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Simulation of the circular economy proposal: analysis of printer remanufacture scenarios

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Abstract: Computational devices, such as printers, usually have a predetermined lifetime and are discarded when they stop working, generating large amounts of electronic waste. Circular Economy, on the other hand, proposes an alternative to the linear model of extraction, transformation and disposal applied in most organizations, starting from the replacement of materials in the production chains without loss of quality in this process. The research objective is to develop and experiment with models to analyze the impact of the remanufacturing of printers from a higher education institution. This article defends the remanufacturing of printers as a way to reduce both the amount of electronic waste discarded and the costs of purchasing new equipment. A computational model was built and, based on the Systems Dynamics approach, scenarios were proposed to simulate the behavior over 10 years. Analyzing data from a Federal Institution of Higher Education, it was found that the remanufacturing of printers can reduce the volume of electronic waste generated by 2.5 times, and achieve financial savings of around 37%.

Keywords: Systems Dynamics; E-waste; Computational Modeling.

Simulação da proposta de economia circular: análise de cenários de remanufatura de impressoras

Resumo: Dispositivos computacionais, como as impressoras, usualmente possuem tempo de vida pré-determinado e são descartados quando param de funcionar, gerando grandes quantidades de lixo eletrônico. A Economia Circular, por outro lado, propõe uma alternativa ao modelo linear de extração, transformação e descarte aplicado na maior parte das organizações, a partir da recolocação de materiais nas cadeias produtivas sem que haja perda de qualidade nesse processo. O objetivo de pesquisa é desenvolver ae experimentar modelos para analisar o impacto da remanufatura de impressoras de uma instituição de ensino superior. Este artigo defende a remanufatura de impressoras como uma forma de diminuir tanto a quantidade de lixo eletrônico descartado, quanto os custos com a aquisição de novos equipamentos. Um modelo computacional foi construído e, a partir da abordagem da Dinâmica de Sistemas, cenários foram propostos para simular o comportamento ao longo de 10 anos. Analisando-se dados de

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uma Instituição Federal de Ensino Superior, verificou-se que a remanufatura de impressoras pode reduzir em 2,5 vezes o volume de lixo eletrônico gerado, e atingir uma economia financeira da ordem de 37%.
Palavras-chave: Dinâmica de Sistemas; Lixo eletrônico; Modelagem Computacional.

1 Introduction

The decrease in the useful life of equipment is a fact that has been recorded throughout recent history. For mobile phones, the service life would be less than two years (WIDMER et. al., 2005), reaching three years in the case of smartphones (ERCAN et. al., 2016). In the case of printers, used both in domestic and corporate environments, it is assumed that the useful life varies from two to eight years (BOUSQUIN et. al., 2012). Therefore, it is necessary to look for ways to mitigate the consequences of high consumption, which, together with programmed obsolescence and the intense pace of innovation, ends up making a large part of electronic equipment technological scrap in short periods of time (ROCHA et. al., 2010).

The rupture of the linear model of extraction, transformation and disposal, applied in most companies, is preached by the Circular Economy, from the search for the replacement of materials in the production chains, without there being, in this process, loss of quality (AZEVEDO, 2015). Circular Economy determines the construction of products with multiple use cycles, reducing the need for resource extraction and reducing waste (AZEVEDO, 2015). It is, therefore, an alternative to the linear model, allowing the return of materials (or part of them), which would be discarded, to the production chain, through processes such as remanufacturing, reuse and recycling (ELLEN MACARTHUR FOUNDATION [EMF], 2013).

Remanufacturing, in particular, is the process of returning a used product to a condition similar to the new one, through inspection, disassembly, cleaning, reprocessing, assembly and testing (HATCHER; IJOMAH; WINDMILL, 2013). The process involves recovering the added value of a product, making it similar to when it was first manufactured, reducing energy costs and costs involved in production (GRAY; CHARTER, 2008). It is, therefore, an intrinsic procedure to the Circular Economy, which returns goods with high potential for disposal to the production chain.

Large institutions need to maintain large technology parks. This is the case of Higher Education Institutions (HEIs), in particular, which maintain electronic equipment both for carrying out their basic activities, such as teaching, research and extension, as well as means, such as the administration / management processes. The equipment of these institutions needs to be properly disposed of as they fall into disuse and new devices are purchased to replace them. Traditionally, used products are discarded by consumers at the end of their useful life (TURKI; REZG, 2018), which has led to the increasing volume of items that are discarded as garbage (WANG, W. et al., 2017). Fadeyi, Monplaisir and Aguwa (2017) point out that, today, about 80% of manufactured products end up being discarded. The focus of this study will be the printers, which is a widely used item in higher education institutions and without a correct disposal plan.

Printers are part of this set of electronic equipment, and usually become electronic waste when they become obsolete or stopped working, being replaced by new ones. Modeling techniques have been used to evaluate scenarios of better electronic waste disposal in HEIs, however without the focus on remanufacturing (SCHNEIDER et. al., 2015), or with computer-oriented remanufacturing (SIMONETTO et. al., 2016). Little has been studied regarding the remanufacturing of printers, although the reuse of their toners and cartridges has been the subject of scientific work (COSTA et. al., 2006; HUANG; SARTORI, 2012; MOURA; OLIVEIRA; AFONSO, 2012; SILVA, 2012).

