Proposal for reducing paper use: an approach using systems dynamics

Proposta para reduzir o uso de papel: uma abordagem que usa a dinâmica dos sistemas

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Abstract

Urban Solid Waste (USW) is a problem both in Brazil and in other parts of the world and this requires thinking about ways to mitigate its negative effects. Paper use has grown over 400% worldwide over the past 40 years. The consequence of this is the massive felling of trees and

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more trees, and this deforestation caused to produce paper is a great threat to the environment. In view of this fact, the main objective of this article is to develop a computational model to analyze the reduction in paper disposal. The results presented reinforce the importance of reducing solid waste and also encouraging the recycling of final stage products.

**Keywords:** Recycling. Higher Education Institution. Computational Modelling. System Dynamics.

**Resumo**
O lixo sólido urbano (USW) é um problema tanto no Brasil como em outras partes do mundo e isso requer pensar em formas de mitigar seus efeitos negativos. O uso de papel cresceu mais de 400% em todo o mundo nos últimos 40 anos. A consequência disso é a derrubada maciça de árvores e mais árvores, e esse desmatamento causado para a produção de papel é uma grande ameaça ao meio ambiente. Em vista deste fato, o principal objetivo deste artigo é desenvolver um modelo computacional para analisar a redução no descarte de papel. Os resultados apresentados reforçam a importância de reduzir os resíduos sólidos e também de incentivar a reciclagem dos produtos finais.


**Introduction**

The environment is the basic condition for the existence of life on Earth, however, Lourenço and Lira (2012) point out that industrial and technological development has culminated in the excessive use of natural resources, which causes serious socio-environmental problems. The same authors understand that this situation made society react by demanding solutions and changes in production systems with the aim of preserving the environment.

An alarming fact comes from the annual reports of the World Fund for Nature, WWF-Brazil (2017) measures the "human footprint", called the ecological footprint, the relationship between consumption and the availability/regeneration of resources in nature. This report points out that the planet needs 1.5 years to regenerate what it consumes in one year, that is, the utilization capacity is 50% greater than the regeneration capacity.
In Brazil, the 2010 WWF-Brasil report shows that Brazilians have an ecological footprint of 2.9 hectares per inhabitant, very close to the world average of 2.7 global hectares per inhabitant, and also presents a positive aspect – the country is still the planet’s ecological creditor – despite the sharp decline in biodiversity and the degradation of ecosystems that it has suffered over the years. Trend projections presented by the Global Footprint Network in 2010 reveal that if the consumption pattern remains unchanged in the year 2050, more than two planets will be needed to maintain consumption (WWF-Brasil, 2017).

In this context, Krupp, Silva and Vieira (2017) say that the global concern with the environment was reflected in institutions and this gave rise to post-consumption policies in the legal sphere. According to Lagarinhos and Tenório (2012), a proposal started in 1999 and approved in 2010 introduced the National Solid Waste Policy which, in addition to other issues, determined that the responsibility for waste management was shared between the federal, state, and municipalities beyond of companies and society.

One of the forms of waste treatment is through recycling, which is a process that can reduce the excessive consumption of raw materials and becomes a path towards sustainable development. Shibao, Moori and Santos (2010) clarify that recycling refers to a set of techniques whose purpose is to take advantage of waste and reuse it in the production cycle they left or in another parallel.

In the case of paper, the object of study of this work, Nossa and Carvalho (2003) apud Santos (2017, p. 19), indicate four points: "a) – it is 100% dependent on natural and recycled forest fibers; b) – it requires intensive use of energy; c) – emits a wide range of toxic and conventional pollutants into the air, water and land; d) – is a large producer of solid waste". Returning to the cycle of responsibilities, Araújo, Freitas and Rocha (2017) note that higher education institutions are special, as in addition to being responsible for their activities, they are also responsible for generating knowledge and training professionals for the future.

