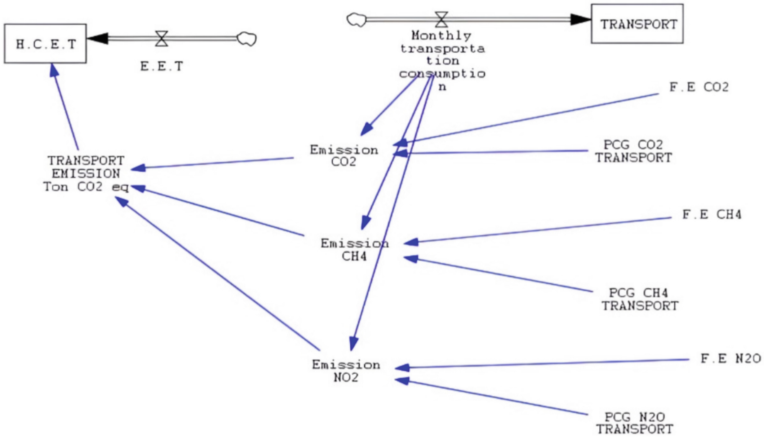

Fig. 5. Forrester diagram for fuel consumption.

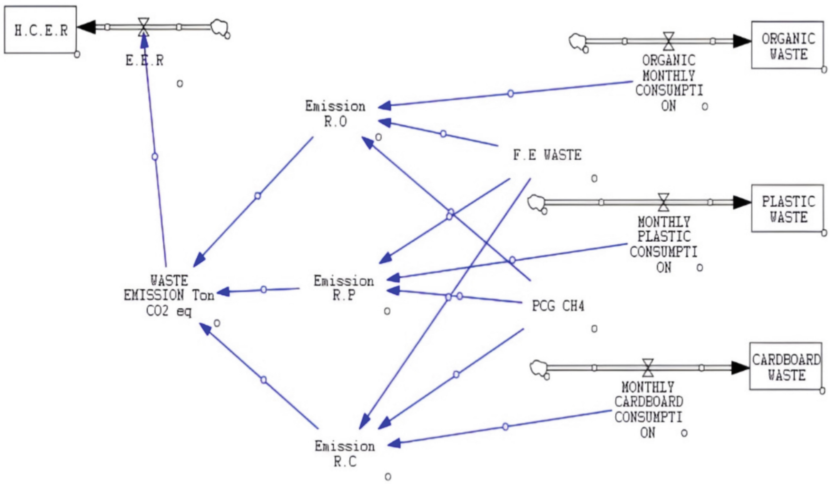

Fig. 6. Forrester diagram for GHG emissions due solid waste production.

Figure 8 shows the GHG emissions measured in tons of CO_2 equivalent during the year 2022 for the following variables: C.E.E.E. (Carbon Footprint - Energy Emission), C.E.E.P. (Carbon Footprint - Potable Water Emission), C.E.T. (Carbon Footprint - Transport Emission) and C.E.R. (Carbon Footprint - Waste Emission) [11].

On the other hand, Fig. 9 shows the carbon footprint for the year 2023 of the sum of the different emissions, which is energy, water, transportation and waste, as shown in Fig. 8.

To evaluate the effect of the implementation of mitigation measures in the reduction of the carbon footprint, especially considering that waste generation is one of the main contributors, a simulation was performed in Vensim where it was assumed that the

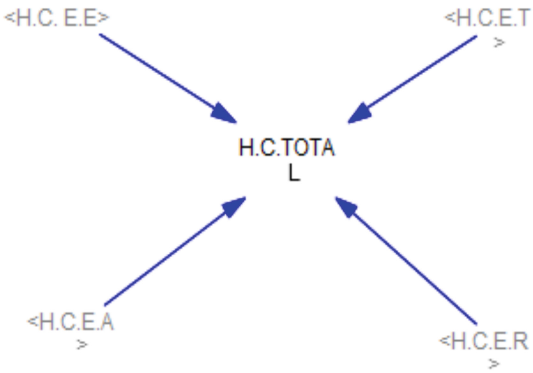

Fig. 7. Forrester diagram for total carbon footprint.

