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An Electronic Voting System as a Tool to Reduce the Carbon Footprint at a Public Higher Education Institution in Colombia

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Abstract: The aim of this research is to demonstrate that a green information and communication technology (green ICT) strategy, such as an online voting system (OVS) for democratic processes at a higher education institution (HEI) in Colombia, could reduce the carbon footprint and contribute to the environment. The OVS was designed, tested, and successfully implemented at the mentioned institution. After implementing the OVS in democratic processes, it became possible to observe a reduction in the carbon footprint to zero in aspects such as energy, gasoline, and paper consumption by measuring the mentioned items segmented by year (from 2011 to 2018) and academic population participating in democratic processes (students, graduates, and professors). The institution no longer needed to use facilities, thus reducing energy consumption and eliminating the need for paper ballots. Additionally, many voters no longer needed to travel to the institution to vote. It is possible to implement other strategies based on ICT to further reduce the carbon footprint and raise awareness among the academic population, with the goal of minimizing the impact of human activities on the planet. Research around OVSs is focused on technical topics such as security improvements rather than humanitarian aspects like using software to reduce the environmental impact of human activities. In this order of ideas, thanks to the implemented system, the HEI reduced equivalent emissions from average energy consumption (121.8 KWh per year) from 19.8 KgCO2e per year to zero and equivalent emissions from average paper consumption (37.17 kg per year) from 11.530 KgCO2e per year to zero, contributing to reducing the carbon footprint from democratic processes.

Keywords: green IT, carbon footprint, online voting system, energy consumption.

哥伦比亚一所公立高等教育机构采用电子投票系统减少碳足迹

摘要：本研究旨在证明绿色信息和通信技术(绿色信息和通信技术)战略（例如哥伦比亚高等教育机构(黑龙江)的民主进程在线投票系统(光学成像系统)）可以减少碳足迹并为环境做出贡献。光学成像系统已在上述机构设计、测试并成功实施。在民主进程中实施光学成像系统后，通过按年份（2011年至2018年）和参与民主进程的学术人口（学生、毕业生和教授）测量上述项目，可以观察到能源、汽油和纸张消耗等方面的碳足迹减少到零。该机构不再需要使用设施，从而减少了能源消耗并消除了对纸质选票的需求。此外，许多选民不再需要前往该机构投票。可以实施基于信息和通信技术的其他策略，以进一步减少碳足迹并提高学术界的认识，目标是最大限度地减少人类活动对地球的影响。围绕光学成像系统的研究主要集

中在技术主题上，例如安全性改进，而不是人道主义方面，例如使用软件减少人类活动对环境的影响。按照这种思路，由于实施了该系统，黑龙江将平均能源消耗（每年121.8千瓦时）的等效排放量从每年19.8千克二氧化碳当量减少到零，将平均纸张消耗（每年37.17千克）的等效排放量从每年11.530千克二氧化碳当量减少到零，为减少民主进程的碳足迹做出了贡献.

关键词：绿色它、碳足迹、网上投票系统、能源消耗。

1. Introduction

Since 2012, in Colombia, the presidential resolution of Zero Paper Consumption (ZPC) [1], approved by the former president Juan Manuel Santos, has paved the way to reduce paper consumption in public institutions, including ministries (e.g., the Ministry of Information Technology and Communications) [2] and higher education institutions (HEIs), among others, to contribute to the Sustainable Development Goals (SDGs) [3]. With this reduction in paper waste, the Colombian state aims to simultaneously address several SDGs such as SDG6 (clean water and sanitation), SDG10 (reducing inequalities), SDG12 (responsible consumption and production), SDG13 (climate action), SDG15 (life on land), and SDG16 (peace, justice, and strong institutions). This is because the paper fabrication process leads to air and water pollution, deforestation, habitat destruction, and greenhouse gas emissions, among other environmental issues.

Colombia may seek to follow the path established by countries like Bulgaria and the rest of the European Union, as documented by the United Nations and the European Union [4], [5]. China has demonstrated reductions in various types of waste, including paper [6], and improvements in waste management, decreasing its carbon footprint. Other countries and institutions around the globe may also realize the benefits of adopting green IT strategies to replace procedures that rely on paper consumption, gasoline, and energy by incorporating digital or non-digital tools [7].

