TOOLS FOR ASSESSING THE FINANCIAL SUSTAINABILITY OF INTEGRATED MANAGEMENT SYSTEMS OF URBAN SOLID WASTE

FERRAMENTAS PARA AVALIAÇÃO DA SUSTENTABILIDADE FINANCEIRA DE SISTEMAS DE GERENCIAMENTO INTEGRADO DE RESÍDUOS SÓLIDOS URBANOS

HERRAMIENTAS PARA EVALUAR LA SOSTENIBILIDAD FINANCIERA DE SISTEMAS INTEGRADOS DE GESTIÓN DE RESIDUOS SÓLIDOS URBANOS

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ABSTRACT
The integrated management of urban solid waste (IMUSW) is considered a challenging task due to the multiple dimensions that make up the system, its changes over time and the fragility of financial sustainability in the sector. Knowing the tools that enable the analysis of this complex system is important to help decision makers in waste management. Thus, this article aims to present the tools, and indicate the most suitable ones to be used to analyze the behavior and interrelation of the elements that affect the financial sustainability of municipalities in the IMUSW over time. As a result, when considering IMUSW systems, System Dynamics (SD) presented advantages over other static tools and methods of operational research due to their complex, changeable and recognizable nature from real world elements. This study provides important contributions for future research and IMUSW management planning, as it provides information on the most relevant and current tools for the development of studies focused on waste management and the financial sustainability of the system.

KEYWORDS
Solid waste management; Financial sustainability; Evaluation methods.

RESUMO
O gerenciamento integrado de resíduos sólidos urbanos (GIRSU) é considerado uma tarefa desafiadora devido às múltiplas dimensões que compõem o sistema, às suas mudanças ao longo do tempo e à fragilidade da sustentabilidade financeira no setor. Conhecer as ferramentas que possibilitam a análise desse complexo sistema é importante para auxiliar os tomadores de decisão no gerenciamento dos resíduos. Desta forma, este artigo tem como objetivo apresentar as ferramentas, e indicar a mais adequada, que podem ser utilizadas para análise do comportamento e inter-relação dos elementos que afetam a sustentabilidade financeira dos municípios no GIRSU, ao longo do tempo. Como resultado, a Dinâmica de Sistemas (DS) apresentou vantagens sobre as outras ferramentas e métodos estáticos de pesquisa operacional, quando se considera os sistemas de GIRSU, por sua natureza complexa, mutável e reconhecível dos elementos do mundo real. Esse estudo fornece importantes contribuições para pesquisas futuras e para o planejamento do GIRSU, pois traz informações sobre as ferramentas mais relevantes e atuais para o desenvolvimento de estudos voltados para o gerenciamento de resíduos e a sustentabilidade financeira do sistema.

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PALAVRAS-CHAVE
Gerenciamento de resíduos sólidos; Sustentabilidade financeira; Métodos de avaliação.

RESUMEN
La gestión integrada de los residuos sólidos urbanos (GIRSU) se considera una tarea desafiante debido a las múltiples dimensiones que componen el sistema, sus cambios en el tiempo y la fragilidad de la sostenibilidad financiera del sector. Conocer las herramientas que permiten el análisis de este complejo sistema es importante para ayudar a los tomadores de decisiones en la gestión de residuos. Por lo tanto, este artículo tiene como objetivo presentar las herramientas, e indicar la más adecuada, que pueden utilizarse para analizar el comportamiento y la interrelación de los elementos que afectan la sostenibilidad financiera de los municipios en la GIRSU, a lo largo del tiempo. Como resultado, la Dinámica de Sistemas (DS) presentó ventajas sobre otras herramientas y métodos de investigación operativa estática, al considerar los sistemas GIRSU, debido a su naturaleza compleja, cambiante y reconocible de los elementos del mundo real. Este estudio aporta importantes aportes a futuras investigaciones y planificación de la GIRSU, ya que proporciona información sobre las herramientas más relevantes y actuales para el desarrollo de estudios dirigidos a la gestión de residuos y la sostenibilidad financiera del sistema.

PALABRAS CLAVE
Manejo de residuos sólidos; Sostenibilidad financiera; Métodos de evaluación.

