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MODELO HÍBRIDO DE SIMULACIÓN DE SERVICIOS PARA LA IMPLEMENTACIÓN DE ECONOMÍA CIRCULAR

Tesis que para obtener el grado de
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HYBRID SERVICE SIMULATION MODEL FOR CIRCULAR ECONOMY IMPLEMENTATION

Thesis to obtain the degree of
Doctor in Engineering Sciences
Presents: Edna Leodegaria Guevara Rivera

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Resumen

Los principios de la economía circular (EC) se han creado en respuesta al agotamiento de los recursos naturales como un conjunto de pautas para eliminar el modelo lineal de toma-uso-disposición de consumo de productos. Las consecuencias de pasar de una cadena de suministro lineal a una circular son difíciles de visualizar a largo plazo. Por tanto, implementar una herramienta de simulación de economía circular en procesos lineales de pequeñas y medianas empresas (Pymes) es fundamental para probar políticas antes de implementarlas en el mundo real. Este estudio tuvo como objetivo evaluar la lógica dominante de servicio, los servicios ecosistémicos, la dinámica de sistemas y el modelado basado en agentes para diseñar una metodología para un modelo de simulación implementado en dos estudios de caso: un banco de alimentos y una fábrica de confitería. En ambos casos se hicieron visitas y entrevistas con las partes interesadas para evaluar el modelo de simulación durante la fase de desarrollo. El prototipo de indicador de economía circular (CEIP), cuya puntuación fue del 52 % (calificado como un producto ”bueno”), se utilizó como medida de madurez circular de la fábrica de confitería. Los simuladores para cada caso de estudio se ejecutaron en el software Netlogo implementando un análisis escenarios basado en políticas de CE. Se utilizaron diversas variables en estos análisis relacionadas con los costos del proceso y con la cantidad de producto deshechado y reciclado. El principal aporte de este trabajo es la metodología implementada en dos casos de estudio reales en México en el que se diseñó dos modelos de simulación para evaluar estrategias de economía circular en escenarios futuros. Además, en el caso de la fábrica de confitería el simulador permitió a los interesados comprender el funcionamiento del proceso de reciclaje y visualizar todas las variables involucradas en el sistema.

Summary

The circular economy (CE) principles have been created in response to the depletion of natural resources as a set of guidelines to eliminate the linear take-use-disposition model of product consumption. The consequences of moving from a linear supply chain to a circular one are difficult to visualize in the long term. Therefore, in some cases, implementing a circular economy simulation tool in linear processes of small and medium-sized enterprises (SMEs) is essential to test policies before implementing them in the real world. This study aimed to evaluate the dominant service logic, ecosystem services, system dynamics, and agent-based modeling to design a methodology for a simulation model implemented in two life cycle case studies: a food bank and a confectionery factory. In both cases, visits and interviews were made with interested parties to evaluate the simulation model during the development phase. The circular economy indicator prototype (CEIP), whose score was 52% (rated as a ”good” product), was used as the circular maturity measure of the confectionery factory. We used NetLogo software to execute the simulation models for each case study, implementing a scenario analysis based on CE policies. Various variables were used in these analyses related to the process’s costs and the amount of discarded and recycled products. The main contribution of this work is the methodology implemented in two real case studies in Mexico, in which we designed two simulation models to evaluate circular economy strategies in future scenarios. In addition, in the case of the confectionery factory, the simulator allowed interested parties to understand the operation of the recycling process and to visualize all the variables involved in the system.

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Introduction

The current and traditional linear production system is unsustainable due to the traditional one-way (linear) throughput flow of materials and energy between nature and the human economy. In response to this global sustainable issue, a circular economy aims to redefine growth by proposing a cyclical flow of materials and energy [47, 70]. However, the outcome when transitioning from a linear to a circular supply chain system is not readily visible in the long term. For this reason, stakeholders fear investing in sustainable policies, and it is not easy to convince them [70]. Following this premise, there are academic contributions related to developing frameworks and simulators that support stakeholders during the decision-making process when implementing CE strategies within their organization. For example, [98] developed a framework to implement business model innovations related to CE. Likewise, [73] combined agent-based (ABM) and discrete-event simulation (DES) models to develop a tool where the product's design and production were evaluated in different scenarios according to its carbon footprint. Furthermore, DES and system dynamics (SD) theory are used to develop a simulation model that helps identify a correct CE strategy when upgrading, refurbishing, remanufacturing, or recycling the desired product [19]. In this sense, [56] designed a hybrid services simulation model (HSSM), a nine-step methodology for designing a simulation tool to prove several circular policies before implementation. This methodology is based on four perspectives: service–dominant logic [133], ecosystem services [86], agent–based modeling [140], and system dynamics theory [46].

The EMAF (Ellen MacArthur Foundation) classified the flow of materials through the supply chain into two different cycles: biological and technical [33]. EMAF published a report on food systems and their performance in big cities regarding biological cycles. This paper explains why the current feeding systems are no longer sustainable. Several causes can be attributed to the substantial quantities of food waste generated by large cities, including food production processes that are harmful to humans and the long distances between food production sites and cities that increase the food surplus and packing. Addressing these problems, EMAF proposes three objectives that cities can accomplish to catalyze a circular economy for food: (1) source food is grown regeneratively and locally where appropriate, (2) make the most of food, and (3) design and produce healthier food products [32].

Moreover, the food industry may not be producing enough nutritious food for the growing global population, leading to alterations in the overall nutritional needs [128]. Besides, water scarcity, energy use, and land availability need to be addressed to transform a food system into a healthy, nutritious, and environmentally sustainable practice [42, 88, 130].

The methodology proposed in [56] was implemented in a food bank as a case study in [55] regarding the food sector. We concluded from this implementation that food processes are complex and different from regular products even though it behaves like a value chain in this industry. This complexity varies depending on the food production stage, from farming and collection to the final disposal. The confectionery sector is not the exception. The challenges faced by food processes are essential in the connection between nutrition, health, and environmental issues [128]. On this basis, the increasing consumption of confectionery products is pressuring global supply chains. For example, cocoa and palm oil are only grown in certain parts of the world [88], and in 2018, Mexico was the second place in confectionery consumption in Latin America and the sixth place in the world, with an estimated consumption per capita of 4.5 kg per year [31].

Since confectionery products are diverse, the entire supply chain is complex, like raw material supply, specialized equipment acquisition, tasty and nutritious recipe design, product packing, commercialization strategies, and the final disposal of confectionery products. A system-view approach across the confectionery supply chain is required from raw material use to the final disposal, considering a cradle to grave assessment to attend to the transition towards environmental sustainability [88]. There is a significant growth in confectionery waste valorization in the European Union, for example, the production of bioethanol and biogas as bioenergy products and bio-based and biodegradable polymers [58].

Therefore, this study aims to assess service-dominant logic, ecosystem services, system dynamics, and agent-based modeling to design a methodology for a simulation model implemented in a Mexican small and medium-sized enterprise [38], particularly in a confectionery factory with a value chain configuration within its business model. The obtained simulator will allow stakeholders to analyze and decide on the CE strategies to implement in their business process.

This doctoral dissertation is organized as follows:

Chapter 1 presents an overview of the circular economy and the four perspectives used in the proposed methodology design.

Chapter 2 explains how the Methodology was obtained from the four perspectives.

Chapter 3 introduces the problem of the first case study, a food bank located in Jalisco, México.

Chapter 4 develops the agent-based model for the food bank case study.

Chapter 5 explains the implementation of the simulation model in Netlogo software.

Chapter 6 presents some validation proposals for the simulation model obtained.

Chapter 7 explains the context of the second case study, a confectionery factory.

Chapter 8 presents the methodology implementation of the second case study.

Chapter 9 describes the different indicators to measure circular economy implementation in circular supply chains.

Chapter 10 analyzes the proposed scenarios for the confectionery case study.

Chapter 11 presents an update of the recent literature concerning the circular economy and the four perspectives.

Finally, this thesis includes two appendices. Appendix A shows the reference list of the eleven internal research reports presented during the doctoral studies, and Appendix B shows the list of conference and journal papers published.

1. Literature Review

1.1. Circular Economy

Circular economy (CE) is a concept recently used in the European Union as an alternative for producing products and services [70]. Instead of using the traditional industrial scheme "make-use-dispose," CE proposes to imitate nature's way of using the resources and renewing the waste produced by nature's process. Whereas industrial processes commonly use energy from non-renewable resources, nature only uses solar energy to accomplish its processes. The waste generated through these processes is reintegrated into the soil, and when the living beings achieve their end of life, they serve as food to other microorganisms. According to Webster [138], the circular economy rests on five principles:

a) Design out waste: "Waste does not exist when the biological and technical components (or 'materials') of a product are designed to fit within a biological or technical materials cycle, designed for disassembly and re-purposing."

b) Build resilience through diversity: "Diverse systems with many connections and scales are more resilient of external shocks than systems built simply for efficiency – throughput maximization driven to the extreme results in fragility."

c) Work towards using energy from renewable sources: "Systems should ultimately aim to run on renewable energy – enabled by the reduced threshold energy levels required by a restorative, circular economy."

d) Think in systems: "The ability to understand how parts influence one another within a whole, and the relationship of the whole to the parts, is crucial."

e) Think in cascades: "For biological materials, value creation lies in the opportunity to extract additional value from products and materials by cascading them through other applications."

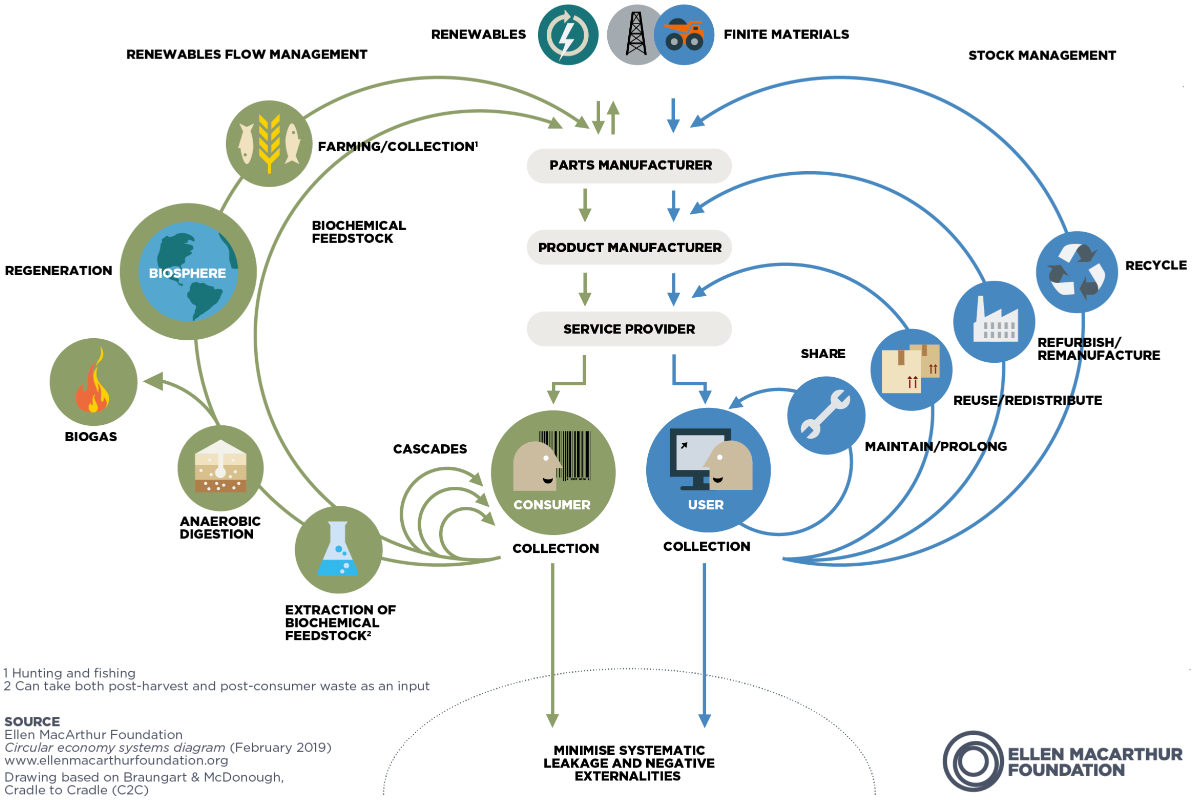
These proposed principles are similar from those three that the Ellen MacArthur Foundation (EMAF) explains [36]:

a) "Preserve and enhance natural capital. By controlling finite stocks and balancing renewable resource flows."

b) "Optimize resource yields. By circulating products, components, and materials at the highest utility at all times in both technical, biological cycles."

c) "Foster system effectiveness. By revealing and designing out negative externalities."