For instance, to reduce paper consumption, it may be necessary to utilize various types of technologies and tools, including both hardware and software [8], [9], in accordance with an organization's needs and requirements. An example of such a strategy is e-voting, also known as an online voting system (OVS). If e-voting is implemented, a HEI could consider this action as a dual-purpose initiative: a democratic exercise and a strategy to reduce the carbon footprint.

In this process, voters submit their votes electronically through a website from any location for the election of representatives [10]. This can lead to a reduced consumption of various resources, including water, electricity, fuel, and paper. These resources are integral to every stage of the election process, from paper fabrication to final voting, as HEIs need to use these resources to ensure the normal progression of the democratic process. Throughout this process, emissions falling under Scopes 1, 2, and 3 are generated.

In addition to the mentioned reduction in consumption, it is essential to emphasize the decrease in fuel consumption within the academic community. With the ability to vote from remote locations, academic community members no longer need to travel to the HEI, resulting in a reduction in fuel consumption and, subsequently, a decrease in CO2 emissions.

In this research, the researchers decided to design and implement an e-voting system at the Higher Education Institution "Unidad Central del Valle del Cauca (UCEVA)", located in Tuluá, Valle del Cauca, Colombia. This system is intended for use in various election processes, including those for students', graduates', and professors' representatives. It serves as a testing mode with the aim of potential future deployment in university presidential elections and as a tool to contribute to several Sustainable Development Goals (SDGs), such as SDG6, SDG10, SDG12, SDG13, SDG15, and SDG16, in alignment with the Zero Paper Consumption (ZPC) presidential resolution [11].

2. Methodology

This study was conducted using a mixed approach. The data obtained were collected and integrated into the study in a complementary manner, which facilitated the acquisition of a more comprehensive and in-depth understanding of the research problem (Fig. 1).

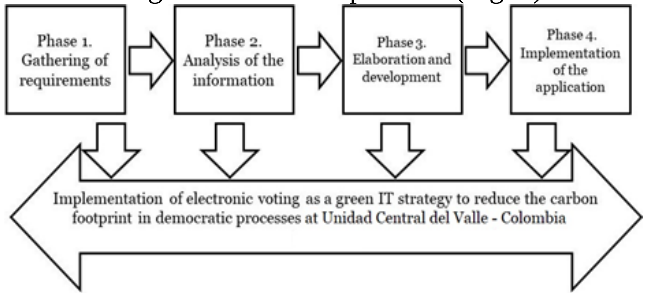

Fig. 1 Methodology (Developed by the authors)

2.1. Phase 1: Gathering of Requirements

In this initial phase, the research design was carefully planned, and the project team was structured, involving a project manager, a Systems Engineering student, and two teaching advisors specializing in software engineering. Data were gathered by conducting interviews with the administrative personnel such as the General Secretary, their assistant, and the IT office engineers at the institution. These interviews provided direct insights from key sources regarding UCEVA's election processes.

2.2. Phase 2: Information Analysis

During this phase, the team verified and analyzed relevant documents on the research topic. This encompassed internal documents, reports, records, and any other information pertinent to the research.

2.3. Phase 3: Elaboration and Development

At this stage, the team defined the technologies to be used in the project, such as the ICONIX development methodologies. These methodologies facilitate the handling of scenarios, including the incremental model, which involves developing detailed models, use cases, and sequence diagrams. These methodologies outline user interaction, support model-driven design, and assist in software visualization and documentation.

Additionally, for programing and coding, the team employed the Atom code editor, the MySQL database management system, the Apache web server, and interpreters for scripting languages like PHP (XAMPP) and Laravel (framework). In addition, tools such as Sybase Power Designer and the Enterprise Architect interface platform were used in the development process.

2.4. Phase 4: Implementation of the Application

During this phase, the implementation of the electronic ballot box was executed. Scrutiny was conducted within UCEVA for the different instances mentioned earlier. The implementation involved incorporating interactivity, accessibility, security, and navigation that were suitable for electoral processes.

3. Development of the Solution

The research conducted significantly improved the election processes at "Unidad Central del Valle del Cauca" by enhancing data collection activities. It also identified the potential for implementing an information system to centralize electronic voting control. The study followed the methodology outlined in the reference, with a focus on user interaction and requirements analysis.

