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ANALYZING WASTE PREVENTION BEHAVIORS BY APPLYING AN ABMS FRAMEWORK

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ABSTRACT

Nature and society have undergone fast and intense changes in the last decades. Consumption is expanding at a hyperbolic rate. Technological innovation has bypassed some environmental problems, but it is hardly sufficient to solve them. As a result, understanding the factors related to people's behavior is imperative when finding a novel approach for intervention policies that can effectively alleviate environmental impacts caused by human activities. A promising alternative to designing waste prevention (WP) policies is to develop strategies to endure behavioral change through collective actions. This paper briefly reviews some WP status worldwide and highlights the possibility of using agent-based modeling and simulation (ABMS) to plan WP policies and programs. ABMS enables a more in-depth analysis since experiments with a large sample in real situations are financial, temporal, and social cost-demanding. Preliminary results show an influence of the social norm on the adoption of reusable bags by individuals with medium and lower pro-environmental motivations. Understanding these dynamics relations in which WP policy is embedded makes it possible to forecast future waste generation and composition scenarios. Also, a framework for planning WP with ABMS is proposed.

1. INTRODUCTION

Even though waste prevention (WP) is exhaustively presented at the top of the waste hierarchy in waste policies globally, this topic has been overlooked by academics, policymakers, and managers (Hou & Sarigöllü, 2021). The current implementation of programs arising from these policies is far from being considered satisfactory with an increase in waste generation and not the opposite (see Kaza et al., 2018). Even in places where extensive regulation is already in place, there is still a gap between what is expected and what is observed. Despite WP being at the top of the "waste solution hierarchy", Minelgaitė & Liobikienė (2019) notice that EU waste policies primarily defined targets for waste reduction mostly by recycling. An extensive literature review by Hutner et al. (2017) concluded that the overall implementation status is low due to an apparent lack of proper professional guidance. Johansson & Corvellec (2018) stated that most WP policies are based on conventional waste management goals neglecting consumption, the primary driver of waste generation. Information campaigns are one of the most widespread tools for waste management (Hou & Sarigöllü, 2021). They are typically the focus of WP policies which are not necessarily connected to incentives and consequences for the actors involved. A 2017 European Union report on policies, status, and trends in reuse activities shows important progress in WP policies. Still, it points out that the lack of shared targets and indicators for WP, data quality concerns, and delays between adopting and implementing programs are problematic for review processes (EEA, 2017). The existing space for prevention policies becomes even more critical when one looks at countries that still have the primary challenge of dealing with the proper disposal of their waste, where most of it is deposited in dumps. Also, WP policies face another obstacle directly connected to rethinking consumption since considerable portions of the population in these locations still struggle to have more dignified living conditions, for instance, access to adequate nutrition.

Strict avoidance, reduction at source, and product reuse are the core of WP actions (OECD, 2000). WP policies must be comprised of measures, priority areas, objectives, and visions integratively. For European Commission (2012), vertical integration (i.e., between different governance levels) is critical. The challenge is how policies can reciprocally strengthen each other by bearing in mind the competencies for policymaking of the diverse structures implied. Unfortunately, WP is often treated as a purely tech-

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nological issue, requiring specialized applications. These processes are fundamentally necessary within industry and agriculture.

Nevertheless, the same logic cannot be applied when analyzing WP from the consumers' perspective (within the household), as the action point is based on behavioral change. WP behavior is a complex issue, consisting of a multifaceted mix of actions related to various physical contexts and susceptible to multiple factors. Moreover, WP encompasses all social conditions in which waste is generated (not only a problem of individual behavior) (Zacho & Mosgaard, 2016). For Fell et al. (2010), more and better data is required (from household behaviors through to economy-wide linkages between waste arising and other variables), and more and better models must be developed and tested to shrink the scale of 'unexplained' variance.

Increasing people's engagement in WP behavior depends on how it occurs and which influential factors are significant in promoting behavioral change. Previous studies have argued that encouraging pro-environmental behavior (PEB) is an alternative to achieving WP policy targets. (Bortoleto, 2015; Eppel et al., 2013). For Li et al. (2019), studying the factors that shape PEBs could be a central aspect of future development strategies and policymaking. In this study, PEB is defined analogously to the concept of goal-oriented behavior: a set of actions that individuals take with the specific goal of preserving and conserving the natural environment (Kaiser & Wilson, 2004). To infer PEB, Kaiser & Wilson (2004) developed the General Ecological Behavior (GEB), a tool to rank PEB actions in a specific population according to their engagement level (i.e., intrinsic motivation and difficulty) related to the activities. The GEB is also an instrument to formulate public policies regarding behavioral change toward environmental conservation (see Ribeiro-Rodrigues et al., 2021).

The way WP policies have been traditionally formulated needs to be reviewed. New public policies require large-scale experiments, as they demand a high financial investment and a social investment once the objective is that the people conduct more PEBs (i.e., show an increasing set of WP behaviors). Since social systems (and the PEBs conduction) are often classified as complex adaptive systems (CAS), conducting experiments in situations with real individuals or realistic environmental stimuli can have several inherent difficulties and may become unviable in specific contexts (e.g., case and field studies). It is the case for studies of how people evaluate future scenarios and those that involve thousands of people's behavior because large samples are often expensive to manage (both temporally and monetarily). Likewise, there is a considerable risk of interference from unknown variables, and data collection is demanding (Steg et al., 2013). Environment-independent settings as self-report measures of PEBs are cost-effective for reaching large populations and have high external validity. However, social desirability is unfavorable (Lange & Dewitte, 2019; Sjöström & Holst, 2002). Another possibility is to conduct simulation studies as computer simulations through agent-based modeling and simulation (ABMS). Although characterized as an artificial approach compared to laboratory experiments, simulation studies allow for a good balance between internal/external validity and a realistic visualization (Steg et al., 2013). As every study has limitations, a good solution is to use multiple methods to measure PEB (Lange & Dewitte, 2019). The typical joint use of GEB and ABMS is promising. According to Fell et al.(2010), the human behavior complexity and the intricacies of waste demand robust and reliable models that could be used formally to investigate policy interventions that do not yet exist for household waste.

ABMS studies in waste-related PEBs had recently been published in areas such as recycling (e.g., Barbuto et al., 2017; Ceschi et al., 2021; Luo et al., 2019; Meng et al., 2018; Scalco et al., 2017), waste disposal (e.g., Rangoni & Jager, 2017) and consumption in a broader way (e.g., Bravo et al., 2013; Delcea et al., 2019; Du & Wang, 2011; Liu et al., 2017; Nassehi & Colledani, 2018; Raihanian Mashhadi & Behdad, 2018; Zhang & Zheng, 2019) but not necessarily directed to WP. ABMS experiments need to gain space, especially in WP policies. These are highly complex, as they involve and depend on people's behavior inside and outside their homes. Unlike recycling, there is no physical data to know whether the prevention policy was successful or not (measuring what does not exist) as the premise is the non-generation of waste. This problem and ambiguous definitions of WP are cited by Wiprächtiger et al. (2021) as barriers to developing the quantitative targets necessary for the WP programs implementation and evaluation. ABMS is a possibility to give feedback a priori, i.e., before the implementation of WP policies and programs. This feedback becomes even more pertinent when it is required to test different scenarios, including extreme cases. For instance, the covid-19 pandemic has changed several behavior patterns that pose even greater challenges for public policymakers. Lavagnolo (2020) explains that there is an evident conflict concerning the pathway identified by the Circular Economy (CE) tending toward a reduction of single-use plastics and the need to increase their use since the pandemic began. As claimed by Stegmann (2021), the scientific community, together with stakeholders, must develop new ideas and further develop WP concepts in theory and practice. Hence, this study highlights the possibility of using ABMS to plan WP policies and programs.