These three principles are better explained in Fig. 1.1, where the circular material flows proposed by CE are shown. Furthermore, Fig. 1 shows the different levels where these principles are applied. Both proposals, those from Webster [138] and EMAF [36], are similar. This chapter, makes several references to these principles to explain their impact.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough,
Cradle to Cradle (C2C)

Figure 1.1: Circular Economy proposal from Ellen MacArthur Foundation (figure taken from[33])

The main objective of the EMAF is to "create evidence-based original research on the benefits of a CE, and how it can contribute to solving global challenges like climate change and biodiversity loss" [33]. The EMAF is formed by European stakeholders who have contributed to implement the concept of CE in some industries. On their web page, it is possible to find some successful study cases [33]. On the other hand, it is necessary to measure some indicators to determine the actual processes' ecologic impact. EMAF proposes the Material Circulating Indicator (MCI) in industrial processes. This indicator is calculated from other measurements of recycling products and refurbishing a specific industrial process [80]. The European Union established a standard that contains the ecological impact of some materials during their fabrication and consumption: "the lifecycle assessment (LCA) is a widely applied methodology in the context of environmental analysis to support cleaner production and greener supply chains" [48]. Besides, [62] proposes several metrics for evaluating CE in several dimensions, like economic, social, environmental, and technical. In future work, these metrics might help evaluate the case study performance according to CE.

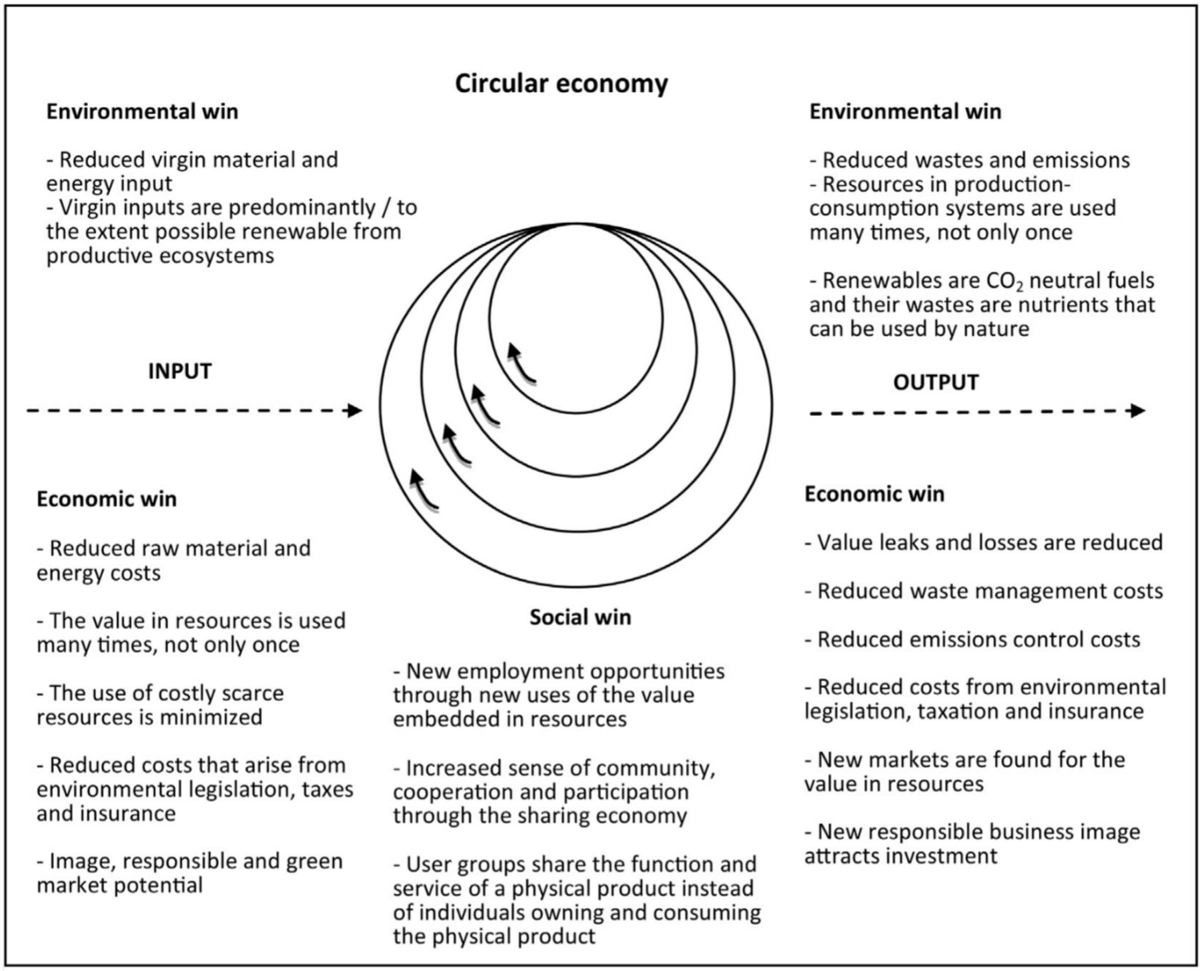


Figure 1.2: Circular economy for sustainable development in three dimensions: economic, environmental, and social. (figure taken from [70])

Beyond these concepts, the implementation of CE on a physical system depends on several factors, and it is necessary to consider the limitations of CE, as Korhonen recently did [70]. In his article, he suggests six limitations according to the impact of the CE implementation in three aspects: environmental, economic, and social (see Fig. 1.2). The limitations summarized in Table 1.1 refer to real problems found when the systems are converted to CE. We focused on the fifth limitation: ”Limits of governance and management” (intra-organizational vs. inter-organizational strategies and management), where the author discusses the willingness of the participants or actors for changing to a circular working mode with the critical question: “How can an individual firm convince its stakeholders, customers, and authorities that its strategy of waste maximization is beneficial for the environment and sustainability?” [70]. In the next sections we will present the importance of a simulation model for explaining and convincing to decision makers for adopting CE in their processes.

1.2. Service-Dominant Logic

We explored another concept concerning service ecosystems. Vargo and Lusch in [133] stated that marketing or economic activity is best understood in terms of service-for-service exchange rather than an exchange in terms of goods-for-goods or goods-for-money. In other words, the source of value in a service ecosystem consists of the activities emanating from specialized knowledge and the abilities that people do for themselves and others (i.e., service, applied abilities), not the goods. Value is co-created by several actors and subsequently delivered (see Fig. 1.3).

Vargo and Lusch [134] identified eleven foundational premises, and five have become axioms (see Table 1.2). These axioms serve as a foundation of Service-Dominant (S-D) logic. Furthermore, these authors have publicized other inputs to this research line. One of their most recent articles exposes future research concerning the S-D logic from different perspectives [135]. In this article, the need to find a meta-theory that explains the use of S-D logic is assessed. Among other perspectives, the system and ecosystem theory is explained from its roots, which are in “natural” science and attributed to Tansley as “the basic unit of nature” [125]. In SDL, the term ecosystem is used in the business environment as “networked constellations of firms, often centered on a central actor” [136].

TABLE 1.1. SIX LIMITS AND CHALLENGES FOR THE CIRCULAR ECONOMY CONCEPT [**KORHONEN**]

Limit	**Description**
Thermodynamic limits	Cyclical systems consume resources and create wastes and emissions
System boundary limits	Spatial: problems are shifted along with the product life cycle. Temporal: Short-term non-renewables use can build long-term renewable infrastructure
Limits posed by the physical scale of the economy	The rebound effect, Jevon's paradox, the boomerang effect
Limits posed by path-dependency, and lock-in	First technologies retain their market position despite in-efficiency
Limits of governance and management	Intra-organizational and intra-sectoral management of inter-organizational and inter-sectoral physical material and energy flows.
Limits of social and cultural definitions	The concept of waste strongly influences its handling, management, and utilization. The concept is culturally and socially constructed, and the concept of waste is always constructed in a particular cultural, social, and temporal context that is dynamic and changing.

Vargo and Lusch propose several aspects for studying their S-D logic impact on the future. One of them is related to dynamic strategy development and implementation. There is a need to implement theories of strategy development "to develop ongoing, dynamic, cooperative relationships that enable access to and integration of resources resulting in new resources" [135]. Emphasizing: (1) considering the ecosystem diversity where the organization is located, and (2) the collaboration between other actors and beating the competition. This issue is summarized in the following question: "How can strategic planning and implementation be co-created with multiple stakeholders, and what is the impact of these co-creation processes on the firm and its stakeholders?" [135]. Another aspect is complexity economics, which studies the economic and social actors under more

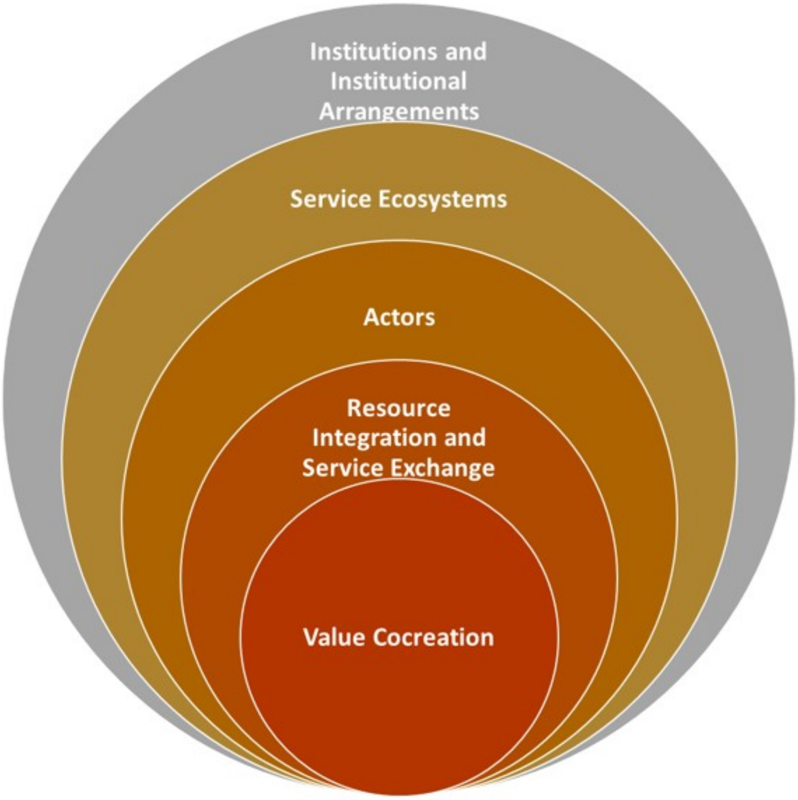


Figure 1.3: The narrative and process of S-D logic [134].

realistic assumptions, such as non-linearity, actor created rules that can become law-like through institutionalization within a network of other actors (also named ecosystem). Complexity economics uses computational economics, which integrates computer science and learning with economics. The computational economic tools can be agent-based modeling, cellular automata, and genetic algorithms, among others, to model and understand complex service ecosystems and the broader economy comprising them. The question proposed by Vargo and Lusch in this sense is: "How can concepts from complexity economics be used to develop a general model of a complex service ecosystem that could then be used to further research on markets and the economy?" [135].

The third theme we consider essential for this research is environmental sustainability. Vargo and Lusch establish that S-D logic, focusing on service ecosystem viability and resiliency, can be used as an informative and robust framework for environmental sustainability. The salient research question concerning this theme is: "How can S-D logic and ecosystem service(s) be used to advance environmental sustainability?" [135]. We have considered these aspects the most critical issues

TABLE 1.2. THE AXIOMS OF SERVICE-DOMINANT LOGIC

Number	Axioms
1	Service is the fundamental basis of exchange
2	Value is co-created by multiple actors, always including the beneficiary
3	All social and economic actors are resource integrators
4	Value is always uniquely phenomenologically determined by the beneficiary
5	Value co-creation is coordinated through actor-generated institutions and institutional arrangements

that the simulator software will impact. However, depending on the research inclination, the results could answer other questions that Vargo and Lusch propose [135]. These questions are summarized in Table 1.3.

