CONTINUING EDUCATION TO FOOD WASTE MANAGEMENT: A SYSTEM DYNAMICS SIMULATION

EDUCAÇÃO CONTINUADA NO GERENCIAMENTO DE RESÍDUOS ALIMENTARES: UMA SIMULAÇÃO DE DINÂMICA DE SISTEMAS

RBGDR

REVISTA BRASILEIRA DE GESTÃO E DESENVOLVIMENTO REGIONAL
V.19, N°2, Mai-Ago/2023 | Taubaté/SP - Brasil | ISSN 1809-239x

CONTINUING EDUCATION TO FOOD WASTE MANAGEMENT: A SYSTEM DYNAMICS SIMULATION

EDUCAÇÃO CONTINUADA NO GERENCIAMENTO DE RESÍDUOS ALIMENTARES: UMA SIMULAÇÃO DE DINÂMICA DE SISTEMAS

Received: 08/04/2022
Accepted: 08/01/2023

Carla Tognato de Oliveira[1] | Mariele Canal Bonfante[2]
Mauricio Uriona Maldonado[3] | Sebastião Roberto Soares[4]

[1] PhD student in Environmental Engineering (UFSC).
Florianópolis - SC, Brazil.
Email: carlatog@hotmail.com

[2] PhD in Science and Materials Engineering (UFSC).
Florianopólis - SC, Brazil.
Email: marielebonfante@gmail.com

[3] PhD in Engineering and Knowledge Management (UFSC).
Professor at the Federal University of Santa Catarina.
Florianópolis - SC, Brazil.
E-mail: m.uriona@ufsc.br

[4] PhD in Waste Management and Treatment (INSA DE LYON). Professor at the Federal University of Santa Catarina.
Florianópolis - SC, Brazil.
E-mail: s.soares@ufsc.br

ABSTRACT

Few studies investigate the relation of continuing education to municipal waste management. Therefore, a better understanding of the impact of these actions in the long term is needed. This study aims to evaluate the impact on municipal food waste management, comparing a prevention policy based on continuing environmental education program and a command-and-control policy. In a Brazilian city, four scenarios - Business as usual; Strengthening continuing environmental education; Ordinary Law No. 10,501/2019 Regulation and; the combination of Strengthening Continuing Environmental Education with Ordinary Law No. 10,501/2019 Regulation - were analyzed using a system dynamics model to divert 90% of organic waste from landfill. The results show that continuing environmental education is a good supplement to achieving the law goals. Hence Strengthening Continuing Environmental Education together with Ordinary Law No. 10,501/2019 Regulation, they obtain the best results for food waste management. Moreover, combining Continuing Environmental Education and the law is ideal for achieving the municipality's goal, once the citizens are more willing to reduce waste generation and compost waste. The transition into a more sustainable food consumption through achieving food waste reduction and sustainable municipal solid waste management are great challenges considering the dependence on the individual behavior of citizens. Environmental education is a path to reducing food waste and promoting waste diversion. Therefore, the study is socially relevant and helps policymakers take the necessary actions to optimize food waste management with social participation.

Keywords: Food loss. Environmental Awareness. Systems dynamics. Public policy. Municipal solid waste.

INTRODUCTION

The economic value loss from food waste (FW) worldwide was estimated at 1 trillion USD in 2015 by the Food and Agriculture Organization (FAO, 2015). FW is the unused food discarded during retail and final consumption stages (FALASCONI et al., 2019) and is generally related to individual behavioral issues (GALLI; CAVICCHI; BRUNORI, 2019). The food products that no one consumes may lead to unnecessary greenhouse gas (GHG) emissions (TSENG; HSU; CHEN, 2019) and environmental problems that arise, such as soil, water, and air quality degradation.

In Brazil, municipal solid waste (MSW) generation has a higher rate than population growth (ABRELPE, 2018). Brazilian landfills receive about 40 million tons of organic waste annually (IPEA, 2012), generating costs for the public administration (LEE et al., 2019) and GHG emissions (TSENG; HSU; CHEN, 2019).

The Brazilian city of Florianópolis has the third-highest score in the human development index of all Brazilian capitals (0.847), making it one of the most livable and safest cities in the country (GUERRA et al., 2017). Therefore, the city attracts more residents each year. With more residents, the domestic consumption pattern increases (DE ANDRADE JUNIOR; ZANGHELINI; SOARES, 2017). This relationship is perceived in the per capita waste generation. Between 2000 and 2010, the waste generation rate increased by 47% (COMCAP, 2020a), and the projected waste generation for 2030 is 1,405 kilograms per inhabitant per day. In 2018, the city created an initiative to achieve 90% of municipal organic waste (MOW) diversion by 2030. The initiative is based on one of the goals of the National Solid Waste Policy (PNRS) and the city's sanitary plan. For this, a regulatory law will be implemented, but, in the meanwhile, environmental education interventions have already started.

Environmental education encourages the reduction of MSW generation and the correct waste separation at the source. Previous studies prove that informative eco-awareness actions result in a decrease in the FW generation (PEREIRA; DOS SANTOS; DE MATTOS, 2020; ANTÓN-PESET; FERNANDEZ-ZAMUDIO; PINA, 2021), and if such actions are focused on organic-waste-diversion programs, a significant part of the participants also change their habits and start composting their organic waste (PICKERING et al., 2020). When households adopt sorting and composting FW practices, the municipalities have positive economic returns and environmental and social gains (LEE et al., 2019).

Studies about environmental education's impact on urban waste management are still rare and need to be further studied. Moreover, the authors Read and Muth (2021) also highlight the need to understand the cost-effectiveness of FW reduction interventions better. The same is true in Florianópolis city. Although there are already education initiatives focused on FW reduction and management, there is no data on such actions' long-term impact on the municipal solid waste management (MSWM) system.

Therefore, this study aims to evaluate the impact on municipal food waste (MFW) management, comparing a prevention policy based on continuing environmental education program (CEE) and a command-and-control policy. For this purpose, this study presents a comprehensive model of the MSW system in Florianópolis and evaluates FW diversion behavior through quantitative and qualitative analysis using system dynamics (SD). Therefore, these study steps were: (1) modeling a MSWM system, (2) predicting MSW and FW generation in Florianópolis by 2030, (3) assessing the prevention policy and a command-and-control policy for FW diversion, and (4) understanding the dynamic interactions.

The study results can contribute to public policy decision-making towards more effective MSWM, focusing on MFW. These findings address essential aspects for the regional development of Florianópolis and can be applied to other regions, taking into account their unique characteristics. The results highlighted in this study encompass potential initiatives in various sectors such as science, education, urban infrastructure, social development and access to essential public services. These programs have the potential to promote sustainable practices and preserve the environment, striving for a balanced development that respects the region's natural resources and aims to enhance the best quality of life for the local population.