2. WASTE PREVENTION POLICIES

UNEP and ISWA (2015) provide a global picture of WP policies. According to them, WP has been at the top of the waste hierarchy since the 1970s, when the concept was first defined. However, the term has only recently become the main focus of tangible actions in some developed countries. The causes for this delay were pragmatic, as the initial priority was the gradual elimination of uncontrolled and poorly controlled disposal practices. Then they started to raise environmental standards and restructure recycling rates. Alternatively, the main priority in developing and underdeveloped countries is at an earlier stage: guaranteeing universal access to waste collection services, eliminating uncontrolled disposal and burning, and moving towards environmentally appropriate treatment facilities are the main challenges. The waste generated by their urban populations is further pressing the already overburdened municipal services. It is compounded by considering the changes in waste composition toward more plastics and electronic waste (e-waste). Thus, developing effective WP policies needs to become an even higher priority.

The European Union (EU) stands out as one of the pioneers, with several directives related to WP since 1975. The Thematic Strategy on the Prevention and Recycling of Waste was established in 2005 (Sakai et al., 2017). The milestone was the waste hierarchy introduced by the Waste Framework Directive, which required all members to have established their WP Programmes by 2013 to move up in the hierarchy. Regulations enter into all EU Member States, and strategies are guidelines to be considered in future waste legislation, although each country may decide how to implement them (Pires et al., 2019). The European Environment Agency (EEA) is responsible for the topic. The country profiles on WP show updates (although very concisely) for each member and associated countries (EEA, 2021). The profiles vary in detail and about the effectiveness of programs and metrics. Close to completing ten years since mandatory implementation, the EEA and Eionet have recently published a guideline for aiding policymakers evaluate expiring WP programs at national and regional levels (EEA, 2021). The most recent publications are the WP status programs in reuse (EEA, 2017) and the EEA (2019) focused on plastic WP. The latter identified that most prevention measures refer to voluntary agreements and informative instruments. Merely nine countries have explicit WP targets incorporated in their programs. In general, European local authorities have not been able to substantially reduce the amount of waste they manage (Domingo & Melchor, 2022). Bartl (2020) emphasizes that it is impressive that although the core of the European CE package (European Commission, 2022) addresses the minimization of the waste amount based on some ideas that are more than four decades old, there are still no adequate measures nowadays to get WP off the ground.

According to the Asia Waste Management Outlook, waste management hierarchy is referred to by 15 out of the 25 countries in the region. Nevertheless, only 3 out of the 25 countries refer to prevention, 8 to reduction, 9 to reuse, 11 to recycling, 7 to recovery, 8 to treatment, and 22 to disposal. This result shows that the focus of many Asian countries is still limited to disposal (UNEP, 2017). Japan seems to be the pioneer Asian country in WP measures (see Law No. 110/2000) which aims to limit the consumption of natural resources and minimize the environmental damage associated with the 3R's concept (reduce, reuse, recycle) and environmentally sound waste management practices (Sakai et al., 2017). The Basic Act serves as a basis for other national programs. Eco-design and life-cycle thinking are emphasized in all Japanese waste programs, not just in reusing and reducing activities (European Commission, 2012). Liu et al. (2017) identified that over 200 national circular economy standards and laws in China were established in the CE system. However, policies and regulations systems are still insufficient, particularly for end-of-life vehicles, packaging waste, and other specific waste. When comparing China with the EU, McDowall et al. (2017) concluded that the CE's Chinese version is more linked to pollution and the broader sustainable development category, while the European versions are related to waste and opportunities for the industry. Nevertheless, both versions could be recognize as examples of ecological modernization (see Spaargaren & Mol, 1992), i.e. applying technological and social innovation to solve conflicts between environmental and economic perspectives.

UNEP & GA Circular (2019) show a lack of a wide-ranging policy approach for the packaging waste issue in Asia despite the effort to address producer responsibility by many countries of the Association of South-East Asian Nations (ASEAN). Despite some nations' movement to create producer responsibility mechanisms, there has been no significant progress on the packaging issue. UNEP & Food Industry Asia (2020) show dissonance between expectations and actions on reducing plastic waste in South-East Asia. Consumers and businesses have identified key steps to target plastic waste: source separation, improving collection systems, littering fines, and developing waste labels. Australia and New Zealand also implemented "zero waste" strategies (Australia, 2018; Government of South Australia, 2020). In New Zealand, the 2018 Waste Minimization Regulation forbids retailers to sell or distribute single-use plastic shopping bags (New Zealand, 2019). Majority of Oceania countries are islands with no space for landfills, some with open dumpsites problems and reduced opportunities to implement international reverse logistics and take-back/end-of-life logistics (EIA, 2020). Nevertheless, few WP policies and programs were implemented in these countries. Despite being a central problem, most of these countries failed to address marine plastic pollution beyond the traditional approach to waste management, according to the Environmental Investigation Agency (EIA, 2020).

The African continent also lacks WP policies. Governments still focus on structural problems linked to waste generation (low collection rate, uncontrolled dumpsites, and low recyclable rate – 4%). However, countries intend to achieve that at least 30% of all waste generated is reused, recycled, or recovered by 2030, in addition to encouraging WP policies (UNEP, 2018a). The Africa Waste Management Outlook shows regional policies like the Regional Indicative Strategic Development Plan (2001) for the Southern African Development Community with an integration agenda from 2005–2020. The Economic Community of the West African States developed an e-waste regional strategy (2012), a regional strategy on chemicals management and hazardous waste (2015), and a plastic waste management strategy (2016). East African Community Development Strategy, with goals for 2011-2016, aimed to have a policy for plastic waste and e-waste. Only Rwanda (2008) and Kenya (2017) have successfully imposed a total ban on plastic bag use, and others have introduced a partial ban (UNEP, 2018a). Reuse measures are detailed in only 3 cases: reuse of waste tires in Burkina Faso, reuse of e-waste in Cotê D'Ivoire, and reuse of plastic waste as schoolbags in South Africa. As for the single-use plastic issue, the focus is on plastic bags. Of the 30 countries, only Botswana applies a levy, and the rest are banned. Among the problems faced by waste management and, consequently, for WP policies, the report highlights that there is no clear distinction between the responsibilities attributed to governments, municipalities, service providers, and waste generators (UNEP, 2018a).