In addition, Vamberto, Lacerda, Silva and Silva (2013) understand that the search for new sustainable habits is a lengthy process and that universities can be compared to small urban centers for having in their environment the development of various activities, operations and integration of diversity of cultures and coexistence between the parties. Given the above, the problem of this research then arises: How much natural resources would not be consumed with paper recycling?

Thus, the objective of this article is to develop a computational model through the construction of scenarios in order to analyze how much natural resources can be saved in a
Higher Education Institution (HEI) with the use of paper recycling. For this, a computer simulation model was adopted using the System Dynamics methodology to evaluate paper recycling scenarios in a future horizon of eight years. This study is justified by the fact that recycling is very important for the preservation of the environment (Rossato, & Sens Neto, 2014; Santos, Galdino, Akabane, & Santos, 2015), since adopting it reduces the amount of waste discarded (Lopes, 2003), as well as, the environment is less polluted and less virgin raw materials, water and energy are used (Mello & Fonseca, 2010). Therefore, in the view of Rodrigues and Cavinatto (2003), the positive environmental balances are indisputable.

Furthermore, regarding the method, Leuck (2008) comments that via simulations it is possible to describe the consequences of decisions or policy decisions based on which decisions or policies can be carried out. Simonetto and Löbler (2014) consider that the use of quantitative techniques in solid waste management is a viable option for treating the complexity characteristic of the process, because through the use of these tools it is possible to have a representation of the real world, analyze their behavior and make decisions based on the conclusions drawn. Therefore, this research can help raise awareness about the importance of recycling, in this specific case, through the results obtained through the simulation made for a time horizon of eight years, analyzing a HEI and investigating the role for such purpose.

Aiming to achieve the proposed objective, this work is organized as follows: right after this introductory section, section two contains the theoretical framework that supported the study. Then, in section three, the adopted research methodology is described. Next, section four refers to the model developed with due exposure of the results obtained. Finally, section five presents the final considerations accompanied by suggestions for future studies.

**Theoretical Reference**

This section is divided into two topics: in the first there is a brief discussion about environmental management and in the second there is a theoretical exposition about paper recycling.

**2.1 Environmental Management**

The Environment can be defined as everything that involves or surrounds living beings, Planet Earth with all its elements, natural, altered or built by humans. Man is part of
this system and has always used natural resources for its existence, initially due to the reduced scale of use and disposal there was no so-called environmental degradation (Barbieri, 2007).

However, the initial balance between the environment and man was broken. Jacobi (2015) reports that economic and industrial development caused profound interference in the capacity of support of the planet's ecosystems. Similarly, Barbieri (2007) considers that the industrial revolution was a milestone in the intensification of environmental problems and that the increase in production and consumption allied to the belief that nature exists to serve man caused an environmental crisis.

Jabbour and Jabbour (2013) recall that since 1970 efforts to solve this problem have been applied, the authors cite the United Nations Enviromental Conference as the landmark of the 1st era of environmental awareness. In the 1980s, major environmental accidents such as Exxon Valdez and Union Carbid marked the 2nd era, with the first evidence of global warming being presented. In the 1990s, the theme gained greater emphasis in the sense that there could be mutual benefits between organizations and the environment, which the authors considered the 3rd era of awareness. Today, planning and organization aim to reduce environmental impacts, taking advantage of the benefits associated with this improvement.

Falkner (2008) exposes that environmental crises are global and cause climate change and the loss of biological diversity, also alleges that the globalization of production, consumption and economic exchange is fueling environmental destruction, while complicating the search for political solutions. Tinoco and Kraemer (2011) add that this growing and frightening environmental degradation makes companies incorporate social responsibility into their objectives, which covers the population's well-being.

For Jabbour and Jabbour (2013), even though some organizational leaders insist on disregarding environmental aspects during administrative practice, it is understood that the inclusion of environmental concerns in the daily lives of world-class organizations is an irreversible process. Chen (2011) considers that environmental management has reached an important level within organizations and is becoming a crucial part of business management.

