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Açai pulp waste reverse channels modelling under the system dynamics perspective

ABSTRACT

The goal of this paper was analyze the different agents, interactions and loops in the reverse channels of açai pulp production waste under the perspective of system dynamics modelling. For this purpose was performed a Bibliographic and field research for data collection regarding reverse channels, and system dynamics methodology of soft modelling to build a causal loop diagram. The methods were applied in the city of Castanhal-PA, North of Brazil. As a result, was found that demand to the large producer of pulp increases the generation of waste, since more of it is added to the pasteurization process. Furthermore, legislation is an important agent since it can reduce the number of large and small producers, although it also diminishes the inadequate waste disposal. Our study provided information on the agents that influence the waste production and the directions of this loop. With reliable data, simulations can be performed to observe the impacts of those links. Hence, it can support the identification of the capacity and limitation of this complex system it became a novel application of system dynamics to understand and comprehend the complex system of reverse channels of the açai pulp production.

Keywords: Açai. Reverse Channel. System Dynamics.

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INTRODUCTION

Actions towards the adequate disposal, recycling and reutilization of waste are growing worldwide due to the increase of ecological awareness and the application of public policies on several types of waste.

The complexity within the operation of Reverse Channels (RC) depends on factors, such as the type and variety of waste, number of actors (links or institutions) in the supply chain, the performed activities and policies (from companies or government) that drive the operations management of that channel, which hinders its management.

Therefore, it has been important the search for methods and tools that assist the comprehension of those systems to drive and improve their RL operations.

In this context, System Dynamics (SD) is a useful tool to back up the understating of those channels since it aims to comprehend a system's structure, its physical elements, decision rules and interrelationships to explain the system's performance (Maldonado, 2016).

Despite the widespread of SD in several management fields, waste management still has not taken full advantage of SD modelling (Li Hao et al., 2008). The perspective of SD is ideal to investigate and assist the decision-making process of different projects in the environmental field of study by contemplating the system's and its integration (Golroudbary, 2015).

Hence, we can observe those benefits in studies have considered a SD perspective with RL activities: waste management (Vélez & Mora, 2016); volume reduction and prediction of waste generation (Dyson & Chang, 2005), sustainable welfare and "green image" (Vlachos et al., 2007); reduction of environmental risks (Rizzetti, 2016); economic (Ferri et al., 2015) and ecologic (Simonetto, 2014) feasibility; and product reutilization (Dace, 2014).

According to the Brazilian Institute of Geography and Statistics (IBGE, 2015), in 2014 Brazil produced 198,149 tons/year of açai pulp, from which 109,775 tons/year (55%) were in the State of Pará, turning it into the largest producer and consumer of açai waste. Sotirakis (2009) has measured that, from the national pulp production (112,676 tons/year), 93,521 tons/years are açai pulp waste, which yields to different problems.

Those characteristics compose the reserve cycle complexity of açai pulp production waste in the region. In the city of Castanhal, the components from the reverse channels of pulp waste were not clearly known and, thus, it was necessary to identify and characterize those channels to comprehend the relationships within the system.

Therefore, our study aimed to analyze the reverse channels waste generated from açai pulp production (APP) under a SD perspective, considering a qualitative modelling of interactions and cycles (loops) among different agents in these channels.

Açai is a fruit highly present in the Brazilian North region and its production has increased significantly in recent decades due to its demand growth in both internal and external markets.

A large amount of its production takes place in the city of Castanhal, State of Pará, and its waste comprehends the açai seed and fibers, which composes tons of waste per years. In this city, there are already reverse channels, which were formed spontaneously without a specific incentive from public or private institutions, and where the waste flows to various destinations.

LITERATURE REVIEW

Reverse Logistics and Reverse Channels

The concept of Reverse Logistics (RL) became strong since the 80s, being its discussion extended in Brazil circa 1998 (Dias, 2012). The Council of Logistics Management (CLM) has published the first definition of Reverse Logistics, which was revised by the Council of Supply Chain Management Professionals (CSCMP, 2013): a specialized branch of logistics towards the transportation and management of after-sales and post-delivery resources that includes the return of products for repair.

Other definitions were also considered and proposed to broader the RL concept as its range of activities has gained importance. For more details, see Fonseca et al. (2017).