The United States announced in 2015 the first domestic goal to cut food loss and waste in half by 2030 and implemented the US 2030 Food Loss and Waste Reduction Goal program (US EPA, 2016). Canada is one of the biggest waste generators worldwide (per capita); however, only in 2021 launched its National Zero Waste Council aiming to reduce waste generation and impact the circularity of material flow (NZWC, 2021). Latin American and Caribbean countries still face structural problems implementing waste management initiatives. Only 10% of the waste is recovered, and recycling rates are low (1-20%) (UNEP, 2018b). Although waste regulations in the region include the concept of WP, there is no detailed information on how to implement it (UNEP, 2018b). There are isolated efforts on some WP actions, for example, regulations focusing on single-use plastics and plastic bags. Chile was the first to ban plastic bags, while Argentina, Guatemala, and Mexico have restricted their use in some regions (Peñaloza, 2018).

In Brazil, the federal legislation only cites WP without detailing specific regulations or measures to implement it (see Law No. 12,205/2010). At the local level, most municipalities have not drafted their MWS plans yet. According to data from the Brazilian Sanitation Information System (SNIS), in 2017, of the 5570 existing municipalities, only 3617 were submitted to the system. Of these, less than half (49.63%) have the plan implemented (SNIS, 2019). Among the governance findings related to waste, the UNEP's report shows imprecisely defined or overlapping competencies that create the "vacuum of government responsibilities" that reflect low actions and monitoring. This scenario results in infrequent law enforcement (when existing) both in the public and private sectors. Despite being a principle in legislation, citizen participation is still limited regarding access to information and public decisions related to waste issues. Another point is the difficulty of articulating national waste management and environmental education policies, with communication efforts usually isolated. This means that most of the time, there is no reliable support information system; in these scenarios, NGOs' cooperation that intervene where government actions are limited is significant. As for the findings in the financing, among other aspects, they point to the persistence of financially unsustainable management mechanisms and ignorance of the direct and indirect costs of waste management, which seem to be factors that make effective WP policies adoption even more challenging. In general, the report does not seem to point out detailed strategies that are directly linked to the population behavior, being more restricted to recommendations for the entire chain that precedes the user (e.g., generators and manufacturer's commitments) (UNEP, 2018b).

This overview of WP policies worldwide shows that despite many initiatives, they are still insufficient to deal with the waste problem as they should. Many of the actions are focused on two mainstreams: food and plastic waste, driven mainly by the Sustainable Development Goals of the United Nations for 2030 (see United Nations, 2022). However, even in Europe, where WP policies are the majority, there are problems concerning WP targets and indicators, data quality, and implementation of WP programs (EEA, 2017). According to Zapata & Campos (2019), WP policies have been criticized for only expressing good intentions rather than achieving actual results and changes. Another problem is the adoption of "zero waste" programs as a form of strategic WP. There is a misunderstanding about the application of Circular Economy, "zero waste," and "cradle to cradle" as approaches valid to solve any waste management problem (Stegmann, 2021). For Lavagnolo (2020), identifying waste recycling as the focal point of a Circular Economy while simultaneously advocating for "zero waste" is a sort of oxymoron. "Zero waste" is a term that refers to uncontrolled disposal or landfill and mainly includes recycling and incineration as preferred options (Zorpas et al., 2014). Valenzuela & Böhm (2017) argue that they also functioned to de-politicize the discourse around capitalism's unsustainability, allowing ever-increasing levels of consumption and waste while legitimizing unsustainable production and notions of limitless growth. As claimed by Sattlegger (2019), different distributions of income, wealth, and knowledge create disparities in an individual's freedom of action. For all those reasons, WP policies need to be planned considering individuals' behavioral and context aspects in depth.

3. METHODS

3.1 Waste prevention policy design

Behavioral influences are contextual and intrapersonal variables that affect motivation and perceived difficulty (i.e., behavioral costs) in performing a behavior. Situational factors (e.g., regulations, social interactions, culture, the economy, climate) can influence how individuals interpret the context and experience difficulties conducting PEBs. Social norms (SN) are related to these factors, as social interactions often occur across various contexts, and how individuals act in one context can radically change their behavior when moving into another (Hackel et al., 2020). In line with Horne (2018), norms are usually defined as "rules or expectations that are socially enforced." Norms may be prescriptive (encouraging positive behavior, e.g., "donate unused products") or proscriptive (discouraging negative behavior; e.g., "don't throw away a product that can still be repaired"). SN are rules and standards that members of a group assume and that guide and constrain human interactions with others without the force of laws. They are what is commonly done or (dis) approved, which refers to what other people think or do for specific situations (de Groot et al., 2013; Steg et al., 2013). Rodrigues et al. (2015) stated that norms are learned and constitute one of the most critical social control mechanisms.

Studying SNs in the context of PEBs is critical to explaining the environmental policies' acceptance or not. They can be explained by the social dilemmas concept, brought from Hardin (1968) on the "tragedy of the commons". It is a situation in which individual and collective interests' conflict. Each self-interested decision produces a negative result (or cost) for the other people involved (von Borgstede et al., 2013). If many people make selfish choices, the negative results pile up. This outcome creates a situation where everybody would have done better had they not acted in their interest. Cialdini et al. (1990) stress that although SNs characterize and guide behavior within society (i.e., descriptive or injunctive influencers of human motivation), they should not be uniformly in force at all times and in all situations. SNs need to be activated to motivate the behavior (i.e., highlighted or otherwise addressed). People willingly or temporarily focused on normative considerations are more likely to act consistently with the norms.

For Chung & Rimal (2016), SNs can be an efficient alternative to legal rules since "they guide against negative externalities and provide social signals with little or no cost". Many well-established SNs in society end up becoming legal norms (e.g. not throwing garbage in public places), but the opposite is not always valid. It happens when the legal standard does not consider the current SN (e.g., recyclables separation in a social group that does not usually do it for any reason: lack of knowledge, contextual barriers, etc.). Conforming to SNs is often associated with social acceptance or rewards, whereas violating norms entails disapproval and social sanctions. Individuals conform to standards to gain social approval or to avoid social sanctions. SNs mold individual needs and preferences as they function as criteria for selecting alternatives. These criteria are shared by a particular community and incorporate a standard value system. Individuals may choose what they prefer, but what they prefer is in line with social expectations (i.e., behavior is influenced because they become part of their motives for action) (Bicchieri et al., 2018).

The desire for social approval indicates that individuals will act more prosocially in the public sphere than in private situations (Ariely et al., 2009). In contrast, SNs influence stated opinions and personal behavior (Keizer & Schultz, 2013). Changing empirical expectations is easily accessible in the case of public practices as people learn from observing and communicating with others. Still, not all practices are visible (such as most WP activities) (Bicchieri, 2017). Norms that regulate private behaviors are challenging to change because other people's behavior is not regularly observed. Tucker & Douglas (2007) point out that WP is primarily a private activity with no explicit normative pressure and has an unknown SN. Nevertheless, the authors emphasize that when some activities become public, they may be misjudged socially or unjustifiably stigmatized. Besides, the isolated and erroneous analysis of an individual action that does little to reduce impacts can lead to a lack of recognition that these actions are part of a more extensive set of environmental tools.

