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System Dynamics Modeling For Co2 Emission Reduction Through Paper Replacement By Electronic Processes In A Public Institution

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Abstract:
Background: *The study addresses the importance of reducing CO2 emissions to mitigate climate change, focusing on replacing paper use with electronic processes in a public institution. Paper usage significantly contributes to CO2 emissions, while electronic management can reduce these emissions. The study is a proposal that encouraged the electronic processing of administrative tasks to ensure speed. Decree 8.539/2015 made the electronic processing of documents in federal public administration mandatory. The Judiciary branch was a pioneer in implementing electronic processes in Brazilian public institutions. For this article, the Systems Dynamics (SD) methodology was used, and a simulation model was developed to assess the environmental impact of process automation at the Federal University of Santa Maria (UFSM). Key results highlighted the reduction of CO2 emissions and cost savings. The implementation of digital processes resulted in a significant reduction in CO2 emissions, and the adoption of electronic processes generated financial savings. Therefore, System Dynamics modeling is a useful tool for institutions to plan scenarios and promote environmental sustainability. The transition to electronic processes in public institutions can bring significant environmental and economic benefits.*

Keyword: *Electronic Processo ; Public Institution, System Dynamics*

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I. Introduction

Climate change is already a major challenge for today's society, and significant reductions in net greenhouse gas (GHG) emissions will be needed to mitigate further problems and move toward a sustainable future (Peixer, 2019). Currently, there is a large body of research and efforts to make this reduction effective and reverse a climate process with worrying trends for humanity.

The greenhouse effect is a natural phenomenon that occurs due to the presence of gases in the atmosphere that can retain part of solar radiation and maintain the stability of global average temperatures. However, excess GHGs, such as CO2, CH4, N2O, and halocarbons, have caused a significant imbalance in the Earth's energy balance, raising the global average temperature.

Human activities are the main drivers of these climate changes, with CO2 emissions from fossil fuel burning, biomass burning, industrial processes, and deforestation practices being identified as the primary contributors to global warming (IPCC, 2021). According to the World Meteorological Organization (WMO), the concentration of this gas in the atmosphere increased by 147% compared to pre-industrial levels, reaching 407.8 parts per million (ppm) in 2018. This CO2 accumulation in the atmosphere contributed to a 1.1°C rise in global average temperature in 2019, with the last five recorded years being the hottest in history (WORLD METEOROLOGICAL ORGANIZATION, 2019).

The effects of global warming on the environment, such as melting ice sheets, rising sea levels, changes in precipitation patterns, and the occurrence of extreme events like droughts and floods, have become more frequent and intense. Antarctica has lost about 148 billion tons of ice per year from its ice sheet since 2002, while the Arctic ice sheet has shrunk by 13.1% per decade since 1979 (NASA, 2020). Sea levels have risen by 178 mm in the last 100 years and are rising at an average rate of 3.3 mm per year since 1993. Additionally, the indirect effects of warming affect socioeconomic development, human health, migration and displacement, food security, and terrestrial and marine ecosystems (IPCC, 2021).

In the current state of climate emergency, there is a great need to bring together efforts to establish national and international policies to reduce greenhouse gas emissions and limit the impacts of these changes. The creation of the United Nations Framework Convention on Climate Change (UNFCCC), adopted by 197 signatory countries in 1992 during the Rio-92, was a milestone in global mobilization to develop strategies to prevent harmful human activities from interfering with the climate system (UNFCCC, 2020).

The Paris Agreement, the current treaty in effect, was ratified in 2016 during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-21). The agreement set targets to keep global warming below 2°C, aiming to limit it to 1.5°C by 2100. The implementation of the agreement's goals is based on Intended Nationally Determined Contributions (iNDCs), where signatory governments develop their own GHG emission reduction commitments (EPE, 2018). After ratifying and enacting the Paris Agreement in each country, these goals became Nationally Determined Contributions (NDCs) with legal value. Brazil's NDC committed to reducing GHG emissions by 37% by 2025 and 43% by 2030, compared to 2005 levels. To achieve these goals, one of the directives of Brazil's NDC is to promote new clean technology standards, increase energy efficiency measures, and develop low-carbon infrastructure in the industrial sector (BORGES, 2020).

