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# Analysis of the Indirect Carbon Footprint Due to Electricity Consumption in an Environmental Services Company in Bucaramanga, Colombia

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Geological evidence accumulated over time reveals climatic variations on planet Earth. However, the current concern lies in acceleration of these changes, caused by industrial and service activities in society. This acceleration contributes to increase in magnitude and duration the effects of climate change, significantly affecting all forms of life on the planet.
In this context, an analysis of carbon footprint was conducted in an environmental consulting company located in Bucaramanga, Colombia. The goal was to quantify the company's contribution to climate change, specifically global warming, through the emission of greenhouse gases. To do this, a close life cycle assessment approach was adopted, using the current emission factor in Colombia. Through the characterization of the company's operational and administrative processes, an indirect emission of 1.39 tons of $CO_2$ eq per month was determined, which extrapolated to an annual emission of 16.68 tons of $CO_2$ eq. The laboratory process was identified as the main generator of $CO_2$ eq, contributing 86% of the total.
With the carbon footprint calculated, a detailed analysis of compensation strategies, environmental education and technological updating was conducted. These strategies were designed with the objective of optimizing electrical energy consumption and, consequently, mitigating the environmental impacts derived from $CO_2$ emissions. The implementation of these measures seeks not only to reduce the company's carbon footprint, but also to promote more sustainable and conscious practices in the business and social spheres.

## 1. Introduction

Climate change has been a focal point of contentious discussions spanning social, cultural, ethical, political, environmental, and economic spheres throughout history. In the 1970s, escalating environmental concerns, epitomized by energy crises and industrialization trends, spurred pivotal responses. These circumstances precipitated the establishment of the Club of Rome in 1970 and the convening of the United Nations Conference in Stockholm in 1972, marking the inaugural global dialogue on environmental matters. During this seminal conference, the ramifications of human activities on the environment were comprehensively assessed, paving the way for targeted preservation and enhancement objectives (Günter, 2012).
In 1985, a significant milestone was achieved with the adoption of the Vienna Convention, aimed at safeguarding the ozone layer, informed by collaborative research conducted by multinational corporations. Subsequently, in 1987, the Montreal Protocol was enacted, mandating the verification of chlorofluorocarbon emissions, known to pose a threat to the ozone layer. This protocol heralded a worldwide decline in chlorofluorocarbon consumption between 1988 and 1993 (Günter, 2012).
The 1992 Earth Summit held in Rio de Janeiro reiterated the objectives set forth by the 1972 United Nations Conference on the Human Environment, aiming to foster inclusive global partnerships. This summit yielded Agenda 21, a pivotal document addressing paramount environmental issues and instituting international accords such as the United Nations Framework Convention on Climate Change and the Convention on Biological