Although several field experiments have confirmed that SNs have a powerful influence on PEBs and motivate others to become involved, people still tend to underestimate their power (Corsini et al., 2018; Keizer & Schultz, 2013; Truelove & Gillis, 2018). Since SNs can positively or negatively impact the waste prevention behavior (WPB) interventions, studying how they influence WPB would be an initial step toward building an intrinsic motivation to prevent waste. Previous studies in WPB have addressed its influential factors; some focused on situational factors (Bortoleto, 2015; Cecere et al., 2014; Hutner et al., 2017; Johansson & Corvellec, 2018; Kurisu & Bortoleto, 2011; Zacho & Mosgaard, 2016) while others on psychological factors (Bortoleto, 2015; Bortoleto et al., 2012; Gilli et al., 2018; Tucker & Douglas, 2007). Although some of these studies have included SNs among the variables analyzed, there is still no detailed emphasis on the normative aspects of WPB. Therefore, SNs related to WP behavior were addressed in this study as understanding the dynamics in which SNs operate within a context assists the effective planning of WP policies. Salience, group size, reference groups, subjective norms, and personal norms are SNs moderators (Keizer & Schultz, 2013). Understanding the dynamics in which the SNs operate within a context helps to draw better strategies in WP program planning and opens a range of interventions options that can stimulate the establishment of positive norms or weaken existing harmful norms without necessarily imposing certain behaviors through banishments or taxes, which may have undesirable and even opposite consequences for the primary objective.

3.2 Agent-based modeling and simulation - ABMS

The ABMS is an important research method in CAS theory and can represent low-level flexible and intelligent behavior in a dynamic environmental context (Klügl, 2016; Luo et al., 2019). CAS is based on the theory of systems science and it can be considered as a "crystallization" of complex system theory proposed by Holland (1992). CAS refers to a network system composed of nonlinear interacting elements which can be composed of multiple sub-systems that depend on and cooperate with each other (Shi et al., 2021). In CAS theory, the complex systems (e.g. individuals or populations) can adapt their behavior and structures according to their environment (Haken & Portugali, 2015). Consequently, a macro level phenomenon emerges from local interactions on a micro-level. Gilbert & Troitzsch (2005) expound on simulation's logic as a method, so it is up to the researcher to develop a model based on presumed social processes (prior context study and the actors involved these processes). The model is computationally constructed, executed, and measured. Its execution generates simulated data that can be compared with the data collected in traditional ways to verify if the model generates results similar to the real processes that operate in the social world.

The ABMS's importance relays on their capacity to support decision-making in practical settings. According to Rai & Henry (2016), once theoretical factors are detailed and models are calibrated and validated, ABMS becomes suitable for analyzing scenarios that reflect policies and planning. When validation is adequate, the models can be used to make predictions about the individuals' behavior considering spatial and temporal aspects (i.e., given location and over time). Thus, one can estimate the potential effects of policies (including costs and benefits for various groups of stakeholders) before any action has been taken. In resume, ABMS involves a set of agents, relationships, and a framework to simulate behaviors and interactions. It models complex systems through a bottom-up approach starting from individual agents (Moon, 2017).

ABMS has three main elements: the environment, the agent, and the interactions. The virtual world is where the agents live during the simulation, so the interactions occur. When spatially explicit, it can provide information on spatial location or more detailed information through geographic information systems. The setting could represent other features but geographic information (Gilbert, 2008). An agent is a discrete virtual entity with established goals and behaviors, acts autonomously, and can modify its behavior by adapting at any time. Agents can be dynamic (e.g., people groups, organizations, animals), moving in free space, within a delimited context such as a geographical information system (GIS), or static. Agents have specific states and sets of functional attributes, properties, or rules (Abar et al., 2017). They can also be programmed to choose behavioral options to fulfill their needs (Gilbert & Troitzsch, 2005). The agent seeks the maximum utility value considering their specific circumstances, attitudes, and values. Agents are programmed to respond individually to external stimuli, such as policy interventions. The interactions are a set of languages and exchange protocols between agents and between agents and the environment. As reported by Banos et al. (2015), interactions can be low level (e.g., physics models) or high level (e.g., language acts). Agents can communicate by sending messages to each other or through perception and action mechanisms, where agents can perceive a change in others or the environment and then act.

There are currently around 85 ABMS toolkits, which differ in application, ease of use, and scalability levels (see Abar et al., 2017). Here, it was sought to choose a platform that considered the strategic level for application outside the academic field, i.e., it allows future uses by public policy formulators and was not limited to only operational level aspects (e.g., licensing, software manipulation). From Abar et al. (2017), we adopted the GAMA (Geographic Information System - GIS Agent-based Modeling Architecture) platform. It is a free open-source software offering greater reliability, interoperability, and extensive support sources (Tailandier et al., 2018). GAMA runs on most operating systems (Mac OS X, Windows, and Linux) using the GAML language. It has extensible libraries for agents, architecture designing, and statistical and spatial analysis functions. Also, it has a good equation regarding ease in model development (Medium-scale modeling strength) versus the model's scalability level (large-scale simulation models' scalability level). The application domains are 2D/3D modeling and development platform for building spatially explicit agent-based simulations in land-use and land planning, social, institutional, economic, or biophysical systems through reactive behavioral agents (Abar et al., 2017).

3.2.1 Standard scenario for waste prevention

As WP behavior is a set of activities, it is necessary to restrict and determine what will be modeled. One of the GEB application's primary purposes was to be the tool for selecting the WP activities to be implemented in ABMS. The GEB allowed ordering the 54 pro-environmental activities according to their difficulty level according to a set of people. The standard scenario represents the status quo of those previously selected behaviors (i.e., how the behavior has been conducted). Based on the results of Ribeiro-Rodrigues et al. (2021) in Campinas, Brazil, behaviors related to plastic and reusable bags were chosen as they are the most wide-ranging among the analyzed WP behaviors (high and medium difficulty levels). The model seeks to reproduce with simplicity (but with plausibility) the entire set of elements (i.e., actions and attributes) that involve the plastic bags (PB) and reusable bags (RB) use in a limited context (e.g., the situations in which something exists at a specific time, the influences and events related to the need to pack and transport purchases).

The model aims to study SNs related to the bag behaviors to transport purchases when shopping in the supermarket while observing emerging behaviors. Initially, most agents do not necessarily conduct the activity pro-environmentally. This means that the WP behavior was modeled according to the legal and social norms in Campinas city and the frequent behaviors observed in the population. After studying the local context, a third action form was introduced. Many consumers eventually use cardboard boxes (CB) to take their purchases home. This happens when the supermarket places them free of charge in front of the checkouts (they are CBs used to transport the products sold in the store). Most people believe that the CB use is preferable from an environmental and social point of view, as it avoids plastic use and because of the recycling scenario in Brazil (especially considering the cooperatives of recyclable material). But it is important to note that it does not prevent waste generation. So, the WP action modeled is the RB use. Each householder was considered an independent agent, and different conditions were established, such as the agent's cognition and the characteristics of where it lives (the agent's environment). GIS data forming the background were taken from the Campinas spatial database provided by the prefecture (DIDC, n.d.). Any previous treatments before importing into GAMA used the QGIS® software v.3.4.11 – Madeira.