Among various efforts, there has been a growing interest in increasing renewable energy sources, including bioenergy. Forests can sequester carbon by removing CO2 from the atmosphere, and there is ongoing debate about how to use forest components—whether vegetation, soil, minerals, or biomass products—to mitigate climate change. The same phenomenon occurs in areas where timber is cultivated for cellulose production. For this reason, replacing paper with an electronic system for administrative activities, both in the private and public sectors, would be beneficial for reducing CO2 in the atmosphere by promoting photosynthesis. This led to the issuance of Decree No. 8.539/2015, encouraging educational institutions to replace paper with electronic systems for managing their administrative actions (SEARCHINGER et al., 2018).

The Federal University of Santa Maria (UFSM), motivated by the aforementioned decree, already uses PEN-SIE (National Electronic Process - Information System for Education) and has statistical data on the performance of the electronic system. This study used that data to create a Systems Dynamics (SD) model using Vensim® software (VENSIM, 2023) to quantify the environmental benefits of CO2 reduction and the economic details of the implementation. PEN at UFSM is a web-based implementation of the SIE platform, accessible via https://portal.ufsm.br/documentos. The PEN-SIE system allows all documents that make up administrative processes at the institution to be available in digital format, eliminating the need for paper-based documentation processing, as mandated by the decree.

Internal paper consumption encourages industrial production. The paper and pulp industry presents a globally positive outlook for Brazil, with expected market growth in the coming years. More than half of the cellulose production is destined for export, driven by increasing demand from Asia and the high productivity of eucalyptus. The anticipated increase in cellulose production will promote GHG emissions from the sector, primarily related to the combustion of fuels for steam and energy generation used within the industry. Black liquor, a byproduct of the cellulose manufacturing process, is the primary energy source for the pulp industry in Brazil. In the coming years, an increase in black liquor consumption is expected, whose combustion in recovery boilers constitutes the largest source of CO2 emissions in the pulp industry (IEA, 2022).

Despite high CO2 emissions, the paper and pulp industry is a sector with significant biomass usage for energy generation in its processes, making it a strong candidate for applying BECCS (Bio-energy with carbon capture and storage) technology. BECCS has an advantage over conventional CCS systems due to its potential to remove CO2 directly from the atmosphere, making it an important option for mitigating greenhouse gas emissions. Therefore, this study aims to estimate CO2 emissions from paper use in internal processes and evaluate the current potential for reducing these emissions through increased use of electronic processes via PEN-SIE.

II. Material And Methods

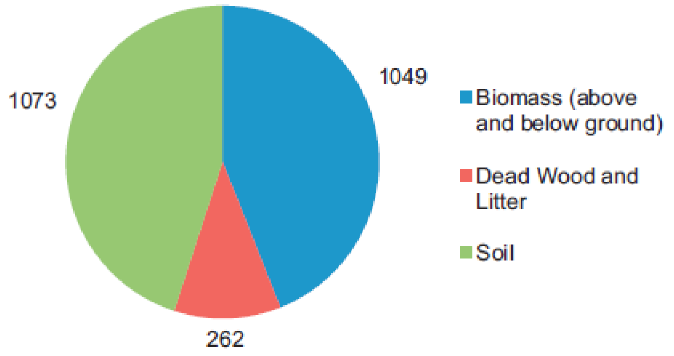
Co2 Absorption In Forests And The Irrelevance Between Virgin Or Recycled Paper

The management of biospheric carbon differs from the management of fossil fuels, as carbon can be sequestered and emitted by the biosphere over varying times, leading to different trajectories for atmospheric CO2 concentrations (BRANDÃO, 2013). Although significant efforts are being made to develop robust methods, there is currently no consensus on how to account for temporary carbon removals and emissions. This challenge highlights the understanding that the most beneficial approach is to maintain the largest possible area of green spaces with active photosynthesis potential to mitigate environmental problems.

As for the advantages of using recycled paper over virgin paper, several authors have observed that the fossil carbon footprint of recycled paper can be higher than that of virgin paper (DE FEYTER, 1995). This is supported by the decision of the British newspaper The Guardian to opt for virgin cellulose over recycled paper to reduce its carbon footprint (JAMES, 2012).

According to James (2012), there are five carbon reservoirs in agricultural and forest systems: aboveground biomass, underground biomass, deadwood, litter, and soil, with global forests storing 650 billion tons of carbon (2,383 billion tons of CO_2 equivalent). However, as shown in Figure 1, more than half of this carbon is not stored in living biomass.

Figure 1. Carbon Storage In Forests (Billion Tons Of CO2 Equivalent).