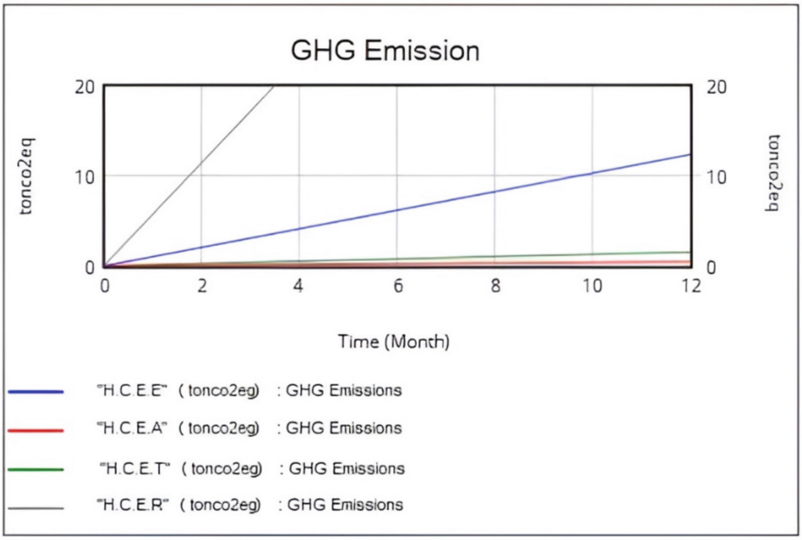

Fig. 8. GHG emissions

implementation of LED lighting for electrical energy stands out as a highly efficient measure, achieving a reduction of 80%. In the case of water, the installation of a flow control pump results in a 20% reduction. Transportation for alternative fuel generates a 30% reduction, waste management through sorting achieves a 70% reduction in organic waste, 50% in plastics and 30% in cardboard, each of the proposed strategies reduces the GHG of each footprint [14].

It can be seen that effective waste sorting can lead to a significant reduction of 16% of GHG emissions, as graphically represented in Fig. 10, which illustrates the carbon footprint with the application of these mitigation measures (Fig. 11).