Thus, environmental management is considered as the new business function and enables companies both to assess and correct environmental damage in the present and to avoid future damage (Sanches, 2000). Several studies positively point to the relationship between proactive environmental practices and better economic and environmental performance of organizations (Christmann, 2000; Wagner, 2005; Wilson & Williams; Kemp, 2012; Martin-Penã, Díaz-Garrido, & Sanchez- Lopes, 2014).
Martin-Penã, Díaz-Garrido and Sanches-Lopes (2014) understand that the evolution of environmental performance improves the relationship between companies and their stakeholders. Ceruti and Silva (2009), on the other hand, conclude that the main difficulties in the company-environment relationship are the release of resources for environmental demand, followed by the relationship with regulatory bodies and the lack of personal and structural training of companies to deal with the environmental area. Furthermore, in the same study, the authors show that for most of the companies analyzed, the environmental importance is given only to comply with legal aspects.

2.2 Paper Recycling

Lomasso et al. (2015) explain that recycling refers to the operation where residues of products that have already been consumed and objects that would be disposed of in the environment because they are judged as useless are put back into the production cycle through its use as a raw material for the manufacture of new products. In other words, it is a process of valuing products and materials that after being used generally do not keep their functionalities intact, allowing some or all of it to be reused to re-enter the chain, as original products or as inputs for new products (Moura, 2006).

Souza, Paula and Souza-Pinto (2012) point out that the useful life of a product corresponds to the period of time between its production and the occasion of its disposal, from that moment on, its useful life can be extended through the reform, reuse or via selective collection where products and packaging in the post-consumption phase are properly separated and sent to the recycling process, being inserted again into the production process as secondary raw material. Thus, through recycling there is the reuse of materials and it applies to many products consumed by society - items that are or would be being disposed of in the garbage - and in the case of paper recycling, it is the reuse of cellulosic fibers from scraps and other papers used for the manufacture of new papers (Ferreira Junior & Santos, 2014).

Toutouchoup (2016) recalls that over the last three decades campaigns have sought to encourage paper recycling, as in addition to reducing pollution and landfill space, the main argument is the preservation of trees, as they generate positive externalities, such as such as: direct amenities, soil conservation and carbon sequestration. In addition, among the benefits of paper recycling, Gauto and Rosa (2013) mention the reduction in the consumption of water used in production and the reduction in energy consumption, in addition, with recycling, trees
are no longer cut – it is estimated than 15 to 20 for each ton of trimmings (cut papers used in recycling).

It is noted that the paper recycling cycle begins with the receipt of the chips, then goes through a process so that its fibers are separated, then chemical products are added aiming at its bleaching, after, depending on the quality of the paper that one wants to produce can be added to virgin cellulose, finally, there is the finishing and the paper will be ready for consumption again. According to Rocha, Rosa and Cardoso (2010), paper recycling seeks to produce paper, cards, as well as cardboard and cardboard from leftovers/shavings during the manufacturing process and artifacts of these materials in the post-consumer phase.

However, Pereira, Boechat, Tadeu, Silva and Campos (2012) comment that paper is composed of cellulosic wood fibers and has the following factors as main difficulties for recycling, namely: non-homogeneous chips; as well as the non-elimination of impurities existing in the cellulosic mass that was collected; disposal and treatment of waste and paper residues; the complexity of the quality of the various types of paper used; and also the high costs of transporting scraps and residues to the centers that carry out recycling.

**Metodology**

In this work, the research method adopted for the development of the computational model was based on the System Dynamics methodology. Systems Dynamics was created in the 1950s at the Massachusetts Institute of Technology's Sloan School of Management School of Management (Pidd, 2001). According to Villela (2005), System Dynamics aims to present the following basic characteristics of any system: Cause and Effect Relations, Response Times and Inventory. Villela (2005) understands that System Dynamics combined with modeling is capable of expressing in a more adequate and graphic way the complex events present in nature.