Based on the concept of Velte, Scheller and Steinhilper (2018), who define the circular economy as a model that establishes a relationship with different forms of creation and conservation of value. The circular economy may occur through reuse, reform, remanufacturing or recycling, for this study remanufacturing was chosen. Therefore, we have the following research objective. "Develop and experiment with models to analyze the impact of the remanufacturing of printers in a higher education institution".

In this work, remanufacturing is considered as the process of taking advantage of parts in good condition, removed from defective equipment, for the construction of a functional device similar to a new one. Based on the model, it is expected to assist managers in making decisions regarding the destination of printing devices, thus contributing to the Circular Economy and the reduction of electronic waste. The scenarios to be evaluated will be from a federal public higher education institution, but it is believed that the model can be used in other circumstances, with the necessary adaptations.

The article is divided into 5 sections, in addition to this introduction. Section 2 provides a literature review, covering work-related topics; section 3 presents the method used for the construction of the work; section 4 presents the model developed; Section 5 presents the results of the simulation in the built scenarios. Finally, in section 6, the results of the article are discussed, and future work and research limitations are presented.

2 Literature Review

The following sections discuss the central problem of this article - electronic waste - bringing as a possible solution the application of circular economy, focused on remanufacturing.

2.1 Circular Economy and Remanufacturing

Circular Economy (EC) seeks to break with the traditional linear model of extraction, transformation and disposal applied in most companies, using methods that enable the reinsertion of materials in the production chain without loss of quality (AZEVEDO, 2015). The Circular Economy model is based on nature to promote more sustainable development, with the closure of the products' life cycle and the reduction of energy, raw materials and water consumption (LEITÃO, 2015).

Circular Economy avoids waste by proposing the creation of multiple product use cycles, which circulate efficiently and are replaced in production chains instead of being discarded (AZEVEDO, 2015). If, on the one hand, biodegradable materials can be reused as biological nutrients by the environment, synthetic or mineral materials can, on the other hand, be kept in closed cycles as "technical nutrients"; EC minimizes waste production, maximizing the use of natural resources and the economic value of products. (LEITÃO, 2015). Still for the author, it is a regenerative model, which goes against the model of destructive and predatory industry.

The EC is based on some principles, according to EMF (2013): (i) waste-free design, that is, the elaboration of products with the possibility of disassembly and reuse; (ii) building resilience through diversity, present in characteristics such as modularity, versatility and adaptability; (iii) confidence in renewable energy sources; (iv) systems thinking, based on the ability to understand how the parties influence each other and the whole; and (v) waste is food, that is, components that would be discarded end up being reintroduced into production chains.

The circular economy can be defined as a model of sustainable and economic development with the objective of making the use of resources more effective and preserving the natural environment (ENGELAGE; BORGRT; SOUZA, 2016). For Petit-Boix and Leipold (2018) the circular economy has been gaining popularity at the most different levels with the promise of creating processes that are more sustainable.

For Geissdoerfer et al (2018) EC can be understood by a system that reduces the entry of resources in addition to assisting in the elimination of waste, pollutants and energy. Muranko et al (2018) believe that it is applied in the idea of placing business at the service of the transition to a system that is more sustainable. Alamerew and Brissaud (2019) believe that the circular economy is also a type of economic and industrial model that seeks to maintain components, materials and emotional resources for the longest possible period of time.

Remanufacturing is a process of transforming used products into products with the same quality, functionality and guarantee as when new, consisting of processes to disassemble, clean, inspect, repair, replace and reassemble the components of a product to restore it to its original state initial condition (MATSUMOTO et. al.,2016).

For Hatcher et al. (2013), remanufacturing is the process of returning a used product to a condition similar to the new one, through inspection, disassembly, cleaning, reprocessing, assembly and testing. Remanufacturing involves recovering the added value of a product, making it similar to when it was first manufactured, reducing energy costs and costs involved with production (YANG, 2016; ZHANG; YANG; CHEN, 2017). Remanufacturing brings economic, environmental and social benefits, since it reduces production costs, reduces energy costs and waste disposal, and allows the generation of jobs and the sale of products at more accessible prices than new ones, which, in recent years, has attracted increasing global attention (MATSUMOTO et al., 2016).

Remanufacturing is an important industrial activity, essential for sustainable production, with enormous potential to generate positive impacts in the economic, environmental and social areas. Increased competition and the imposition of increasingly stringent environmental laws mean that companies are forced to seek alternatives, along the product value chain, that are able to increase their profits (CORREA, 2019).

The practice of remanufacturing not only brings economic benefits, since it reduces the costs for production, it allows the generation of jobs and the sale of products at more accessible prices than the new ones, but also environmental and social, as it reduces energy costs and the disposal of waste, which, in recent years, has attracted increasing global attention (MATSUMOTO et. al, 2016).