1. INTRODUCTION

On the 28th of July, 2022, the UN (the United Nations) announced a new human right, a resolution on the right to "a clean, healthy and sustainable environment" (UN, 2022). The United Nations General Assembly declared that this issue should be a universal human right and requested that countries, companies and international organizations increase their efforts to obtain this goal. In order to make this become reality, governments should engage in one of the biggest challenges of current times: solid waste management.

Municipalities consider the management of waste to be a challenge due to various factors, the main factor being the high financial demand of the process. According to Chaves et al. (2020), municipalities are unprepared to efficiently manage urban solid waste (USW), which unfolds into multiple dimensions: management (administrative and technical), political and budgetary-financial. According to Byamba and Ishikawa (2017), the interconnectivity of various waste management aspects is important to the general system's function and performance. Therefore, the analysis must consider socioeconomic, environmental, financial and political (institutional) aspects since the integrated approaches are promising tools to face the current situation of waste management, especially in developing countries.

Various authors still highlight deficits in public management (LEAL FILHO et al., 2018), such as the lack of specialized labor force and local technical qualification (MARINO; CHAVES; SANTOS JUNIOR, 2018), the involvement of political interests (CHAVES; SANTOS; ROCHA, 2014), the lack of planning (MUÑOZ et al., 2021) and information (DUTRA; YAMANE; SIMAN, 2018), low efficacy in implementing policies (XIAO et al., 2020), lack of technology improvement (KHAN et al., 2022) and limitation of financial resources to perform the necessary changes (AGATON et al., 2020; CAMPOS-ALBA et al., 2021; CETRULO et al., 2018; FERRONATO et al., 2018; PLASTININA et; al., 2019; REBEHY et al., 2017; VIOTTI et al., 2020), which are restrictive factors for efficient USW management. Therefore, one of the main aspects of USW management is linked to financial sustainability.

Financial sustainability is defined as a set of financial strategies, administrative, accounting and operational procedures that aim to guarantee continuous operations, all of which the institution must be able to financially fulfill their present and future obligations (HURST; LUSARDI, 2004; KAKATI; ROY, 2021). From the point of view of financial sustainability in Integrated Management of Solid Urban Waste (IMUSW), the goal is to guarantee the provision of services such as waste collection, transportation, recycling, processing and disposal, in order to financially cover all costs, as well as the expansion of services that accompanies population growth and future uncertainties, maintaining financial balance.

The management cost of USW in the world should grow by almost 100% by 2025, going from costing R$ 1 trillion (US$ 205 billions) to almost R$ 2 trillions (US$ 376 billions) in 2025 (RAZZAQ et al., 2021). According to the World Bank (2018), costs with USW management in developing countries represent up to 20% of the municipal budget (KAZA et al., 2018). In Brazil, according to data from the National System of Information on Sanitation (SNIS), the expenses per capita for USW management in municipalities increased in 13.2% between 2017 and 2019 (SNIS, 2020), achieving R$ 25 billions in 2020 (SNIS, 2021), which compromises the balance of bills from USW management service holders.

Besides high costs, the management of solid residue is associated to the lack of understanding on various factors that affect the whole management system and to the connections necessary to allow the operation of the whole system (ABDEL-SHAFY; MANSOUR, 2018; GUERRERO; MAAS; HOGLAND, 2013). In light of this, this study seeks to clarify the following question: Which tools can be applied to analyze the behavior and interrelationship between the elements that affect the financial sustainability of municipalities in IMUSW over time? Therefore, the main contribution of this article is to identify the tools (and indicate the most adequate ones) that can be used to analyze the behavior and interrelationship of the elements that affect financial sustainability of municipalities in IMUSW over a time frame.

It is worth noting that no similar study to the one proposed in this research was found in the literature. This gap was even identified in the study conducted by Brumatti et al. (2024), where the authors aimed to highlight research gaps in the literature related to the financial sustainability of Integrated Solid Waste Management Systems (ISWMS) in municipalities across different countries.