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Diversity. Concurrently, discussions on combating desertification ensued, leading to the formulation of the Kyoto Protocol. Signed by 155 nations and ratified in Colombia via Law 164 of 1994, this protocol sought to mitigate adverse anthropogenic environmental impacts (Díaz et al., 2009).
In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). Collaborating with the UN, the European Union, and 195 member nations, the IPCC conducts annual assessments of scientific, social, economic, and technical literature on climate change, with the overarching goal of promoting sustainable development to safeguard the well-being of present and future societies. Consequently, legislative frameworks and mechanisms were introduced to curb carbon emissions, including the inception of the carbon footprint concept to quantify greenhouse gas emissions from activities undertaken by countries, industries, or organizations. This initiative gave rise to mechanisms such as product or service life cycle analysis and carbon emissions trading, acknowledged as one of the most effective measures, boasting twenty global platforms for implementation (Hua et al., 2011).
In this context, businesses have been compelled to embrace enhanced energy efficiency measures, equipment, and processes, while also optimizing decisions within their supply chains to minimize their carbon footprint. Nonetheless, findings from a 2009 survey conducted by Accenture reveal that 37% of supply chains lacked awareness of emissions generated across their networks, with only 10% employing carbon footprint modelling through life cycle analysis, thereby hindering the development of successful sustainability initiatives (Accenture, 2009).Carbon footprint management within supply chains has garnered significant attention in academic research. Noteworthy studies, including those by Carbontrust (2006) and Cholette and Venkat (2009), have devised methodologies to assess the carbon footprint of products across supply chain networks. Sundarakani et al. (2009) proposed an analytical model for quantifying carbon emissions in both stationary and dynamic supply chain processes. In a similar vein, Chaabane et al. (2012) introduced a framework for designing sustainable supply chains. Meanwhile, Harris et al. (2011) delved into the relationship between overall logistics costs and environmental impact, particularly focusing on $CO_2$ emissions. Additionally, Bonney and Jaber (2010) explored the significance of inventory planning in the context of environmental sustainability, addressing crucial aspects of sustainable supply chain management.
Conversely, research endeavours such as the 2016 investigation by Silvia Solano and Edgar Ortiz, alongside Fabián Chavarría's 2014 study, have scrutinized carbon footprint quantification within the construction sector and at the National University of Costa Rica, respectively. These studies delved into intricate methodologies and innovative approaches to assess carbon emissions and environmental impacts within their respective sectors. Furthermore, assessments have been conducted within the agricultural domain, exemplified by Jose Moreno's 2011 inquiry and Andrade et al.'s work in 2015, shedding light on the environmental ramifications of agricultural practices and offering insights into sustainable resource management strategies.
These efforts underline the growing recognition and proactive measures taken to address climate change on both a global and local scale, particularly in terms of carbon footprint management across various industries and sectors. On the other hand, the use of standardized protocols for measuring the carbon footprint provides the industry with a holistic vision of its processes (hand in hand with life cycle analysis) in addition to providing the necessary information so that each time the limitations of the application of these methods are minor. This scientific article aims to further deepen these studies, with the aim of enriching understanding and encouraging the adoption of strategies to mitigate greenhouse gas emissions throughout the supply chain.

## 2. Methodology

The methodology employed in this study embraced a quantitative framework, aiming to quantify the carbon footprint resulting from electricity consumption and assess the environmental impact attributable to carbon dioxide equivalent emissions. This assessment focused specifically on laboratory analysis procedures and environmental consulting services provided by an environmental services firm. The research process was delineated into three distinct phases to ensure comprehensive analysis and robust findings. By systematically navigating through these stages, the study aimed to capture nuanced insights and provide actionable recommendations for carbon footprint management within the targeted sectors.

### 2.1 Process inventory

During the preliminary phase, an inventory of the company's equipment was carried out in all departments, reviewing the technical sheets of each equipment as well as measuring energy consumption using a voltmeter. This was followed by precise calculations of electrical energy consumption for each process, accompanied by the formulation of exclusion criteria based on the unit evaluated, ensuring a comprehensive evaluation.

### 2.2 Determination of the carbon footprint

In the second stage, precise inventory and calculation results were derived, using Colombia's $CO_2$ emission factor. Adherence to the GHG protocol (Ihobe S.A. & Gobierno Vasco, 2012) guaranteed accuracy. These results provided crucial information on the environmental impact and carbon footprint associated with each process within the company's operations, facilitating informed decision making.
To determine the electrical energy consumption, essential data such as equipment power ratings, duration of usage, and total equipment count are required. These data are then multiplied to calculate the total energy consumption. This value is crucial for assessing the carbon footprint, with the emission factor provided by the Mining-Energy Planning Unit of Colombia used in the calculation. Eq(1) illustrates the detailed procedure utilized to ascertain the energy consumption of each equipment within each process, ensuring accuracy in the assessment.

$$CO_2eq = Eq \times kW \times t \times EF \qquad (1)$$

Where:
$CO_2$eq: Carbon dioxide equivalent
Eq: Amount of equipment
kW: Equipment power
t: Use time according to the functional unit
EF: Emission factor

### 2.3 Analysis of alternatives

In the third stage, bespoke strategies were devised to mitigate the identified environmental impacts. These strategies centered on optimizing energy efficiency, integrating cutting-edge clean technologies, and implementing robust sustainable environmental management practices. The overarching objective was to propose tangible and effective measures capable of significantly diminishing the company's carbon footprint, thereby fortifying its steadfast commitment to environmental sustainability and corporate responsibility.