The paper presents this introduction, a literature review, and the methodology explanation, and finally brings the results, discussion, and conclusion.

THEORETICAL PERSPECTIVES OF FOOD WASTE MANAGEMENT AND SYSTEM DYNAMICS

Food waste is generated throughout the supply chain, and several studies have confirmed that households are the primary FW producers in this chain (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013; FALASCONI et al., 2019). The FW in households is associated with behavioral causes (GALLI; CAVICCHI; BRUNORI, 2019; ZAMRI et al., 2020). Households throw away an enormous amount of food that was, at some point before disposal, perfectly edible (FALASCONI et al., 2019).

The challenge of FW management includes FW reduction (FALASCONI et al., 2019; LEE et al., 2019; ZAMRI et al., 2020) and FW treatment (BABALOLA, 2019; PICKERING et al., 2020; XIAO et al., 2020). The main reasons for the poor performance of FW management can be summarized as follows: (1) relevant laws and regulations are insufficient, and (2) lack of environmental awareness (environmental education) (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013; CHEN et al., 2017; POPLI; SUDIBYA; KIM, 2017; FALASCONI et al., 2019; LEE et al., 2019; PICKERING et al., 2020; ZAMRI et al., 2020). These two reasons lead to the inefficiency of some factors, including waste segregation, mainly in households.

Source separation is a significant process in optimizing collection and MSW treatment, and it is proven to be cost-effective (SUKHOLTHAMAN; SHARP, 2016; CHEN et al., 2017; ZAMRI et al., 2020). On the other hand, landfilling FW mixed with other MSW is a great problem. It results in high disposal, nutrient, and energy recovery costs (LEE et al., 2019), and decreased recyclable materials quality due to contamination with FW substances (SUKHOLTHAMAN; SHARP, 2016). Moreover, the landfill’s lifespan is getting lower. Thus the waste disposal market’s price increases rapidly.

One response is to examine ways to reduce the amount of waste generated and recover waste through recycling. Therefore, there is a need to transition to a more sustainable MSWM system, including waste diversion practices, i.e. redirecting waste away from municipal landfills (PICKERING et al., 2020).

Waste diversion, including composting organic waste, is a practice with multiple environmental benefits, such as lowering GHG emissions (TSENG; HSU; CHEN, 2019). It is important to highlight that waste diversion often requires a decision made by individuals at their residence or in public locations (PICKERING et al., 2020).

The MSWM assumes that the government has sufficient capacity to manage pollution at a regulated level through either a command-and-control system or economic instruments (i.e., waste charging) (CHEN et al., 2017). However, a change in attitude, behavior, and culture is essential for achieving substantial change (PINTO et al., 2018). Consequently, the population is the most important parameter in MSWM (POPLI; SUDIBYA; KIM, 2017). Thus, environmental education supports behavioral, and culture changes initiatives and is a long-term strategy for a permanent awareness of the citizen's attitudes towards reducing and separating FW (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013; SHARMA; VRAT, 2018). For Falasconi et al. (2019) and Pinto et al. (2018), awareness leads to understanding the causes of FW, which results in waste reduction and, consequently, reduces the impact on individual assets and the environment. In addition to increasing the feeling of wasting food that could have been valuable to others.

Some governments are becoming more supportive by promoting awareness campaigns and waste policies to reduce FW (GALLI; CAVICCHI; BRUNORI, 2019; LEE et al., 2019). In Brazil, the PNRS aims to minimize waste generation, reuse, and recycling and has environmental education as a tool to achieve it (BRAZIL, 2010).

Studies have been conducted to clarify the relationship between environmental education and FW management. Some authors sought to understand the relationship between education and FW reduction. Antón-Peset, Fernandez-Zamudio and Pina (2021) analyzed the impact of a didactic action in a Primary School (children aged between 9 and 10 years) in Valencia (Spain) and found out teachers and children's attitudes change right after the intervention. It was possible to observe a reduction of around 30% of FW with the group who participated.

Another example is the study conducted by Pereira, dos Santos and de Mattos (2020) in Sobral, a city in the northeast Brazil. For three months, they applied environmental education strategies in an educational institution, such as hanging posters with educational phrases, demonstrating raw foods, and individual approaches and conversations about FW. The authors observed an 18% FW reduction and noted the need for further continuity of actions to reduce this index.

Pickering et al. (2020) focused their work on the relations between educational interventions and diversion, and composting. They developed a study to understand the drivers and barriers to organic-waste-diversion programs, and one of the conclusions was that after receiving the educational message, 42% of the people who are not used to composting were more likely to start composting. That means education about the benefits of waste diversion encourages engagement.

Read and Muth (2021) analyzed the cost-effectiveness of four FW reduction interventions: consumer education campaigns, spoilage prevention packaging, standardization of date labels, and waste tracking systems. Concerning education, they concluded that the cost-effectiveness of this kind of intervention is surprisingly high. They explain that when consumers make small changes in their behavior, there is a considerable potential to reduce environmental impacts.

System dynamics (SD) is considered one of the best tools to find quantitative and qualitative relations between several variables of waste management, preventing further environmental and social problems (POPLI; SUDIBYA; KIM, 2017). It is a mature method for studying policy impacts on MSW, and it is flexible enough to integrate different MSWM processes from a systematic perspective (XIAO et al., 2020).

Dynamic models of MSWM provide a better understanding of dynamic interactions and key concerns and interdependencies of MSWM processes (SUKHOLTHAMAN; SHARP, 2016). This approach has been used to conduct studies on different simulation targets, such as the entire process of MSW production, sorting, collection, and final treatment, linked with the economy and demography in Shanghai, China (XIAO et al., 2020). They also understand the water-energy-food nexus at an end-use level related to organic waste generation and wastewater quantities in Duhok, Iraq (WA'EL; MEMON; SAVIC, 2017) and the source separation and waste management effectiveness relationships in Bangkok, Thailand (SUKHOLTHAMAN; SHARP, 2016).

Studies on specific FW management, such as landfill capacity and volume-based charging (LEE et al., 2019), charitable food assistance to FW reduction (GALLI; CAVICCHI; BRUNORI, 2019), FW treatment methods (BABALOLA, 2019), the phosphorus recycling diverting FW from landfill and analysis of the positive impacts of using organic waste to produce biogas (methane) (DIANATI et al., 2021) have also been conducted. SD is also used for optimal policymaking related to behavioral/cultural consumption in the FW field. For instance, Sharma and Vrat (2018) used the SD method to predict the impact of several factors on FW in Indian weddings.

Most studies focus on specific and isolated solutions for environmental education and FW. Moreover, the research of dynamic simulation models as a tool to explore the interactions of environmental education and FW management and assess the multidimensional impact of the policy is still rare and needs further study.

METHODOLOGICAL PROCEDURES

This study presents a SD model for MSWM focused on food waste. The main steps of the research are described below.