2. METHODOLOGY

The methodology of this article was developed through bibliographic and systematic research. Bibliographic research analyzes published materials that provide an examination of recent and current literature and may cover a wide range of subjects at various levels of completeness and scope. It may include research findings and offer new perspectives on an issue or highlight an area in need of further research. Systematic research seeks, through selected elements of interest, to systematically evaluate the selected portfolio of articles and synthesize research evidence. (GRANT; BOOTH, 2009).

In accordance with this, Figure 1 displays the steps followed in order to obtain the articles portfolio to develop systematic analysis.

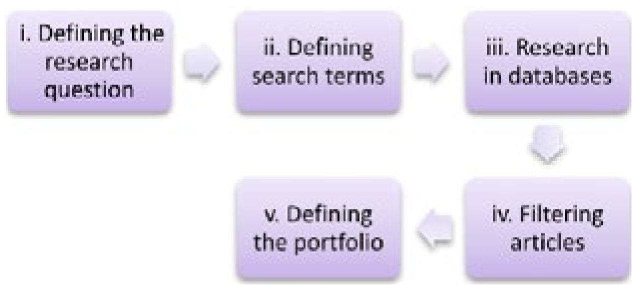

Figure 1: Steps to obtain the portfolio of articles.
Source: Authors.

After defining the research question (step i), the next step defined the search terms (step ii), which were identified in articles, books and documents related to the theme. The identified terms were then inserted into databases to assess their relevance, focusing on approximately three thematic areas: the research object: (financial* sustainab*, financial* stability, financial* viability, financial* viable, financial* self-sufficiency, financial* evaluation, balance financial*, financial* independence, financial* analysis, financial* commitment, financial* planning, financial* performance, financial* efficiency, economic* sustainab*, economic* stability, economic* viability, economic* viable, economic* self-sufficiency, economic* evaluation, balance economic*, economic* independence, economic* analysis, economic* commitment, economic* planning, economic* performance, economic* efficiency), typology of the studied waste (municipal solid waste, urban solid waste), and the action of the involved actors (management, governance) .

For the execution of step iii, the Scopus and Web of Science databases were chosen due to their greater relevance for searching scientific literature (KHUDZARI et al., 2018; SOLIS et al., 2019), and to their extensive coverage, which enables the reaching of a greater number of articles (SALVADOR et al., 2019). The research in databases was developed by combining the presented search terms and using boolean operators, which act as words that inform the search engine to combine search terms by using OR and AND. Furthermore, an asterisk (*) was used in the search terms to capture all variations of the selected terms. This research was conducted in 2022, therefore the temporal delimitation was between January 1st, 2017 and March 17th, 2022, aiming to consider the most recent studies.

Only research articles were contemplated, and the search terms were limited to titles, keywords and abstracts, resulting in a gross total of 356 articles. Following that, the Smart bibliometrics method was used to compile the articles found in the databases into one single Excel sheet and to standardize information such as year, title, authors, impact factor, number of citations, keywords and abstract, in order to analyze and filter the results. This method is employed in the research environment to provide an overview of the state of the art of the scientific knowledge about a specific theme; it is an important technique to guide the selection of bibliographical repertoire and to justify the theoretical discussion (PESSIN; YAMANE; SIMAN, 2022).

Subsequently, step iv was carried out, filtering the articles by elimination duplicates and articles whose titles, abstracts and keywords did not correspond to the researched theme, resulting in a total of 130 articles. Finaly, in step v, the 130 articles were read integrally to verify their compatibility with the previously mentioned research question. Of these, 48 studies were selected to compose the final article's portfolio, when the tools used in each conducted research were surveyed and analyzed. The survey and discussion on the tools, as well as the indication of the most suitable one, prioritized the following criteria: it should be capable of analyzing economic impacts (process costs); it should take into consider innumerable variables; it should have the ability to represent complex systems; it should consider the temporal effects resulting from changes in the system over time; it should be visual and comprehensible to allow the participation of various stakeholders involved in SWM; and its limitations.

3. RESULTS AND DISCUSSION

Figure 2 presents which tools were the most used to achieve the objective in the studies selected for this research.