Massi (2019) demonstrates that the transfer of virgin products to recycled products does not lead to an additional emission of biogenic CO_2. Therefore, the amount of CO_2 emission remains 23 tons for each ton of paper used, whether virgin or recycled.

Motivation Of Federal Institutions To Replace Paper With Electronic Processes

Project Management (PM) has gained importance for companies and institutions to carry out their activities efficiently, effectively, and with optimized time and resources, whether structural or human.

In the public sector, these activities, also known as administrative acts, have led to the production of a large number of physical documents, which has had negative environmental impacts. This situation motivated gradual changes in the internal behavior of public institutions, as detailed below.

Constitutional Amendment No. 45 of 2004, which added Article LXXVIII to the Federal Constitution of 1988, stated that "everyone is entitled to a reasonable duration of the process, in both judicial and administrative proceedings, and to means that ensure its promptness," encouraging the use of electronic processes to expedite procedural acts (BRASIL, 1988).

The introduction of electronic processes in Brazilian public institutions began with the Judiciary. With the enactment of Law 11.419/2006, which deals with the digitization of judicial processes, Brazil's regulatory framework for the use of electronic means in the judicial process was established (ALVES; GURGEL; OLIVEIRA, 2021).

Later, in 2015, through Decree 8.539/2015, the use of electronic means for administrative processes in federal public administration bodies and entities was adopted, encompassing public higher education institutions. This decree mandated the electronic processing of documents across the entire federal public administration, requiring all direct, autonomous, and foundational public administration bodies and entities to use computerized systems for management. This allowed administrative processes to be conducted securely, transparently, and economically, enhancing environmental sustainability, reducing impacts, and generating results in government actions (SILVA; SOUZA, 2020).

Some agencies adopted this transition even before the decree, such as the Ministry of Planning, Budget, and Management (MPOG), the Brazilian Agricultural Research Corporation (Embrapa), the Securities and Exchange Commission (CVM), and the Government of the Federal District (GDF). From this initiative, the National Electronic Process (PEN) emerged, which, according to Uchôa and Amaral (2013), is a tool and solution for public institutions regarding the adoption of electronic administrative processes.

According to Silva and Souza (2020), the electronic process was born out of a state management reform policy with the main aim of achieving efficiency in public administration and utilizing technology for quicker, more transparent, and less bureaucratic procedural acts. It is undeniable that institutions have benefited in terms of productivity, speed, resource savings, and environmental preservation by eliminating paper as a medium for procedural acts. This observation is supported by Uchôa and Amaral (2013), who advocate for the electronic process as a means for public administration to achieve better results, in contrast to the inefficiencies more prone to occur in paper-based administrative processes.

Energy Consumption And Sector Emissions

The paper and pulp industry is considered one of the largest energy consumers. Energy consumption is usually defined in tonnes of oil equivalent (toe), an energy unit that corresponds to the heat released by burning one ton of crude oil. According to the 2020 National Energy Balance, the paper and pulp sector consumed 12.8

Mtoe, representing 16% of the industrial sector's energy consumption and 5% of Brazil's total energy consumption. Despite its high energy consumption, the sector stands out for generating most of the energy used in its production processes, utilizing by-products of its processes to generate thermal and electrical energy. Modern factories, besides being energy self-sufficient, are even capable of generating surpluses for sale to the public grid (IBÁ, 2019).

Brazil's paper and pulp sector is characterized by a strong presence of renewable energy sources in its energy matrix, unlike the global scenario where only 30% of the energy matrix in this sector comes from renewable sources (IEA, 2020). This scenario is primarily due to the use of black liquor and forest biomass, which represent 50.9% and 15.7%, respectively, of the energy used in the sector (EPE, 2020).

A significant portion of this consumption occurs in the form of thermal energy (heat and steam), generated by burning fuels, which is the primary source of GHG emissions in the paper and pulp industries (HORA; MELO, 2016). GHG emissions are measured in CO2 equivalent, a metric used to compare emissions of various greenhouse gases based on the amount of carbon dioxide that would have the same global warming potential. In 2022, Brazil's total emissions amounted to 416.1 MtCO2-eq, with 4.2 MtCO2-eq coming from the planted tree segment (SEEG, 2023). The industrial sector is the second-largest emitter of CO2, accounting for 18.8% of Brazil's energy matrix-related emissions, second only to the transport sector (46.3%) (EPE, 2020). Within the industrial sector, the paper and pulp segment accounts for 3% of emissions.