3 Methodology

The methodology adopted for the development of this work was computational modeling, characterized by prescriptive models. Prescriptive models are based on the representation of objectives and restrictions of a process, for which optimized solutions are sought, which can be solved in an exact or approximate way (GOLDBARG; LUNA, 2005). Based on models, the objective is to represent the real world in an abstract and simplified way, allowing explanations or behavior tests in whole or in parts. Also according to Goldbarg and Luna (2005), a model is not identical to reality, but sufficiently similar so that the conclusions obtained through its analysis and operation can be extended to the real world. Models are systems of relevant human activities, drawn up using the concept of input-output.

Computational Modeling is a multidisciplinary area of knowledge that deals with the application of mathematical models and computer techniques for the analysis, understanding and study of complex problems in areas such as engineering, exact sciences, biological, human and economics. They are incomplete and simpler representations than the object or system in question (COSTA, et. al., 2004).

Chwif and Medina (2015) describe computational modeling as a presentation of real systems, being important to understand its complexity. A simulation model helps to capture characteristics of time, state and nature: from software, these characteristics are repeated with behavior similar to what the real system would present, assisting the decision-making process (CHWIF; MEDINA, 2015).

For Andrade (2006), computational modeling is the process of building models in systems dynamics software, aiming at the development of managerial micro worlds. The advantages of modeling are: (i) the possibility of changing parameters; (ii) the simulation of the passage of time; and (iii) the evaluation of mutual influences in a dynamic way. The main function of the software is to allow the reevaluation of the developed models, since the computer offers a safe place for experiments that generate learning (ANDRADE, 2006).

Systems Dynamics (DS) allows the study of the behavior of systems over time, enabling the evaluation of the consequences of decision making. Due to the need to study the impacts of the remanufacturing of printers in a future time horizon, it was decided to use it together with computer modeling and simulation. DS assists in building models of most known systems so that, with the support of software, we can simulate the behavior of these systems over time (VENTANA SYSTEMS, 2016).

A DS model can be defined as the structure resulting from the interaction of policies. This structure consists of two main components, which are stocks and flows. Ford (2009) defines DS as a combination of stocks and flows that use a computational structure to be simulated. Inventories refer to the model variables that are accumulated in the system and the flows are the decisions or policies. These components can be organized in the form of cause and effect relationships, called balance or reinforcement feedback, and are subject to time lags in the system under analysis.

Although computational representations are similar, they cannot be seen as reliable copies of the reality they describe: they are models that seek to portray it in the best possible way. For Hillier and Lieberman (2013), as the idealized model is not an exact representation of the real problem, there is no guarantee that the best solution presented will prove to be the best possible, or that it can be fully implemented for the real problem. Therefore, measurements are not possible to guarantee absolute certainty of the results, but viable solutions to the model they represent.

Hillier and Lieberman (2013) indicate that models can describe a problem concisely, making its overall structure understandable and helping to reveal cause-and-effect relationships. Law (2015) presents the Systems Dynamics methodology from four stages, which were followed for the development of this work. The steps are:

1. Specification and structuring of the research problem, based on studies in scientific publications and technical reports, interviews with stakeholders and observations of the environment where the data is collected. For this work, from bibliographic surveys, in scientific and technical literature, and interviews with technicians in the area of maintenance in printers, the problem was identified and its variables were raised.
2. Construction of formal models to represent the problem. In this stage, the relations between the variables were structured, and the equations for the generation of each one were defined.
3. Computational implementation of the models, using simulators. The implementation was carried out using the Vensim software (Ventana Systems, 2016), a computer simulator with support for the needs of the model, as well as the Systems Dynamics.
4. Verification and validation of the presented solution, through simulated tests. In addition to verification with specialists in the area, previous tests were carried out, before the execution of the complete simulation, to verify if the data generated in each variable were the ones expected from the input information.

Several authors use this methodology to analyze issues related to the environment and sustainability, among which the studies by (SUFIAN; BALA, 2007; ABELIOTIS et.al.,2009; DYSON; CHANG, 2005; KUM; SHARP; HARNPORNCHAI, 2005; SIMONETTO, 2014).