1.3. Ecosystem Services

Regarding environmental sustainability, Matthies *et al.* [86] compare the ecosystem services (ES) with the service system. ES refers to the benefits humans obtain from natural ecosystems for their well-being. In a service system or ecosystem, the word ‘service’ refers to the process of doing something beneficial for and in conjunction with some entity [136]. Thus, the ES approach is potentially an extension of service sciences. The creation of value by one service system is a nonlinear interactive and dynamic process (see Fig. 1.3). and results are a potential value that can be utilized, missed, or destroyed by various other actors, processes, and resources that are part of a service systems’ value network (i. e. a forest). From this definition, Matthies indicates the role of the natural ecosystem as a service system providing offerings with potential value and proposes a service-dominant value creation (SVC) framework for ecosystem service offerings in value co-creation within a socio-ecological system. In Fig. 1.4, the natural ecosystems are shown as the

TABLE 1.3. RESEARCH FRONTIERS OF SERVICE-DOMINANT LOGIC

Theme	**Question**
Dynamic strategy development and implementation	How can strategies and implementation be cocreated with multiple stakeholders, and what is the impact of these cocreation processes on the firm and its stakeholders?
Market, economy and complexity economics	How can S-D logic incorporate various schools of economic thought and serve as a foundation for developing a theory of the market and the economy as a precursor to a more general theory of society? How can concepts from complexity economics be used to develop a general model of a complex service ecosystem that could then be used to further research on markets and the economy? Will cognitive assistants/mediators, such as WATSON, as they become part of intelligent service systems, improve or hinder the decision-making of marketing personnel and consumers?
Big data	How can Big Data be used to capture actor-centric behavior and provide the means to calibrate nonlinear, dynamic models of market actors (e.g., suppliers, firms, customers) in a service ecosystem?
Macromarketing: ethics, environmental sustainability, social sustainability, and public policy	Can S-D logic and institutional theory be used to investigate the process and types of institutional innovation that could foster ethical decision-making? How can S-D logic and ecosystem service(s) be used to advance environmental sustainability? How can S-D logic, informed by ecological theory, be used to understand issues of social sustainability? How might public policy be modified to benefit society by encouraging collaboration and cooperation among firms in national and global service ecosystems, and what governance (institutional) safeguards would be necessary?

most significant entity, containing social and economic dimensions. The ES is related to three dimensions, and the value creation cascade operates across all of them.

Matthies *et al.* also define the term "value-in-impact as a spatially and temporally dynamic component of value-in-use and value-in-exchange, which represents the co-creation and co-destruction of potential value (positive and negative impact) attributed by actors to how ecosystem services are managed, facilitated, and utilized by human-based service systems". In other words, the ES can be considered a service system where the actors are living beings by themselves (i. e., a forest or a lake), which provides offerings with a potential value that human beings can create or destroy. Finding a clear explanation of the relationships and behaviors between actors and operand resources in

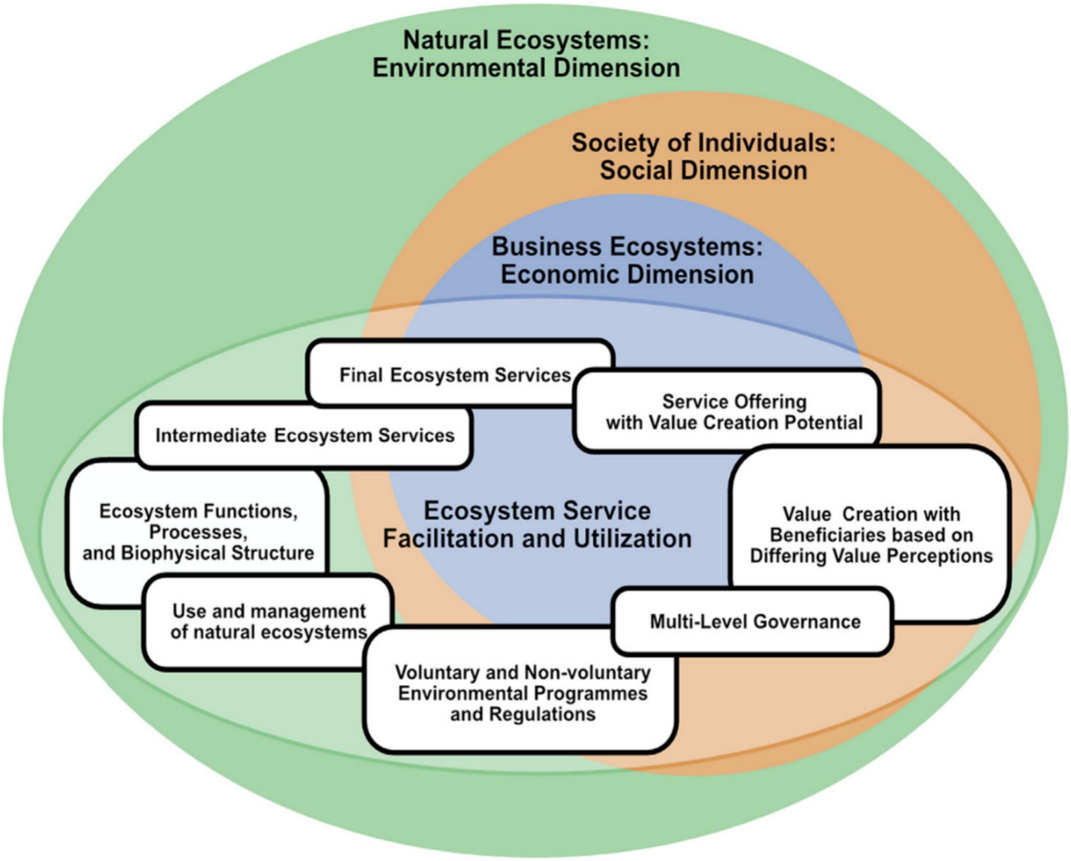


Figure 1.4: A service-dominant value creation (SVC) framework for ecosystem service offerings in value co-creation within the socio-ecological system (figure taken from [86])

an ES is not easy. In recent years, there have been many contributions in computing systems to help understand the behavior of economic and social systems as system dynamics (SD) and agent-based modeling (ABM).

1.4. System Dynamics and Agent-Based Modeling

Nowadays, it is possible to observe different complexity levels everywhere: macrosystems like economic, social, and environmental environments; metasystems like firms, schools, or governments; and micro-level systems like human cells or chemical interactions inside our body. The interactions between the elements or actors of these systems can be direct or indirect. Each actor accomplishes one function and interacts with one or more actors directly and through others indirectly inside the same system or other systems that could be on the same or different level.

These interactions make the system behave in a dynamic form, and this behavior is not perceptible for analysts who try to explain the system's performance. The complexity of the dynamic behavior will also depend on the abstraction level and the feedback loops between system actors, which can be individuals, groups, firms, or nations. In recent years, with the help of computers, it is possible to represent the systems' complexity with certain levels of abstraction and analyze their behavior in the short or long term, for example, System Dynamics (SD) and Agent-Based Modeling (ABM).

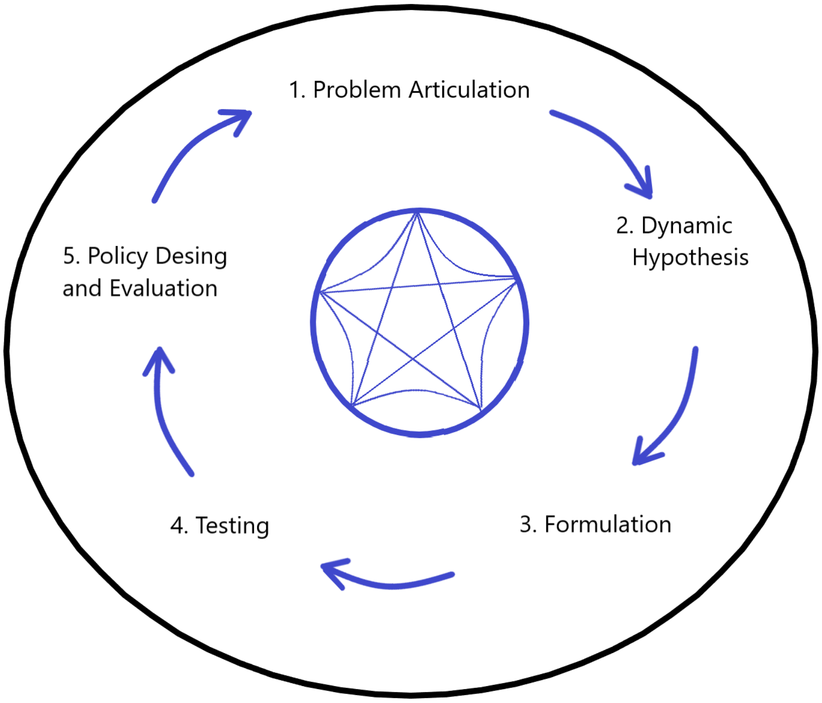


Figure 1.5: The modeling process of System Dynamics (figure taken from [120])

1.4.1 System Dynamics

"System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems, i. e., any dynamic system characterized by interdependence, mutual interaction, information feedback, and circular causality" [123]. In 1961, Jay W. Forrester published the book Industrial Dynamics, where he proposed the notion of this methodology. It is now applied in economics, public policy, environmental studies, defense, theory-building in social science, and its home field: management [46].

The modeling process of System Dynamics (SD) includes five iterative steps: (1) problem articulation, (2) dynamic hypothesis, (3) formulation, (4) testing, and (5) policy formulation and evaluation (see Fig. 1.5). Iteration occurs from any step to any other step (indicated by the interconnections in the center of the diagram). The most crucial step is problem articulation. In this step, the modelers define the reference modes and time horizon. Next, in the second step, they formulate a dynamic hypothesis, map a system structure, and chart a model boundary. In the third step, a simulation model is formulated with equations, parameters, and initial conditions. SD uses the notation of flows and levels proposed by Forrester [46]. The fourth step consists of comparing the simulated behavior of the model to the system's actual behavior. Finally, the policy design includes creating new strategies, structures, and decision rules [120].

1.4.2 Agent-Based Modeling

"Agent-based modeling (ABM) has been used to study socio-technical systems. In ABM, a socio-technical system is modeled by decomposing systems into some heterogeneous entities, called agents, which continuously interact with each other and their surrounding environment. The global behavior of these systems is the result of interaction between agents and environment" [60]. "Agent interactions are defined by a set of decision-making rules to interact with each other and the environment" [122].

Schieritz and Miling [116] compared these approaches, SD and ABM, summarizing their characteristics in Table 1.4. They concluded that "an integrated approach possibly can help decision-makers develop the capacity of thinking of both the forest and the trees." In other words, by integrating both methodologies, it is possible to simulate complex systems on several levels. Simultaneously, these authors have used both methodologies to design and implement hybrid models. They propose different schemes for connecting the SD and ABM blocks depending on abstraction and system hierarchy.

TABLE 1.4. SYSTEM DYNAMICS VS AGENT-BASED MODELING SIMULATION [**SCHIERITZ2003MODELING**]

Property	**System Dynamics**	**Agent-based Modeling**
Basic building block	Feedback loop	Agent
Unit of analysis	Structure	Rules
Level of modeling	Macro	Micro
Perspective	Top-down	Bottom-up
Adaptation	Change of dominant structure	Change of structure
Handling of time	Continuous	Discrete
Mathematical formulation	Integral equations	Logic
Origin of dynamics	Levels	Events

1.5. Conclusions

After analyzing the concepts and principles of a circular economy, we realized that implementing it is not an easy task. It depends on many characteristics, such as the process itself, the willingness of people, institutional policies, and monetary resources, among others. Furthermore, implementing a circular economy in an established process or system requires understanding the system itself, the interactions between the elements, the complex behaviors, and the non-linearities. According to the CE principles, it is necessary to break paradigms to find new forms of maximizing a product's life to preserve the natural ecosystems. One of the principal objectives of service-dominant logic is to find new forms of value-creation to benefit the elements of a system. The next step of this research is to define a new framework that combines CE and S-D logic for establishing a new methodology for the CE implementation in a Mexican system and, later, implement a hybrid simulator based on SD and ABM. This simulator will allow us to represent the system's dynamic behavior and find new policies for adopting CE.

2. Case Study and Methodology Proposal

This chapter explains the first case study, “Jalisco sin Hambre,” and how we built the methodology to design and implement a simulation model from CE strategies. First, we briefly explain the food banks’ background and how they are related to the ITESO University. Next, we analyze related literature to explain how the SDL, ES, SD, and ABM interact in different applications. Then, we describe the nine-step methodology proposed. Finally, we implement the first two methodology steps in the case study.

2.1. Case Study: “Jalisco sin Hambre”

ITESO is a university entrusted to the Jesuits community. Its main objective is the construction of a more fair and human society. Its mission is deployed in three aspects:

a) Form competitive, accessible, and engaged professionals disposed to put their being and job into social service.

b) Expand the knowledge frontiers and culture to the endless searching for truth.

c) Propose and develop viable and pertinent solutions for the transformation of systems and institutions [63].

ITESO has implemented many social projects with a relevant impact on the environment, society, and vulnerable people [94]. The 2030 Agenda for Sustainable Development is determined to end hunger, achieve food security as a matter of priority, and end all forms of malnutrition [27]. Food security is the state where all people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for healthy and active life [41]. According to the Global Food Security Index (GFSI), in 2017, Mexico had a 65.8/100 score occupying 43rd place, below Uruguay, Costa Rica, Brazil, and Argentina [30]. The poverty index of CONEVAL [23] (Consejo Nacional de Evaluación de la Política de Desarrollo Social) considers other indicators: per capita income, educational backwardness, health services access, social security access, household quality, household essential services access, food access lack, and social cohesion grade. The 2016 CONEVAL poverty index indicated 24.6 million persons in poverty in Mexico. Similarly, the food access lack index was 20.1%, and 15.4% for Jalisco.