Class diagrams were created on the basis of these requirements to represent system functionalities, and software development specifications were established for the main menu and initial system interfaces. During the preliminary analysis and design phase, use cases were constructed as primary action sequences, allowing for alternative and exception flows.

The ICONIX methodology emphasized visual representations of object interactions, simplifying the evaluation of narrative text and the identification of participating objects in each case. The design phase involved specifying behavior through sequence diagrams that depicted message exchanges between different objects for each use case. Collaboration diagrams were used to illustrate the object interactions.

3.1. System Architecture

For the launch of the information system, the Laravel platform was used as the development framework, which recommends the use of routes in the traditional MVC (Model-View-Controller) architecture. When the user accesses the application link on the web directly from the browser, it initiates an HTTP GET request.

This request is then directed to the Laravel route file, where it is validated to check if the route exists. If the route exists, it redirects to the controller, which contains the system's logic. The controller can interact with the model (optionally) to retrieve information from the database.

Once this information is obtained, it returns to the controller, which invokes a view. Finally, the view is loaded and displayed in the browser (Fig. 2).

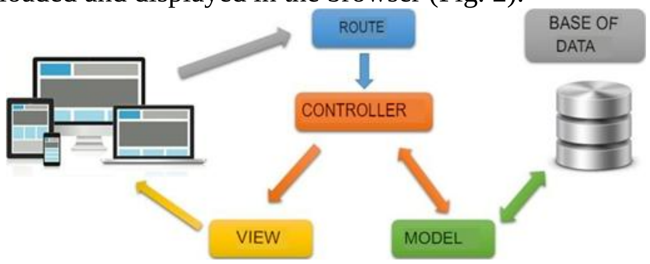

Fig. 2 System architecture (Developed by the authors)

3.2. Description of Design Tools

The application was developed using the PHP Laravel framework, incorporating the JavaScript programing language and the jQuery library. jQuery facilitates client-side data manipulation and allows requests to be sent to the PHP programing language for server-side information management. This encompasses tasks such as data creation, deletion, querying, and updating, all of which are managed through the MySQL database engine.

The administration of the MySQL database is facilitated by the phpMyAdmin program, which facilitates the storage of all application data. For the frontend visual aspect, Bootstrap was employed, and when integrated with Laravel, it becomes an integral part of the Blade template model.

3.3. Application Description

The application features a login system accessed through an email and password, employing AES-256 (Advanced Encryption Standard) encryption. AES-256 is a symmetric encryption algorithm that utilizes a block cipher scheme and is one of the encryption standards adopted by the United States' government through the National Institute of Standards and

Technology (NIST). An example of a login page is shown in Fig. 3. The voting page is located on UCEVA's website.

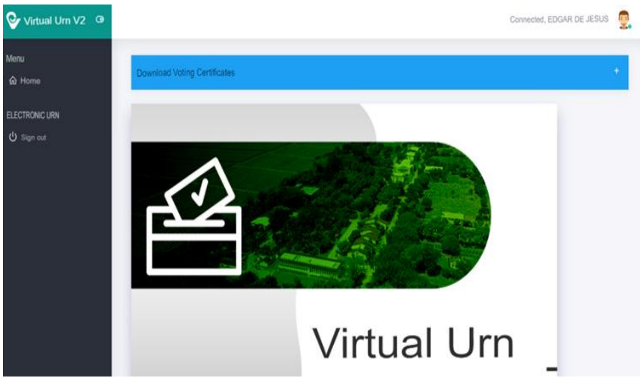

Fig. 3 Interface for accessing the electronic voting system (Developed by the authors)

4. Results and Discussion

After the system was developed and deemed ready for implementation, it was imperative to conduct testing in a range of democratic elections, including elections for the Professors' Representative to the Board of Directors, the Students' Representative to the Board of Directors, the Graduates' Representative to the Board of Directors, and other smaller election processes [12].

Over the period of 2012-2022, approximately 2,620 individuals per year, comprising professors, graduates, and students, responded to UCEVA's call for participation. Representatives were elected without any issues arising from the involved parties [13]–[16].