The System Dynamics methodology fits the objective of this article, in this case, to develop a computational model through the construction of scenarios in order to analyze how much natural resources can be saved in a Higher Education Institution (HEI) using paper recycling. Ford (2009) states that System Dynamics allows the study of the behavior of systems over different periods of time, allowing the assessment of the consequences of new decisions in a future time horizon.

For the development of the computational model, four steps were used. Stage (I) represents the exploratory study in scientific articles, technical reports, dialogues with
stakeholders and observations of the environment where the data were collected. Through these data, the research problem was specified and structured. Step (II) presents the development of the solution through the construction of a formal model capable of representing the problem (definition of variables and their relationships). The computational implementation of the solution (step III) will be carried out with the aid of the Vensim simulator (Ventana Systems, 2016) and, finally, step (IV) is responsible for verifying and executing the model, through laboratory tests and analysis of the historical behavior (with the data that were possible), to verify if the obtained results represent part of the observed reality.

In addition, primary data and secondary sources were used. Thus, the primary data of this research are made up of the amount of paper that were requested in 2017 by the various sectors, departments and centers from the institution's organization chart to the central warehouse sector. Such data are available on the institution's management portal, in the Educational Information System (SIE).

As for secondary data, they are composed of bibliographic elements that were searched in academia, thus, the variables that feed the system are information about the amount of resources needed to transform virgin paper into recycled paper and the number of trees to obtain virgin pap

The variables found were resized at projected rates for this study and used to prospect the results. To obtain the results, the System Dynamics methodology was used, creating a simulation of the possible results with a perspective of three different scenarios, the first said to be current, followed by a median and optimistic scenario. To perform a simulation, according to Ford (2009), it is necessary to generate a computational model. A System Dynamics computational model can be defined as the structure resulting from the interaction of policies. In the next section, there will be more details about computational modeling.

3.1 Computational Modeling

Rondón, Murakami and Sakaguti (2002) clarify that computational modeling seeks to exchange concepts and pertinent knowledge in mathematical equations in order to implement them through logical processes, simulating real cases on the computer. In addition, Andrade, Seleme, Rodrigues and Souto (2006) add that computational modeling is considered one of the artifacts of systemic thinking that add learning to the process and through it microworlds of the real system are built. In this article, two types of modeling were used, modeling from causal models and stock and flow modeling.
Causal models are intended to create diagrams that serve to expose a situation through words that constitute the concepts of a complex system, these words are connected by arrows that reflect the influences of the system. These models seek to demonstrate the cause-and-effect relationships within the context of the problem and their main utility is for qualitative analyses. However, it is the stock and flow models that present the variables, parameters and structure of the system, favoring quantitative analyses (Amaral, 2012; Amaral, Gonçalves, & Hess, 2015).

Madachy (2008) points out that causal and stock and flow computational models qualify the mental models on which decisions are based, and thus contribute to problem solving. Villela (2005) adds that causal models qualitatively represent the relationships between the variables that compose the model studied and that to represent this same problem quantitatively it is necessary to have stock and flow models. In addition, the same author reveals that causal models have their simplicity as their main characteristic, and can be an effective instrument to start the discussion of a problem-situation.

The variables are represented in Figure 2 by circles and refer to the parameters that will be used in the system. If a variable takes on a value that does not change, it will be called a constant (triangle) or change at a certain time, it will be known as an auxiliary. Flows, on the other hand, refer to the transport of resources in the system and are measured in units of a magnitude and per unit of time (meters per second). Stocks are the accumulations or de-accumulations of resources and their values depend on past facts. Information is the link that connects and explains the relationships between the elements and the system, however, they are not able to include or exclude stocks, if they appear with a double dash, it means they will be available in the future. And, finally, the external source that indicates a source of resource that does not interest the model (Villela, 2005).