4 The Simulation Model

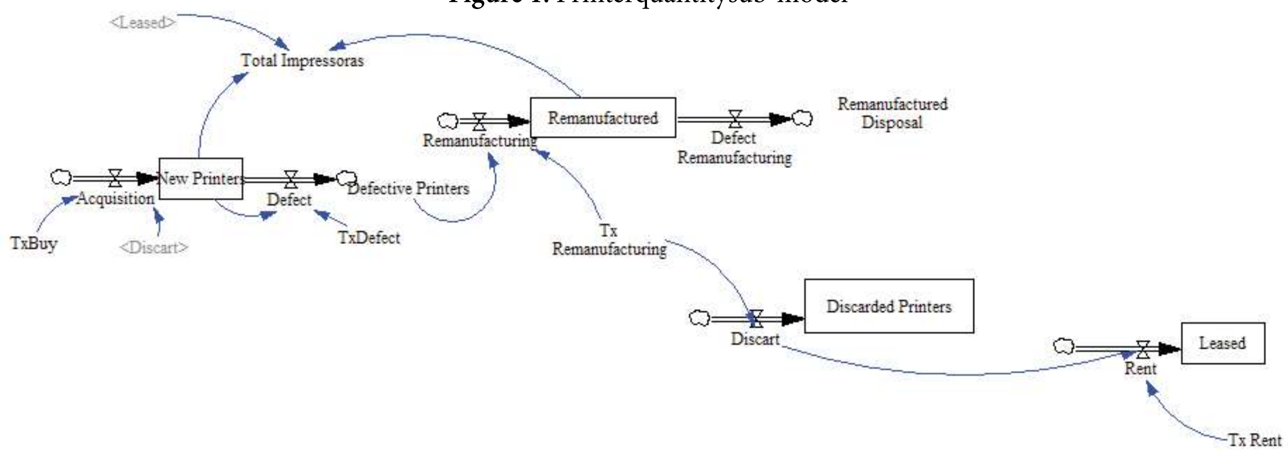
To analyze the economic and environmental impacts of printer remanufacturing, a computer simulation model was built. In order to facilitate understanding, the model was divided into three submodels: (i) the submodel of the number of printers; (ii) the submodel quantity of toners and refills; and (iii) the economic and environmental impacts sub-model. The model variables store, mainly, the number of new, remanufactured and discarded printers in the system; the amount of new, used toners, refills available, used refills and required toners; costs for remanufacturing, purchasing new printers and renting printers; and the volume of printers and toners discarded. In the following, the three submodels are described.

4.1 The Submodel Quantity of Printers

The number of printers sub-model was built to calculate the number of printers available in the system each year, whether they are new (that is, purchased), remanufactured or rented. The new printers are stored in a stock variable, which has as input the acquisition of new printers and the output of these printers that are defective, that is, it stores the purchased printers that are in operation. When a printer becomes defective, it has two ways: to be remanufactured or discarded. If remanufactured, it will feed the inflow of the PrintersRemanufactured stock variable, which stores new printers that have been remanufactured and are in operation. Another inventory variable is PrintersLeased, which stores the number of printers that are rented, based on the printers that will be discarded, and a rental fee.

The variable TxRemanufatura indicates the ratio of use of printers in the remanufacturing process, that is, from how many defective printers a working printer can be generated. The variable TxDeffeito already tells the percentage of printers that will be defective each year. Finally, the variables TxCompra and TxAluguel, respectively, store the list of printers that will be purchased or rented for each discarded printer. These rate variables allow the simulation user to build scenarios that best adapt to their realities, that is, what percentage of printers have defects per year, on average; from how many defective printers it is possible to assemble one in good condition; how many new printers will be purchased for each printer that will be discarded; and how many printers will be rented for each discarded.

Figure 1: Printerquantitysub-model



Source: Authors (2020).

The flows of the printer quantity sub-model are: (i) acquisition, which calculates the number of printers to be purchased; (ii) defect, which calculates how many new printers, in operation, are defective each year; (iii) remanufacturing, which calculates the number of remanufactured printers, based on defective ones, in a given year; (iv) Remanufacturing defect, which verifies the number of printers already remanufactured that will be defective each year; (v) disposal, which calculates the number of printers that will be discarded per year; and (vi) rent, which calculates the number of printers to be rented, in the year.

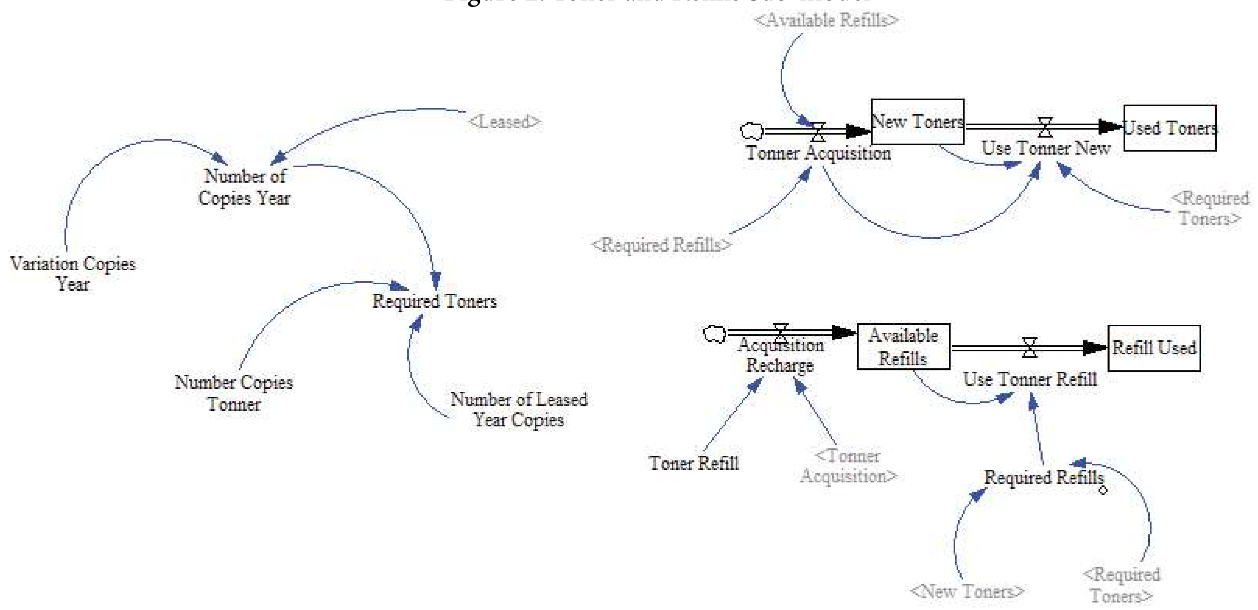
4.2 TheSubmodel Quantity of Toners and Refills