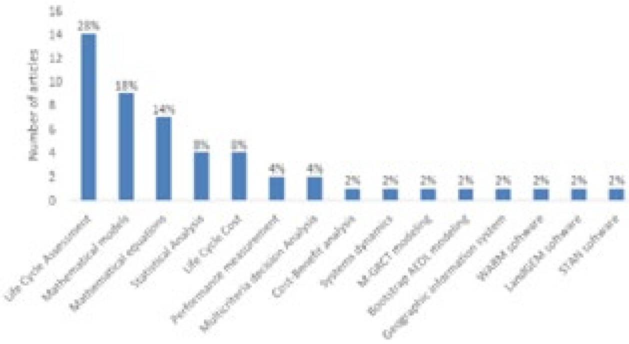

Figure 2: Methods used in the analysis studies of USW management.
Source: Authors.

The Life Cycle Assessment (LCA) was the most used within the selected articles, present in 14 articles, that is, in 28% of the sample gathered. Out of these 14 studies, 3 associated LCA to Life Cycle Cost (LCC), other 3 studies associated LCA to the mathematical model method and 1 other study associated LCA to Multi-criteria Analysis and Cost-Benefit Analysis methods. Thereby, the remaining 7 articles used LCA without association to any other method. Since LCA is considered to be a tool for quantifying environmental impacts and for decision-making intended to improve the environmental performance of products and systems, it cannot evaluate the economic impacts of the processes by itself (DONG; NG; LIU, 2021; ILYAS; KASSA; DARUN, 2021).

Still on the use of LCA, Rizwan et al. (2020), in their study of analysis on processing routes for USW management under economic and environmental criteria, pointed out a limitation in the solution proposed for the multi-objective optimization structure, as it does not lead to an optimal or unique solution. Instead, it provides a series of solutions. Additionally, these authors point out the demand for a large quantity of data for modeling each technological alternative. De Feo et al. (2017), aiming to evaluate the recovery of recyclable materials in municipal solid waste management, pointed out that the economic benefits were only calculated according to the revenue from recovered material, instead of also considering the costs of waste management, increasing the percentage of source separation to calculate revenues. Furthermore, modeling linearity was assumed for environmental evaluation, even in high recycling rates. As it is observed, the tool most used by authors also presents limitations in the variation of variables that compose the system, either due to the lack of information or due to rigidity of the method. In other words, this tool is not capable of absorbing changes in waste management over time.

Some authors, when using mathematical equations, also indicated failures related to the rigidity of the method when using this tool. Azis, Kristanto e Purnomo (2021), by displaying a technical-economical evaluation of a WtE commercial floor plan in Indonesia, warned that the cost was set on US$ 6.76 per ton of waste, not taking into consideration the change this number may suffer regionally, depending on the condition and composition of the waste. Chen et al. (2022), considering environmental impact, energy conservation and economical cost, presented technology combinations for IMUSW in China and pointed out the lack of more management objectives and alternative technology for broader consideration. Habib et al. (2021), who studied the generation and management of USW at Rajshahi City Corporation, Bangladesh, pinpointed the absence of important parameters, such as recyclable residue values, quantity of pollution in waste, among others, for a better comprehension of global waste management. This demonstrates that mathematical equations are not the best tool to work with many variables, such as in the analysis of elements that hinder sustainability in USW management.

Höke e Yalcinkaya (2021) used mathematical models as a tool in their study which intended to develop a model to investigate the optimal location and the economical impacts of USW Transference Stations in Türkiye. Regarding the limitations of the study, the authors revealed that a future projection of waste generation was not considered. An increase of waste generation, of the costs of work force and of the costs of fuels throughout time can make a Transference Station economically inviable in the area of study. This means that uncertainties cannot be considered, compromising the study.

Amal et al. (2020) utilized multi-criteria analysis and a Geographic Information Systems (GIS) to analyze USW at Sfax, the second most populated city in Tunisia. They indicated the existence of different criteria, such as economical, social, political, technical and environmental as a limitation of the method, which implies that the data is ill-defined. Ferreira e Barros (2021), on the other hand, used statistical evaluations to present a panorama of municipal public expenditure between 2009 and 2017 with urban cleaning services for the municipalities that make up the Metropolitan Region of Belo Horizonte - MG, Brazil; they indicated some limitations of the study. The authors suggested a deeper analysis and reported a lack of studies relating the themes "costs and waste", both nationally and internationally, pointing this as a complicator to compare and understand public expenditure behaviors. Bui et al. (2020) also utilized statistical evaluations to analyze the validity and reliability of management attributes in Vietnam. Additionally, they encouraged future studies to extend the research structure by adding more related attributes or by applying the structure present in the study to different areas with waste management.