STUDY AREA CHARACTERIZATION

In 2018, Florianópolis created the initiative "Zero Waste Program" (PMF, 2018a). The MSW recovering and promoting continuing environmental education are tools to reach this goal. Florianópolis is a city located on an island, in south Brazil, as shown in Figure 1.

Figure 1 | Study area's location.

For the first four years to continue environmental education, the amount allocated is BRL 5,180,000.00 (PMF, 2016). The investment will be used for environmental education, community intervention in critical areas (BRL 500,000.00), and further environmental information, disclosure, intervention, and community mobilization (BRL 4,680,000.00). Moreover, the investment for the first four years of the MOW Collection Program is BRL 6,477,400.00 (PMF, 2016; PMF, 2020). Together, these two programs will provide Florianópolis with the title of "Brazil's First Zero Waste Capital."

In 2019, Ordinary Law 10,501 came into force to change the citizens' behavior regarding organic waste. This law provides for mandatory MOW recycling in Florianópolis, which guarantees the continuity of the MOW Collection Program. The policy gradually prohibits legal entities governed by public law and private law, residential or commercial condominiums, from disposing of landfills and MOW incineration. This policy prioritizes (PMF, 2019): (1) Gradual and adequate implementation of MOW diversion considering: (a) pruning, sweeping, and gardening residues; (b) FW large generators; (c) household FW; (2) Varied strategies adoption for an environmentally sound MOW destination; (3) Community encouragement and cooperative initiatives in MFW management; (4) Decentralization strategies adoption in waste management in the municipal territory; (5) Encouraging domestic composting and enabling MFW home collection systems, preferably through community management.

Many initiatives for FW diversion are already in course in Florianópolis, one of the most famous was created in 2008 and consists in community composting activities, where families separate their organic waste to be composted and in exchange receive the compost produced for fertilization of urban gardens (FARIAS, 2010). These initiatives cooperate with private companies, non-governmental organizations (NGOs), and community associations, but they are still insufficient to reach the 90% FW diversion goal. Currently, the MSWM company has a composting center managed by a NGO. In 2019, 5,51% of MOW was composted there (COMCAP, 2020a). Besides that, other non-governmental initiatives for FW composting divert today, on average, 3,852 tons per year from landfills (ZAMBON; LUNA, 2016). These include the community program (DE OLIVEIRA; RODRIGUES, 2017), private companies' partnerships with NGOs, and private companies (ZAMBON; LUNA, 2016).

However, even with the creation of the Technical Commission for studies, standardization, and elaboration, the first movement for implementing the Ordinary Law took place in November 2020 (COMCAP, 2020b). A pilot project was developed to operate on some streets in different city neighborhoods, encompassing, mainly, classes B and C (monthly household income between BRL 2.9 thousand and BRL 22 thousand), and there is no forecast to reach all neighborhoods. Nevertheless, the purpose of the Ordinary Law is to reach all social classes in the municipality.

SCENARIO DESCRIPTION

Based on the information of MSWM in Florianópolis, four future scenarios were defined. The first scenario, Business as usual (BAU), shows that, currently, there is low environmental education on the waste topic. However, there are occasional initiatives to divert MFW from conventional MSW collection. MSW company does not have a differentiated collection for FW. Most of this waste is taken directly to landfills. Therefore, the dominant material sent for composting refers to pruning and gardening performed by Florianópolis´ citizen.

The second scenario, Strengthening continuing environmental education (CEE), presents that according to the "Zero Waste Program," the citizens will be encouraged to MSW segregation at source and even household composting. With CEE, the citizens will reduce MSW generation by 10% per year. By 2030, 60% of the population will be composting 90% of their FW and they will recycle more based on waste diversion. Over time, the citizens will lose motivation in their activities in general (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013). Moreover, it is necessary further continuity of educational actions to reduce this index (PEREIRA; DOS SANTOS; DE MATTOS, 2020). Thus, reinforcements in communication with the population are foreseen in the year 2020, 2023, 2026, 2029, and 2030. Florianópolis has a history of adhering to environmental education initiatives. For example, a municipality project donates composter container kits with worms. Five hundred kits were already given (PMF, 2018b). Therefore, the initial deviation of food waste is expected to reach 292 tons of FW per year (PMF, 2018b).

The third scenario, Ordinary Law No. 10,501/2019 Regulation (OLR), presents that, historically, Brazil has not achieved solid waste targets (JABBOUR et al., 2014; ZOLNIKOV et al., 2018). The same happens in the study area. In Florianópolis, the FW diversion law came into force in 2019, and only after 18 months did the pilot project begin (COMCAP, 2020b). With this information, it is understood that its application to the entire city will take longer than planned by law. Therefore, we can conclude that the Law application is delayed. Based on slow law enforcement, it was assumed that: 1) by 2023, the city will ban landfilling, pruning, gardening, and sweeping residues (31% of all MOW generated in Florianópolis); 2) by 2024, Florianópolis will prohibit landfilling FW from large scale generators (43% of MOW generated); 3) in 2026, the city will forbid landfilling household organic waste (26% MOW generated). However, it is assumed that 5% of MFW will be disposed of in landfills due to residents' and tourists' lack of attention.

The last scenario, Strengthening Continuing Environmental Education with Ordinary Law No. 10,501/2019 Regulation (CEE+OLR), to be evaluated is the union of the continuing environmental education strengthening and the FW diversion law implementation. The assumptions for this scenario are the same as the CEE and OLR scenarios.

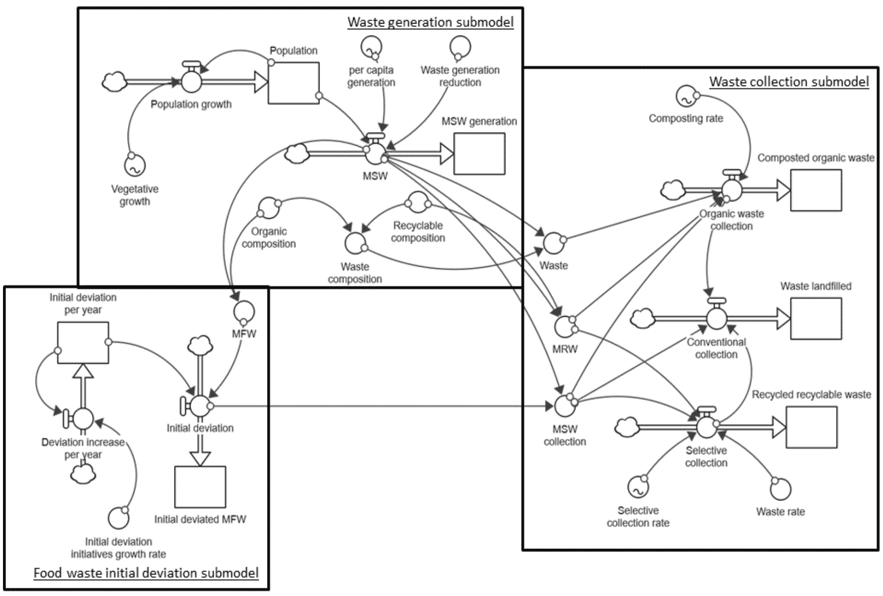
PARAMETER IDENTIFICATION

Parameters expected to be affected by internal factors and/or other parameters within the defined system are classified as "endogenous," while parameters affected only by external factors beyond the system scope as defined in this study are classified as "exogenous" (ERCAN; ONAT; TATARI, 2016). Most of them were extracted directly from government reports for 2016 and 2019. It should be highlighted that MOW historical data comprises FW along with gardening and pruning. On average, 35% of all MSW and 70% of all MOW is FW (COMCAP, 2020a).