The second sub-model deals with calculating the amount of toners needed in each year of simulation and, based on this information, estimating the amount of refills required, as well as the number of new toners that must be purchased. To calculate the number of toners needed each year, divide the number of copies that will be needed by the number of copies that a toner can print. This account also takes into account rented printers, since, for these, there is no need to purchase toners. The number of toners required is stored in the Toners Needed variable. Based on technical toner information, it was found that the number of impressions of a new toner is the same as that of refilled toners.

The stock variables of this submodel are: (i) New Toners, which stores the number of new toners available; (ii) Used Toners, accounting for how many of the new toners have already been used; (iii) Available Refills, which stores the number of refills that can be made; (iv) Refill Used, accounting for how many refills have already been made. In addition to these stock variables, other auxiliary variables are defined in this sub-model: the Recharge-By-Toner variable stores the number of times that a toner can be refilled, while the RechargesNeeded variable calculates the number of refills that must be made in the year, based on the number of necessary toners and new toners available.

The submodel starts from the number of toners needed and prioritizes the use of new toners, since these have already been purchased and have not yet been used. If there are no new toners available to meet the need for toners, we try to use the available refills. Finally, if there are no new toners or refills available, toners are purchased (purchased). The flows of the submodel are AquisicaoToner, which counts how many toners should be purchased; UsageTonerNew, which calculates how many new toners have been used; AcquisitionRoad, accounting for how many new refills can be made, based on purchased toners; and UsoRecargaToner, calculating the amount of toner refills that are made.

Figure 2: Toner and Refills Sub-model



Source: Authors (2020).

4.3 TheSubmodel Environmental and Economic Impacts

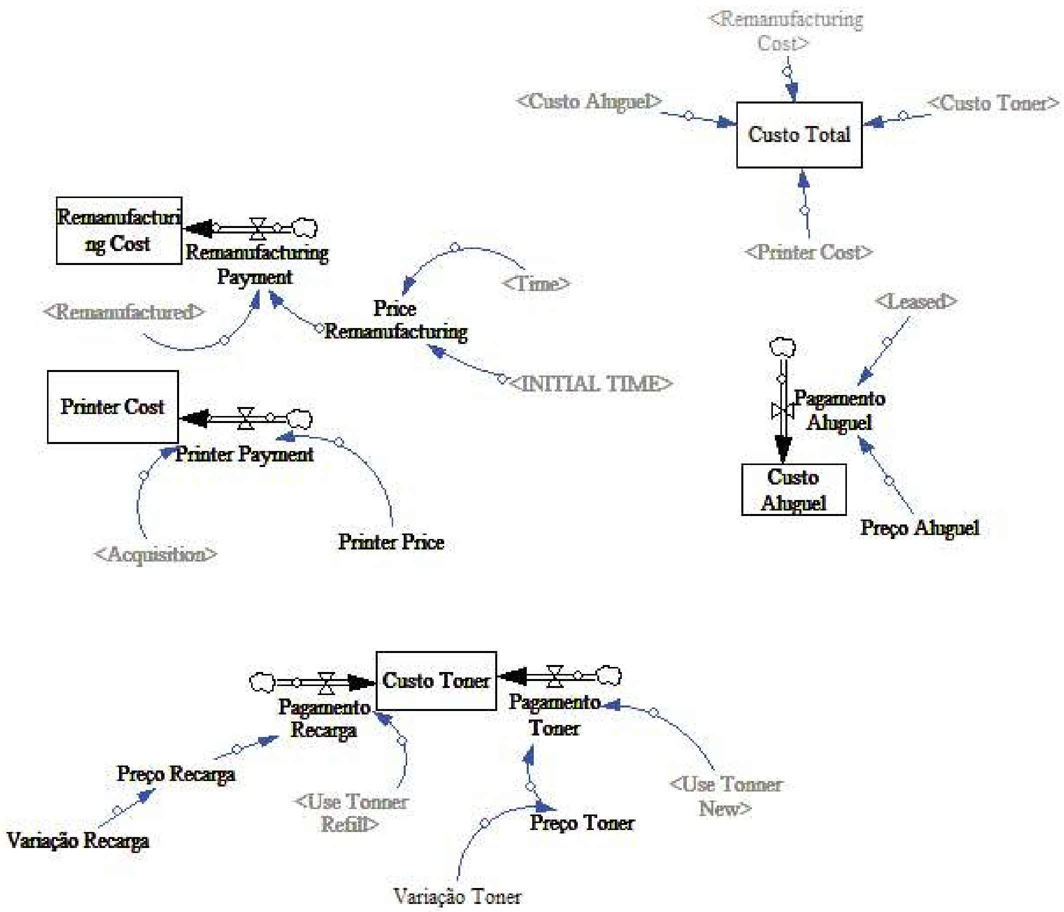
This submodel seeks to estimate the financial impacts (costs) and environmental impacts, in relation to disposal, in the proposed model. The stock variables of this sub-model, referring to financial impacts, are:

(i) CustoRemanufatura, which stores the total spent to remanufacture the printers; (ii) CustoImpressora, with the total spent on the acquisition of printers; (iii) CustoAluguel, with the total value of printer rentals; and (iv) CustoToner, accounting for the amount spent on the purchase and refill of toners. In addition, the TotalTotal variable stores the total amount spent, being the sum of the other four.