In Jalisco, to attend to these poverty and food access situations, there are five food banks located in different cities: Guadalajara, Zapotlanejo, Tepatitlán, Juanacatlán, and Atotonilco. They operate independently from each other, collaborating with local farm producers to collect food that might go to waste and deliver it to people in food insecurity. However, the producers' donations are not sufficient, and in terms of management, it is necessary to improve the food collection and delivery. In addition, it is also vital to reduce the number of people in food insecurity and ensure policies to support the food banks' viability.

On the other hand, "Jalisco sin Hambre" (JSH) is a non-profit organization created to formulate a comprehensive and replicable model that will systemize the processes of food collection, storage, conservation, and distribution to make them more efficient. The organization's purpose is to reduce the number of people with food insecurity in Jalisco. The participants in this project are from different organizations in Guadalajara, Mexico: the Jalisco state government, academic institutions like ITESO (Instituto Tecnologico y de Estudios Superiores de Occidente) and Tec de Monterrey, social organizations like ProSociedad and Germinar, technology institutions like CIATEJ (Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco) and CONACyT (Consejo Nacional de Ciencia y Tecnología), and private sector organizations like Amdocs.

JSH has three main strategies related to food insecurity: (i) operation and management improvement, (ii) environment management, and (iii) beneficiaries' development. The first strategy includes a new logistics model, the implementation of a geo-referenced system, an improvement plan for food management and safety, a strategy to encourage donations, a platform to make good use of donations, and the installation of a food processing plant. JSH is a pertinent case for applying our proposed methodology in the sense of the CE perspective because of the opportunity to use the waste, in this case, Food. Food banks are already installed; the simulator will focus on the first strategy, operation and management improvement of the food banks.

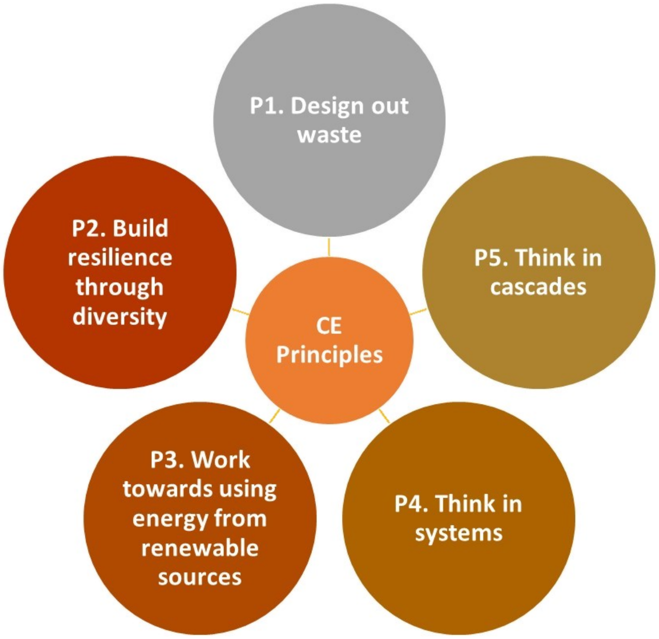


Figure 2.1: Circular economy principles proposed by Webster [138]

2.2. Obtaining the Methodology Proposal

The CE principles proposed by Webster [138] (see Fig. 2.1) are the basis for organizing the concepts. We have assigned Service-Dominant Logic to principles 1 and 5 due to the theory of service innovation and value co-creation concerning how different actors utilize waste during its life. Building resilience through diversity (principle 2) is assessed using ABM since each actor is considered an individual agent within the organization with its characteristics, and the interactions between actors are defined in an agent-based model. The third principle: “work towards using energy from renewable sources,” is related to ecosystem services. In [86] explain the ecosystem as an actor providing services to societies: thus, the non-renewable sources of energy are equivalent to those ecosystem actors.

Finally, regarding the fourth principle, “think in systems,” Webster suggests that organizations or firms are conceived as complex non-linear systems with diverse interactions among their elements. In this sense, system dynamics proposes analyzing systems in search of an explanation for the system’s behavior (see Fig. 2.2).

According to the assignment of the five concepts, we defined six connections to analyze the relevant literature (see Table 2.1).

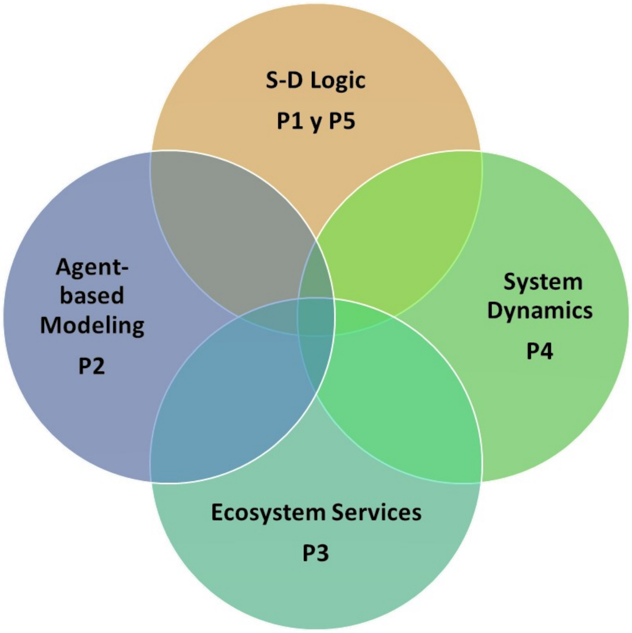


Figure 2.2: Circular economy adoption from its principles assigning the studied methodologies and tools.

Considering the literature review, we summarized that the methodology proposed is based on: (i) CE flows through a value chain (see Fig. 2.3). This configuration proposed by Kalmykova et al. [67] is used for explaining the different strategies implemented in every circular value-chain stage. These authors collected the literature concerning CE and classified the data contained in strategies proposed in the articles. (ii) SDL replaces the concept of a supply chain with a network concept that is referred to as a service ecosystem. A service ecosystem is a structure of coupled value proposing social and economic actors interacting through institutions and technology to coproduce service offerings, exchange service offerings, and co-create value instead of delivering or adding value. In the services ecosystem, there is a strong focus on collaborative processes [76]. (iii) ABM design applied to ES, as [90] implemented for a complex system related to land use. And (iv) The Sterman's SD modeling process, which is iterative, it is necessary to redefine some features related to other steps [120].

The methodology steps are shown in Figure 2.4. The first four stages are considered as previous work, and the following five steps are those proposed by Sterman's (2000) modeling process (see Table 2.2).

In the services ecosystem, there is a strong focus on collaborative processes [76]. (iii) ABM

TABLE 2.1. LITERATURE RELATED TO THE INTERCEPTIONS BETWEEN METHODOLOGIES

Methodologies	**Authors**	**Main Contribution**
S-D Logic and ES	Matthies et al. [86]	Value construction and potential value
S-D Logic and ABM	Lusch and Tay [77], Rajapakse and Terano [106], [127], [105]	ABM in a service industry, ISPAR, NKCS, and customer engagement model
ABM and SD	Schieritz and Milling [116], Cherif and Davidsson [20], Borshchev and Filippov [11], Nava et al. [53], Teose et al. [126], Lektauers et al. [71], Ferrada and Camarinha-Matos [44], Martin and Schlüter [85], Swinerd and MacNaught [122]	Comparison between ABM and DS, ABM and DS for CAS, Examples using ABM and DS, Hybrid models
ABM and ES	Sun and Müller [121], Brady et al. [14], Filatova et al. [45], Bagstad et al. [7]	ABM with BBN and ODM for land-use decisions, ABM with AgroPoliS software, ABM for SES, ABM for ES flows.
ES and SD	Boumans et al. [12], Boumans et al. [13], Arbault et al. [3]	GUMBO model, MIMES framework, LCA on GUMBO model
S-D Logic and SD	Qiu [103]	Dynamic model of a service system

design applied to ES, as [90] implemented for a complex system related to land use. (iv) The Sterman's SD modeling process, which is iterative. It is necessary to redefine some features related to other steps [120]. The methodology steps are shown in Figure 2.4. The first four stages are considered as previous work, and the following five steps are those proposed by Sterman's (2000) modeling process (see Table 2.2).

Each step has its process. From step five to step nine, we propose that the modeling process is iterative in all senses. For example, in building the simulation model in software (step 7), it would be necessary to review a preliminary step if we found inconsistencies. We have chosen a case study

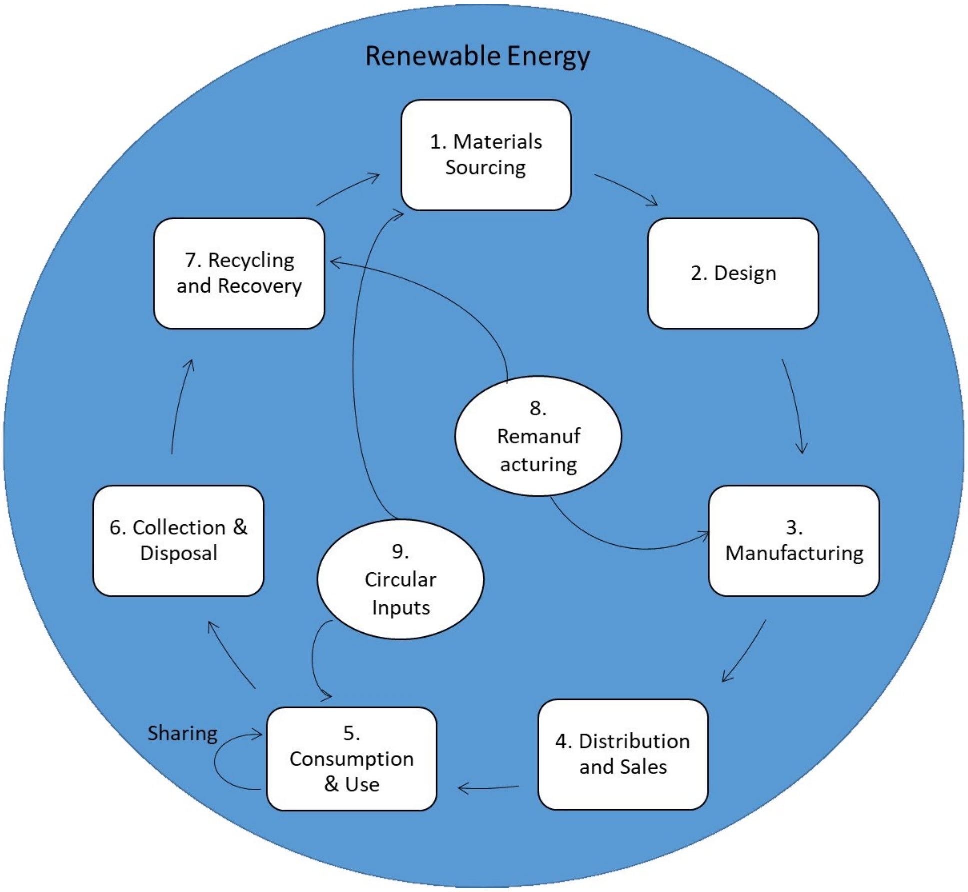


Figure 2.3: Circular economy resource flows through a value chain (taken from [67]).

developed in our community to validate our methodology: “Jalisco Without Hunger.” This project addresses food insecurity in the Guadalajara Metropolitan Area.

2.2.1 Select interacting parts of the value chain

The value chain elements are connected to interact for a value co-creation between them. Lusch [76] claims that S-D logic replaces the concept of a supply chain with a network concept that is referred to as a service ecosystem. A service ecosystem is a structure of coupled value proposing social and economic actors interacting through institutions and technology to co-produce service offerings, exchange service offerings, and co-create value instead of delivering or adding value. In the service ecosystem, there is a strong focus on collaborative processes.