Leite et al. (2022) used the Waste Reduction Model (WARM) software in order to assess application potential, economical and environmental feasibility of different USW treatment technologies in Brazil. The limitation of this work was regarding higher levels of precision in potentiality, since the population projection of each municipality was not taken into consideration, and regarding gravimetry, as average gravimetry was assumed for Brazilian municipalities. In addition, the technology of pyrolysis was not analyzed in the same way as the others. Muhammad and Salihi (2018), in order to evaluate solid waste management in Kano, Nigeria, utilized the SubSTance flow Analysis (STAN) 2 software, in which they encountered difficulties to develop their work due to the limited availability of the necessary data to use this tool.

Pinha and Sagawa (2020) used the Systems Dynamics (SD) tool to develop a USW management model that provides an extensive view of the resources involved in waste destination and in the structure of costs for the services/systems involved. Brazil was chosen for the model simulation, but it can be done with any other country or region. As a limitation of the model, the authors pointed out the absence of consideration of the effect of the specific policies of the system.

Razzaq et al. (2021) used the Auto-Regressive Distributive Lag (ARDL) bootstrap modeling, an empiric model, to estimate the effect of USW recycling in environmental quality and economic growth in the United States. They investigated the co-integration relationship between USW recycling, economic growth, carbon emissions and energetic efficiency. This approach test tool was recently developed, it performs co-integration relationship analysis between variables and, as a result, can obtain recommendation of policies.

The Geographical Information Systems (GIS) is a computerized system used to store, manage and manipulate geographic data to manipulate geographically referenced maps and digital images (SANTOS; BRITO; SILVA-NETO, 2022). The WARM and LandGEM software programs serve the purpose of evaluating environmental impacts in studies that demand estimates of the main gas emissions associated to waste treatment technology (LEITE et al., 2022; SOUZA et al., 2019). The STAN2 software is used to perform material flow analysis of generated waste from its origin until various destinations (MUHAMMAD; SALIHI, 2018). The GIS methods, WARM software, LandGEM software and STAN2 software are tools that do not have the purpose of financial analysis; they only work as auxiliaries in this evaluation. Therefore, considering their limited contribution to this issue, these methods are not approached in depth in this discussion.

The difficulties of the methods lie in encompassing the full complexity of evaluating financial sustainability of IMUSW. The assessment of financial sustainability itself may involve strategic, tactical and operational (accounting) elements (BING et al., 2016), in addition to endogenous and exogenous variables that affect the system, which call for methods that allow handling a several variables. To this end, methods can be associated with the purpose of reproducing a real system as best as possible and obtaining more reliability in results.

Chart 2 contains the description of the main methods for analysis of USW management highlighted in this study, along with their characteristics.

Methods	Objectives	Advantages	Disadvantages
Life Cycle Assessment (LCA)	quantitatively evaluate the environmental impacts of products, services and processes from phases "cradle" to "grave"	- widely used by the scientific community as it can be applied to any area - ready to use software availability	- difficulties in data obtention, thus, it is not used all variables necessary for an in-depth analysis in the study - cannot evaluate the economic impacts of processes - questionable reliability of results - large number of assumptions and leads to diverging results
Life Cycle Cost (LCC)	to determine a product's total cost over the period of time from the point-of-use until the end of its shelf life	- widely used by the scientific community as it can be applied to any area - ready to use software availability - it is adopted to calculate costs and revenues related to all included problems and its results	- it does not necessarily consider technical feasibility and revenue and profit indicators, which are essential for business and decision-making in investment - are generally assumed as constant parameters and linear relationships
Systems Dynamic (SD)	to describe, model, simulate and analyze problems and/or dynamically complex systems in terms of processes, information, limits and organizational strategies	- allows the study of inherent questions in complex systems of qualitative and quantitative perspectives inside a long term dynamic process - enables simulation of scenarios, easing comprehensive analyses - simulates linear and non-linear relationships of complex systems over time - predicts uncertainties in systems - allows for analysis of structure, interactions and behaviors of the system, as well as exploring, evaluating and predict its impacts in an integrated and holistic way - ready to use software availability - easy to understand graphic representation of the system	- it is easy to introduce ambiguity and subjectivity by modelers - in simulation, the feedback mechanism of each system subject is expressed by differential equations, this way it is not possible to express the interaction mechanism as it cannot be expressed by functional equations
Multi-criteria Analysis and Cost-Benefit Analysis	to study high uncertainty questions, multiple interests and objectives, organizing alternatives in a hierarchy by using perspectives from interested shares and information on cost/benefit;	-they are efficient in classifying various potential places and selecting the best among them according to the identifies attributes - allows classification of alternatives and considers actors' point of view - useful in accounting multiple criteria by classifying or optimizing alternatives - used when various parameters influence a task's performance	-- they select ideal alternatives classifying them by using consideration criteria that was subjectively established and solely by one interested share - they possess limitations and are subjective, thus, it is difficult for them to create an objective with a unified pattern to determine the weight of evaluation indicators - this approach fails to find alternative classification derived from all possible combinations of potential places