## 3. Results and discussion

Considering the proposed functional evaluation unit, the processes were meticulously characterized, leading to their classification into three main categories. The first category encompasses the hydrobiological analysis subprocess, involving comprehensive assessments, both quantitative and qualitative, of various aquatic components, including phytoplankton, zooplankton, periphyton, benthic macroinvertebrates, fish, macrophytes, and macroinvertebrates associated with macrophytes. Additionally, the microbiology laboratory process entails analyzing samples to detect total coliforms, thermotolerant coliforms, and *Escherichia coli* in water samples. Furthermore, the water laboratory process is dedicated to evaluating the physical and chemical properties of diverse water samples, encompassing the analysis of metals, non-metallic inorganic compounds, and organic components present in wastewater and receiving waters. Finally, the administrative process encompasses a spectrum of departments, including commercial, customer service, financial, directorial offices, field professionals' office, typing, client reception, accounting, systems, projects, and occupational health and safety. This comprehensive process also entails the management of equipment related to ventilation, lighting, computing, and peripheral devices.The analysis of the carbon footprint, conducted through the employed methodology, enables a comprehensive evaluation across various criteria. In the process analysis, notable significance is observed in the results, particularly in the water laboratory, which recorded 721,349 kg of $CO_2$eq, followed by the microbiology laboratory with 458,177 kg of $CO_2$eq (accounting for 52% and 33% respectively), as illustrated in Figure 1.

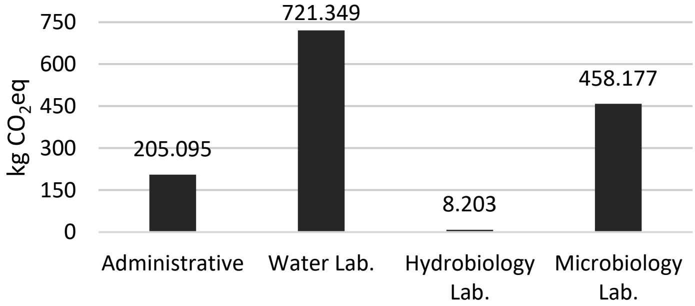


*Figure 1. Carbon footprint of each process*

It discerns significant carbon footprints within the company's service spectrum, notably in the hydrobiology laboratory, microbiology laboratory, and water laboratory processes. Noteworthy findings include elevated carbon emissions in the zooplankton analysis, total coliforms analysis, and heavy metals analysis, showcasing values of 0,492 kg $CO_2$eq, 111,82 kg $CO_2$eq, and 412,029 kg $CO_2$eq, respectively as illustrated in Figure 2.