The stock variables referring to environmental impacts, by disposal, are VolumeImpressorasDescartadas and VolumeTonersDescartados, which account, respectively, for the total volumes of printers and toners discarded, based on the volume of their carcasses.

Each inventory variable in this sub-model receives data from an input stream, with the exception of Total Cost. Figure 4 illustrates the submodel.

Figure 3: Sub-model for environmental and economic impacts



Source: Authors (2020).

5 Simulation and Results

Four simulation scenarios were defined to verify the impacts of the remanufacturing of printers, based on the model developed. The scenarios were designed based on data from a Federal Public University: some of its variables were calibrated with fixed values, for all scenarios, while others had modifications in each of the scenarios, in order to verify their impacts, in financial terms and environmental, over a 10-year period. Only laser printers for personal use were considered, that is, inkjet printers, dot-matrix printers, plotters and other larger printers were excluded. The number of scenarios (4) was chosen based on Andrade (2006).

The initial number of printers, in all scenarios, was defined as 1816 – the institution's estimated number of printers, obtained from patrimonial survey reports. This number was also used as the total number of refills available, as it is not known how many times the toners for each printer have already been refilled. Bearing in mind that the number of employees and students of the institution have not undergone significant changes, it was determined in the first three scenarios that there is no need to increase the number of equipment, that is, it was defined that the initial number of printers is enough to meet university demand, and that new printers can be purchased just to replace defective equipment. For the fourth scenario, a reduction in the total number of equipment was simulated, preaching greater sharing of the devices.

Bousquin et. al (2012) indicate that the life span of printers varies from 2 to 8 years; while Stobbe (2007) apud Bousquin, Esterman and Rothenberg (2011) indicates a time of 5 years. In this way, it was decided to fix the lifetime of all the printers in the study at 5 years, being in accordance with both works and facilitating the understanding of the model; therefore, the defect rate was defined as 0.2 (⅕). The remanufacturing rate was defined as ⅓, that is, for each 3 defective printers, one can be generated, in the scenarios in which there is remanufacturing. This value was obtained from contact with technical specialists from the institution that work in the maintenance of computing devices. The same specialists, technical and administrative servants of the HEI, also contributed to the definition of the cost of remanufacturing: from the average time spent to perform the service (4 hours, indicated by the servers), the salary of the position responsible for maintaining the equipment and the career plan, the cost of remanufacturing a printer was calculated as R$ 72 in the first year, reaching R$ 97 in the tenth year, due to the projected progressions.

The unit price of the printer was kept constant at R$ 687.00, this being the value of the laser printer model available for purchase by the institution. It was decided to keep the value fixed, due to the variation in the value of the printers throughout the historical period analyzed (2007 to 2017) without a defined standard. Likewise, the annual rent value was also constant over the simulated 10 years, at R$ 790.00, as it is the most used bidding value in the institution, currently. The volume for a printer was fixed in all scenarios at 21312cm^3 (volume of the printer model most present in the institution); the toner volume was defined as 4433 cm^3, as it is the most used toner.

To estimate the number of prints made each year, data from A4 sheets used in the institution between 2007 and 2017 were used: it was defined that the behavior of the 10 years of simulation would be similar to that found in the previous 10 years. The initial value set for the prints was double the number of sheets used in the HEI until June 2017. Similarly, the variation in the purchase prices of new toners and refills were defined based on the behavior from 2007 to 2017. For this In this case, data from the most consumed toners in the institution were used. Finally, the number of refills for each toner was set to 3 for all scenarios, and the number of prints per toner was fixed at 2000 copies; these variables were determined based on technical information from manufacturers. Table 1 summarizes some of the variables in the simulation scenarios.

Table 1: Values of constant variables in the scenarios

VARIABLE	VALUE
Initialnumberofprinters	1816
Defect rate (DefectTx)	0,2
Remanufacturing rate (TxRemanufacturing)	⅓ (whenthereis)
Preço de remanufatura (PrecoRemanufatura)	R$72,00 a R$97,00
Price of each printer (PrecoPrinter)	R$687,00 per printer
Rental (annual) price (RentPrice)	R$790,00 per printer
Number of prints per toner (NumeroCopiasToner)	2000 toner copies
Number of refills per toner (RefillByTonner)	3 recargas per toner
Printer Volume (Printer Volume)	21312cm³ per printer
Toner volume (VolumeToner)	4433cm³ per toner

Source: Authors (2020).