The main sources of CO2 emissions in the pulp production process are the chemical recovery boiler, biomass boiler, and lime kiln. CO2 may also be released during effluent treatment, particularly during biogas production. However, these emissions are less relevant compared to combustion processes (KUPARINEN; VAKKILAINEN; TYNJÄLÄ, 2019).

Given the increasing global energy consumption in the paper and pulp sector, with an average growth rate of 0.3% per year from 2000 to 2018 and production growth projections of 1.2% per year until 2030, measures to increase energy efficiency and control emissions associated with energy generation are necessary. Increasing the recycling process, which requires less energy, greater use of bioenergy, and the adoption of heat recovery technologies are important for achieving sustainable development while reducing energy consumption in the sector (IEA, 2020).

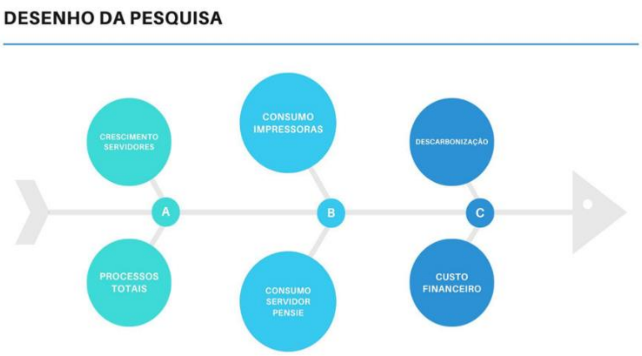
Climate change poses both risks and opportunities for the paper and pulp industry, making it one of the sectors best positioned to support Brazil's goals under the Paris Agreement. Among the sector's challenges are discussions about carbon pricing and the consolidation of a global market focused on the bioeconomy (IBÁ, 2019).

Procedure Methodology

In this article, the research method adopted for developing the computational model was based on the System Dynamics (SD) methodology proposed by Sterman (2018). SD is a methodology used to understand and model complex problems where feedback mechanisms are fundamental to the system. The focus of dynamic system modeling is the cause-and-effect relationships between variables or elements. The foundation of dynamic system models is feedback loops (CHWIF; MEDINA, 2014).

The following steps were necessary to execute the SD approach: (1) conducting exploratory studies and reviewing scientific articles, reference manuals, and demonstration documents on the national electronic process to characterize the problem and research objective; (2) developing a solution by constructing formal models capable of representing the problem; (3) implementing the solution computationally using the Vensim® simulator; (4) evaluating the solution through laboratory tests and data related to the explored theme to verify if the obtained results align with observed reality; and (5) simulating two scenarios for paper recycling.

Figure 2 Presents The Steps For Developing The Created Simulation Model.



Following the steps shown in Figure 2, the first part is to make explicit all the elements that contribute to the increase or reduction of emissions within a defined space. For this modeling, the limitation will be the area corresponding to the main campus of UFSM. Various situations regarding environmental impact have been studied by researchers for some time, and the mathematical equations related to such activities and their emissions were used and cited whenever available. For cases where no existing equation was available, proprietary expressions derived from statistics were employed.

It is also noted that the model converges toward three key interests: verifying if the model tends to zero out CO2 emissions, estimating whether the time for this reduction will align with the 2030 global targets (which countries are striving to meet), and assessing the economic impact, considering the necessary investment and the return on investment time.

From the perspective of SD, the technique for developing a model involves examining the historical evolution of declared independent variables and applying statistics to determine the parameters of the set of equations linking their independent variables. This establishes the system's behavior without considering internal functioning details. The objective of this technique is to understand the structural causes behind a system's performance by evaluating how actions and reactions in different parts increase or decrease behavioral relationships. Analyzing the logic of the model and its structural relationships is the main focus of its construction.

The software commonly used for simulating continuous and dynamic processes is Vensim®, developed by Ventana Systems, which is used for solving management-related problems. It offers the advantage of being programmable in any language (external function) and provides the possibility of importing models developed in other software used for modeling and simulation (RISTIC et al., 2016).

The data used in the model were collected directly from UFSM's Data website, a platform that provides public institutional data. Data from scientific experiments and articles sourced from SCOPUS or Google Scholar were also used. The scenarios that served as the basis for the model's evaluation were generated from analyses that incorporated managerial perspectives and proposals from the modelers.