After the implementation of the E-voting system, an analysis of environmental impacts commenced, comparing the traditional paper voting system (TPVS) with the OVS at UCEVA.

The analysis considered various variables such as energy consumption, paper usage, and fuel consumption of voters' vehicles. Fig. 4 illustrates the energy consumption in three locations at UCEVA (the multi-sport facility, Auditorium 1, and Auditorium 2) that hosted TPVs over the last 10 years before the implementation of the OVS.

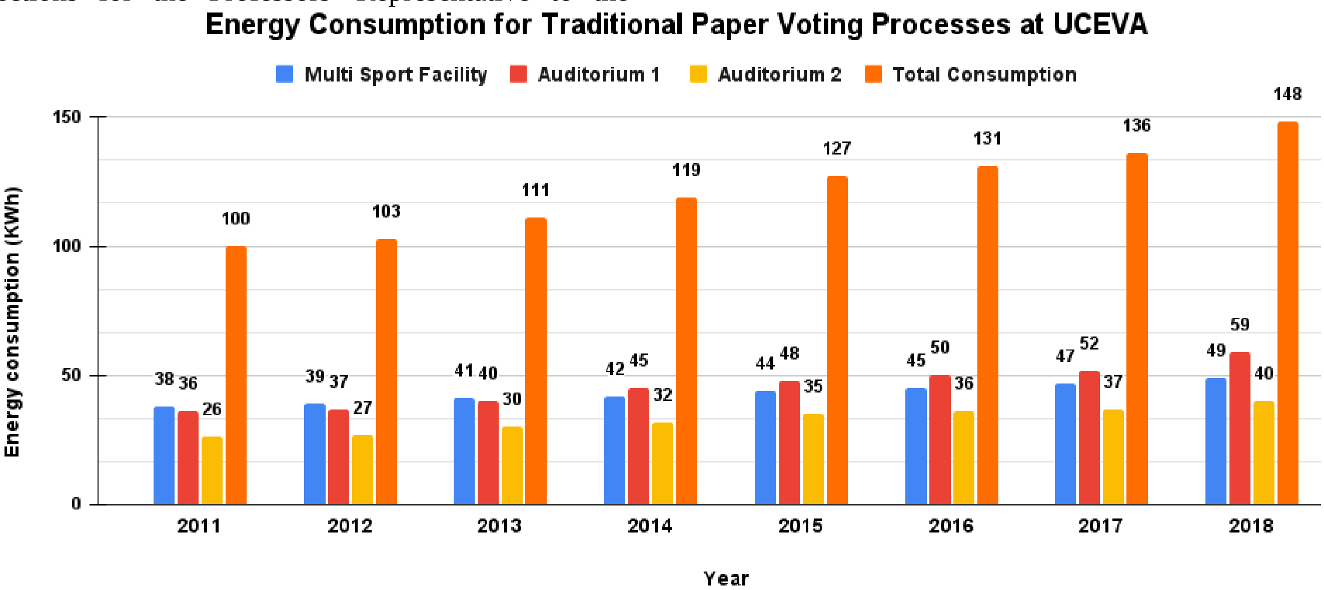

Fig. 4 Energy consumption for traditional paper voting processes at UCEVA (Developed by the authors)

As shown in Fig. 4, the total energy consumption (in one day) in all three locations used for election processes increased annually, rising from 100 KWh in 2011 to 148 KWh in 2018, representing an approximate 50% increment. According to the Energy Mining Planning Unit of Colombia [17, 18], the carbon footprint can be categorized into three scopes:

Scope 1: This includes the direct burning of fossil fuels by the agency (company/institution) reporting carbon dioxide emissions.

Scope 2: This comprises the consumption of fossil fuels generated by a third party to produce electricity, heating, steam, and/or cooling services, which are then purchased by the agency (company/institution) reporting carbon dioxide emissions.

Scope 3: This involves the consumption of fossil fuels generated by a third party to provide services consumed by the user reporting carbon dioxide emissions. Examples of Scope 3 activities include the extraction and production of purchased materials, the transport of acquired fuels, and the use of products and services sold [19].