Methods	Objectives	Advantages	Disadvantages
Mathematical models and mathematical equations	to represent the behavior of the real system under determined conditions through a set of appropriately quantified and structured assumptions and approaches, in order to predict and compare logical alternatives susceptible to simulation	- they are practical instruments for creators of policies as they can be used to solve important problems	- the method is stiff - uncertainties, such as future projection of waste generation, cannot be taken into consideration, which can compromise the study - are not the best tool for working with various variables
Statistical Analysis	to analyze and predict the current situation of USW generation	- efficient and easy to operate	- applicable to scenarios with limited dispersion and tendencies to change obvious sequence - the method is highly dependent and it is hard to guarantee its precision - it is specially used for short-term predictions - it is impossible to explore the influence mechanism of various factors
M-GRCT Modeling	to stimulate systems of solid recyclable waste management in order to analyze circular economy	- decision-making tool - allows studying the implementation of strategies for recyclable waste management by applying a circular economy	- used for low-income municipalities with populations under 20.000 inhabitants and USW generation per capita under 0.70 kg/person.day
Auto-Regressive Distributive Lag (ARDL) bootstrap modeling	to examine co-integration relations between variables, including discrepancies on dependent variables as well as on explanatory variables	- allows the analysis of long-term co-integration relationships between variables; - identifying multiple cointegrating vectors	- cannot be used with small data that is not approximate to the size of the population; the data presents many outliers
Performance measurement	to obtain information on measures related to a product, process, system or magnitude, retaining solely the essential meaning of the aspects analyzed; its main characteristic is synthesizing information	- provides important information for planning and managing processes, possibly contributing to the decision-making process; - measures the success rate of an implemented strategy considering if the established goal was achieved	- reactive and non-indicative tool; - only measures one snapshot; - must be applied to every single evaluation; - displays a specific, punctual contribution; - has complex or difficult to measure indicators that may preclude the operationalization due to the cost to obtain it.

Chart 2: Characteristics of the main methods used in studies on analysis of USW management.

Source: Authors, based on: Ali; Pumijumnong; Cui, 2017; Dong; Ng; Liu, 2021; Hadian; Madani, 2015; Hellweg; Canals, 2014; Ilyas; Kassa; Darun, 2021; Jung, 2017; Kollikkathara; Feng; Yu, 2010; Kunc, 2017; Mahmud et al., 2021; Mak et al., 2019; Massarutto, 2015; Menconi; Grohmann, 2014; Meng; Zhang; Wang, 2021; Mesa; Fúquene; Maury-Ramírez, 2021; Pruyt, 2013; Sabaghi; Mascle; Baptiste, 2016; Soltani; Sadiq; Hewage, 2016; Sterman, 2010, 2018; Vargas-Terranova Et Al., 2022; Wang, Jiang Jiang et al., 2009; Wang, Zhiguo et al., 2020; Xiao et al., 2020; Yadav et al., 2020; Zimmermann et al., 2020.