Agents can interact with each other to establish social exchanges (e.g., SNs) and react individually to external stimuli (e.g., policy interventions, contextual changes). Overall, the model is composed of 3 categories of agents: (1) resident – it is a person who lives in a geographically delimited area (i.e., Barão Geraldo district, in Campinas city, Brazil); (2) household - it is an entity/agent that has a family (e.g., family size, income) and purchases characteristics (e.g., RB, PB, CB amounts, supplies stock/pantry dynamics) which were defined as relevant to model the resident behavior; (3) market – it is the place where the resident purchase items and which has characteristics such as opening hours and reusable bag price, the regulatory agent – it is not an explicit agent, i.e., it appears indirectly, through the sanctions, laws, regulations. 15,340 resident agents were simulated, considering the same number of households in the Barão Geraldo district. The proportionality of the agents' characteristics considered accurate data provided by the prefecture and census (e.g., spatial distribution, lots, income, family size) and previously collected (e.g., environmental motivation, Ribeiro-Rodrigues et al. 2021). Household supplies stock dynamics (pantry) are defined by equations that account for basic nutritional needs, purchase frequency, number of residents, and randomness. The resident agent can choose different transportation modes (e.g., walking/cycling, car, or bus), implying different maximum shopping capacities, shopping frequency, and markets available to shop. Dynamics related to the RBs forgetting were also modeled since the agent may own but not always have an RB available at the time of purchase.

The behavioral theory of the "resident" agent is based on the GEB (Kaiser & Wilson, 2004), mathematically described by the Rasch Model (see Bond & Fox, 2007), and previously analyzed by Ribeiro-Rodrigues et al. (2021) from a sample of 888 residents of Campinas. The calculated GEB values are a basis for constructing the environmental motivation variable (EM) and are intrinsically linked to the agent's behavioral options. Hence, more environmentally motivated individuals tend to choose more environmentally friendly alternatives (i.e., PB avoidance: pick RB or CB). However, EM is not the only influence because the context (e.g., SNs, income, number of RBs at home, forgetting its reusable bags) can also influence the choice between RB, PB, and CB.

The agent's cognition and decision-making processes were designed according to the Belief-Desire-Intention (BDI) architecture paradigm. BEN (Behavior with Emotions and Norms) is one of BDI's proposed updates, which provides social agents with cognition, emotions, emotional contagion, personality, social relations, and norms (see Bourgais, 2018). In this study, cognitive and normative bases allow the SNs implementation. The descriptive SN is considered; thereby, the behavior of the other consumers in the market can exert a negative influence (e.g., most nearby consumers use PB) or a positive one (e.g., most nearby consumers use RB) final choice of how to load purchases. Residents with lower EM are more susceptible to the influence of SNs.

The entire process of building and validating the experiments used the OFAT - one-factor-at-a-time technique (e.g., Ahanchian & Biona, 2017; Azar & Menassa, 2014; Delcea et al., 2019; Zarei & Maghrebi, 2020; Zhang et al., 2014) for model calibration. The OFAT changes the parameters individually within ranges, followed by the observation results. Nevertheless, it should be noted that future scenarios proposition (i.e., intervention scenarios) are a type of sensitivity analysis since all input data will remain the same and only a few changes can be introduced and compared to the standard scenario.

3.3 Data collection procedures

A pre-condition for a useful ABMS in public polices planning is a data collection that allows policies to bridge between the real world and the world. This means an input and output data collection protocol for the model must be established. For the input data, sociodemographic and contextual data were collected to bring the simulated population as close to reality as possible. Questionnaires generally provide a good collection of this information for larger groups only if adequately planned. Defining ABMS objectives and assumptions is critical to determining which questions to ask the sample. A non-representative pilot survey was conducted with a sample of 20 respondents to adjust possible problems of interpretation that could lead from short answers inconsistency to the total infeasibility of the respondent's answers.

Since the number of agents in a simulation can be as large as the modeler/stakeholder defines, it is possible for an entire region (such as an entire city) to be simulated. Agents need to be replicated (sample to population), and the replication quality depends substantially on the collected data. Modelers should be careful about the questionnaire's dissemination strategies so that the sample is as representative as possible (qualitatively and quantitatively). Here, the questionnaire was widely disseminated (April 2019 – June 2020) through printed posters in educational institutions, bus stops, and shops; via social networks (Facebook®, Instagram®, and Whatsapp®), e-mails, website (www.campinasrepense.wordpress.br), and also verbal communication with passers-by on some streets in the city center during one week. This strategy resulted in a representative sample of Campinas with 888 responses with a 95% confidence level and a margin of error of 3.29% (see Ribeiro-Rodrigues et al., 2021). Other data such as gender, age, marital status, neighborhood, level of education, type of housing, participation in selective recyclable collection, source of information on environmental issues, diet (vegetarianism, veganism, and omnivores), professional participation/ volunteer in environmental organizations and perception of environmental action in the surroundings were also collected. Still, they were not directly used in the ABM construction. These data provided subsidies for three ABMS processes: (a) determination of the WP behavior to be simulated; (b) sociodemographic and contextual data collection used to establish attributes and parameters calibrated for the computational model, and (c) GEB application, which allowed the environmental motivation calculation, a fundamental attribute within the agent's decision-making process mechanism.

Local context data such as georeferenced data, customs/habits, and contextual restrictions were also collected. GIS data are preferable to more simplified topologies, as they allow the real scale (befitting or as reliable as possible) processes to be modeled. Streets, residential lots, and supermarkets layers were used so that the travel distances are those that the consumer travels considering the location and market size (small, medium, large vs. RBs price). Other contextual data such as customs/habits (CB usage, average consumption to determine pantry dynamics) and contextual constraints (e.g., bag size, maximum walking distance, maximum load) are also inputs to the model.

The simulation output data will allow quantifying WP through the agent's preference for RB, PB, and CB over time. Each purchase made by the resident is stored throughout the one-year simulation. Purchase attributes include the date, chosen market (and RB price at this establishment), transportation type to go to the selected market, pantry data (pantry level when deciding to go shopping and the actual amount of purchases made), RBs available at home, available cash to purchase RBs; and the most relevant: RBs, PBs and CBs amount used. The decision-making flow and booleans related to the RBs forgetting and the influence exerted or not by the SN are also stored. In addition to the individual analysis of the agents, it is fundamental to observe the collective behavior. Average global values (e.g., RB, PB, and CB; consumers who forget their RBs) are also observed and will be analyzed statistically in the future. The crossing of the outputs mentioned above and observing the agents' timeline sets ABMS apart from traditional measures.