4.1. Carbon Footprint due to Energy Consumption

The carbon footprint related to energy consumption fits Scope 2. It is possible to calculate its equivalent CO2eq using the online calculator proposed by the Energy Mining Planning Unit of Colombia (UPME) [20]. This calculation can be expressed as follows:

$$HdC = DA \times Fe \tag{1}$$

Here, HdC corresponds to the carbon footprint, DA represents the consumption activity data, and Fe is the emission factor issue by the UPME (Utilizing Equation (1) and the energy consumption values year by year, the carbon footprint (HdC) can be calculate for the years 2011 to 2018, as shown in Table 1.).

Table 1 Equivalent emissions from energy consumption (Developed by the authors)

Year	Consumption (kWh)	Emission Factor (kgCO2/kWh)	Total Emissions (kgCO2)
2011	100	0.126	12.6
2012	103	0.15	15.45
2013	111	0.2	22.2
2014	119	0.19	22.6
2015	127	0.19	24.13
2016	131	0.21	27.5
2017	136	0.11	14.9
2018	148	0.13	19.2
		Total	158.58 kgCO2e

According to Table 1, UCEVA generated C02eq equivalent emissions from 2011 to 2018, totaling 158.58 kgCO2e. However, these emissions decreased to zero as UCEVA began using the OVS, and these locations were no longer used for this purpose.

Fig. 5 depicts the estimated participant population in the democratic process, including students, graduates, professors, and others.

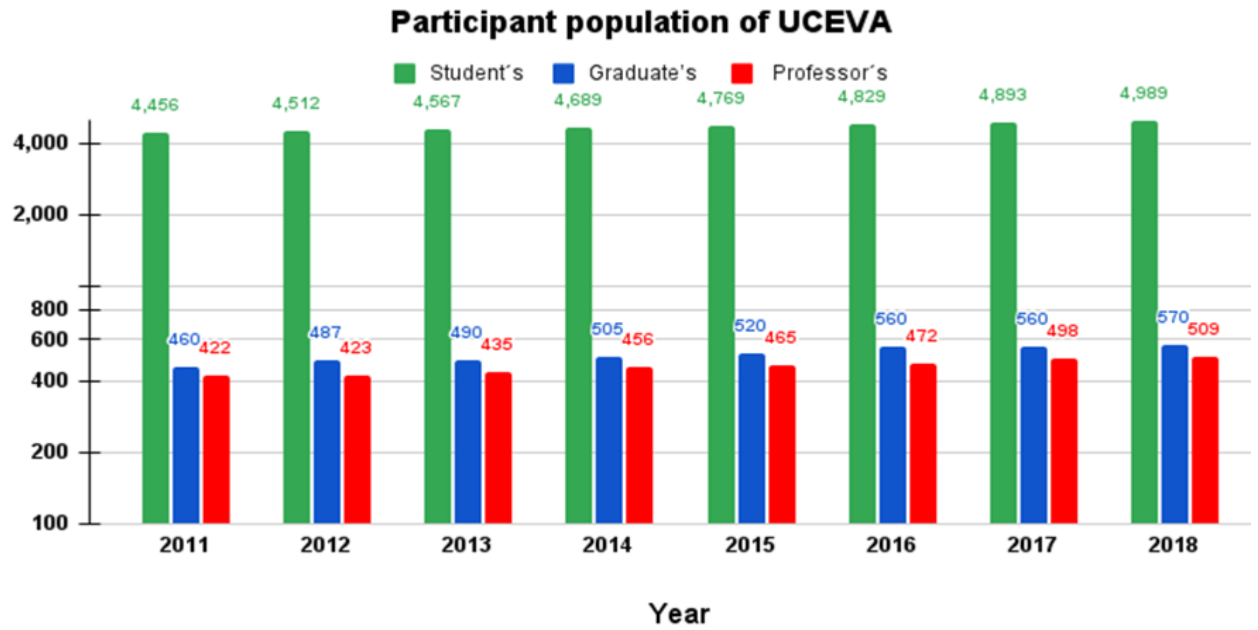

Fig. 5 Participant population in democratic processes (Developed by the authors)

4.2. Carbon Footprint due to Paper Consumption

To ensure the rights of all participants in these processes, it was necessary to have an adequate supply of 6-g bond paper voting ballots in stock. As shown in Fig. 5, the amount of paper required increased linearly with the academic population, from 35 kg in 2011 to 39.4 kg in 2018, indicating an increment of approximately 8.33% (Table 2).