The first step of our methodology is to choose two or more actors in the CE value chain or service ecosystem that interact among themselves. For example, we will choose the seventh element

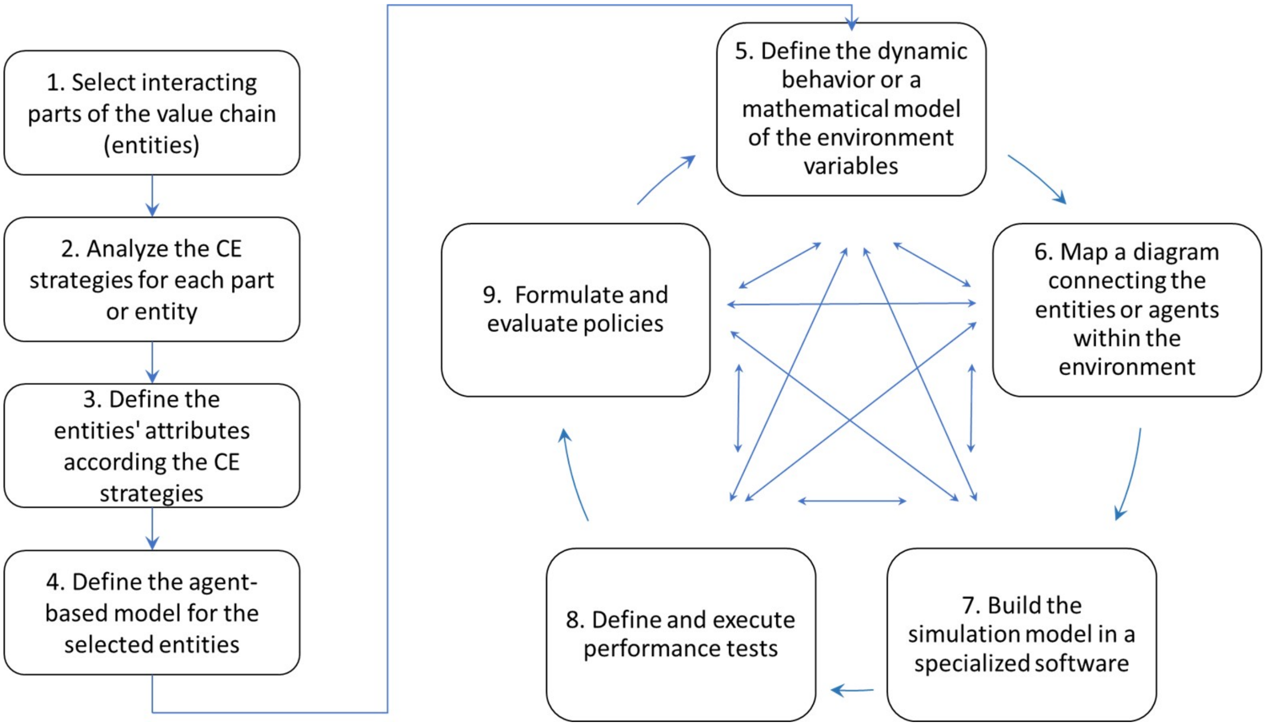


Figure 2.4: Methodology proposal for implementing a hybrid-service simulation model for CE

of the CE value chain: recycling and recovery. According to Fig. 2.3, this entity interacts with collection and disposal, remanufacturing, and materials sourcing. We select two entities: recycling and recovery (R&R) with collection and disposal (C&D). In the JSH case study, the main actors are the donors as the C&D part and the food banks as the R&R part.

2.2.2 Analyze and choose the CE strategies for each part or entity

According to Porter [101], it is required to find the intersection points between the organization and society where the CE strategies have the more significant impact. For the entities selected, R&R and C&D, Kalmikova et al. [67] made a CE strategies summary and found some implementation cases in four strategies related to food waste. R&R's strategies are by-products use, cascading materials, and restoration. For C&D, the strategy found is logistics/infrastructure building.

By-product utilization refers to products from other manufacturing processes, and their corresponding value chains are used as raw materials for manufacturing new products. A concrete case, for instance, is the reuse of grain residues as food for fish. We can find cascaded uses in the food and beverage processing industry for cascading materials in the food sector, and restoration in the

TABLE 2.2. STEPS OF THE METHODOLOGY PROPOSAL TO IMPLEMENT A CE SIMULATION MODEL

Step	Description
1	Select interacting parts of the value chain
2	Analyze the CE strategies for each part or entity
3	Define the entities' attributes according to the CE strategies
4	Define the agent-based model for the selected entities
5	Define the dynamic behavior or a mathematical model of the environment variables
6	Map a diagram connecting the entities or agents with the environment
7	Build the simulation model in a specialized software
8	Define and execute performance tests
9	Formulate and evaluate policies

food waste sector, requires establishing requirements to set up composting and digesting. According to the agricultural food sector, logistics service providers should invest in tools to optimize the information link between retailers and consumers to assess consumer needs more accurately.

One of the main strategies in the JSH case study is the operation and management improvement, which includes: a new logistics model, a georeferenced system implementation, an improvement plan for food management and safety, donations encourage strategy, donations exploitation platform implementation, and food processor plant installation. This strategy can be compared with those presented by Klamikova [67].

2.2.3 Define the entities' attributes according to CE strategies

The attributes entities in the JSH case study can be defined individually for each actor. For producers, the attributes are status score, location, and food characteristics like type, quantity, and expiration date. The food bank provider (FBP) gives the status score producer, and it depends on the previously donated food conditions. This score is helpful for FBP because he will know before accepting the donation and spending economic resources if the food donation is in good condition for assembling food boxes that later will be delivered to needed people.

For food banks, the attributes are location and economic resources availability. There is another entity in the interaction between producers and food banks: the transporter. The transporter must pick up the food at the producer's location and take it to the food bank. The transporter's attributes are travel duration, travel price, and available schedule.

2.2.4 Define the agent-based model for the selected entities

In order to define the agent-based model, it is essential to define the interactions between entities. There are several interactions between the three entities defined before in the donation process: producer, food bank, and transporter. When the producer is aware that some food remains, he registers the donation attributes in a donation platform. The food bank is notified about the possible donation, and the food bank provider (FBP) analyzes the donation attributes, mainly the producer status score. This status score is the priority for accepting or rejecting the donation. If the producer score is good, the FBP asks for the transportation availability sending a request with the producer attributes and FB location. The transporter answers with a notification containing the travel duration, travel price, and schedule. Next, the FBP answers the transporter with the transportation acceptance or rejection and, at the same time, confirms to the producer about the donation acceptance and the transporter schedule.

2.3. Conclusions

The present chapter established the basis for proposing a methodology for the hybrid simulator implementation. We also presented the case study "Jalisco sin Hambre", where the simulator will be implemented. We explained the JSH importance for Guadalajara's metropolitan zone and the magnitude of the food sector in the CE context. Following the proposed methodology, we defined the first four steps at the JSH entities: producers, food banks, transporters, and the interactions between them. In the next chapter, we will describe the visit to the food bank in Tepatitlán, Jalisco, to observe the FB functions and dynamics.

3. “Jalisco sin Hambre”: Tepatitlán Food Bank

In chapter 2, we proposed a methodology for implementing a simulation model to evaluate Circular Economy strategies based on four perspectives Service-Dominant Logic (SDL), Ecosystem Services (ES), System Dynamics (SD), and Agent-Based Modeling (ABM). Also, we introduced the current situation in Mexico regarding food insecurity. We briefly explained the “Jalisco sin Hambre” organism and how the food bank (FB) operates in a general form. In order to collect actual and accurate data, we visited three food banks: Tepatitlán, Guadalajara, and Zapotlanejo. We observed their functioning and interviewed the FB directors to obtain a better understanding. For simplification issues, we chose the Tepatitlán FB (TFB) for implementing the methodology proposed.

Figure 3.1: The fifteen regions attended by the Tepatitlán Food Bank in Jalisco.

3.1. Food Bank Process

The operation of the food banks is as follows: Food Banks' value chain begins with producers that have some food available. They communicate with the food bank manager, indicating a possible donation. The food bank manager sends a truck to pick up the food donation, and the food bank pays the logistic' expenses. When the food donation arrives at the food bank, the food in good condition is separated. Later, it is classified and packed to be delivered to needy people, who pay a minimum. This money is utilized to cover the food bank's operating expenses.

This TFB was established in 2007. It delivers to 4300 families (19,500 people) a food bag that contains a mix of vegetables, fruits, grains, bread, and tortillas, to each family at a low cost every two weeks. The family density is about 4.7 people per family. Besides the families, the TFB attends rehabilitation centers, orphanages, public dining rooms, and the patient's family at the Regional Hospital of Tepatitlán. They deliver the food bags to people from fifteen different regions (see Fig. 3.1) in three different colors: green for vegetables and fruits, orange for semi-processed food, and red for highly-processed food. The price of the red bag is higher than the others. This configuration was chosen for teaching people which food is the healthiest.

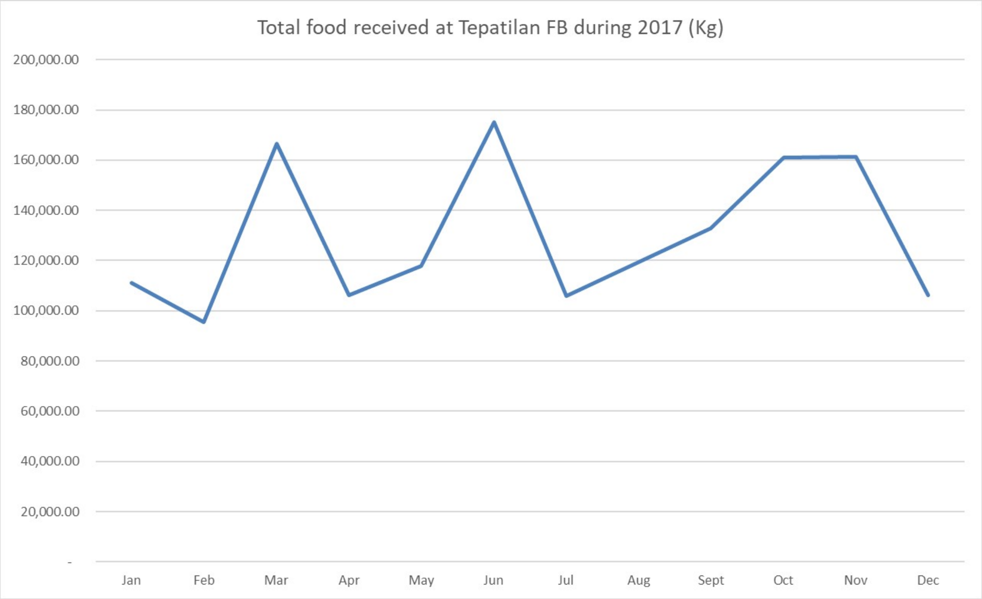


Figure 3.2: Total food received at Tepatilán FB during 2017 (kg).

Besides the food bags, the TFB delivers other services: the mobile kitchen, vegan cooking classes, purifying water for tortilla production, a bakery, and four rehabilitation centers; dental care; psychological care; and home gardens workshops. The TFB process begins with the food bank provider (FBP), who is in charge of contacting the producers for food surplus. If the producer has available food, the FBP will send a truck to pick up the food; the whole food received during 2017 can be seen in Fig. 3.2.

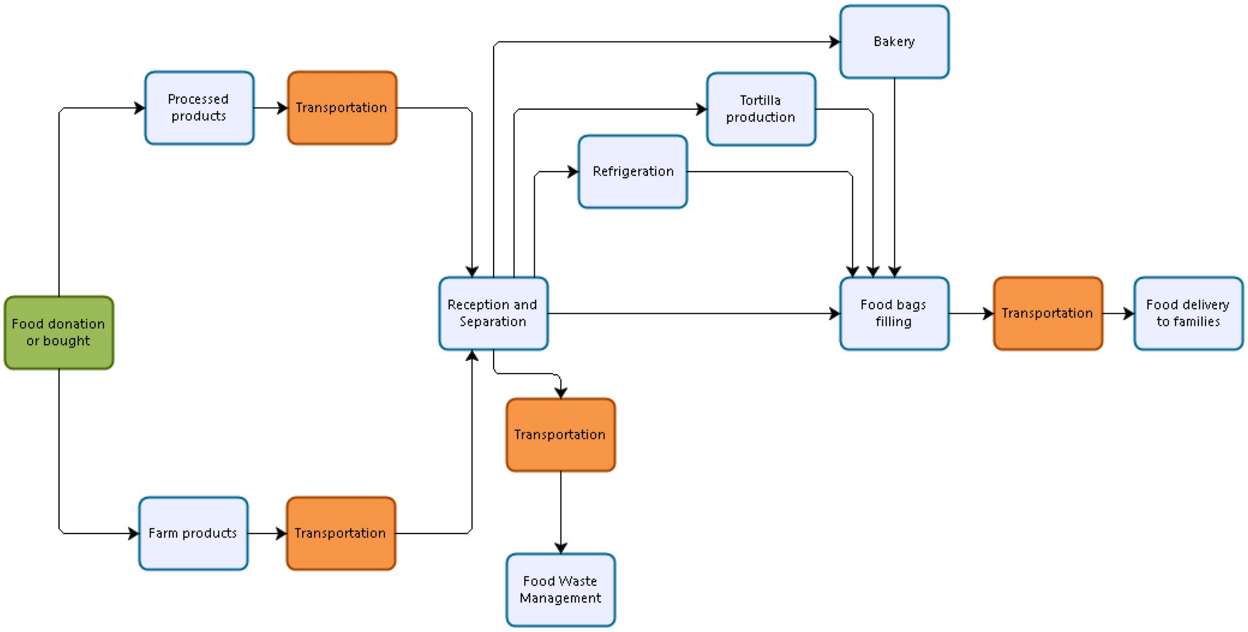


Figure 3.3: Tepatitlán food bank process, from the food donations until the food bag delivery to families.