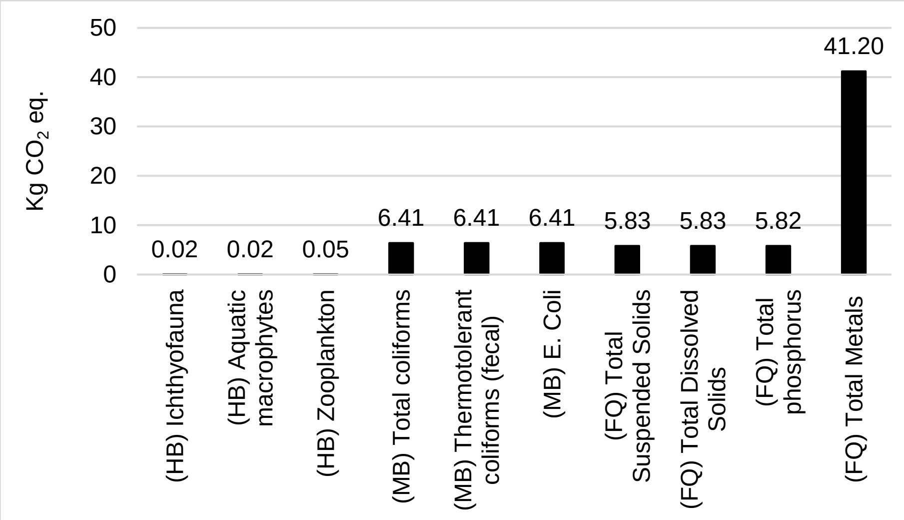


*Figure 2. Carbon footprint by parameters: (FQ) Water laboratory, (MB) Microbiology laboratory and (HB) Hydrobiology laboratory*

The contribution to the carbon footprint generated by parameter is related to the number of analyses quoted per sample in each month, this is illustrated in table 1. Where when evaluating the company's energy consumption by consolidating the analyzes carried out in In the first quarter of 2023, it was found that the greatest contribution to the carbon footprint by parameter quoted in the month of January corresponds to total metals with 15327,470 kg of $CO_2$ eq, in the month of February to nitrates with 27935,549 kg of $CO_2$ eq and in the month of March to total metals with 8652,604 kg of $CO_2$ eq, making it evident that the subprocess responsible for the largest global contribution of the carbon footprint by quoted parameters corresponds to the water laboratory. This evaluation provides valuable information on areas that justify environmental intervention and optimization strategies, since they are linked to direct and indirect environmental impacts due to the consumption of electrical energy such as atmospheric pollution by greenhouse gases, degradation of ecosystems, increase in respiratory diseases, among others.

*Table 1. 2023 quarterly carbon footprint*

| **Parameter** | **Carbon footprint generated per sample analysed (kg $CO_2$ eq)** | | |
|---|---|---|---|
| | **January** | **February** | **March** |
| $BOD_5$ (Biochemical Oxygen Demand) | 320,038 | 411,477 | 200,463 |
| COD (Chemical Oxygen Demand) | 33,827 | 47,804 | 20,661 |
| Total phosphorus | 564,969 | 862,015 | 634,863 |
| Fats and oils | 287,497 | 402,120 | 169,116 |
| Hydrocarbons | 31,981 | 67,406 | 33,457 |
| Dissolved metals | ---- | 7,936 | ---- |
| Total Metals | 15327,470 | 27935,549 | 8652,604 |
| Nitrates | 591,670 | 771,744 | 373,009 |
| Ammonia nitrogen | 26,068 | 39,449 | 17,994 |
| Total Dissolved Solids | 174,884 | 279,815 | 326,451 |
| Total Suspended Solids | 804,468 | 1311,633 | 495,506 |
| E. coli | 19,227 | 32,044 | 70,498 |
| Thermotolerant coliforms (fecal) | 281,992 | 455,032 | 185,858 |
| Total Coliforms | 288,400 | 506,303 | 185,858 |
| Mesophile Count | ---- | ---- | 13,729 |

Upon detailed examination of the carbon footprint results obtained from each laboratory, significant values are evident, primarily due to the extensive use of air conditioning units aimed at maintaining optimal temperature and humidity levels within workspaces. This prominence of energy consumption by air conditioning systems overshadows the importance of equipment dedicated to specific functions crucial for the company's services, as visually represented in Figures 3a and 3b. These findings underscore the substantial impact of environmental control measures on overall energy usage within the company's operational framework.