MODEL DEVELOPMENT

The following three subsections present the model designed for this study, as shown in Figure 2. The following stocks and flows illustrate the visual expression of model relationships developed using Stella 9.0.1 software. Excel software was used for analysis and results presentations.

Figure 2 | Integrated waste management model



- **Waste generation submodel**

The MSW generation submodel was developed to replicate waste generation behaviors and historical values from recent years while projecting expected values for future years. This submodel serves as the foundation for all other models. Since waste is generated by people, the total population of the study area is used as the starting point for the model. By considering the per capita waste generation growth rate, we can calculate the annual waste generation. The primary focus of this system is on MSW generation and its characteristics. Therefore, the first input is the waste generated by Florianopolis' population (starting in 2018), which can be represented by the following compositions: Organic waste (35%), Recyclable waste (43%), and non-recyclable waste (22%) (COMCAP, 2020a). Based on the sensitivity analysis (refer to Model sensitivity analysis in Results) of these variables in relation to the presented historical data, we can assume that waste characterization will remain relatively consistent from 2018 until 2030.

In this submodel, the waste generation reflects the population growth and the per capita waste generation for the city as in Equation 1. The other variable in the equation is the waste generation reduction applied in the CEE and CEE + OLR scenarios.

MSW = population*per_capita_generation*(1-waste_generation_reduction) (1)

- **Food waste initial deviation submodel**

This submodel presents the part of the MFWs diverted before the MSW collection. The food waste initial deviation submodel emerged to recreate the behavior and value of the initiatives for FW landfill diversion in recent years. The FW initial deviation flow starts at 3,852 tons/year (ZAMBON; LUNA, 2016) and grows 1% per year in BAU and OLR scenarios, as shown in Equation 2.

Deviation increased per year = Initial_deviation_per_year*Initial_deviation_initiatives_growth_rate (2)

In CEE and CEE+OLR scenarios, the initial deviation grows more because the scenarios involve population environmental education, which influences the initial deviation. Even if the initiatives grow and more waste deviates, it cannot exceed FW generation in Florianópolis. Therefore we used the built-in function MIN, as shown in Equation 3.

Initial deviation = MIN(initial_deviation_per_year, MFW) (3)

- **Waste collection submodel**

This submodel presents the MSW collection. The overall collection is the sum of MRW, non-recyclable waste, and MFW subtracting the initial deviation from MFW (submodel already discussed). The model goal is the landfilled waste amount identification, whereby the MRW that is not sent for recycling, the untreated MFW, and the non-recyclable waste are landfilled. Hence, the MSW collection considers the total waste generation minus the diverted waste before collection, as shown in Equation 4.

MSW collection = MSW-Initial_deviation (4)

The organic waste collection flow removes the waste already collected as MRW and the non-recyclable waste, as shown in Equation 5.

Organic waste collection = (MSW_collection-MRW-Waste)*Composting_rate (5)

The waste influences the selective collection sent erroneously for recycling. In addition, it must be remembered that MRW cannot exceed all the waste collected in Florianópolis. Therefore, we also use the built-in function minimum as presented in Equation 6.

Selective collection = MIN(MRW,(MSW_collection*Selective_collection_rate)-(MSW_collection*Selective_collection_rate*Waste_rate)) (6)

Consequently, all the generated waste that is neither sent for composting nor recycling is collected to be landfilled, as shown in Equation 7.

Conventional collection = MSW_collection-Selective_collection-Organic_waste_collection (7)

MODEL ANALYSIS

Several model variables have undergone sensitivity and confidence analyses to adjust the model and bring it as close to reality as possible, and the MSW compositions are the main variables analyzed. We comprehend that these percentages are not fixed. However, the solid waste composition requires a more in-depth study on urban waste generation. It requires data for low and high seasons and all regions that make up the municipality’s collection. Thus, there are few studies on the MSW composition in Florianópolis. Table 2 shows the results of the 1988 MSW composition (BAASCH; PHILIPPI, 1988), the 2002 MSW composition (COMCAP, 2002), and the 2014 MSW composition (PMF, 2016). The latter is the one used today by the city hall.

Table 2 | Municipal solid waste composition in Florianópolis

Composition	1988	2002	2014
Waste	7%	18%	22%
Recyclable	46%	36%	43%
Organic	47%	46%	35%

Source: Baasch and Philippi (1988), COMCAP (2002), and PMF (2016).

Based on the MSW composition history, a confidence analysis was performed on Stella Architect. We adopted the Latin Hypercube Sampling method with 50 rounds and varying parameters: organic composition [0.35, 0.5], recyclable composition [0.36, 0.5], and waste composition as presented by Equation 8.

Waste composition = 1-Organic_composition-Recyclable_composition **(8)**

Sensitivity analysis allowed us to track the influence intensity of our model's two most uncertain parameters (LUNA et al., 2020) related to environmental education. When no historical values existed for formal calibration, procedures estimations were made. Such estimation can also be seen as author assumptions. For example, the waste generation reduction rate per year was assumed as 10%, based on the knowledge of environmental educators (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013). Therefore, the model has undergone behavior sensitivity (FORD, 2009) to help verify its usefulness. The sensitivity analysis was performed based on the experimental design of Table 3, considering the data variation related to "waste generation reduction" and "composting rate."

Table 3 | Experimental design to sensitivity analysis

		Waste generation reduction (%):			
		0.00	2.50	5.00	7.50
Composting rate (%):	7.50	Scenario 01	Scenario 03	Scenario 06	Scenario 09
	11.50	BAU	Scenario 04	Scenario 07	Scenario 10
	15.50	Scenario 02	Scenario 05	Scenario 08	Scenario 11

Eleven simulations were run and compared against the BAU scenario with simultaneous percentage increases in the parameters' values of "composting rate" and "waste generation reduction" since both parameters involve environmental education and population awareness. Thus, each scenario represents the combination of the specific values for each parameter and identifies the effect of such a combination on the landfilled waste amount.