**Modeling and Results**

Whenever a decision is made and any action is taken there will be consequences and these may be within our control or may be considered a risk or uncertainty. This article is based on an uncertain tomorrow, as the data collected will not provide a certain future. According to Pidd (2001), a model must be based on the analysis in some predetermined time scale, where there is enough time to try to evaluate all the output options of the developed model. Thus, the experiment in practice will tend to fit the reality better. Pidd (2001) also
emphasizes the need for replication, that is, the model should allow its application in more than one study environment.

The present model was developed using the System Dynamics methodology through the Vensim software. Thus, Figure 1 represents the interaction between the variables of the computational model developed where there are six outputs that will serve as a basis for the analysis of the results proposed by this research and all are auxiliary variables: Wasted Energy, Wasted Trees, Wasted Water, Energy Saved, Trees Saved, Water Saved. The model has three stock variables ("Sheet Qt", "Recycling", "Discard"), these are fed by three flow variables ("Package No.", "Disposal Tx", "Recycling Tx"). The variables are shown below in Figure 1.

Figure 1 Simulation model developed.
Source: Authors (2023).

According to data from Waste Management (2013), a eucalyptus is capable of producing twenty thousand leaves and eleven trees produce a ton of paper, with a leaf having an average weight of seventy-five grams. The Brazilian Technical Association of Pulp and Paper (ABTCP, 2007) states that a ton of paper needs approximately forty thousand and five hundred liters of water for its manufacture, an amount on a large scale if we thought of massive production. Another production detail is the electrical energy consumed, a ton of paper lacks approximately 2.5 MW/h of electrical energy (Waste Managemente, 2013).

For the modeling developed in this study, three scenarios were generated, as shown in Table 1. Marcial and Grumbach (2005) mention that prospective techniques, such as scenario
generation, originated among the military during the Second World War and were used in such a way system, mainly by the United States of America, to support mechanisms for the formation of war strategies. In France, according to Godet (2000), these devices were used in geographic prospecting studies, from this fact on, this method was used in sectors of industry and agriculture.

<table>
<thead>
<tr>
<th>Scenery01</th>
<th>TxDisposal</th>
<th>Recycling fee</th>
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<tbody>
<tr>
<td>Scenery 02</td>
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<td>0.5</td>
</tr>
<tr>
<td>Scenery 03</td>
<td>0.2</td>
<td>0.8</td>
</tr>
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</table>

Table 1 Modeled Scenario Rates
Source: Authors (2023).

The creation of scenarios made it possible to analyze the proposal of different decisions that will be at the discretion of the managers responsible for the area. It should be noted that the rates were varied annually as shown in Table 3, thus enabling changes in the flows, inputs and outputs of the created model. In the next section, the result of these changes resulting from the studied time will be presented.

4.1 Results

Soon after the definition of the three scenarios for the experimentation of the model, the simulations were run in Vensim software (Vensim, 2016) on a computer with a Pentium Core i5 processor and 8 Gb of RAM memory. The simulation execution time was in the order of millionths of a second. The time horizon simulated in the experiment was 8 (eight) years, however, the configuration of this variable is up to the designer/user as it depends on the analysis to be performed.

The model has three output variables – Wasted Energy, Wasted Trees, Wasted Water, respectively – with the objective of storing the values accumulated by the waste of natural resources since 100% recycling will not be simulated. With regard to the variables that store data on paper recycling, there are three auxiliary variables, namely: Energy Saved, Trees Saved, Water Saved, respectively. The results of the interaction of the model variables will be shown below.

The first analysis carried out seeks to minimize the use of water in the production of the paper used in the sheets. Graph 1 shows two situations generated by the Vensim simulator, where the left side refers to wasted water and the right side reveals the variation in water saved in the eight years simulated. The optimistic scenario, if applied, will generate savings of
approximately 122,830 liters of water, whereas the current scenario will waste around 138,000 liters of water.