Grant (2012) claimed that, in the supply chain, the final customer cannot be a supplier, since there is no financial input flow after this agent, however, there has been a need for the disposal of waste generated after the product use.

Hence, RL begins at the final users (first customers), the products are collected from them (return items), followed by the management of those products to different decisions, which include recycling (turn used products into raw material for other processes), refurbishment (repair of products for resale in the first or secondary markets), and, finally, the elimination of used parts (Govindan et al., 2015).

Hence, the logistic network that presents direct flows (traditional distribution flow) started to offer final disposal of the products. In this context, it included the Reverse Channel (RC) into the scope of planning and logistic control, since the latter will enable the reverse flow, which considers materials, components and products, from the consumption point to the origin that may correspond to the pickup or delivery of used products, components or their waste (Lu & Bostel, 2007; Caxito, 2011; Otay & Çebi, 2016).

According to Guarnieri (2011), the reverse logistic flow can use the whole or only a part of the direct channel or it may require an exclusive project that will allow the adequate disposal of the product.

In other situations, these flows are not present due to the lack of channels.

However, the emerging demand from society or the government has leveraged and driven the structure process of these flows.

System Dynamics

System dynamics (SD) is a simulation technique that joins the behavior of the components and the basic structure of a system to foresee future performance (Das, 2013). Therefore, it is a methodology to fit, comprehend and discuss complex issues within the system (Das, 2013).

In the cycles that compose system dynamics, there is the system nature, within the Systems Theory, that yields to Systems Thinking, which is a wider thought that carries the comprehension of complex systems and contributes to clarifying the structure and the behavior of the system.

When one applies this idea to the real world, it promotes efficiency in management within other areas, by practical and theoretical approaches. The contribution in assisting decision-making process in real problems has encouraged the development of systemic approaches (Alcântara, 2013).

Complex systems are considered non-linear, whose response is not proportional to their stimuli, opposed to linear systems. In nonlinear systems, the same action can produce different effects in the short or long term and even in the intervention point, different for any other part of the system (Bastos, 2003), Hence, system dynamics was developed to simulate those complex interactions.

In system dynamics, the feedback loops show the existing non-linear relationships, the dominant and subjugated parts, and the negative or positive influences (Bastos, 2003; Pinto, 2007).

Hence, feedback is the main concept of system dynamics (Silva, 2006), which corresponds to any mutual flow between two parts. In systems thinking, one principle is that every influence is simultaneously cause and effects (Senge, 2014).

The feedback assumption is that decisions are derived from information regarding the system, and they yield in actions to change it, which define new future situations and new adjustment in the system at each new information (Sterman, 2001; Silva, 2006).

Vaz (2016) states that the main difference between system dynamics and other simulation methods (process-oriented techniques) is the important of the system structure, the decision-making process, physical elements, decision rules and their interrelation, with the goal of explaining the system's behavior.

Therefore, Sun (2017) simplifies the standard approach of system dynamics in the following steps: first, specify the problems and understand the system limits; present a dynamic hypothesis, formulate the problem and test the simulation; and, finally, evaluate the designed strategy.

The two first steps are defined as Soft and Hard modelling, respectively, and are described as follows.

Soft modelling approach

The soft modelling starts with the identification of system, its limits and interfaces along with the objective of the analysis, the input and output variables (Ghisolfi, 2017).

The modeler should filter and arrange the information from mental models and real data, which allows the formalization of the knowledge regarding complex systems and the identification of interconnected structures, known as feedbacks (Barnabè, 2011; Yuan, 2014).

From this soft model, one can analyze different perspectives and obtain a picture from the intended future, which guides the building of mental models to achieve the desired goals (Vaz, 2015).

Hence, in this step, the objective is the development of causal loop diagrams (Fernandes, 2003), which are flexible tools to represent the feedbacks in systems.

Those diagrams show the causal links among variables using directed arrows from a cause to its effect, making explicit the feedbacks (Sterman, 2000; Das, 2013).

The designing of a causal loop diagram requires the participation of system specialists and users, allow them to share their perspectives regarding the system (mental models) and facilitating the mutual learning among them (Villela, 2005).