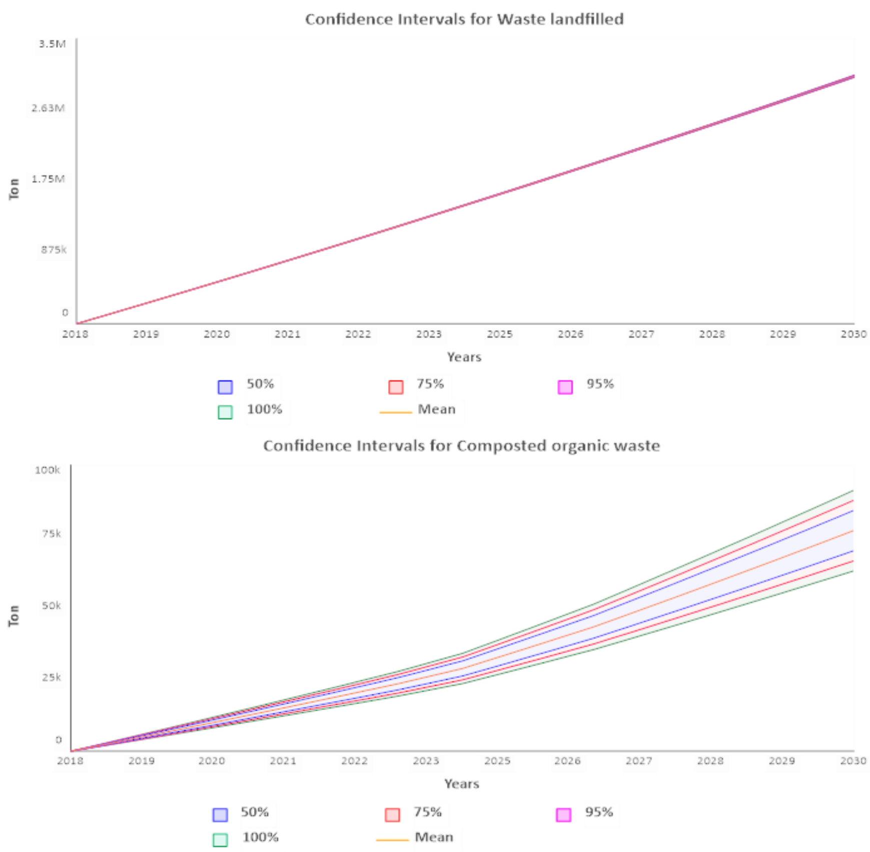
RESULTS

This topic highlights the results of model sensitivity analysis and the scenario analysis of MSWM for FW in Florianópolis.

MODEL SENSITIVITY ANALYSIS

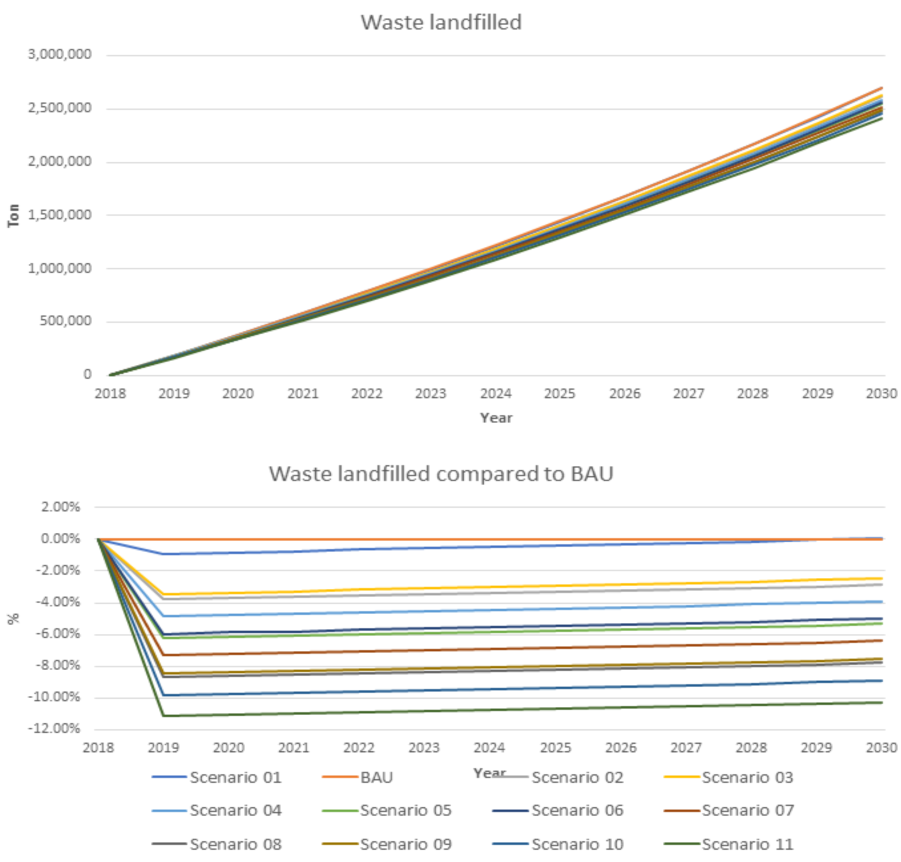
Based on the MSW composition history, the confidence analysis confirms that the chosen values for "organic composition," "recyclable composition," and "waste composition" parameters are trustable since no large variations in the simulations were found as Figure 3 shows.

Figure 3 | Confidence intervals for waste landfilled and composted organic waste



Waste generation reduction is directly affected by environmental education. However, the "composting rate" is also influenced by other parameters, such as composting capacity area, temperature, and humidity. In this sense, we can test the model's sensitivity to a wide range of values for both parameters. Figure 4 shows the range for sensitivity based on the percentage of waste landfilled compared with the BAU, offering a good confidence level for the forthcoming scenario tests. Only Scenario 01 is pessimistic compared to BAU, with a lower composting rate and no waste generation reduction. The most optimistic scenarios present a landfill diversion of more than 200 thousand tons of waste compared to BAU in 2030.

Figure 4 | Sensitivity analysis for waste landfilled



Waste and environmental education initiatives and the law regulation commenced in 2019. Therefore, in 2018, we can see the waste diversion focusing on existing activities rather than waste generation reduction. As a result, the graphs illustrate a significant difference in the amount of waste being landfilled between the years 2018 and 2019.