Table 2 Paper consumption (Developed by the authors)

Year	UCEVA's Participant Population	Bond paper units	Paper (kg)
2011	5338	5838	35.028
2012	5423	5923	35.528
2013	5492	5992	35.592
2014	5677	6177	37.062
2015	5754	6254	37.524
2016	5866	6366	38.196
2017	5951	6451	38.706
2018	6068	6568	39.408
	Total	43568	297.414

The carbon footprint associated with paper consumption fits Scope 3, and it is possible to calculate its equivalent CO2 emissions using the equation proposed by [19]. For the calculation of the carbon footprint from paper consumption, from the base year 2011 to 2018, a total of 297.414 kg of paper was used.

This quantity is then multiplied by the emission factor, which, as per the values adapted from [21] and [22], is quantified by the following equation:

$$Carbon\ footprint = Paper\ weight(Kg) \cdot Emission\ factor \quad (2)$$

Substituting the total paper weight (297.414 kg) and emission factor in (2), it is obtained carbon footprint for paper consumption in the mentioned democratic processes:

$$Carbon\ footprint\ = 297.414\ Kg \cdot 3\ KgCO2/Kg\ paper$$
$$= 892.242\ \text{KgC02eq} \quad (3)$$

These emissions decreased to zero as the institution began using the OVS, and paper was no longer used.

4.3. Carbon Footprint due to Fuel Consumption

The average population of UCEVA's community, including students, graduates, and professors, who traveled from their places of origin to the institution to participate in democratic processes between 2011 and 2018 is summarized in Table 3.

Table 3 Academic community with cars (Developed by the authors)

Year	Students	Graduates	Professors
2011	1522	208	391

Continuation of Table 3

2012	1568	249	401
2013	1589	271	415
2014	1613	291	427
2015	1712	304	436
2016	1873	317	438
2017	2014	328	441
2018	2489	328	451
Average	1797	288	425

To calculate the fuel consumption of a gasoline engine, the following formula is applied [20]:

$$FC = \frac{0.1154}{D}(0886HC + 0.429CO + 0.273CO2) \quad (4)$$

where FC (L/100 km) is fuel consumption, HC (g/km) is hydrocarbon emission, CO (g/km) is carbon monoxide emission, CO2 (g/km) is carbon dioxide emission, and D (kg/L) represents the fuel density at 288 K.

According to Table 3, the average number per year of total participants' vehicles on the voting days between 2011 and 2018 was approximately 2510. These participants traveled in various types of vehicles, including motorbikes and different models of cars, such as sedans, hatchbacks, and SUVs. Given this information, the average gasoline tank capacity among the vehicles used is estimated to be 2,200 cm^3. The academic population resides both inside and outside Tuluá.

On average, each participant is estimated to travel approximately 15 km (about 9.32 mi) from their point of origin to the institution. The fuel consumption for the entire participating population, which comprises an average of 2510 vehicles per year, is then calculated by substituting HC = 0.1 g/km, CO = 1 g/km, CO2 = 168 g/km, and fuel density = 0.75 kg/l in (3). This calculation results in an estimated consumption of 7.1 L of gasoline per vehicle, making the total fuel consumption by the 2510 vehicles equal to 17912.8 L.

Calculating the amount of carbon dioxide (CO2) emitted by the combustion of 17912.8 liters of gasoline uses the density of gasoline and the CO2 emission factor [23]: Amount of CO2 (kg) = Volume of gasoline (liters) × Density of gasoline (kg/l) × C02 emission factor (kg CO2/kg gasoline).

To obtain the CO2 emission factor, refer to the information provided in the search results. According to the EPA, the amount of carbon dioxide emitted per gallon of gasoline burned is 8.89 × 10-3 metric tons, which is equivalent to 8.887 grams of CO2 per gallon of gasoline consumed [24]. To convert this quantity to kilograms and liters, it can be divided by 1000 and 3.78, respectively. This calculation results in 0.002351 kg of CO2 per kilogram of gasoline.