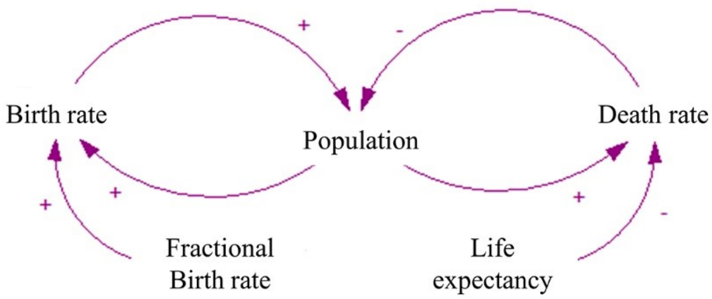
Sterman (2000) states that dynamics appear from two types of feedback loops: the positives, which leads to increase or reinforce what is already present in the system; and the negatives, which neutralize and are opposed to changes.

One can also consider time lags in those interactions, known as delays. They represent the gaps between the decisions and their corresponding results, which generate fluctuations and are responsible for long term trade-offs between causes and effects in the system (Sterman, 2000; Maldonado, 2016).

The delays can yield to instability and breakdown in dynamic systems especially when they are extended (Vitor et al., 2007).

The causal loop diagrams have two roles in system dynamics: first, in the modelling phase, they are preliminary drafts of causal hypothesis; and second, they can simplify the representation of a complex system (Rogers, 2012). An example is shown in Figure 1.

Figure 1. Example of a causal loop diagram.



Source: Sterman (2000)

In this sense, this qualitative approach refers to a mental model that complements a computational model. The latter is the basis of daily decisions and, thus, contains a large amount of information. However, the human mind is not reliable regarding the full comprehension of this information and its meaning.

Hence, computational models fit adequately to mental models to organize the information and show the consequence of its dynamics in the system. (Vilardo, 2016).

For this reason, Sales (2013) asserts that the building of a soft model and the causal loop diagram should focus on critical variables of a dynamic system, which can materialize a state condition relevant to the performance and that can be quantified to enable the analysis in the quantitative approach, the Hard modelling.

Hard modelling approach

To perform a continuous quantitative analysis, that has its structural characteristics defined in the causal loop diagram, it is necessary to develop an approach which enables the study of a system's evolution, during a certain period, using the stock and flow diagrams (Vaz, 2015).

This step is known as the Hard model, in which one aims to turn the causal loop diagrams into stock and flow diagrams (Fernandes, 2003), it is recommended that a soft model has been built previously (Vitor et al., 2007).

Simonetto (2016) affirms that stocks and flows are two main components of a dynamics system model: the first are variables that accumulates in the system, and the second are decisions or policies.

Therefore, a formal system dynamics models is formulated, which can be implemented using a software that allows the users to simulate the system and analyze results of different scenarios (Yuan, 2014). For more details, see Vaz (2015) and Simonetto (2016).

System Dynamics perspective within Reverse Logistics and Reverse Channels

Although the system dynamics perspective has been applied in other research regarding environmental impacts (Golroudbary, 2015), there is a small frequency of studies that approach this methodology with reverse logistics as shown in the bibliometric study of Vaz et al. (2016), which verified the ascending evolution of researchers, specially in 2013. This increase in publications demonstrates the relevance of this topic in the current seek for cleaner processes.

Other related studies followed this opportunity and applied the system dynamics methodology to different problems in the management of solid waste from constructions.

Hao et al. (2007) used dynamics systems in Hong Kong, which assisted the reduction, reutilization, and recycling of this waste to diminish environmental impacts and agree stakeholders' interests.

Kollikkathara et al. (2010) also emphasized the importance of city waste management and its interconnects, such as the capacity of landfills, environmental impacts, and financial expenses in Newark, USA.

METHODS

This research comprehended the soft modelling of the açai pulp production waste reverse channels system. We analyzed the system in the city of Castanhal, State of Pará, North of Brazil, since it has a large presence of açai in the region, which is a raw material for several companies, small producers and local consumers due to its cultural influence as food.

Therefore, açai has a significant presence in the city's economy in for internal and external markets (other states or countries), either as fruit or its waste. Hence, we conduct this study in two phases: the data collection regarding the generation of pulp waste as well as its reverse channels composition and links; and a field research, which are described as follows.

In Phase 1, we collected information from official documents and scientific studies regarding the açai pulp waste as well as the main disposal destinations situated in the city of Castanhal.

The research from Nascimento et al. (2017) had already identified the reverse channels from this waste in the same region and provided data as a process map, which highly assisted and guided our research towards the Soft model.