III. Result

One trend that is becoming prominent in organizational and business environments is the set of actions and activities related to sustainability (BEZERRA, 2022). In the conception of Bezerra (2022), the economic reconfiguration involving the incorporation of environmental and social obligations is happening slowly but effectively. Mascarenhas and Silva (2013) support this by stating that, given the proximity to the limit of resource extraction, there must be a shift in improving production processes, generating value in the supply chain, achieving conscious consumption, and post-consumption procedures, such as the proper disposal of products and packaging, to contribute to sustainable management.

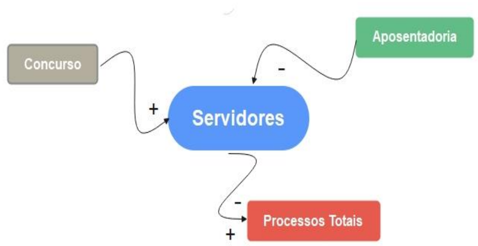
In this context, the PEN system (National Electronic Process) will be used as the central point of modeling. The PEN system consists of the automation of processes in federal institutions, which, in most cases, results in the elimination of paper use, making the process "paperless" (SOUSA; SILVA; NUNES, 2023). Process automation is an essential part of the digital transformation journeys of organizations, and for the purposes of case analysis, we will examine its environmental impact at UFSM.

The model will use three principles as the simulation basis:

1. Adopting practices that embrace a preventive, responsible, and proactive approach to environmental challenges;
2. Developing initiatives and practices to promote and spread socio-environmental responsibility;
3. Encouraging the development and dissemination of environmentally responsible technologies.

Initially, a model was developed to calculate the number of processes within the institution, following the logic developed in the causal loop shown in Figure 3.

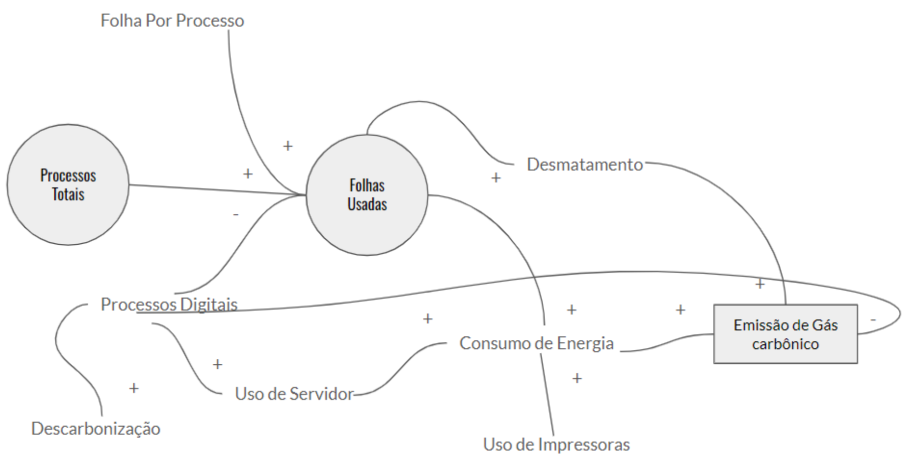
Figure 3: Causal Loop For Calculating The Number Of Processes



To calculate the number of processes, it was necessary to map three variables. Initially, the central variable "employees" has two input variables. The variable "recruitment" stores the number of employees joining per year, a value that can be added to the "TotalProcesses" variable. In turn, the "negative" variable is responsible for storing the average volume of employees retiring per year. These values, when correlated, are added to the initial number of employees set in the central variable, which in this study was 4,790 employees. This number is multiplied by the average number of processes per employee, with this data collected directly from the UFSM in Numbers page.

The next step was the development of the environmental model. Figure 4 presents the loop of variables responsible for sustaining the environmental model of the study.