4. RESULTS AND DISCUSSION

Although the ABMS is still under development, the first simulation attempt generated results that made it possible to compare the RB, PB, and CB global use proportion for over a year. Figure 1 shows the 15,340 agents distributed according to their EM level. In agreement with the GEB, the agent population also follows a normal distribution, with moderately environmentally motivated agents being the majority. Figure 2 shows the cumulative proportion of events (i.e., purchases) where agents used RB, PB, and CB divided by EM bands. These bands come from the action's difficulty level brought by the GEB. Note that agents with EM≥1.67 never use PB, as it is the difficulty value of the "PB avoidance" action measured in Ribeiro-Rodrigues et al. (2021). Agents with EM<0.89 may be subject to the SN influence within their context.

Figure 3 shows a crosstab performed to compare EM with family monthly income. Each point represents one purchase. At large, the preliminary results indicate that the greater the EM, the greater the tendency of the agent to use RB or CB. There is an initial preference for RB for highly environmentally motivated agents in the first months, later opting more for CB use. Individuals with extremely low motivation tend to opt for PB; however, they increased their RB and CB, possibly influenced by the SN. Individuals with medium motivation gradually increase their option for RB in the first months, starting to use CB more frequently later. When considering income and EM, we note that: (a) residents with low EM: the PB use is always much higher than CB and RB, and PB use is higher for higher incomes. However, the higher the per capita income, the greater the tendency to use PB; (b) residents with average EM: income is not the decisive factor, we can see an increase in the RB and CB use, but there was no such drastic decrease in PB use, which indicates the mixed-use; (c) residents with high EM: mixed-use of RB and CB is well accepted by lower-income residents. As income increases, so does RB usage. However, the higher income range has a higher initial RB use and starts to be surpassed by CB use. Statistical analysis of an agent's individual trajectories is expected to try to identify the leading causes of the above observations.

The main element of the results' analysis is the resident agent's behavior change. When experiments are executed with real people, they usually involve two stages: baseline and follow-up. The comparison between them is the change determinant, i.e., if the person did not perform the PEB at the baseline and began performing at the follow-up, there was a positive behavior change. In simulations, the advantage is monitoring the parameter throughout the studied period. The agent's behavioral change depends on the constancy of the performed actions. ABMS allows several comparisons between agents to be made not only from the EM but also from all other sociodemographic data and contextual processes to which the agents are subjected (e.g., SN, RB forgetting, chosen transportation mode,

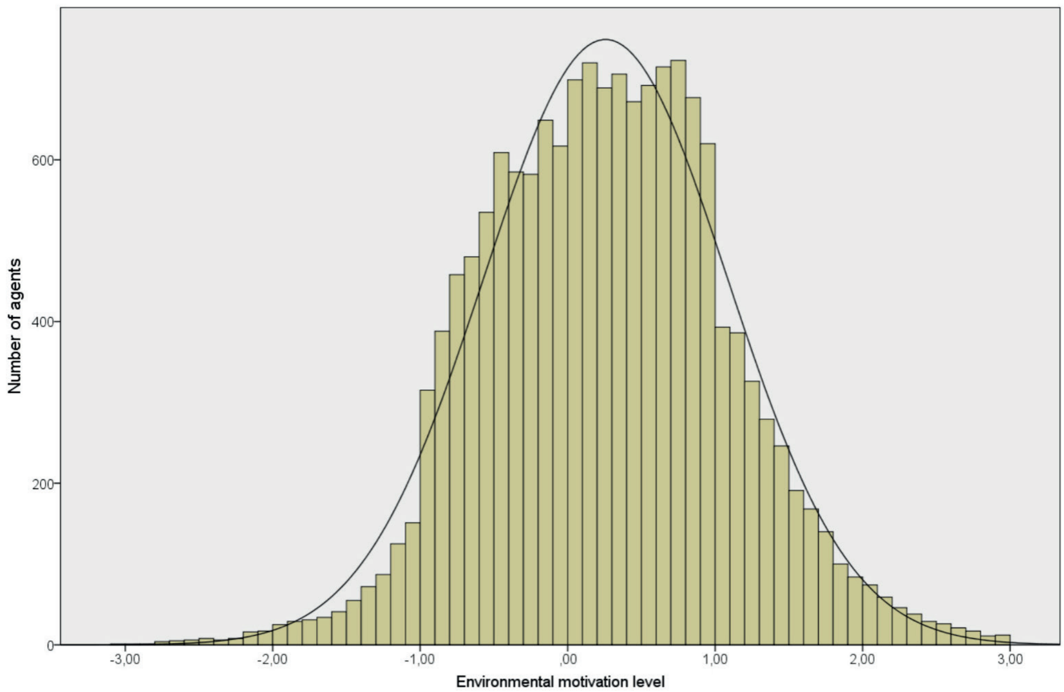

FIGURE 1: Distribution of the 15,340 simulated agents' environmental motivation level.