As demonstrated in the Chart 2, each method has different objectives and is indicated for different types of study. In studies on USW management, when comparing methods, the statistical model can be used when bigger applicability is desired, enabling inferences on population, being able to even generalize it for other municipalities. When the study aims at higher precision, mathematical models are more suitable; however, they may ignore qualitative and subjective considerations, such as the impact of illegal disposal of USW inadequate places, as well as other socioeconomic and environmental factors that are essential for IMUSW. The multi-criteria analysis tool is used when there are conflicting interests or objectives and when the results should present the alternatives in a hierarchical manner. Cost-benefit analysis is useful to monetize costs and benefits related to the investment options of public resources to reduce environmental risks, which requires technical data and information produced by climate science and economics. M-GRCT modeling is characterized as a numeric model which, despite encompassing the calculus of financial indicators that measure the economic feasibility of waste commercialization, is geared towards simulating systems of recyclable solid waste management for circular economy analysis. ARDL bootstrap modeling is a new approach that analyzes the co-integration between the variables of the model, leading to similar results to those of statistical models. Only one article applied this method, maybe because this method was first proposed more recently. This leaves an opening for possibilities and opportunities in this research area.

On the other hand, performance measurement, which is a method frequently used for financial evaluation in organizations (SILVA; BORNIA; PAMPLONA, 2006), including the proposition of comprehensive performance measurement systems, such as Balanced Scorecard (KAPLAN; NORTON, 1992; TSAI, 2020), was used in only two articles from the database. It is a significant tool for planning, obtaining information on a given reality, but it possesses specific contributions, meaning it must be applied to each evaluation.

If the purpose of the USW management analysis is more detailed and it aims at assessing a study around the diversity of variables, LCA and SD can be utilized. LCA was the most employed tool among the USW management studies, but it is angled towards the environmental process analysis, thus, LCC should be used for economic studies. The use of SD for USW management studies has been increasing in the scientific community since it enables the evaluation of non-linear relationships. This tool is highly suitable for studies on systems that are not static and in which time inference is desired. Various studies in the field of solid waste management have been utilizing this tool lately, as exposed by Galavote et al. (2023), Joviˇci´c et al. (2022), Phonphoton and Pharino (2019), Sancheta, Chaves and Siman (2021), Silva, Fugii e Santoyo, 2023 e Xiao et al. (2020). However, only one article from our search scope used this method, thus, revealing an opportunity for studies that aim to incorporate the influence of causal relations and the temporary aspect of financial sustainability in USW management. In this regard, it is worth mentioning that the method Agent Based Model (ABM) also enables the analysis of various components from one system, as well as time analysis (BORSHCHEV; FILIPPOV, 2004). Although this was not found in the articles collected for this research, the ABM can simulate simultaneous operations and interactions between the different agents of a determined environment. Individual agents are assumed as rational (limited), acting on maximizing their performance measurement (in order to obtain economic benefits, for example), by using heuristic concepts or simple rules for decision-making (NUZZOLO et al., 2018). Therefore, this method, which has also been applied to financial analyses (BOOKSTABER; PADDRIK; TIVNAN, 2018) and USW management (SOUZA; BLOEMHOF; BORSATO, 2021), may signal opportunities for future studies.

SD and ABM can model various systems, however, there are differences between the methods. One important characteristic of the SD model is the loop structure of interactive feedback which interconnects different variables (TAKO; ROBINSON, 2010) and leads to endogenously-generated behavior, a type of behavior that greatly interests dynamic systems. As for the ABM, its structure is based on the agent, in which the environment is modeled according to one or more agents, displaying different properties of the actors. Each agent receives a set of rules according to how it interacts with other agents; this interaction generates the system's general behavior (SCHIERITZ; MILLING, 2001). However, the agents used in modeling practice are diverse, and there is still much discussion about universally accepted definitions regarding the type of characteristics an object must possess to “deserve” to be denominated as an agent: pro- and reactivity, spacial conscience, learning ability, social ability, "intellect" or others (BORSHCHEV; FILIPPOV, 2004). Another difference between these two methods is that in ABM, the approach is known as the bottom-up type, because it is done by analyzing the behavior of individual units and how these behaviors change due to interactions, which, then, makes it possible to obtain the behavior of the entire system (BUSCH et al., 2017). Meanwhile, SD is known as the top-down, that is, the system is modeled by dividing it by its main elements and modeling the interactions of the components (MACAL, 2010).