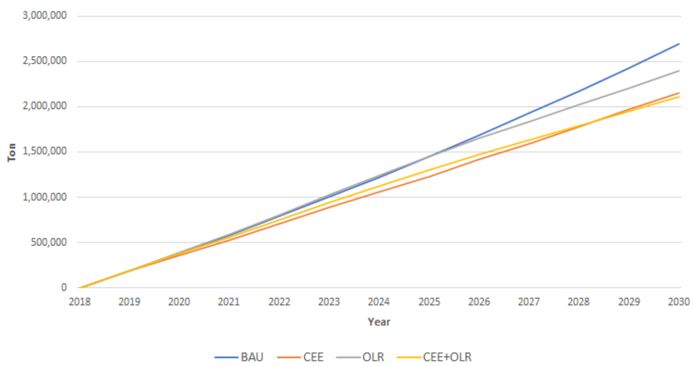
The sensitivity analysis confirms that the chosen values for “composting rate” and “waste generation rate” parameters are trustable since no large simulation variations were found.

SCENARIO ANALYSIS

The scenarios outcomes were divided into two sectors: (1) waste landfilled; and (2) total MFW deviation (MFW composted at MSW plant and MFW initially diverted from landfill).

The waste landfilled is the sum of MOW and municipal recyclable waste (MRW) that have not been composted or recycled, besides the non-recyclable waste. Non-recyclable waste is the only waste that must be disposed of in landfills. Hence, any action that improves waste composting or recycling results in a substantial landfill diversion. Figure 5 identifies that the CEE scenario reduces more waste sent to landfills than the OLR scenario, and the CEE+OLR scenario yields favorable results for landfill waste diversion.

Figure 5 | Waste landfilled



In Figure 5, the CEE scenario deviates more MSW than the OLR scenario from landfills since the CEE scenario influences waste reduction, best MSW segregation, household composting, and other initiatives.

The CEE scenario could divert 20% of waste, the OLR scenario could divert 11%, and the CEE + OLR scenario could divert 22% compared to the BAU scenario by 2030. Based on the statistical sensitivity analysis of the model, it can be observed that the 2% difference found between the CEE scenario and the CEE + OLR scenario is not significant. Moreover, Figure 6 corroborates Figure 5 by showing that both scenarios compost a large amount of MFW. However, the CEE scenario has an advantage compared with the OLR scenario.

Figure 6 | MFW diverted

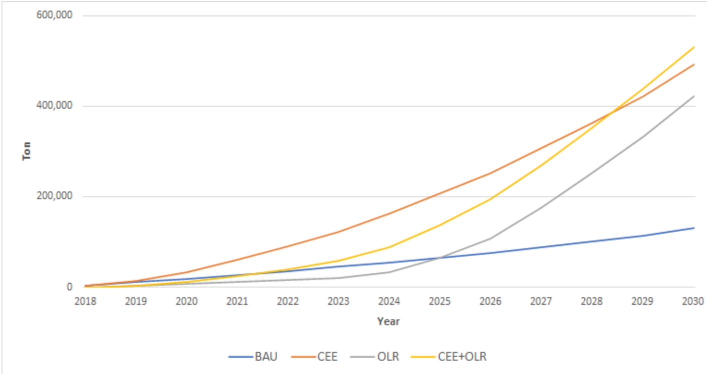


Figure 7 shows the scenario behavior for all MFW diverted in Florianópolis. The initially diverted MFW and the composted MFW were analyzed together to avoid misleading interpretations.

Figure 7 | Percentage of food waste landfill deviation per year

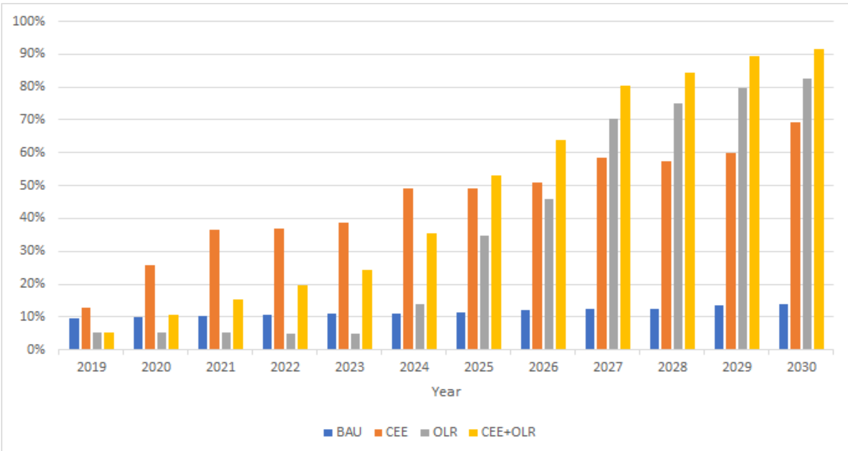


Table 5 presents each scenario's cumulative total food deviation and money saved by 2030.

Table 5 | Cumulative total diversion of food waste to 2030

Scenario	BAU	CEE	OLR	CEE+OLR
Deviation (ton)	121,362	491,059	421,867	530,532
Money saved (BRL)*	20,891,762	79,060,486	67,920,658	85,415,647

*BRL 161.00 /ton (PMF 2021)

CEE and OLR scenarios divert the large amount of MFW but do not reach the 90% target. In its final amount, the CEE scenario diverts 69,192 tons more than the OLR scenario, saving BRL 11,139,828.00 more. As the initial investment from CEE to Florianópolis is BRL 5,180,000.00 and infrastructure focused on OLR is BRL 6,477,400.00, the CEE scenario has the best result. The cost-saving analysis did not consider household waste generation reduction. The calculations and comparisons were made solely based on landfill deviation, the waste was produced but was not take to landfill.

Nonetheless, for Florianópolis's goal, only the scenario CEE+OLR can achieve the primary goal of 90% of organic waste diverted from landfill by 2030 and saves more money from MFW landfill deviation, as Table 5 and Figure 7 show. Therefore, combining CEE and OLR is ideal for achieving the municipality's proposed goal.

DISCUSSION

There is a link between wastefulness and MSWM, which generates the great potential for exploiting environmental education to make this issue more socially relevant, as the citizens understand their responsibility. This responsibility becomes more evident, especially when it comes to the consumption of critical products such as food, as it is a vital resource, and these resources' wastefulness is the source of major social problems (SHARMA; VRAT, 2018).

In addition, environmental education focused on selective collection contributes to Sustainable Development Goal number 11, "Sustainable Cities and Communities," more specifically to target 11.6, which establishes that by 2030, there should be a reduction in the negative environmental impact per capita of cities, including paying special attention to air quality, municipal waste management, and others.

Continuing environmental education directly impacts the MFW initial deviation and the amount of MFW collected by the MSWM company since the population starts to generate less MFW or compost at home. In addition, understanding the environment's relevance leads people to collaborate and separate their waste, facilitating the application of an OLR since the population feels engaged with the cause and not just obliged by law.

On the other hand, applying an OLR law is important for scaling the scope since everyone will need to join and have new habits with obligatoriness. Therefore, when the two scenarios come together, CEE+OLR, there is an increase in the potential for waste generation reduction, initial FW deviation, and correct waste separation.