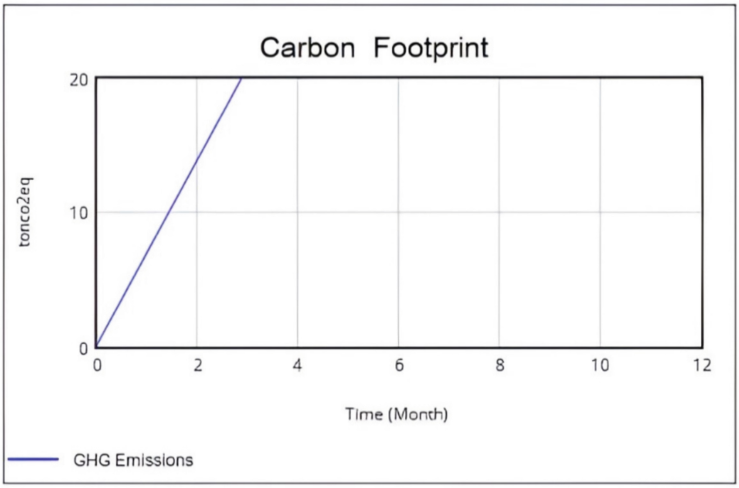

Fig. 9. Carbon footprint

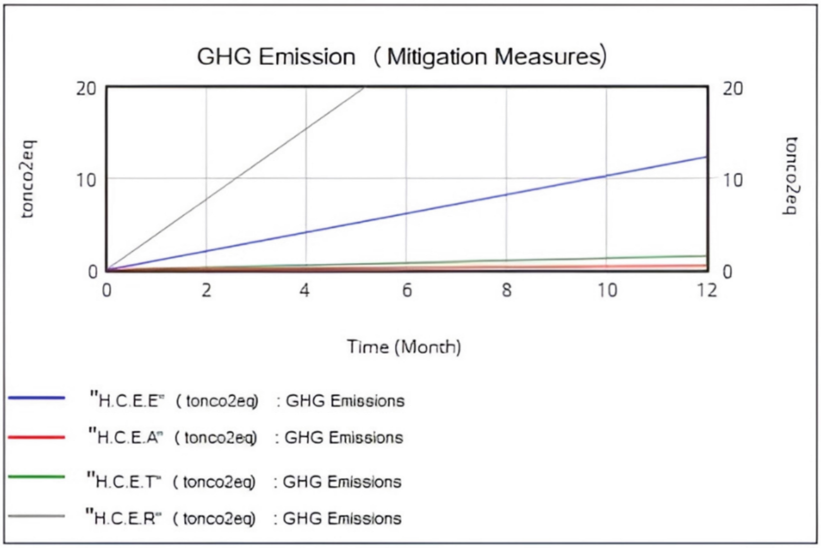

Fig. 10. Mitigation measures for carbon footprint reduction

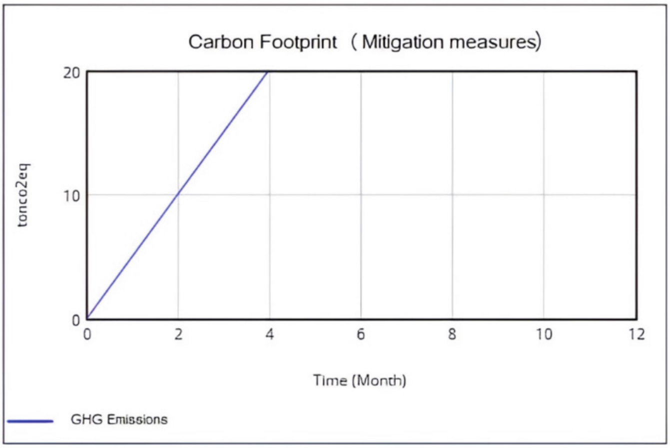

Fig. 11. Carbon footprint reduction.

4 Discusion

The results of the simulation reveal that the carbon footprint of the Salesian Continuous Training Center - San Bartolo amounts to 88.28 tons of CO_2 equivalents, exceeding the acceptable range of greenhouse gas emissions. The largest contribution comes from waste, totaling 73.92 tons of CO_2 equivalents. In second place is electric power, generating 12.32 tons of CO_2 equivalents, while transportation and water have the lowest emissions, with 1.55 and 0.49 tons of CO_2 equivalents, respectively. These findings highlight the importance of implementing reduction strategies, especially focused on waste management, to mitigate the environmental impact of the Salesian facility [15].

For carbon footprint reduction, mitigation measures have been proposed that prove to be effective in reducing emissions.[16]. The implementation of LED lighting for electrical energy stands out as a highly efficient measure, achieving an 80% reduction. In the case of water, the installation of a flow control pump results in a 20% reduction. For transportation, the adoption of alternative fuels can generate a 30% reduction. Finally, addressing the most significant emission, waste management through sorting achieves a 70% reduction in organic, 50% in plastics and 30% in cardboard, each of the proposed strategies reduces the GHG of each footprint. These strategies prove to be fundamental to achieve a more sustainable and responsible environmental management [17].

With the implementation of mitigation measures, the carbon footprint was reduced to 27.7325 tons of CO_2 equivalent. These results significantly indicate that the mitigation measures adopted are effective in decreasing the greenhouse gas emissions that the institution emits into the environment [19].

5 Conclusions

In conclusion, the carbon footprint of the institution amounts to a total of 88,2776 tons of CO_2eq, exceeding acceptable emissions limits. Waste accounts for most of these emissions, with a total of 73.92 tons of CO_2eq, followed by energy, transportation, and water. Mitigation measures, such as the installation of LED lighting, flow control pumps, the adoption of alternative fuels, and waste sorting, have been implemented and have proven to be effective in reducing emissions.

For the development of these reduction strategies, system dynamics were used in the Vensim program, which facilitated the integration of mitigation measures to reduce the carbon footprint generated by the institution. As a result of these strategies, the carbon footprint was reduced by 68%, reaching a total of 27,7325 tons of CO_2eq.

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