TFB pays the transportation expenses. When the food arrives, after being unloaded, it is inspected for separating the bad conditions food from the rest in order to form the food bags. When the food bags are completed, they are uploaded to the transportation and delivered to the families previously selected for receiving the help (see Fig. 3.3).

3.2. Methodology Steps

The following paragraphs will describe the modeling process based on the proposed methodology [56] applied to our case study "Jalisco sin Hambre" (JSH).

3.2.1 Choose interacting parts of the value chain (entities)

The circular value chain for biological cycles [82] is shown in Fig. 3.4. The biological processes are different from technical processes because of the product nature. In biological processes, the product has an expiration date to be consumed. As described in the TFB process, we have chosen two entities from the circular value chain in this context are the farmer and the product manufacturer. In the JSH case study are the producer and the FB provider.

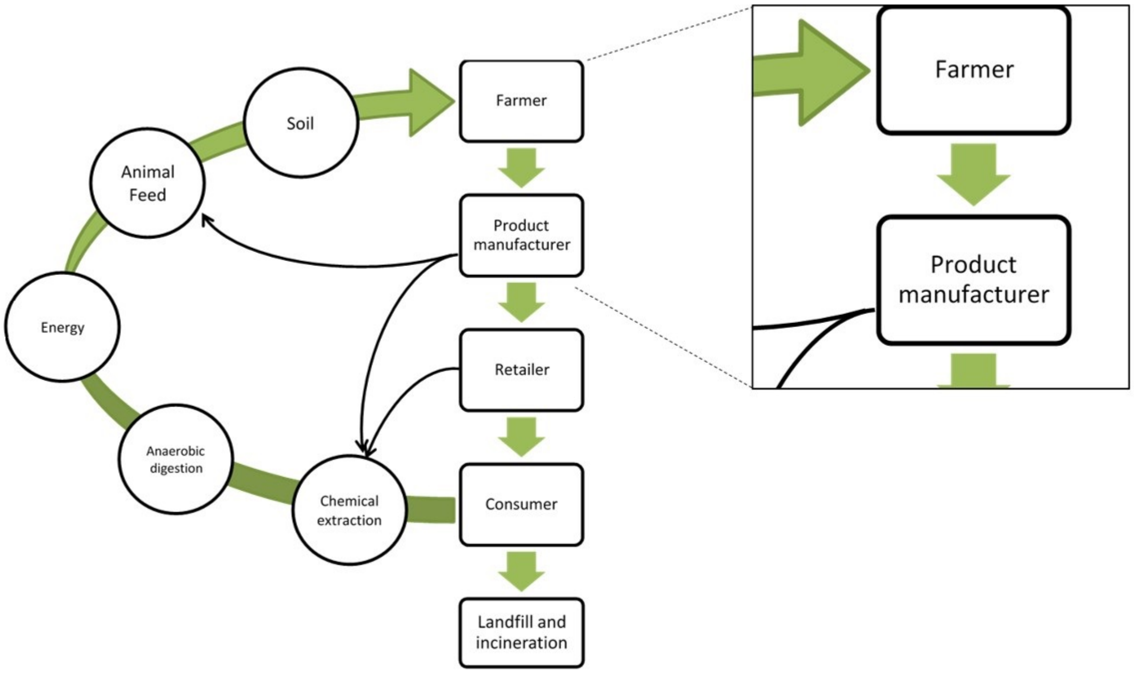


Figure 3.4: Circular value chain for biological cycles (obtained from [82]).

3.2.2 Analyze the CE Strategies for each part or entity

Kalmikova et al. [67] analyzed several circular strategies from different authors and products and services. Recently we found other authors who propose circular strategies for avoiding food waste [95]. These strategies are ordered from those who deserve more attention to the little attention (see Fig. 3.5). The best strategy for food waste reduction must be prevention and avoiding surplus food generation throughout food production and consumption. The next one is to re-use surplus food for human consumption for people affected by food poverty through redistribution networks and food banks. The third strategy is to recycle food waste into animal feed and composting. The fourth strategy is to recover energy: e.g., via anaerobic digestion. Moreover, the last strategy is to dispose of unavoidable waste in engineered landfills with a landfill gas utilization system. The TFB attends the second and third strategies.

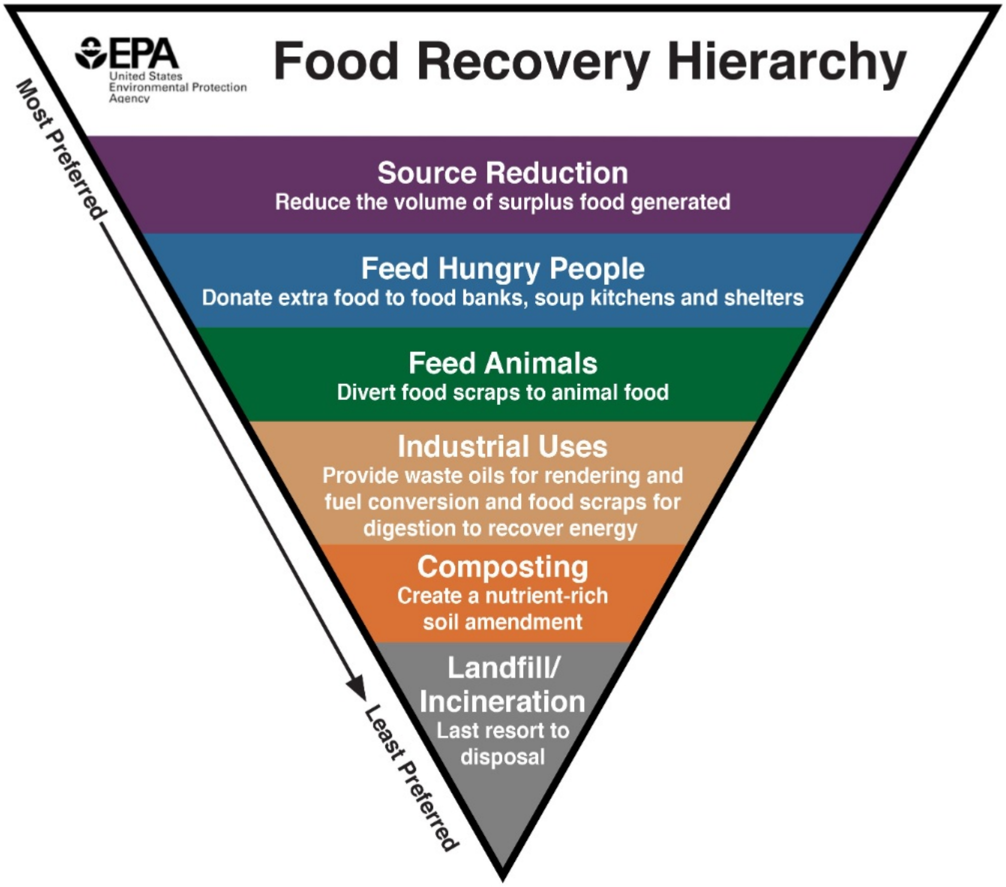


Figure 3.5: Food waste hierarchy strategies (taken from [95]).

From this analysis, the main objective of the hybrid service simulation model (HSSM) is to generate and provide information to policymakers about the advantages of implementing circular economy strategies in the short and long term. The HSSM specific objectives and boundaries are defined from the JSH strategies and the service dominant logic (SDL). The HSSM will be capable to:

a) Visualize the improvement in the TFB logistics and donations to the food banks

b) Quantify the environmental impact of the food waste generated for the FB

c) Verify the policies defined for implementing circular economy strategies in order to improve donations and economic resources

d) Quantify the value generated by the JSH actors in the FB processes.

These boundaries will allow us to define the entities attributes according to the CE strategies for step three.

3.2.3 Define the entities attributes according to the CE strategies

From selecting of the entities described in step 1: producers and food bank provider, it is essential to understand how they interact with each other and the decisions that each one make. The food producers usually calculate the food production according to the market demand, season, and land and weather conditions. If the producer has a food surplus production, they usually give it to the cattle owners for animal consumption; in Tepatitlán, there are also dairy and meat producers.

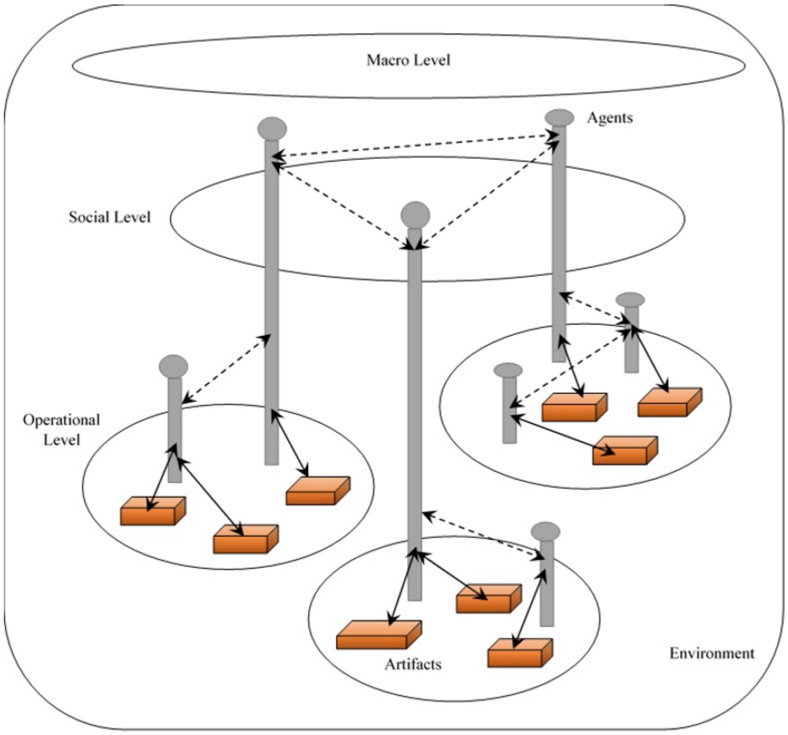


Figure 3.6: Three layers meta-model. (taken from [43]).

The task of the food bank provider is to contact the producer for a possible donation or sale at a lower price for the food surplus production. If the producer decides to donate the food, the food bank provider will send transportation to pick up the food. When the food arrives at the food bank, the operators separate the good-condition food from the bad-condition food; the later is separated as food waste, and a composting organization collects it.

3.2.4 Define the agent based model for the selected entities

To define the agent-based model, we first define the meta-model based on [43] and [26], who define a multi-agent system as having six essential elements (see Fig. 3.6): (a) an Environment, E; (b) a set of objects (artifacts) that exist in E; (c) a set of agents, A; (d) A set of relationship, R, which defines the relationship between objects and agents; (e) A set of operations, O, that agents can use to affect objects; and (f) a set of universal law which determine the reaction of the environment to agent operations.

Furthermore, it is also important to define the hierarchy among different environment levels and distinguish between social agents and non-social agents [60].

TABLE 3.1. IDENTIFICATION OF THE META-MODEL ELEMENTS IN JSH

Meta-Model Element	**Element in JSH**
Environment, E	Emissions to air, food waste deposition, weather conditions, rainforests
A set of artifacts that exist in E	Land-use, cattle
A set of Agents, A	Social level: producer, FB director, social worker, beneficiary; Operational level: food bank providers
A set of relationships, R	Social level: Producer – FB Director – Social worker – Beneficiary; Operational level: Producer – FB Provider – FB Director – Social worker – Beneficiary
A set of operations, O	Food production, Food bank collection and separation, Food bags delivery
A set of universal laws which determine the reaction of the environment to agent operations	Food waste deposition will deplete the land.

According to our case study JSH we have defined the elements of the meta-model in Table 3.1. The entities selected will be agents: producers and FB provider. Also, we identified three other agents who interact with them directly and indirectly: the FB director, the social worker, and the beneficiary.

Figure 3.7: Causal diagram of the natural environment related to food production.

There are three main processes to be modeled at the operational level: food production, FB operations, and food bags delivery. The agents will decide on these three processes.

3.2.5 Define the dynamic behavior of the environment variables

In the previous step, we defined the environmental variables as emissions to air, food waste deposition, weather conditions, and rainforests availability. The only data available is the food waste generated from the TFB during 2017, which in total was 105,123.3 kilograms.

3.2.6 Map a Diagram connecting the entities or agents with the environment

We used a causal diagram to define the relationship between environmental variables and food production (see Fig. 3.7). At the highest level, we find the rain that influences the growth of the forest positively and, at the same time, the land use conditions. The more forest growth increases, the density of the forest will be higher. If the density of the forests grows, the land-use conditions will be better, then the surface of the soil to be sown will be greater. However, if this surface increases, the growth of the forest will decrease. At this point, we find the first balance cycle, B1.