The density of gasoline can vary on the basis of its type, but for the purposes of this calculation, an average value of 2 kg/liter can be used [25]. A compensation factor of 120 is used regarding different types of vehicles used by the academic community. Therefore, the amount of CO2 emitted by the combustion of 17912.8 L of gasoline can be calculated as follows:

$$Amount\ of\ CO2(Kg) = 17912.8l \cdot 2(Kg/l) \cdot 0.00235106(KgCO2/Kggasoline) \cdot 120 = 10107.3\ \text{KgCO2} \quad (5)$$

Hence, the combustion of 17912.8 L of gasoline results in the emission of approximately 10 tons of carbon dioxide (CO2). This represents the quantity of carbon dioxide that was no longer released into the atmosphere because of the use of the virtual ballot box.

4.4. Comparison with Other Studies

The adoption of digitalization in HEIs has emerged as a strategic initiative to curtail resource consumption, aligning with global sustainability goals. An empirical study [26] showed that transitioning from non-digital to digital processes significantly decreases paper usage in administrative operations. This finding aligns with the results obtained in our research, which also indicated a reduction in paper consumption. In concordance with this, [27] emphasizes the environmental impact of paper reduction. Their findings underscore the positive correlation between electronic voting implementation and diminished demand for paper resources in academic settings. As an example of this, more than 35 kg of paper ballot per year were no longer needed due to the substitution of paper by the website platform for democratic process within UCEVA.

Beyond paper conservation, [28] presented an insightful perspective on the energy-saving potential of electronic voting systems. Their research uncovered that the efficient processes of digital voting systems result in a significant reduction in electricity consumption. This aligns with the findings of our research, which showed that an average of 121.8 KWh per year was saved when UCEVA ceased using its facilities for representative elections. In sum, the collective evidence from [26]-[28] underscores the multifaceted environmental benefits of implementing electronic voting systems in higher education institutions, offering a comprehensive and sustainable solution to mitigate human activities on the planet.

5. Conclusion

This study examined the effects of introducing an OVS on the election processes for students, graduates, and professors' representatives at HEI Unidad Central del Valle del Cauca from 2011 to 2018.

Through the implementation of the OVS, it was discovered that approximately 10 tons of carbon dioxide emissions from gasoline consumption (equivalent to over 17,000 liters of gasoline from 2011 to 2018) were eliminated. Additionally, more than 1 ton of carbon dioxide equivalent emissions were avoided due to the reduction in paper ballot usage (approximately 297 kg from 2011 to 2018) and electricity consumption (over 900 kWh from 2011 to

2018) as a result of the decreased need for physical facilities. Students make up over 80% of the academic population that utilizes resources such as voting paper and gasoline. With this initiative, UCEVA achieved optimization in the utilization of resources, time, and rental spaces. It also improved the logistics of distributing personnel responsible for vote counting and verification. As a result, the costs related to transportation, storage, waste generation, and disposal were reduced by 100% compared to the years before its implementation.

To accurately compare the effectiveness of applied strategies, it is recommended to calculate the equivalent emissions of all devices (laptop, PC, mobile phone, and tablet) used by voters that allow them to connect to the institution's website to vote for community representatives. To do so, it is necessary to characterize the use of such electronic devices by the community. Also, it is recommended a socialization campaign to create consciousness among academic community looking to create a real change in future professionals and society itself, measurable with surveys that allows to indicate if the implementation of such strategies have impacted as is expected. For future work related to measuring the impact of such strategies, it would be necessary to characterize the transportation vehicles used by the academic community. It is also recommended to optimize OVSs periodically to improve their energy and time consumption, minimizing the environmental impact of the system.

According to these results, UCEVA may try to implement other strategies to minimize the environmental impact of human activities on the planet by the digitalization of processes that typically require significant resources such as energy, gasoline, and paper. The significant participation of students, accounting for more than 80% of the total population, in institutional electoral processes through the OVS showcased the effectiveness of this strategy in engaging students. This demonstrates UCEVA's influence over its academic community, highlighting the institution's commitment to mitigating the impact of human activities on the environment while also prioritizing participation in institutional processes. Also, UCEVA's influence on the region may lead to other institutions academic or not to implement such kind of strategies to mitigate climate change.

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