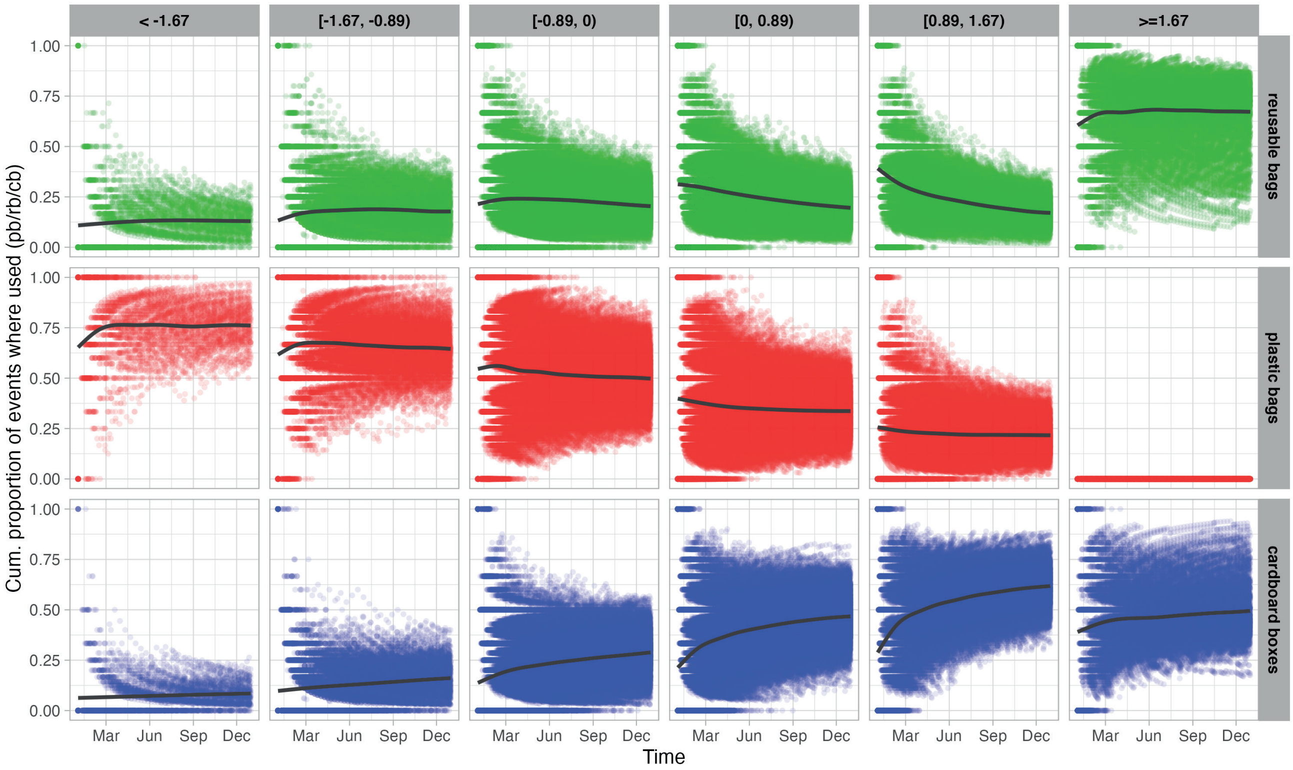

FIGURE 2: Proportion of reusable bags, plastic bags and cardboard boxes used over a year according to the agents' environmental motivation levels bands.

among others). Analyses to identify the SN influence and its relationship with the context are still being processed. Quantifying waste streams (RB, PB, and CB) while comparing agents' EM and SNs are the core when considering the standard scenario and new intervention scenarios that will be performed.

ABMS experiments can help understand behavior as it occurs and can be used as a support tool for the decision-making, as different scenarios can be tested and their consequences measured and analyzed. Figure 4 is a proposed framework to incorporate ABMS experiments in WP programs design and evaluation from an adaptation of ABMS concepts (see Gilbert & Troitzsch, 2005; Heath et al., 2009). The starting point is target identification, i.e., the actors and activities. As WP encompasses a comprehensive set of activities, delimiting the study is essential to avoid falling into generalist assumptions. Then, formulate the problem and define the objectives. System theories, assumptions, and conceptual model building are parts of conceptual validation. The planner can use different techniques such as flowcharts, mind maps, etc. This is the process' most delicate phase, as wrong assumptions lead to the construction of an agent-based model that (although it may be free of code implementation errors) might lead to unrealistic results. In this phase, external/situational context and internal/intrapersonal data are researched. Data concerning the social context, such as culture-related behaviors (traditions, customs, habits) and regulations, are detailed, as well as considerations regarding climate, affluence, and local infrastructure. Similarly, psychological factors and sociodemographics are integrated into the EM and PEBs' perceived difficulty calculation. The joint analysis of the behavioral influences and the GEB is the basis for the conceptual model construction.

The standard WP simulation is run after the translation into a computer model. Among the (numerous) data that can be generated, we highlight the waste flows, (in)adequacy to SNs in force, and behavior conduction. At this stage, one must be careful with validation procedures such as verification; face validation, sensitivity analysis; calibration, and statistical validation (see Klügl, 2016 for an overview). Once validated, intervention scenarios and subsequent simulations will generate results to be compared to the standard scenario. As any implemented variable can be constantly monitored, the efficiency of the proposals can be estimated. In this phase, the stakeholders' evaluations are essential, although it is expected that these will be present since the conceptual validation. WP program planning is built based on the ABMS results and other relevant methodologies to the target. Note that ABMS experiments do not replace the requirement for experiments with people but can be a strong ally for better planning of WP pilot programs. If results are considered satisfactory, proceed to the WP program implementation. Furthermore, these results can be used for external ABMS validation and to improve the model (if deemed relevant).

Finally, we highlight two central points for the ABMS application in WP: (i) EM and the context are significant factors. Hence the policy must be considered at the application levels. Understanding the population, its habits, culture, and any characteristics that may facilitate or hinder

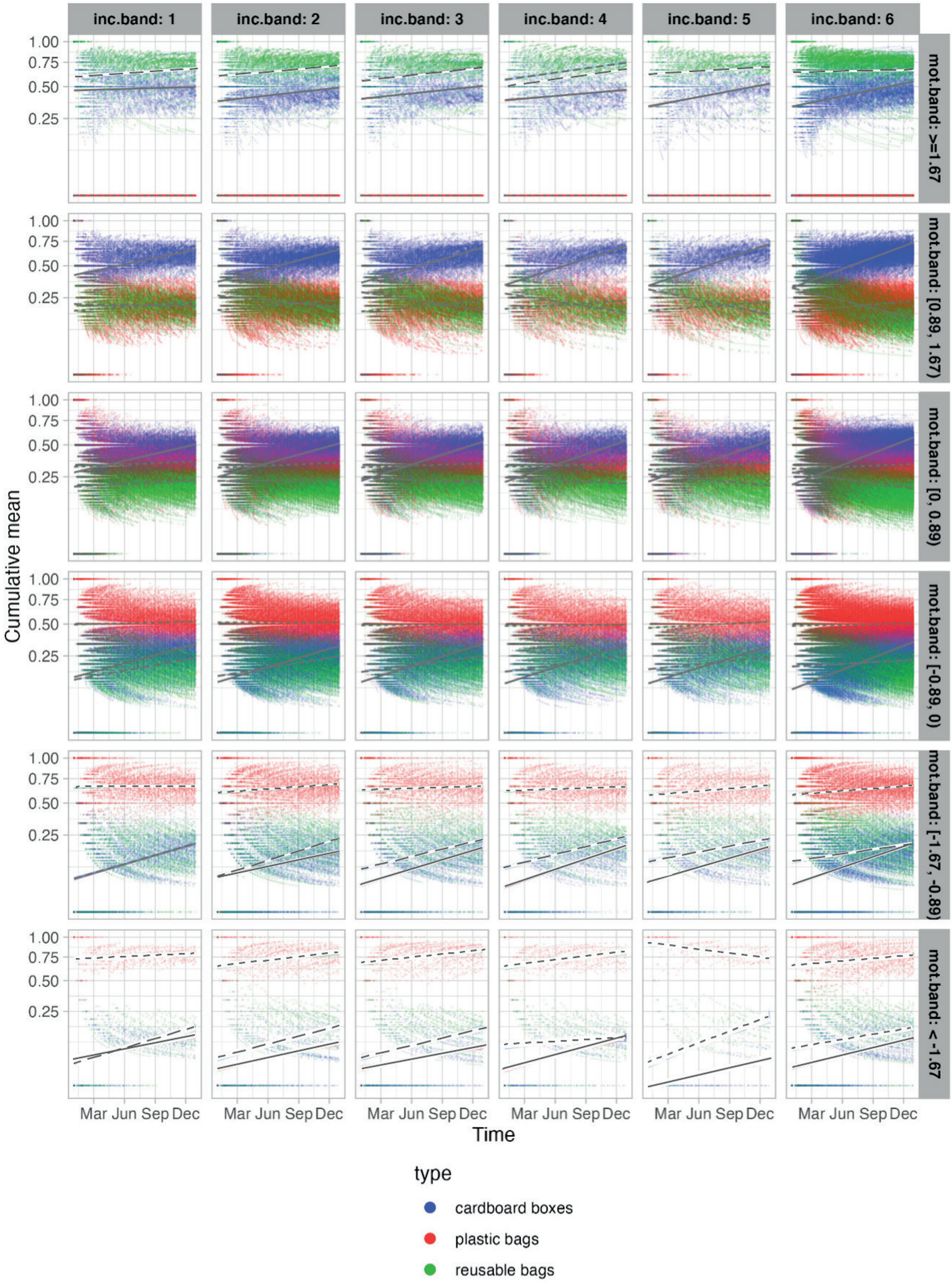

FIGURE 3: Proportion of reusable bags, plastic bags and cardboard boxes used over a year according to the agents' environmental motivation levels and their family income bands.