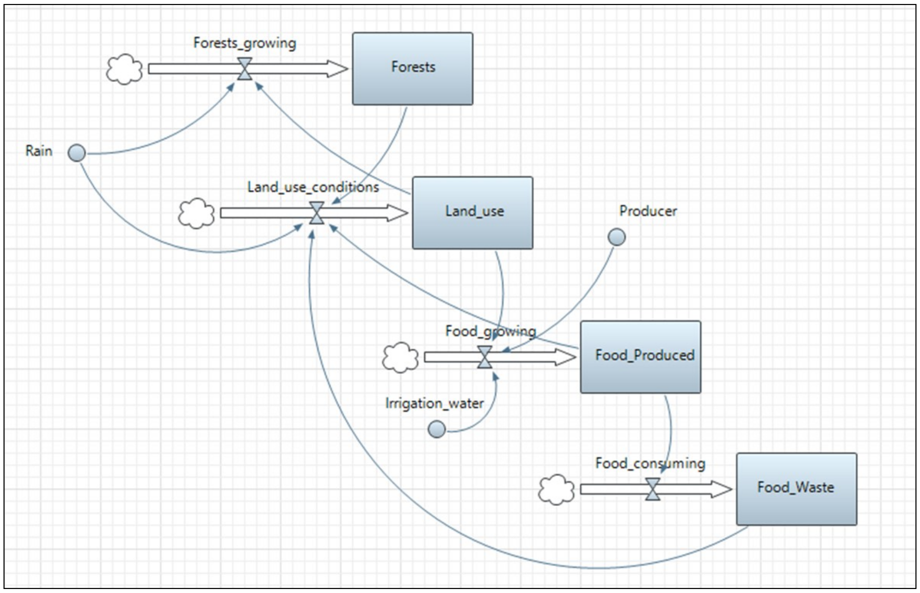


Figure 3.8: Interaction among environment variables and food production, using stocks and flows.

The second balance cycle, B2, is described by the variables related to land-use surface, which will allow that food growth increases, and at the same time, the food produced will increase. Nevertheless, food production will decrease the land-use conditions. The balance cycle B3 begins with the food-produced variable. Food consumption will also increase if this increases, and food waste will grow. The food waste deposed on the soil will decrease the land-use conditions. This causal diagram has been translated into flows and stocks (see Fig. 3.8) as system dynamics methodology suggests. In this representation, we are already considering the agent Producer.

3.2.7 Build the simulation model in a software

The TFB operation has been modeled using system dynamics with stocks and flows (see Fig. 3.9). In this model, we considered two types of food: produced and semi processed food. The produced food comes from the farmers directly, and the semi-processed food is bought for the food banks to complete the food bags for the families. We are already contemplating the decision makers, even if they are not programmed as agents. Also, the food waste stock is missing.

The software used for the model construction was Anylogic [2], the advantage of using this package is that system dynamics and agent-based modeling can be programmed in the same system. In the next step, we will present the first performance tests for this model.

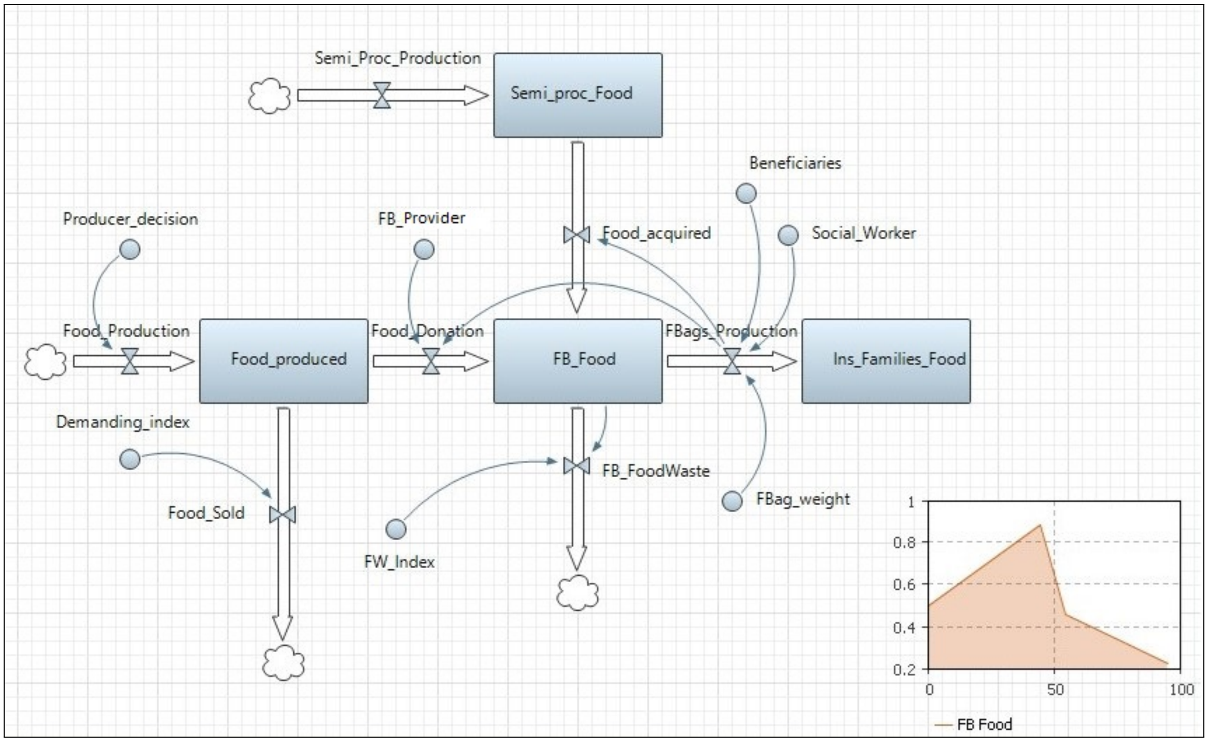


Figure 3.9: Tepatitlán food bank operations using stocks and flows.

3.2.8 Define and execute performance tests

The first performance test for the food bank operations considers the stock's initial values equal to zero, and the values of the variables are defined in Fig. 3.10. The FB food at the beginning is growing until it stabilizes, which means that the food produced is equal to the food consumed by the families. It is also possible to observe that the agents are considered parameters so that agent programming will substitute these parameters. Independently of these performance tests (see chapter 5), we have investigated some CE policies related to food waste deposition.

3.2.9 Formulate and evaluate policies

We studied the Life Cycle Assessment (LCA) approach [8] to evaluate policies. This analysis quantifies the energy used and environmental impact on the air, water, and soil during its life cycle (see Fig. 3.11). From its raw materials until its final utilization, this study requires many data about the chemical process, i.e., the chemical compounds emitted to the air, water or soil.

According to the TFB, the energy used is gas for the bakery and tortilla processes, oil for trans-

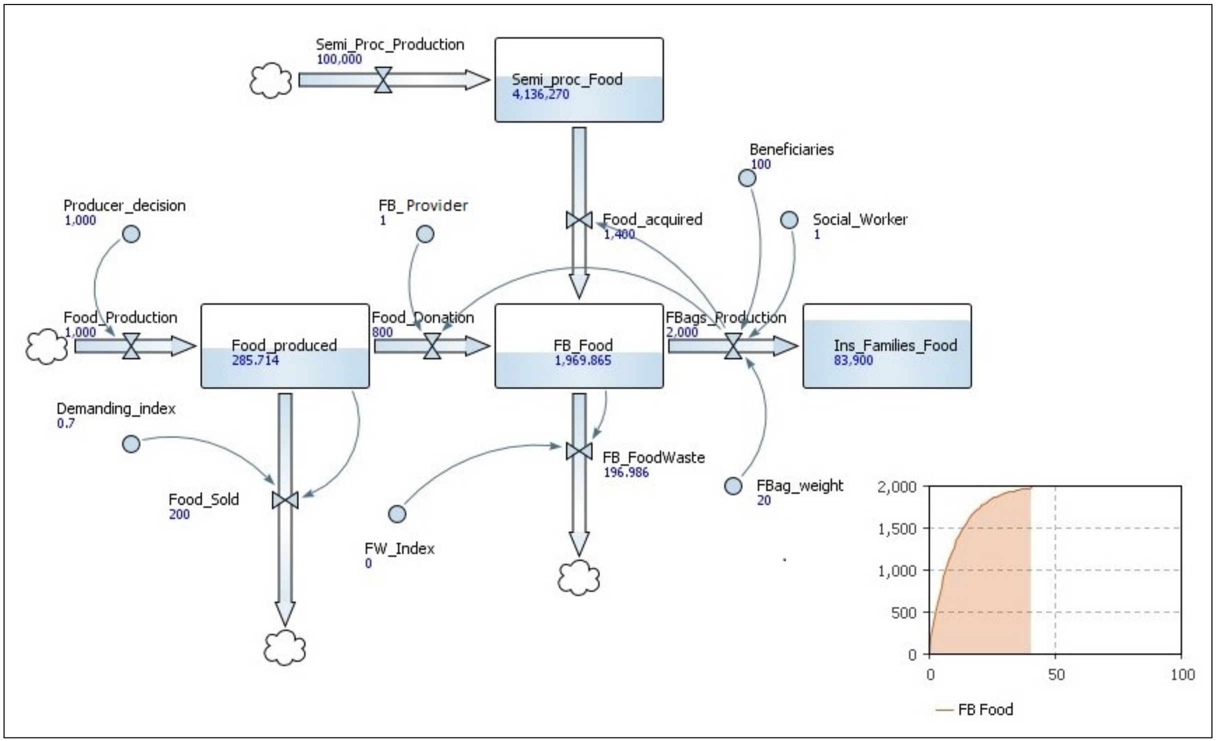


Figure 3.10: Tepatitlán food bank operations using stocks and flows.

portation, and electricity for the food bank operation. Air emissions and food waste are from transportation, freezing, tortilla production, and bakery processes. From this analysis, we realized that the particular emissions measurements for each process do not significantly impact in the food bank analysis, as we are focusing on the food waste treatment of the food bank as a whole. On the other hand, in August 2018, the TFB installed a food processor plant (FPP) to transform into puree and juices the food that will soon expire. This FPP will be added to the daily operation of the food bank. The analysis of this process is pendant as future work. In this part of the policies evaluation, we found some waste management alternatives [65, 84]. These alternatives are:

a) Anaerobic digestion: is a biochemical pathway able to convert almost all biomass sources (including wet materials such as organic wastes and animal manure) to biogas.

b) Composting: is a natural process where microorganisms and fungi decompose organic material into a humus-rich soil product (compost).

c) Incineration: is the controlled combustion of the waste material with a surplus of air. It is used for treating heterogeneous waste such as mixed food and packaging waste.

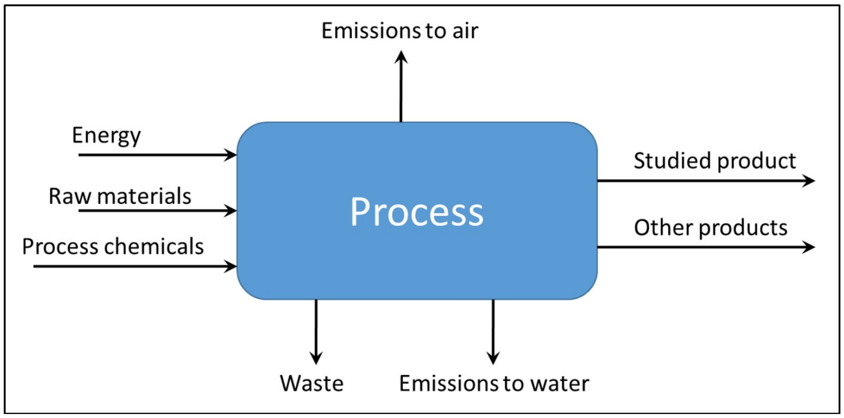


Figure 3.11: Life Cycle Analysis elements for any process (taken from [8]).

d) Landfilling with landfill gas collection: landfill gas generation is the result of anaerobic degradation of organic matter.

e) Dry/wet feeding: is employed for livestock animals, and it is another alternative. Some food requires heat treatment to reduce the risk of foreign animal diseases and eliminate possible harmful pathogens.

f) Pyrolysis and gasification: is a thermochemical process that, by heating in the absence of oxygen, converts organic material to solid, liquid, and gaseous fractions of charcoal, bio-oil, and biogas, respectively.