In addition, we also searched norms and law related to the disposal, handling and transportation of pulp waste that could impact the flows within the reverse channels. Then, with the information regarding the total amount of generated waste, possible destinations and effects from the current legislation, we planned the field research.

In Phase II, the field research comprehended the acknowledgement of the system by identifying the possible waste generation spots and their disposal, which were both in or out from the bibliographic research in the previous phase.

Then, we collected information using a checklist and performed unstructured and interviews with small and large (companies) producers of açai pulp, potteries, and truck drivers (transporters), to understand the volumes of pulp waste, their origin location, their transportation mean, their destination, and purpose of disposal.

We obtained the local of small producers using Google Maps API and registered their address and name. A total of 111 points were identified in city of Castanhal, however we were only able to obtain information regarding 56 of them.

For the large producers (companies), we searched their web address to obtain information, which resulted in 15 large companies. However, we only obtained data from a few who responded to the checklist.

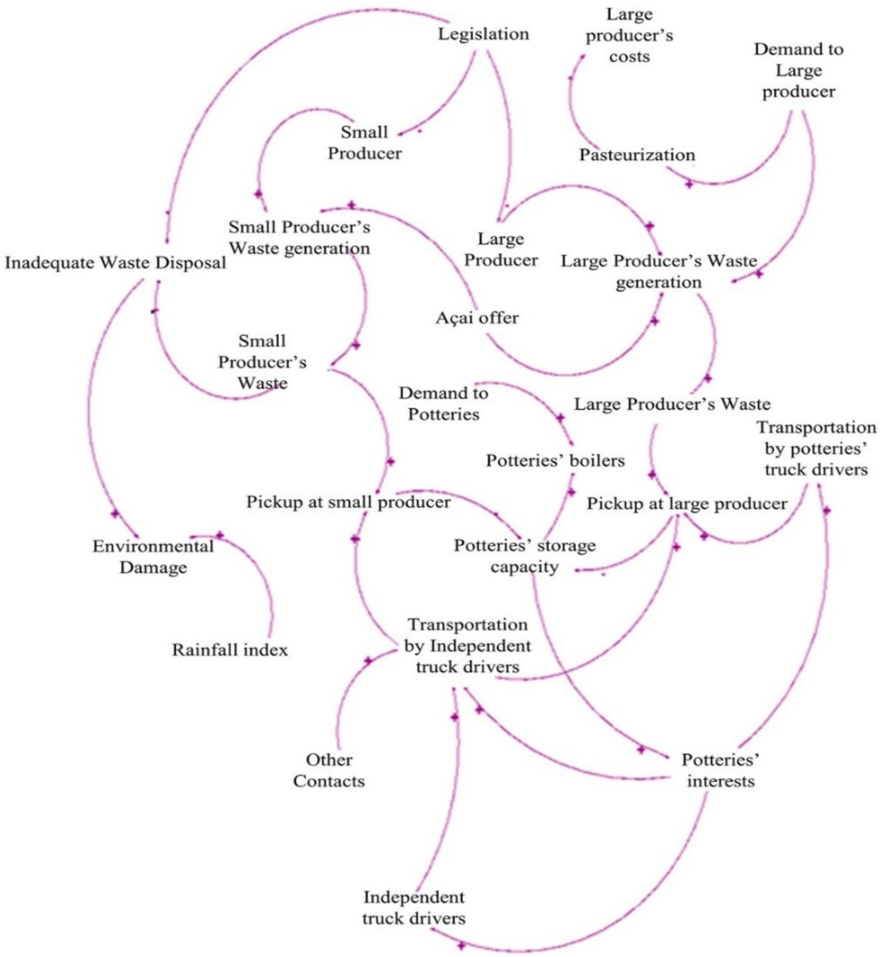
We also collected information regarding occupation area of the potteries and their workers, as well as the truck drivers. Hence, we could understand the current state of the system and its relationships which resulted in the possible variables that compose the reverse channel.

The variables we found through the research steps assisted the creation of the soft model. However, we prioritized those considered as more important, as input and outputs, to create the causal diagram and deliver the soft model. Therefore, we obtained an overview comprehension of açai pulp reverse channels using the tools from system dynamics e compare to previous studies. Diagrams were obtained using Vensim Personal Learning Edition (Vensin PLE) version 7.0.