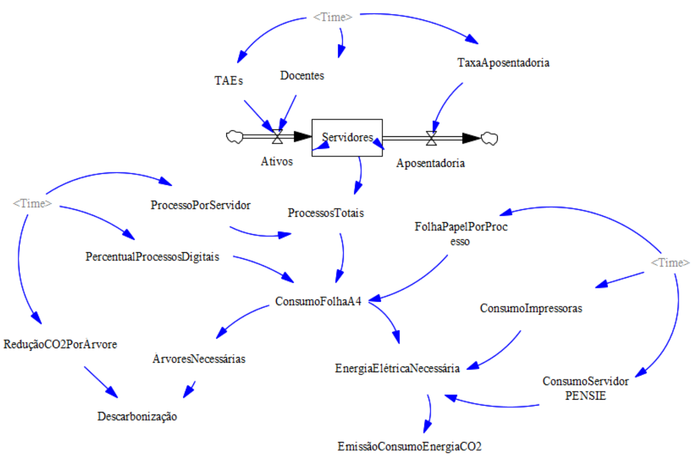
Figure 4: Causal loop of the environmental model



There are three variables that carry the most weight in this model: the "total processes" variable, previously explained, the amount of paper used, and carbon dioxide emissions. To understand the environmental impact of the simulated proposals, it was necessary to incorporate issues such as deforestation, energy consumption, and decarbonization into the study. The purpose of the scenarios is to introduce different percentages of electronic process usage.

The use of PEN-SIE is an alternative that provides environmental benefits, such as the preservation of natural resources, energy savings, and the reduction of deforested areas, while also aiming to raise awareness among the population regarding environmental sustainability issues for the planet. These practices align with the sustainable management outlined by Mascarenhas and Silva (2023), which aims to reduce environmental impacts, generate wealth and value, and meet social demands. The developed DS model is presented in Figure 5 below.

Figure 5. Developed System Dynamics Model



The developed model is based on the stock and flow logic. The stock model, responsible for storing the number of active employees per year, consists of the inflow "Active" and the outflow "Retirement." This is a negative variable in the model. The variables "TAES," "Faculty," and "Retirement Rate" are responsible for setting the input values of the aforementioned flows. Both auxiliary variables are connected by a temporal variable called "Time", which allows the auxiliary variables to input their data annually, enabling changes to the system's projected annual values. It is up to the decision-maker to modify the values according to the existing data, and they can also project artificial changes.

To calculate the A4 paper consumption in the institution, the auxiliary variable "A4PaperConsumption" was developed. It receives input values from three other auxiliary variables:

- "TotalProcesses": Responsible for calculating the number of annual processes;
- "PercentageDigitalProcesses": A variable that will set the behavior of the proposed scenarios; through its use, the model's values will be altered;
- "PaperSheetsPerProcess": Sets the average number of paper sheets per physical process in the model.

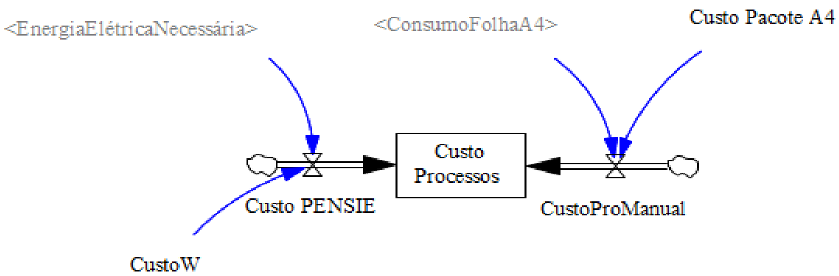
Regarding decarbonization through reduced paper usage, Villalobos (2021) highlights that high paper production volumes lead to the extrapolation of deforestation limits, resulting in significant losses to nature and even the destruction of ecosystems. With this in mind, the auxiliary variable "Decarbonization" was developed, which will calculate the reduction in tree cutting and how this action will contribute to preventing CO2 emissions.

Another point brought up in the model is related to the energy needed to keep a server active. Data collected directly from the institution's Data Processing Center was used, allowing for better precision in the developed model. To calculate energy consumption, the auxiliary variable "RequiredElectricEnergy" was created, which receives values from the following variables:

- PENSIE ServerConsumption: Stores the energy usage of the servers where PEN data is stored;
- PrinterConsumption: HP 1047W, HP Deskjet ink advantage 2774, and Epson Ecotank L121 printers were used. The data was collected directly from the companies' websites.

Finally, the auxiliary variable "CO2EnergyConsumptionEmissions" will store the simulation of the developed logic, allowing for the assessment of whether the designers' proposals are environmentally positive or not. Whenever a decision is made and an action is taken, there will be consequences, which may be within our control or considered a risk or uncertainty. This article is based on an uncertain tomorrow, as the collected data will not provide a definite future. Regarding the financial part of the model, Figure 6 presents the proposed cost model.

Figure 6. System Dynamics Model for Cost.