It is noteworthy that only continuing environmental education is capable of reduction and segregation at the source, increasing the selective collection as well, which translates into a decrease in the waste volume that goes to landfills. Moreover, Read and Muth (2021) ratify and add that environmental education also reduces potential environmental impacts and costs.

Therefore, the money that would be used to manage the MSW is saved and could be invested in more continuing environmental education programs, such as consumer education campaigns (READ; MUTH, 2021), since the city's planned investment value is five times lower than the benefits that CEE + OLR scenario brings. Continuous investment is important because behavior changes occur immediately after the CEE intervention, but it is well-known that over time behavior fades away (GUTIÉRREZ-BARBA; ORTEGA-RUBIO, 2013). Nevertheless, Read and Muth (2021) study show that even with higher cost-effectiveness results for consumer education campaigns, uncertainty in cost-effectiveness was relatively high.

Figure 7 clarifies that the CEE scenario maintains a high level of MFW diversion from landfills but stabilizes. Thus, we can conclude that CEE is important for obtaining the diversion of landfills. However, if the municipality does not provide support with infrastructure and tools, as in the case of public command and control (OLR) policies and investment in infrastructure, the CEE can stagnate, and the separation and diversion of the landfill as well. Thus, the joint development of environmental education with public command and control policies is important.

The results show the success of MFW separation, conservation, and collection. This success depends on a complex set of political-institutional factors, such as policies and law regulation (OLR scenario), and also greatly depends on each citizen's participation and environmental awareness (CEE and CEE+OLR scenarios) (PICKERING et al., 2020). Thus, dynamic interactions serve as a decision-making instrument to assess how social changes improve the MFW system (BABALOLA, 2019).

CONCLUSIONS

This paper aims to evaluate the modeled long-term impact of environmental education interventions and compare the results when combined with a command-and-control policy for MFW deviation. The focus is on understanding these impacts on MFW management in future. Therefore, we concluded that environmental education plays an important role in MSWM systems.

Environmental education gives citizens a better understanding of the policy and how to apply it correctly. Thus, creating a more conducive environment for achieving the policy goals. Consequently, the command-and-control law reinforced by environmental education would increase the total waste management budget and environmental benefits. Ergo, strengthening the continuing environmental education is crucial to the MSWM's suitability and the MFW.

The Ordinary Law (OLR scenario) shows its potential for FW diversion. Moreover, the CEE+OLR scenario achieves 90% of FW diversion by 2030, with CEE speeding up the annual rate once the citizens are more willing to reduce waste generation and compost waste. More sustainable food consumption in households reduces the amount of wasted food. Conversely, the MSWM is robust enough to give a sustainable destination to the losses when food waste occurs.

The SD model reached the objective of effectively evaluating the different public policies, allowing the understanding of the CEE program's relevance. Our results inform policymakers about the possibility of allocating more investments to CEE programs together with command-and-control policy implementation. Nevertheless, waste generation reduction and separation are not easily quantified, and it is difficult to relate to government investment in education.

The results brought insights for future work, such as investigating the interactions between the CEE program and FW diversion law adhesion, including the trade-offs of CEE and control investment. Future works may also examine the correlation between investing in the CEE program and waste reduction and segregation. Finally, we recommend further study to achieve the optimal design of an FW collection and composting system.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

REFERENCES

ABRELPE. **Panorama dos resíduos sólidos no Brasil 2017**. Disponível em: http://abrelpe.org.br/panorama/. Acesso em: 21/07/2022.

ANTÓN-PESET, A.; FERNANDEZ-ZAMUDIO, M. A.; PINA, T. Promoting Food Waste Reduction at Primary Schools. A Case Study. **Sustainability**, 13(2), 600, 2021.

BAASCH, S.S.; PHILLIPPI, L.S. **Caracterização dos Resíduos Sólidos do Município de Florianópolis**. ENS /UFSC. Florianópolis, 1988.

BABALOLA, M. A. A System Dynamics-Based Approach to Help Understand the Role of Food and Biodegradable Waste Management in Respect of Municipal Waste Management Systems. **Sustainability**, 11(12), 3456, 2019.

BRAZIL. **Law No. 12305/2010**, Política Nacional de Resíduos Sólidos (PNRS), Diário Oficial da União. Brasília, Brasil: Congresso Nacional, 2010.

CHEN, H.; YANG, Y.; JIANG, W.; SONG, M.; WANG, Y.; XIANG, T. Source separation of municipal solid waste: The effects of different separation methods and citizens' inclination—case study of Changsha, China. **Journal of the Air & Waste Management Association**, 67(2), 182-195, 2017.

COMCAP. **Caracterização Física dos Resíduos Sólidos Urbanos de Florianópolis**. Florianópolis, 2002.

________. **Valorização de resíduos sólidos.** 2020a. Disponível em: http://portal.pmf.sc.gov.br/entidades/comcap/index.php?cms=valorizacao+de+residuos+solidos&menu=6. Acesso em: 20/06/2021.

________. **Coleta seletiva de orgânicos porta a porta vira realidade em Floripa**. 2020b. Disponível em: http://www.pmf.sc.gov.br/entidades/comcap/?pagina=notpagina&menu=&noti=22764. Acesso em: 11/06/2022.

DE ANDRADE JUNIOR, M. A. U.; ZANGHELINI, G. M.; SOARES, S. R. Using life cycle assessment to address stakeholders' potential for improving municipal solid waste management. **Waste Management & Research**, 35(5), 541-550, 2017.

DE OLIVEIRA, C. T.; RODRIGUES, C. M. T. Sistema de coleta de resíduos orgânicos em nível comunitário em um país em desenvolvimento: estudo de caso em Florianópolis, Brasil. **Revista Metropolitana de Sustentabilidade**, 7(2), 152-169, 2017.

DIANATI, K.; SCHÄFER, L.; MILNER, J.; GÓMEZ-SANABRIA, A.; GITAU, H.; HALE, J.; LANGMAACK, H.; KIESEWETTER, G.; MUINDI, K.; MBERU, B.; ZIMMERMANN, N.; MICHIE, S.; WILKINSON, P.; DAVIES, M. A system dynamics-based scenario analysis of residential solid waste management in Kisumu, Kenya. **Science of The Total Environment**. 1, 2021.

ERCAN, T.; ONAT, N. C.; TATARI, O. Investigating carbon footprint reduction potential of public transportation in United States: A system dynamics approach. **Journal of Cleaner Production,** 133, 1260-1276, 2016.

FALASCONI, L.; CICATIELLO, C.; FRANCO, S.; SEGRÈ, A.; SETTI, M.; VITTUARI, M. Such a shame! A study on self-perception of household food waste. **Sustainability**, 11(1), 270, 2019.

FARIAS, E. **Revolução dos Baldinhos**: Um Modelo de gestão Comunitária de resíduos Orgânicos que Promove a Agricultura Urbana. Relatório de estágio de conclusão de curso de Graduação em Agronomia UFSC, 2010.