Among USW management studies, understanding the system's behavior in time is important because the system obligatorily undergoes changes, that is, it possesses dynamic nature. Population and city growth constantly modifies tons of generated waste and the configuration of collection routes, in which even the capacity of the garbage truck influences the design of the route. Landfill options can be exhausted, entailing on shut down and on the necessity of new waste disposal alternatives. Additionally, the number of transference stations needed for effective USW management may increase or the best places for transference stations may change. All these changes that IMUSW go through in a time frame may require an increase in financial resources for management, demanding policies directed at raising funds, environmental awareness, monitoring and encouraging recycling.

Considering all that has been discussed regarding tools applied to behavior analysis and interrelation between critical elements that affect the financial sustainability of IMUSW in a time frame, especially regarding the countless variables that compose the system and the possibility of time analysis, to answer the research question, the most suggested tool is SD. In a lesser indication, ABM is favored, as the feedbacks of system components are considered important for the dynamism of the analysis.

Kuo et al. (2019) point out that SD is the most appropriate tool to simulate system performance when multiple variables change at the same time and for dynamically optimize the effects of mixed policies. According to Sterman (2010, 2018), SD is a technique used to study complex systems, being able to depict different temporalities and display, through this, existent feedback mechanisms over time. In accordance with Mak et al. (2019), using SD also allows simulating scenarios, which facilitates wider analyses of quantitative and qualitative results. Popli, Sudibya e Kim (2017) point to distinctive advantages to analyze waste management, connecting it to environmental, social, political and economical approaches.

4. CONCLUSIONS

The elements that affect the financial sustainability of IMUSW are interconnected, so that when one is affected, there is an effect on the other. Policy changes affect other elements, such as management, economy and social aspects. A management element may entail a higher cost, but but bring higher social benefits, for example. This means that factors are correlated, and in order to perform the effective assessment of the financial sustainability of IMUSW, it is necessary that the chosen methods consider the interrelationship of these elements. Preferably, a more comprehensive study would involve an integration of all the analyzed elements. However, this was not found in the literary analysis, indicating a gap to be filled.

It is also necessary to analyze the behavior and interrelation between these elements throughout the time frame due to the changing nature of the USW management systems. To this end, we advise that future studies use tools able to consider these systems' complexity, simulate linear and non-linear relations, and predict uncertainties. In this sense, Systems Dynamics is the most adequate method to correlate the financial sustainability elements of USW management and to evaluate these elements' behaviors and interrelation over time. Its dynamic characteristic displayed advantages over other static tools and methods of operational research in IMUSW systems due to the complex, changing and recognizable nature of the real-world elements. In addition, the graphic representation of the system is easy to understand, which allows people that are not familiar with this type of model simulation approach to easily understand the model and participate in the construction process.

Life Cycle Assessment was the most used tool in the studies surveyed, however, by itself, the tool cannot be used for financial analysis of the process. Moreover, this analysis is based on linear relations and this tool does not allow time analysis. Since Auto-Regressive Distributive Lag bootstrap modeling is a new approach that allows long-term co-integration analysis between the variables of the model, it presents new possibilities and opportunities for this research area.

This study provides useful contributions to the managers for planning, altering or implementing IMUSW systems in cities, providing information on the tools used in the most relevant and current articles on developing studies for waste management. The analyses conducted provided suggestions for the development of future studies by researchers, indicating the need for integration among the elements affecting financial sustainability in USW management, as well as the methods with potential for this approach.

IMUSW is a multifaceted system and is one of the most challenging, complex and multidisciplinary tasks for municipalities. It cannot be viewed in a unidimensional perspective since many of its decision issues of different levels are interrelated. It is difficult to balance social, economic and management perspectives in IMUSW, while also meeting environmental policies, due to the inevitable conflict between the objectives related to the sustainability pillars. Management should therefore be analyzed through tools that enable a holistic approach and a systemic and multidimensional perspective, indicating an integration of various disciplines in order to understand and propose improvements in financial sustainability performance.

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