![Graph 1 Wasted versus saved water.
Source: Authors (2023).](image1)

All scenarios use a certain amount of water to generate a leaf. However, the difference is the amount of water wasted, that is, while the optimistic scenario wastes 500,000 liters of water, the average scenario, in turn, will waste about 1,000,000 liters of water. Another decision that could be used by the model is related to electricity. The current scenario applied in the studied HEI will use approximately 855,000 Kw/h in eight years and while the optimistic scenario will have used approximately 190,000 Kw/h in 2027. This fact is shown in Graph 2.

![Graph 2 Wasted versus saved energy.
Source: Authors (2023).](image2)

The median scenario will also generate more sustainable results compared to the current scenario, it will save 45,000 kW/h more and about 30,000 kW/h than the optimistic scenario. Finally, the last decision analyzed by the modelers focuses on deforestation, scenarios were generated seeking to reduce deforestation on the planet. The current scenario will need 2,000,000 tree trunks to manufacture the amount of leaves to be used by the IES in 8 years, while the optimistic scenario will need 500,000 tree trunks. This means savings of
approximately 1,500,000 tree trunks. The wide difference represents the great need to apply more sustainable decisions. Graph 3 shows the comparison between wasted and spared trees in the dimensioned scenarios.

Graph 3 Wasted versus spared trees.
Source: Authors (2023).

Among the analyzes carried out, the optimistic scenario showed the best performance according to the visualized data, proving that the use of recycled sheets will affect the environment. In this way, sustainability policies, if applied, can help the environment and reduce the problems caused by deforestation, lack of drinking water and electricity. The application of the moderate scenario, which is the most realistic, will offer a better future for the planet, helping to reduce environmental catastrophes, which have been increasing in recent years. The results generated by the model can help management in the process of raising awareness in the community regarding the importance of recycling, demonstrating, in a quantitative way, how much can be saved and/or wasted, in particular about resources such as energy, water and the cutting of trees in the scenarios simulated in the period studied.

Final Considerations

The agglomeration of solid waste is a problem that affects every corner of the planet and several studies have been carried out in an attempt to reduce the impact of disposal and accumulation of this waste. Among the existing solid waste, this article had paper as its object of analysis. One proposal would be the recycling on a larger scale of the paper used in public HEIs in Brazil, where among other advantages in the application of this strategy are: the reduction in the cutting of trees, the preservation of a good amount of drinking water and the reduction of electricity consumption.

In the case of the present study, for the development of the simulation model, the concept that System Dynamics models that are composed of stock and flow variables, both endogenous variables, was taken into account. One of the central objectives of the System
Dynamics methodology is to have a model that can simulate real behavior. That is, the source of problems in a system is an inherent part of the developed model. Thus, the System Dynamics methodology helped in mapping the structures of the developed system, seeking to examine their interrelation in a broad context.

Through the developed simulation, the applied dynamics aimed to understand how the analyzed system evolved over time and how changes in its parts affected its behavior. Based on this understanding, it was possible to diagnose and prognosticate the system, in addition to making it possible to simulate more scenarios over time. It is worth noting that the scenarios obtained in this article were generated for this specific experiment, however, the model can be configured in accordance with the needs of whoever uses it, that is, it is an open and reconfigurable model.

The results presented were obtained through simulations made using the Vensim software. However, it is possible to affirm that the reduction of the environmental impact generated for an 8-year scenario justifies the application of the results generated by the model. Based on the results generated by the simulation, managers will be able to define paper purchasing policies taking into account environmental sustainability in the decision-making process.

Furthermore, considering that other variables may be included in a new model, as a future work we intend to expand the model presented here to other HEIs. In addition, it is suggested to include in a new research the social benefits that can be generated by recycling, among others, one can mention the issue of generating employment and income for those directly and/or indirectly involved in all stages of the cycle. In addition, other analyzes may be prepared considering matters of interest to both environmental and organizational managers - as in the case of the cost of generating recycled sheet - that is, investigations aimed at pointing out ways to reduce the consumption of materials, costs, at the same time, preserving the environment.

Referências


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