As organizations transform their physical processes into digital ones, they reduce expenses, generate savings, and contribute significantly to the environment. The savings, however, go far beyond the elimination of paper. It also represents a reduction in printing expenses and outsourcing of printers. Therefore, the automation of processes, especially those that are document-intensive, contributes to a more sustainable planet, which in turn provides a better quality of life for all. The model measures whether the larger-scale use of digital processes leads to a lower cost of purchasing A4 paper packages. For the model to be simulated, equations were developed, and these equations are presented below.

Table 1. Equations and Data

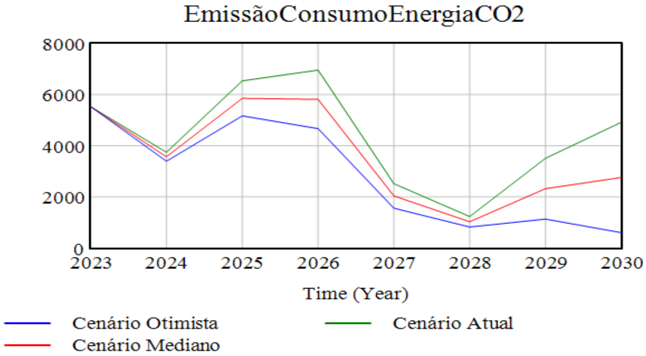
(01) TreePerSheet = 1/10
(02) RequiredTrees = PaperConsumptionA4 * TreePerSheet
(03) PaperConsumptionA4 = (TotalProcesses - (TotalProcesses * DigitalProcessesPercentage)) * PaperPerProcess
(04) PrinterConsumption = PaperConsumptionA4 * KwPerSheet

(05) ProcessCost = INTEG (PENSIECost + PaperCost)
(06) PENSIECost = CostPerWatt * NecessaryElectricity
(07) PaperCost = (PaperConsumptionA4 / 500) * A4PackageCost
(08) Decarbonization = RequiredTrees * CO2ReductionPerTree
(09) Teachers = WITH LOOKUP (Time, ([(0,0)-(10,10)], (2023,-839),(2024,816),(2025,20),(2026,-75),(2027,29),(2028,-647),(2029,-13),(2030,29)))
(10) CO2EnergyConsumptionEmission = CO2PerWatt * NecessaryElectricity
(11) NecessaryElectricity = PrinterConsumption + PENSIEServerConsumption
(12) PaperPerProcess = WITH LOOKUP (Time, ([(0,0)-(10,10)],(2023,4),(2024,3),(2025,5),(2026,6),(2027,2),(2028,-),(2029,4),(2030,5)))
(13) DigitalProcessesPercentage = WITH LOOKUP (Time, ([(0,0)-(10,10)],(2023,0.2),(2030,1)))
(14) ProcessesPerEmployee = WITH LOOKUP (Time, ([(0,0)-(10,10)],(2023,12),(2024,16),(2025,15),(2026,14),(2027,13),(2028,9),(2029,11),(2030,14)))
(15) TotalProcesses = ProcessesPerEmployee * Employees

IV. Discussion

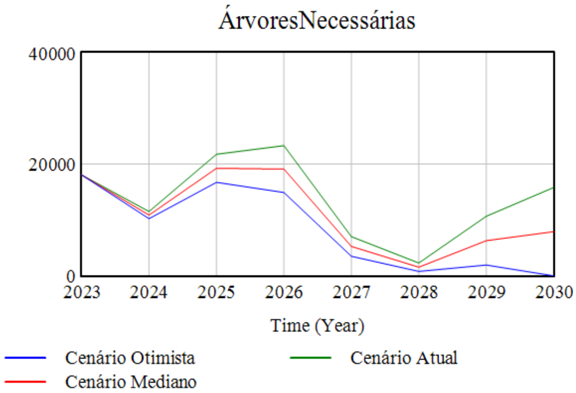
After defining the scenarios for conducting the experiment using the model, the simulations were executed. As previously described, the data used in both scenarios were from UFSM, and additional information was obtained from technical documents, as already presented in the previous section. The simulation considered a time frame of 7 (seven) years, which can be adjusted by end users or model designers for projections over a shorter or longer period. The developed model is applicable for simulating any institution. The Vensim® simulator was used to execute the simulated scenarios on a computational structure with an Intel Core (i5 2450) processor at 2.5 GHz and 4 GB of RAM. The execution time for simulating the three scenarios was in the order of millionths of a second. The results initially present the relative analysis of CO2 emissions. Figure 7 shows the results of the developed model.