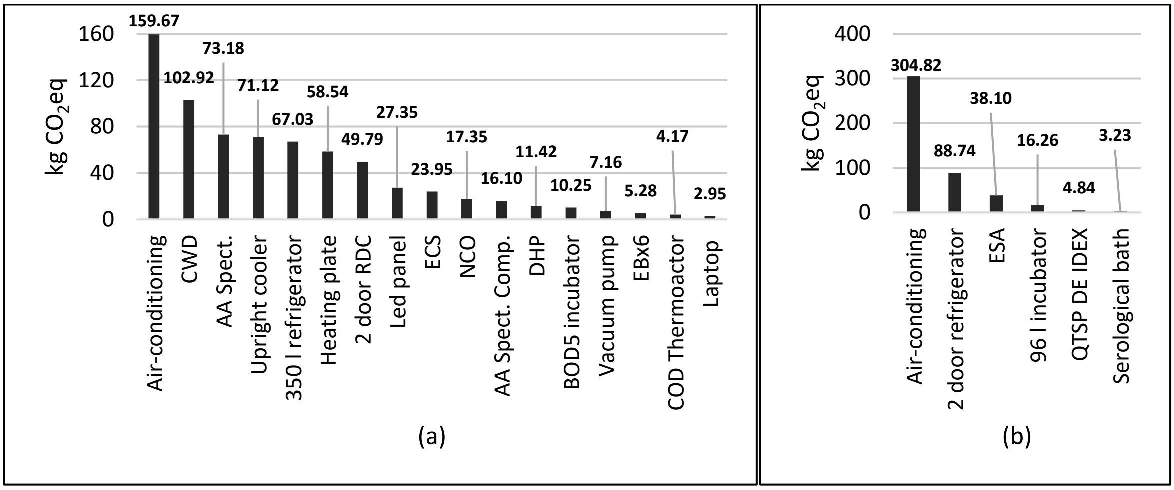


*Figure 3. Carbon footprint by equipment: (a) Water laboratory, (b) Microbiology laboratory*

Following the comprehensive assessment of the carbon footprint, a set of mitigation strategies was developed adapted to the specific circumstances of the company and the geographical context. Recognizing the importance of profitability, strategies were meticulously designed to leverage the company's locational advantages. One of the key proposals involved the implementation of a reforestation initiative, which not only aimed to mitigate carbon emissions but also fostered collaborative partnerships between the company, its customers and local environmental authorities. This strategic collaboration seeks to sustain and improve existing green carbon sinks, taking advantage of the unique attributes of native species such as the oak (*Tabebuia rosea*), managing to store up to 21,4 tons per hectare already in its adulthood, and the red ceiba (Bombacopsis *quinata*) with a capture of up to 17 tons per hectare in already developed specimens (González-Martínez, et al., 2013). This strategy was proposed keeping in mind the native species of the region where the company is located.

Additionally, it is advised that the company consider upgrading outdated equipment with older technologies, as they contribute to higher electricity consumption and, consequently, increased $CO_2$ equivalent emissions. This upgrade should encompass ventilation, lighting, and energy backup systems, potentially reducing total emissions by up to 30%. Such upgrades would not only enhance energy efficiency but also align with the company's commitment to sustainability and environmental responsibility.

## 4. Conclusions

Throughout the analysis carried out, it became clear that the laboratory analyses, sampling processes and environmental consulting services provided by the company constitute a substantial source of greenhouse gas emissions. These emissions directly contribute to increased global warming, underscoring the urgency of taking proactive measures such as meticulous documentation detailing all equipment that relies on electrical energy, ensuring its condition and operational efficiency. This monitoring allows you to quickly identify possible malfunctions or inefficiencies that could inadvertently increase the company's carbon footprint and subsequently cause an increase in expenses attributed to electrical energy consumption.

During field inspections, data collection, and analysis of results, it became clear that the laboratory process significantly influences the consulting company's carbon footprint. This segment alone accounted for an emission of 1392,82 metric tons of $CO_2$ equivalent, constituting 86% of the total carbon footprint. Further examination within the laboratory process revealed notable contributions from the water laboratory and microbiology laboratory subprocesses, recording quarterly emissions of 721,349 and 458,177 metric tons of $CO_2$ equivalent, respectively.

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