RESULTS

From the bibliographic and field research, we considered the work from Nascimento et al. (2017) which performed a process mapping at Castanhal city regarding the reverse channels of Açaí pulp waste. With the identified channels, we proceeded to the Soft modelling to provide a simplified and effective representation of the system. We also present the causal loop diagram in Figure 2. The reverse channels agents and their roles are described in Table 1. We emphasize that those relations are non-linear.

Figure 2. Proposed causal loop diagram of the açai pulp waste reverse channel



We identified that six agents represented the reverse channel and the causal loop diagram show their relationships which are associated to activities regarding the pulp waste production, disposal means, storage, transportation between stakeholders, and the impacts that may occur depending on the decisions made by each agent. We present the discussion regarding those relationships as follows in the next section.

Table 1. Agents within the açai pulp waste reverse channels and their main roles Influences within reverse channels

Agents	Role
Small Producer	Waste generation point. Although the small producer alone does not produce a large amount of waste, when combined with other similar points around the city, the final quantity of waste is large, which is often disposed inadequately, and there has been a lack of surveillance from authorities and part of society. The waste from small producers is mostly disposed by the independent truck drivers.
Large Producer	Waste generation point. The large producers generate a large amount of waste in isolated spots, which are disposed less inadequately, since the Legislation is more rigorous, surveillance is present and the pressure from society is higher, compared to small producers. A few large producers have reported the use of pulp waste in the production process as fuel to boilers, which reduce costs and the quantity of discarded waste.
Pottery	We identified potteries as large waste consumers. They perform contracts to collect waste from with large producers with their own truck drivers and buy waste from independent truck drivers.
Pottery's Truck driver	They pickup waste from large producers and transport them to the potteries.
Independent Truck driver	They offer services to waste generators to pickup their waste and give them a destination. However, many of them sell to or trade waste with the potteries. This activity corresponds to an extra income, and they transport waste to surrounding cities.
Other Contacts	Agents that consume pulp waste in low quantities, such as individual small farmers or cooperatives that use it as fertilizers.

From the proposed model depicted as the causal loop diagram in Figure 4, one can observe explicitly the positive and negative relationships among the reverse channel agents, and the implicit feedbacks that underlie these interactions. We discuss the main relations in the following.

The "Demand to Large Producer" (Demand) influences the total volume of pulp waste to be consumed by the activity "Pasteurization", since the higher the pulp production in the large producer to attend its customer, the bigger is the amount of generated pulp waste, which are used in the pasteurization boiler.

Hence, the use of only a part of the waste can reduce the costs that the Large Producer would have to obtain other resources in the pasteurization, such as wood chips and sawdust, and facilitate the logistics for those materials.

Furthermore, we found that the Legislation is another important factor, which was also observed in Georgiadis (2008) that comprehended the implementation of system dynamics in Greece regarding ecological motivations and technology innovation in the activities of recycling, considering legislation, renewable and nonrenewable resources, and the condition of landfills.

In our study, the effectiveness of Legislation can reduce the number of producers in the reverse channels and, consequently, their generation of pulp waste, which also impacts negatively on the "Inadequate Disposal" from the small producer.

In addition, the Legislation affects the "Environmental Damages", since the more effective and rigorous the law is, the lower the "Inadequate Disposal" will be which also increases the responsibility imposed to the waste generators.

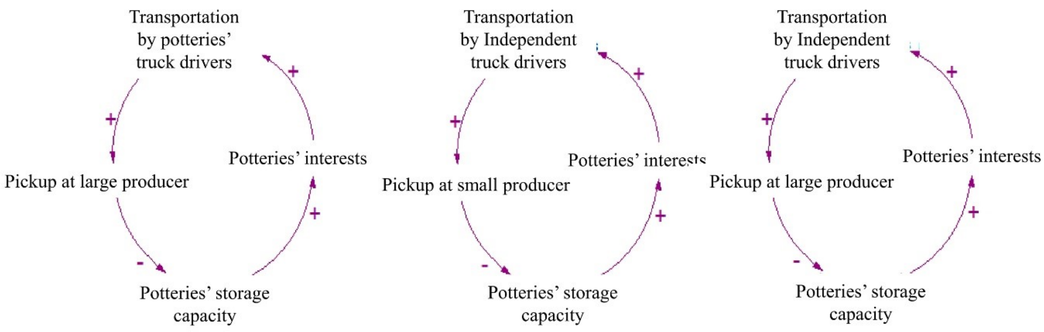
Then, when applied correctly, the legal intervention acts on in the actions from and the disposal means used by the reverse channel agents, and it hinders the entry of new agents in the system that are not keen to follow the right norms and seek to avoid conflicts with the responsible institutions.