The 4 scenarios were listed (I, II, III and IV) and defined as described below. Table 2 shows the value of the variables that were changed in each scenario.

1. **Scenario I**: considers that no defective printer will be remanufactured or rented, that is, all will be discarded, and new printers will be purchased.
2. **Scenario II**: there is remanufacturing of the printer at a rate of 1 remanufactured printer for 3 damaged, and purchase of new printers for each discarded (that is, 2 purchases for every 3 defective ones, and 1 purchase for each defective remanufactured printer).
3. **Scenario III**: 1printer is remanufactured for 3 defective ones, and for every 2 discarded printers, 1 new one is purchased, and 1 is rented. The total numberofprintersisalsokeptconstant.
4. **Scenario IV**: there is remanufacturing at a defective 1 to 3 rate, but there is no purchase. For every 5 defective printers that will be discarded, 1 new one is rented. Thus, a policy of reducing the total number of printers is attributed over time, using rent instead of purchase.

Table 2: Variables changed in each scenario

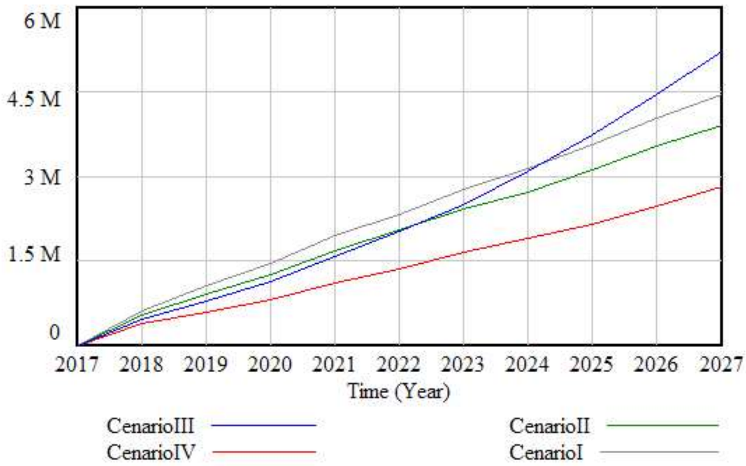
VARIABLE / SCENARIO	CENÁRIO I	CENÁRIO II	CENÁRIO III	CENÁRIO IV
TxPurchase	1	1	1/2	0
TxRent	0	0	1/2	1/5
TxRemanufacturing	0	1/3	1/3	1/3

Source: Authors (2020).

After defining the scenarios, simulations were carried out using the model implemented in the Vensin simulator (Ventana Systems, 2016), over a 10-year time horizon. It is noteworthy that the model can be changed, as well as new scenarios can be produced by changing variable values, providing users (managers) with an analysis of the "what (happens) if (condition is present)" type. Financial and environmental impacts were analyzed, discussed below.

In relation to costs (financial impacts), it can be seen in the graph in Figure 4 that Scenario III has the highest cost after 10 years (R$ 5,209,860.00), although at the beginning it remains lower than Scenarios I and II . This is due to the replacement of half of the defective printers, which would be discarded, with new leased printers, whose payment is made annually for each printer. Scenario IV is the least expensive (R$ 2,825,410.00), as there is no purchase of new printers, and 1 printer is rented for every 5 discarded. This scenario has a cost of 54.23% of scenario III, the most expensive. Scenario I, which consists of just replacing defective printers with new ones, purchased, and not remanufacturing, results in expenses of R$ 4,452,870.00 after 10 years. In Scenario II, in which there is remanufacturing, the expense totals R$ 3,925,680.00. Thus, it appears that, with remanufacturing alone, there would be savings in the order of 12% of costs. With the policy of reducing printers (Scenario IV), it generates a cost of 63% of Scenario I.

Figure 4: Total Cost



Source: Authors (2020).

From the amount spent in each scenario, it appears that a small portion is for remanufacturing. Scenario II is the one in which there is the greatest expense with remanufacturing, accumulating R$ 181,105 reais over the 10 years. Scenarios III and IV reach, respectively, R$ 117,036 and R$ 76,190.00 at the end of the considered horizon. It appears, therefore, that it is a low cost process, when compared to the total spent for the purchase of printers and toners, in addition to refills.

With regard to environmental impacts, it appears that Scenario IV is the one that generates the least amount of printer waste, (Figure 5), while Scenario III is the one that generates the least toner volume (Figure 5). Scenario I has the highest disposal of printers, in the order of 77 m^3, 2.5 times greater than Scenario IV, which disposes of 30 m^3. The inclusion of remanufacturing in Scenario II avoids the disposal of 22 m^3 of printers, since the disposal of this scenario reaches 55 m^3 in 10 years. For toners, Scenario III generated the least amount of waste, around 9m^3, while Scenario IV generated approximately 32m^3; scenarios I and II, on the other hand, have the same quantity of toners discarded, as they do not use rent: 56m^3, that is, 1.75 times greater than the volume of Scenario IV and 6.2 times greater than scenario III. It is worth mentioning, however, that the use of rent does not end the problem of disposing of toners, it just removes this responsibility from IES.