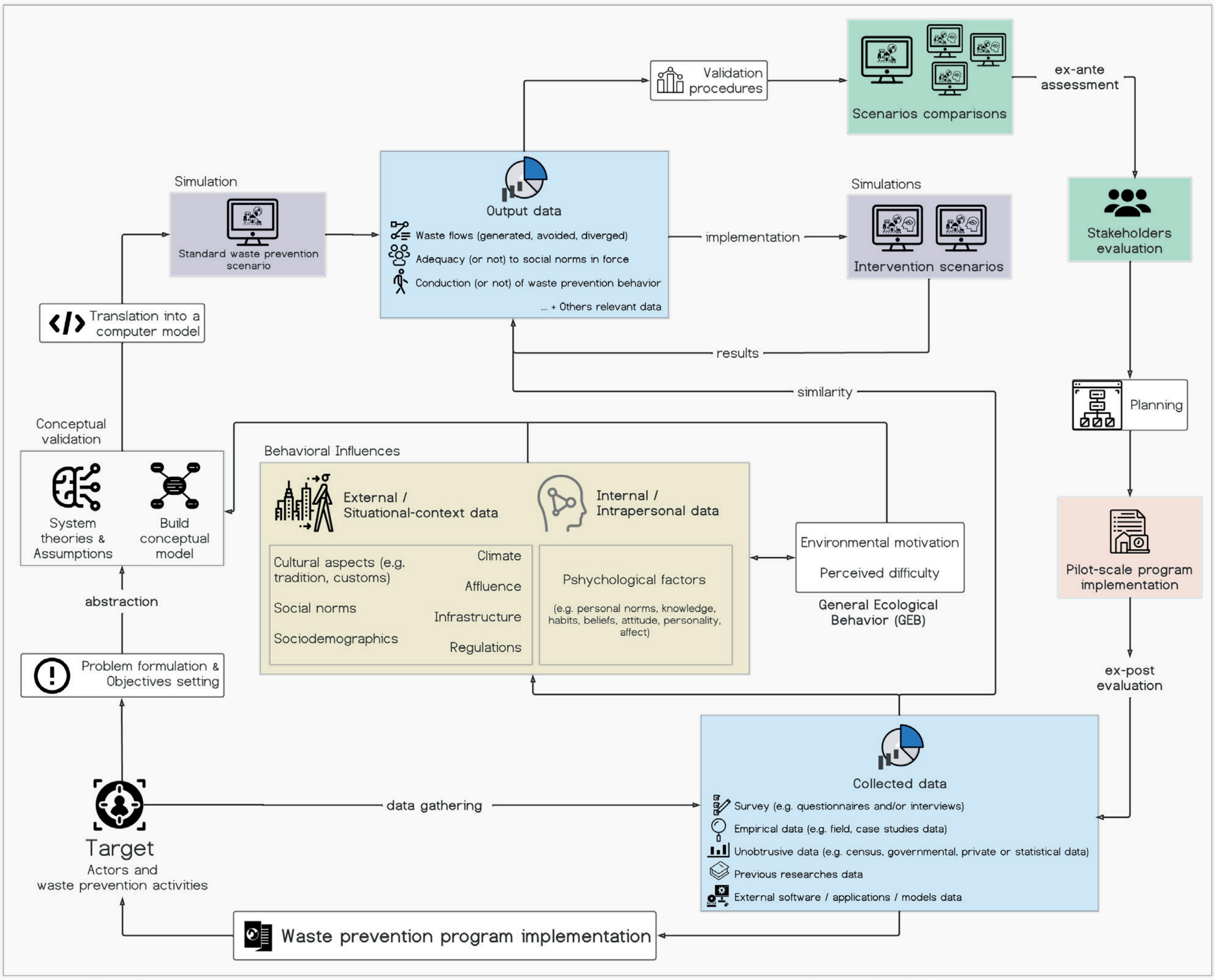

FIGURE 4: Proposed framework to incorporate agent-based modeling and simulation (ABMS) experiments in waste prevention programs design and evaluation.

the behavior in question (infrastructure, climate, affluence, etc.) are fundamental; (ii) WP programs are constituted by a set of actions, so the agent-based models for WP should be built in a modular process. The standard scenario must add modules that are increasingly complex and robust and that can, over time, consider more prevention actions acting together. The key to the success of the WP programs and policies lies in the study of people's behavior, in careful planning with the mixed-use of methodologies to bring a good cost-benefit to formulators and decision-makers in addition to efficient monitoring.

5. CONCLUSIONS

WP policy requires an integrative approach to effectively address economic affordability, regulatory demands, infrastructure implementation, and social aspects. Behavioral intervention policies are conceived from several causes, as different behaviors can conflict with each other and have undesirable consequences if applied in inappropriate situations. This study assumes that various psychological and contextual factors will likely affect any behavioral options people may consider environmentally friendly or harmful. Consequently, their choices' effect can change the WP practice elements. ABMS allows the visualization of a complex system as a set of smaller components that interact among themselves. This flexibility enables its application in future WP interventions based on the effectiveness of each element assessed. Thus, ABMS opens a window of opportunities for WP to be thought and planned from a different perspective, which can be the basis for new public policies that address specific mechanisms by which citizens perform PEBs. WP policies should focus on individuals' motivation level toward a particular changing a specific behavior. It will allow identifying obstacles and benefits of different behavioral change strategies. Nevertheless, further research is still needed to analyze WPB to successfully implement any behavioral policy intervention. The approaches until now have been based mainly on self-reported WPB measures. However, as commonly argued, self-reported behavior does not always reflect actual behavior as respondents may be influenced by social desirability bias. It is important to build an interview instrument with calibrated questions, and the use of online panels may increase the response rate. In this regard, ABMS experiments may be of extreme value since real experiments with large samples are cost-demanding both in time and money. Nonetheless, further studies must focus on developing improve variability in the equations to provide more realistic behavior analysis.Therefore, mixed methodologies, as shown in this study, are an effective alternative to overcome these issues to analyze behavior and support WP policies design without providing superfluous insights.

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