FAO. **Global initiative on food loss and food waste reduction**, 2015. Disponível em: http://www.fao.org/3/a-i4068e.pdf. Acesso em: 11/02/2022.

FORD, A. **Modeling the environment** (second ed.), Island Press, Washington, DC, 2009.

GALLI, F.; CAVICCHI, A.; BRUNORI, G. Food waste reduction and food poverty alleviation: a system dynamics conceptual model. **Agriculture and Human Values,** 36(2), 289-300, 2019.

GUERRA, J. B. S. O. A.; RIBEIRO, J. M. P.; FERNANDEZ, F.; BAILEY, C.; BARBOSA, S. B.; DA SILVA NEIVA, S. Reprint of: The adoption of strategies for sustainable cities: A comparative study between Newcastle and Florianópolis focused on urban mobility. **Journal of Cleaner Production**, 163, S209-S222, 2017.

GUTIÉRREZ-BARBA, B. E.; ORTEGA-RUBIO, A. Household food-waste production and a proposal for its minimization in Mexico. **Life Science Journal**, 10(3), 1772-1783, 2013.

IPEA. **Diagnóstico dos Resíduos Sólidos Urbanos**, 2012. Diagnóstico dos Resíduos – Relatório de Pesquisa. Disponível em: http://www.ipea.gov.br/portal/images/stories/PDFs/relatoriopesquisa/121009_relatorio_residuos_solidos_urbanos.pdf. Acesso em: 11/02/2022.

JABBOUR, A. B. L. S.; JABBOUR, C. J. C.; SARKIS, J.; GOVINDAN, K. Brazil's new national policy on solid waste: challenges and opportunities. **Clean Technologies and Environmental Policy**, 16(1), 7-9, 2014.

LEE, C. K. M.; NG, K. K. H.; KWONG, C. K.; TAY, S. T. A system dynamics model for evaluating food waste management in Hong Kong, China. **Journal of Material Cycles and Waste Management**, 21, 433–456, 2019.

LUNA, T.F.; URIONA-MALDONADO, M.; SILVA, M.E.; VAZ, C.R. The influence of e-carsharing schemes on electric vehicle adoption and carbon emissions: An emerging economy study. **Transportation Research Part D: Transport and Environment**, 79:102226, 2020.

PEREIRA, A. L. F. F.; DOS SANTOS, L. K. C.; DE MATTOS, A. C. R. M. Educação Ambiental como estratégia de redução do índice resto-ingesta no restaurante acadêmico de uma instituição federal de ensino no município de Sobral (CE). **Revista Brasileira De Educação Ambiental (RevBEA)**, 15(1), 310-327, 2020.

PICKERING, G. J.; PICKERING, H. M.; NORTHCOTTE, A.; HABERMEBL, C. Participation in residential organic waste diversion programs: Motivators and optimizing educational messaging. **Resources, Conservation and Recycling**, 158, 104807, 2020.

PINTO, R. S.; DOS SANTOS PINTO, R. M.; MELO, F. F. S.; CAMPOS, S. S.; CORDOVIL, C. M. D. S. A simple awareness campaign to promote food waste reduction in a University canteen. **Waste Management**, 76, 28-38, 2018.

POPLI, K.; SUDIBYA, G. L.; KIM, S. A review of solid waste management using system dynamics modeling. **Journal of Environmental Science International**, 26(10), 1185-1200, 2017.

PMF. **Plano Municipal de Gestão Integrada de Resíduos Sólidos**, 2016. Disponível em: http://www.pmf.sc.gov.br/sistemas/pmgirs/caderno2.php. Acesso em: 20/11/2021.

___. **Decree No 18.646/2018**, 2018a. Programa Florianópolis Capital Lixo Zero.

___. **Projeto Minhoca na Cabeça**, 2018b. Disponível em: http://www.pmf.sc.gov.br/sistemas/MinhocaCabeca/. Acesso em: 20/11/2021.

___. **Ordinary Law No 10.501/2019**. Dispõe sobre a obrigatoriedade da reciclagem de resíduos sólidos orgânicos no município de Florianópolis, 2019.

___. **PMF investiu R$ 10 milhões para acelerar metas lixo zero**, 2020. Disponível em: http://www.pmf.sc.gov.br/mobile/index.php?pagina=notpagina&noti=22693. Acesso em: 20/11/2021.

___. **Indicadores da geração de resíduos**, 2021. Disponível em: http://www.pmf.sc.gov.br/entidades/comcap/index.php?cms=indicadores+da+geracao+de+residuos&menu=6&submenuid=1414. Acesso em: 22/11/2021.

READ, Q. D.; MUTH, M. K. Cost-effectiveness of four food waste interventions: Is food waste reduction a "win–win?". **Resources, Conservation and Recycling**, 168, 105448, 2021.

SHARMA, N.; VRAT, P. Impact of various factors on stock-induced food waste in Indian weddings. **Journal of Advances in**

Management Research, 15 (1), 37-57, 2018.

SUKHOLTHAMAN, P.; SHARP, A. A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand. **Waste Management**, 52, 50-61, 2016.

TSENG, C. H.; HSU, Y. C.; CHEN, Y. C. System dynamics modeling of waste management, greenhouse gas emissions, and environmental costs from convenience stores. **Journal of Cleaner Production**, 239, 118006, 2019.

WA'EL A, H.; MEMON, F. A.; SAVIC, D. A. An integrated model to evaluate water-energy-food nexus at a household scale. **Environmental Modelling & Software**, 93, 366-380, 2017.

XIAO, S.; DONG, H.; GENG, Y.; TIAN, X.; LIU, C.; LI, H. Policy impacts on Municipal Solid Waste management in Shanghai: A system dynamics model analysis. **Journal of Cleaner Production**, 121366, 2020.

ZAMBON, M. M.; LUNA, M. M. M. Resíduos orgânicos urbanos: um olhar sobre Florianópolis. In **ENGEMA**-Encontro Internacional sobre Gestão Empresarial e Meio Ambiente, São Paulo, 2016.

ZAMRI, G. B.; AZIZAL, N. K. A.; NAKAMURA, S.; OKADA, K.; NORDIN, N. H.; OTHMAN, N.; AKHIR, F. N. M. D.; SOBIAN, A.; KAIDA, N.; HARA, H. Delivery, impact and approach of household food waste reduction campaigns. **Journal of Cleaner Production**, 246, 118969, 2020.

ZOLNIKOV, T. R.; DA SILVA, R. C.; TUESTA, A. A.; MARQUES, C. P.; CRUVINEL, V. R. N. Ineffective waste site closures in Brazil: A systematic review on continuing health conditions and occupational hazards of waste collectors. **Waste Management**, 80, 26-39, 2018.