Another observed relationship was the presence of feedback processes. The system has shown two important feedbacks: the interaction among the several activities of Waste Collection from the Small and the Larger producers, the Potteries' interest, the transportation by the potteries' truck drivers, and the independent truck drivers. Those feedback loops are illustrated in Figure 3.

We identified the Potteries as the main agents interested in the açai pulp waste. These are used as fuel in the boilers for the production of roof tiles and bricks, which contributed to the acceptation of the açai stone due its high calorific power. The feedback shows that if the interest of the Potteries is high, it increases the frequency of waste collection.

However, if the volume of total collected waste is large, the pottery may present an insufficient storage capacity, thus, it begins to have a low interest. Therefore, the reduction in waste collection yields in a high storage capacity, which leverages the interest from the potteries, consequently, increases the number of transportations and ends the loop.

Figure 3. Feedback loops within the açai pulp waste reverse channels



CONCLUSION

The adequate management of reverse channels, especially regarding the solid waste, requires a strong comprehension of its flows to understand its system complexity.

Considering this context, our study contributed with a concept (soft) model of reverse channels, under the system dynamics perspective, regarding the açai pulp production waste, located in the city of Castanhal, north of Brazil, which has been one of the important production centers of açai pulp.

We also have identified that the application of system dynamics modelling to reverse waste reverse channels and reverse logistics has not been widely considered in the literature, thus presenting a research gap to be explored.

From a bibliographic and field research, we proposed a system dynamics soft model using a causal loop diagram that displayed the interactions presented in the pulp waste reverse channel system.

Two main relationships were identified among agents: The demand to the large producer propels the generation of pulp waste due to the increase of their use in the pasteurization process; and the Legislation, which can reduce the number of large and small producers, though it also diminishes the inadequate waste disposal.

Our study found similar interactions compared to previous studies regarding the solid waste management, specially the impact from legislation. Hence, government policies are substantial in the process of driving and reinforce the waste reverse channels, aiming for the adequate disposal and reduction of environmental impacts. Furthermore, we verified a feedback loop between the interest from potteries and their storage capacities, which influences the generation of pulp waste.

Our research presented limitations in respect to the incomplete responses during the interviews, and the restrict contact from a few agents, which prevented the collection of consistent and quantitative data of the interactions in the causal loop diagram, such as the quantities of each flow. Therefore, we

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suggest future work to explore a hard modelling approach of system dynamics to perform the simulation of the system and verify its capacity and constraints.

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Modelagem de canal reverso de resíduos de polpa de açaí sob uma perspectiva da dinâmica do sistema

RESUMO

O objetivo deste artigo foi analisar os diferentes agentes, interações e loops nos canais reversos dos resíduos da produção da polpa de açaí sob a perspectiva da modelagem da dinâmica do sistema. Para tanto foi realizada uma pesquisa bibliográfica e de campo para coleta de dados referentes a canais reversos, e metodologia de dinâmica de sistemas de modelagem suave para construção de um diagrama de laços causais. Os métodos foram aplicados na cidade de Castanhal-PA, Norte do Brasil. Como resultado, constatou-se que a demanda ao grande produtor de celulose aumenta a geração de resíduos, visto que mais deste é adicionado ao processo de pasteurização. Além disso, a legislação é um agente importante, pois pode reduzir o número de grandes e pequenos produtores, embora também diminua a destinação inadequada de resíduos. Nosso estudo forneceu informações sobre os agentes que influenciam a produção de resíduos e os rumos desse loop. Com dados confiáveis, simulações podem ser realizadas para observar os impactos desses links. Assim, pode apoiar a identificação da capacidade e limitação deste sistema complexo tornou-se uma nova aplicação da dinâmica do sistema para entender e compreender o complexo sistema de canais reversos da produção de celulose de açaí.

Keywords: Açaí. Canal Reverso. Dinâmica de Sistema.

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