Figure 7. Environmental results of the simulation



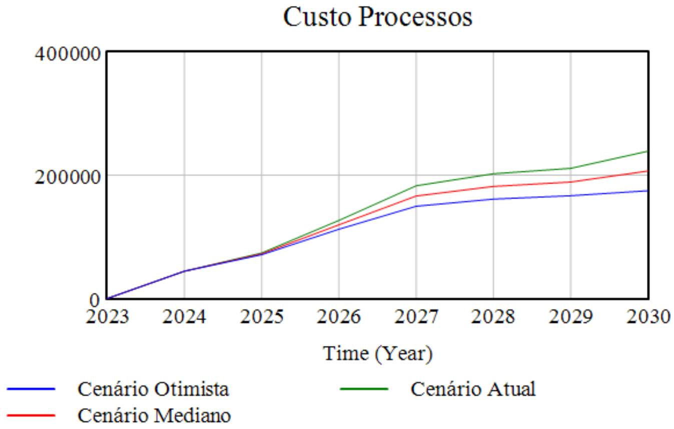
In this analysis, a significant reduction is observed in the optimistic scenario, which decreases by 12 tons compared to the current scenario. In this same analysis, the current scenario reaches an emission level of approximately 35 tons. By the 7th year of the simulation, the optimistic scenario would reach approximately 23 tons, which is 6 tons lower than the median scenario. Given that the study's objective is to estimate the reduction in CO2 emissions, along with the electricity and trees that can be saved through the use of PEN-SIE, the simulation results for the number of trees (Figure 8) that are no longer cut down over the seven simulated years are presented below, according to the indices provided by (WASTE MANAGEMENT, 2022).

Figure 8. Required trees



This analysis highlights the benefit of reducing paper use for the environment. Figure 8 clearly shows the importance of scaling up the use of PEN. Such a result justifies the implementation of the scenarios developed in the study. The current scenario also shows a slight reduction in tree usage, as it is already being employed at the institution analyzed. Finally, the financial results of the study's model are presented in Figure 9 below.

Figure 9. Cost of Processes



Among the analyzed scenarios, the current one incurs the highest cost for the institution, as it will spend around R$ 239,027 over seven years of simulation. The optimistic scenario will yield a savings of approximately R$ 64,120 when compared to the current scenario. The savings reach R$ 32,060 when compared to the median scenario.

V. Conclusion

The study clearly and quantitatively demonstrates the environmental and economic benefits of replacing paper use with electronic processes in public institutions. Through modeling in System Dynamics, it was possible to verify a significant reduction in CO2 emissions, as well as substantial cost savings and tree preservation. The transition to electronic processes, encouraged by legislations such as Constitutional Amendment No. 45 of 2004 and Decree 8,539/2015, not only promotes administrative efficiency and speed but also contributes significantly to environmental sustainability.

The Judiciary's experience as a pioneer in implementing these processes serves as a positive example for other public institutions. Moreover, the analysis of the paper and cellulose sector reveals the importance of energy efficiency measures and emissions control to mitigate environmental impacts. The Brazilian sector, with its focus on renewable sources, still faces challenges related to greenhouse gas emissions, but adopting more sustainable practices can help reduce these impacts.

The implementation of digital processes resulted in a significant reduction in CO2 emissions. In the optimistic scenario, the reduction reaches 12 tons compared to the current scenario, which generates approximately 35 tons of CO2. By the seventh year of simulation, the optimistic scenario achieves around 23 tons, which is 6 tons less than the median scenario. The adoption of electronic processes generated substantial financial savings. In the optimistic scenario, the savings amount to approximately R$ 64,120 compared to the current scenario, which would cost R$ 239,027 over seven years of simulation. Compared to the median scenario, the savings amount to R$ 32,060. Replacing paper with electronic processes contributed to tree preservation. The simulation indicated that a considerable number of trees would not be cut down over the seven years analyzed. These results highlight the importance of using electronic processes not only for administrative efficiency but also for environmental sustainability.

Therefore, modeling in System Dynamics proves to be a valuable tool for institutions seeking to plan future scenarios and implement strategies that promote environmental sustainability. The transition to electronic processes is not only an administrative necessity but also an environmental responsibility that can bring lasting benefits to society and the environment.

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