Figure 5: Volume of Discarded Printers

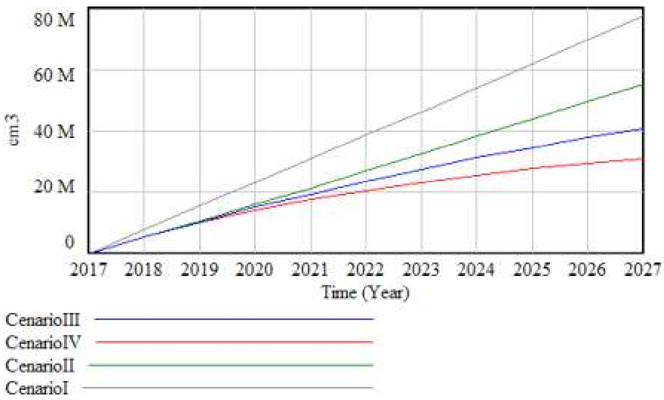
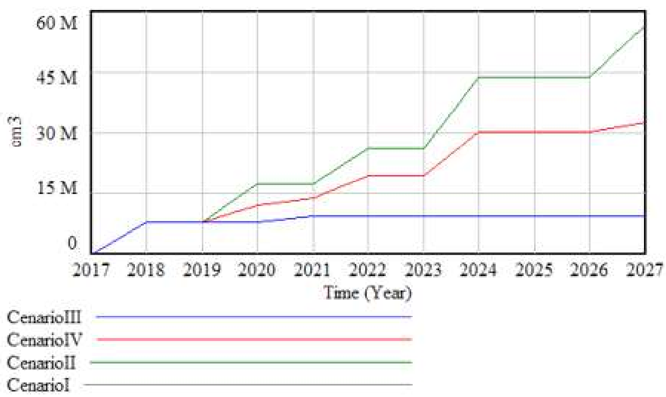


Figure 6: Volume of discarded toners



Source: Authors (2020).

With specific regard to the results obtained, for the evaluated scenarios, the simulated scenarios were successful, corroborating the authors' theory Wang et al (2017), Weelden, Mugge and Bakker (2016), Wel, Wang and Zhao (2018). Such a finding was already expected, since the comparison of the scenarios was not the main objective, this being to demonstrate that whatever the result obtained, the scenarios with remanufacturing are better than the current situation of the institution, with regard to the reuse of your electronic waste.

6 Final Considerations

If, on the one hand, the evolution of information technology makes available a large number of electronic devices that assist in the performance of routine tasks in organizations, on the other, the short lifespan of such equipment, such as printers, accelerates the generation of large quantities of electronic waste. Circular Economy preaches the reallocation of materials, probably discarded, in the production chain, reducing the generation of waste and bringing positive financial impacts.

A proposal for a circular economy, remanufacturing stands out as a mode of production that can reconcile sustainable development and economic development. However, remanufacturing is a practice that has numerous benefits in the environmental, economic and social spheres. It is a field of activity that is configured in a very complex way in relation to the traditional manufacturing sector.

The main objective of this research was the development and experimentation of computer simulation models to evaluate scenarios for the remanufacturing of printers in a higher education institution, in which there is no circular economy policy and reuse of electronic waste.

This article proposed to evaluate the environmental and financial impacts of the remanufacturing of printers, as an alternative to disposal, in the context of a Higher Education Institution, promoting the circular economy. For this, a computer simulation model was built and 4 scenarios were evaluated, analyzing both the costs and the volume of discarded devices.

It was found that remanufacturing generates positive financial impacts, being about 12% less costly over the 10-year horizon of the analyzed HEI and, together with a policy of reducing equipment, through rent in exchange for the purchase of new printers, due to a reduction of around 37% of the amounts spent. Similarly, the disposal was reduced through remanufacturing, by about $22m^3$, so that the scenario with remanufacturing generated a volume of about 71% of the scenario without remanufacturing. On the other hand, with the policy of reducing the number of printers, the volume generated was 2.5 times smaller than the scenario without remanufacturing and without rent. For toners, the scenario with the lowest generation of waste was III, which ends up replacing the institution's printers with other leased ones, which does not generate toner disposal for the IES. The volume generated in this scenario is 28% of the volume generated by the second best scenario (IV).

From the analysis of the results, it can be concluded that it is important to seek new destinations for electronic equipment before discarding them, putting them back in the production chain. It is suggested, therefore, that organizations, such as the HEI studied, make efforts to implement the remanufacturing of printers, and that they seek policies to manage the quantity of this equipment, reducing them through the use of shared printers.

The main contribution of the model developed for the academic community is the possibility of assessing the impacts arising from remanufacturing. In addition, as it is an open model, it can be changed for application in other cases and types of organization, making possible new research from this one already started. For IT managers from other organizations, the model generated can assist in planning purchases and disposing of equipment, in order to minimize losses related to ICT expenses, as well as contributing to environmental sustainability through circular economy initiatives.

As limitations of the study, it is pointed out that the waste generated by the rented printers was not considered. As for future work, the aim is to both improve the model, investigating other data that may be relevant, as well as expanding it to take into account other equipment such as scanners and other types of printers.

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