3.3. Conclusions

In this chapter, we first described the Tepatitlán food bank operation in more detail, given some operational numbers. Then, we defined the hybrid service simulator model (HSSM) and the boundaries or specific objectives that the simulator must meet. Additionally, we presented the first iteration of the proposed methodology. The purpose is to classify collected information regarding the JSH project, specifically the Tepatitlán food bank, and present some modeling assumptions for the simulator construction. As we mentioned in the second chapter, the construction of the simulator is an iterative process; in this work, the first iteration is described for obtaining the simulator.

In the construction of this first iteration, some pending tasks were identified. The first is to define and program the agent-based model for the actors identified in the meta-model. The second task is to add the food waste stock to the food bank operation model. In third place, it is crucial to define the performance tests of the model. Finally, it is important to define and model the food waste policies in the simulation model.

4. Agent-Based Modeling

4.1. Introduction

A system modeled as a collection of autonomous decision-making entities or agents is known as an agent-based modeling system. Each agent individually assesses its situation and makes decisions based on specific rules, and agents may execute various behaviors appropriate for the system they represent [10].

"The emphasis on modeling the heterogeneity of agents across a population and the emergence of self-organization are two distinguishing features of agent-based simulation compared to other simulation techniques such as discrete-event simulation and system dynamics." [79]

Agent-based modeling (ABM) captures emergent phenomena resulting from individual entities' interactions. Application of ABM in environmental issues is diverse [14, 45, 59, 109, 121]. On the other hand, there are studies of ABM implemented in products and services systems [106]. Lusch and Vargo suggest using computing tools to find the explanation of complex service ecosystems [135].

A typical agent-based model has three elements: (i) a set of agents, (ii) their attributes and behaviors: a set of agent relationships and methods of interaction, and (iii) the agents' environment, i.e., agents interaction with their environment in addition to other agents [79].

Furthermore, a computational engine for simulating agent behaviors and interactions is needed to make the model be executed successfully. In other words, to have agents repeatedly execute their behaviors and interactions.

However, simulating a supply chain system using systems dynamics modeling (SDM) takes a continuous-time approach and constructs models with differential equations. SDM involves stocks as a representation of state variables and flows as the rate of the stocks changes over time. Flows get in or out of stocks and can be represented continuously or at discrete time points [120].

This chapter defines the agent-based model for the case study *Jalisco sin hambre*. We utilized the modeling sequence described in the Modeling Agent systems based on Institutional Analysis (MAIA) meta-model proposed by [49]. Furthermore, We have replaced the Physical Structure, which describes the Food behavior using SDM.

4.2. The MAIA Meta-Model in the case study JSH

The MAIA model describes a methodology to construct an agent-based model from any socio–technical system (STS). It is organized into five structures or categories: Collective Structure (agents and their attributes), Constitutional Structure (the social context), Physical Structure (the physical aspects of the system), Operational Structure (the dynamics of the system), and Evaluative Structure (the concepts that are used to validate and measure the outcomes of the system) [49]. The author defines and describes an agent-based model according to these five structures. In the following sub-sections, we explain how each structure functions and the valuable concepts for our case study JSH.

4.2.1 Collective Structure

The Collective Structure (CS) describes the characteristics of the community composed of agents. The agents in the simulation all take an agent type, and they are individual or composite entities that make decisions, act and react in a social system. According to [49], an agent type is described with the subsequent attributes: name, properties, personal values, information, physical assets, possible roles, intrinsic capabilities, and decision-making criteria.

According to the case study JSH, we describe six different agent types: *producer*, *FB provider*, *FB director*, *distributor*, *social worker*, and *beneficiary* (see Table 4.1). We realized that all the agents manage the same physical component: Food.

The *producer*'s properties are Food surplus, Food type, and quantity, and his values are geographical distance and the Status given by the Food bank providers. This agent requires information from the environment and physical structure like market demand, Food production, and Food expiration date.

Its principal decision-making criterion (DMC) is Food Donation (see Table 4.2). There are some conditions to be considered prior to Food donation. First, the Food bank (FB) provider must contact the *producer* to ask him if there is a Food surplus in his Food production. If the Food surplus exists, the *FB provider* must collaborate with the Food transportation according to location,

TABLE 4.1. COLLECTIVE STRUCTURE OF JSH AGENT MODEL

Agent	**Properties**	**Personal values**	**Information**	**Possible role**	**Physical Component**	**Decision-making criterion**
Producer	Food surplus, Food type, Food quantity	Geographical distance, Status	Market demand, Food production, Food expiration date		Food	Food donation
FB provider		Location	Food Bank Stock, Number of benefited families		Food	Contact producers
FB director		Money for buying Food	Food Bank Stock, Number of benefited families		Food	Contact distributors *Distributor*
Food type	Geographical distance, Lower Food price, Status	Market demand, Retailer price, Food expiration date		Food	Food selling price	
Social worker			Number of benefited families	Food deliverer, the Family interviewer	Food	New family addition
Beneficiary	Age, Gender, Community Id, Location, Telephone	Geographical distance, Money for buying Food bags	Delivery dates	New candidate, Active, Inactive	Food	Delivery attendance

transportation time, and capacity. If this decision tree is actual, the *producer* donates the Food. The value of the *FB provider* is the location. He will require information about the number of benefited families and the Food available in the Food bank. The DMC is Contact Producers to obtain Food donations (see Table 4.2). Before contacting the producers, the *FB provider* must review if the Food available in the Food bank is sufficient for covering the Food requirements of the beneficiaries. If there is still missing Food, the *FB provider* will choose a *producer* to contact him and review his Status. If the *producer* Status is greater than 7, he will decide to call him. The *producer* Status is a score given to producers according to the Food delivered in previous donations. The larger the score, the smaller the Food waste.

TABLE 4.2. DECISION-MAKING CRITERION

No.	Rule name	Condition	Consequence
1	Producer Surplus	Food Surplus > 500 kg AND Contact date < Food lifetime	
2	Food transportation	Location is in route = True AND Transportation time < 1 day AND Transportation capacity > Food surplus	Transportation available = True
3	Producer donation	*FB provider* Contact = True AND Food available = True AND Transportation available = True	Food donation = True
4	Producer contact	Food required > Food Goal AND Producer Status ≥ 7	*FB provider* Contact = True
5	*FB director* contact	Food required > Food Goal	Contact Distributor = True
6	Food purchase	Available money ≥ Food Total Price AND Contact Distributor = True	Food purchase decision = True
7	Set retail price	Required Food ≥ 10 tons AND Payment type = cash	Retail price = Food Total Price
8	New family addition	Food access frequency < once a day AND Family study Status < 0.5	Family active = True
9	Transport Food	Vehicle for Food = True AND Cost of vehicle < $20	Food bag transportation = True
10	Delivery attendance	Food bag transportation = True AND Delivery distance < 3 km AND Money for Food bag ≥ $150.00	Go for Food = True

The third agent is the Food bank (FB) director. His value is the money for buying the Food. He will require the same information as the *FB provider*: the number of benefited families and Food available in the Food bank. His DMC is Contact Distributors, for buying the required Food at the lowest prices. First, he will check the Food needed for completing the Food requirement. Then he will contact the *distributor* and will ask for a Food quotation. Then the FBD will revise if there is available money for buying Food. If there is enough money, he will decide to buy the required Food.

The *distributor* is the fourth agent, and his properties are the Food type available, Food quantity, and the Food expiration date. His values are geographical distance, the lower Food price, and the

Status given by the Food bank. The information that the *distributor* requires is the market demand and retailer price. Moreover, this agent's decision is related to the Food selling price. There are a few pre-conditions that the *distributor* has to consider before setting the retail price: the quantity of Food required and the payment type. The first one must be greater than 10 tons and the second if the payment is in cash. If both conditions are actual, the *distributor* will set the food price and communicate with the food bank director.

The person who deals with the beneficiaries is the *social worker*, the fifth agent. We considered that this agent does not have properties and personal values that are important for the model's objective. The information required for the *social worker* is about the number of families that will be benefited. In contrast to the previous agents, the *social worker* performs two roles that are important to the system behavior: he is a Food deliverer every 15 days, and also he is the family interviewer that will decide if a new family will be added the Food security program.

For adding a new family to the program, the *social worker* must ask about the Food access frequency of the family. We have considered it less than once a day. If this condition is true, the *social worker* collects information about the family in a sheet (see Table 4.2), like the number of family members, if the family chief has a job, the family chief's age, and calculates the nutritional index of the family members. Then they are added to the list of beneficiaries who receive the Food bags every 15 days.

The last agent that we defined is the *beneficiary*, and his properties are age, gender, community, and telephone. His values are geographical distance and money for buying the Food bags. The *beneficiary* needs to know the delivery dates. His possible roles are new candidate, active *beneficiary*, and inactive *beneficiary*.

The attendance of the Food bags delivery is the decision he needs to make. The first condition is to revise if there is transportation for the Food bags. A Food bag weighs around 30 kilograms; it is crucial to have some vehicle to transport the Food bags: a bicycle, tricycle, wheelbarrow, car, or truck, depending on the distance between the *beneficiary*'s home and the delivery location. The following condition to check is the available money for buying the Food bag price: 150.00 pesos. If this condition is met, the *beneficiary* will go for the Food bag.

4.2.2 Constitutional Structure

The Constitutional Structure is a collection of roles, institutions, and dependencies. To be part of a social system, agents take roles and behave according to specific institutions. The institutions are social rules, norms, or strategies that influence behavior and decision-making [49]. The formal definition for institutions is the ADICO institutional statement and contains five components: Attributes, Deontic, aIm, Conditions, and 'Or else' (ADICO). Attributes are any value of a person to whom the institutional statement applies. Deontic can be one of the three modal verbs using deontic logic: may (permitted), must (obliged), and must not (forbidden). Aim describes the particular actions to which the deontic is assigned. Conditions are answered by the questions when, where, how, and to what extent an aim is permitted, obligatory, or forbidden. 'Or else' define the sanctions imposed for not following the rule. The shared strategies can be written as AIC (attributes, aim, conditions); all norms as ADIC (attributes, deontic, aim, conditions); and the rules as ADICO (attributes, deontic, aim, conditions, or else) [24].

Six institutions were identified for the Food bank process in the case study JSH (see Tables 4.3 and 4.4). Food reception, Food collection, Food delivery, Food bought, Food price, and Food conditions. The Food reception institution is attributed to the *beneficiary* and is an obligation to attend Food deliveries always. If the *beneficiary* misses twice is out of the program. Due to this institution having a sanction is considered a rule.

Food collection is an institution attributed to the *FB provider*. It is an obligation to pick up Food from donators from Monday to Thursday, as this institution does not have any sanction (or else component) is a norm. Similarly, the Food delivery and Food reception institutions are norms attributed to the *social worker* and *FB director*. The institution for Food delivery is an obligation to deliver Food bags to the beneficiaries twice a month, which is considered a norm. The Food bought is permission to deal the Food price with the *distributor* until the Food price is less than the retail price, and is considered a shared strategy. The Food condition is attributed to the *FB provider*: is "an obligation to separate Food in bad conditions", and is considered a norm because it does not have any sanction.

TABLE 4.3. CONSTITUTIONAL STRUCTURE

Role/Agent	**Objective**	**Institution**	**Entry Condition**
New candidate/*beneficiary*	Have enough Food to feed his family		Contact *social worker*
Active/*beneficiary*	Attend the Food deliveries every 15 days	Food reception	Attendance to Food deliveries
Inactive/*beneficiary*			Do not attend to Food deliveries two times
Family interviewer/*social worker*	Register *beneficiary* characteristics		Contact beneficiaries
Food Deliverer/*social worker*	Deliver Food every 15 days	Food delivery	Deliver all the Food bags every 15 days
FB provider	Get Food to achieve Food goal	Food collection, Food conditions	Food required for the FB stock
FB director	Get money to buy Food and pay FB people	Food bought, Food price	There is no economic resources
Producer	Income		Not income expected
Distributor	Income		Not income expected

4.2.3 Physical Structure

The physical structure specifies relations between physical components in a composition diagram and a connection diagram [49]. For our case study JSH, we identified only one physical component: Food (see Table 4.5). Its properties are type, weight, expiration date, purchase price, and status. As all the agents in the model have access to it, the Food is considered a public component. Its behavior is to feed people. Moreover, according to the MAIA model, its affordances (potential uses) are: produced, sold, bought, donated, processed, semi-processed, packed, delivered, and wasted.

On the other hand, System Dynamics (SD) analyzes system behavior through the definition of flows and stocks. In a supply chain, the stocks represent containers of a quantity of some product,

TABLE 4.4. INSTITUTIONS

Name	**Role**	**Deontic**	**Aim**	**Condition**	**Sanction**	**Institution type**
Food reception	Active *beneficiary*	Obligation	Attend Food deliveries	Missing attendance ≤ 2	*beneficiary* is out of the program	Rule
Food collection	*FB provider*	Obligation	Pick up Food from donors	From Monday to Thursday	-	Norm
Food delivery	Food deliverer	Obligation	Deliver Food bags	Once every 15 days	-	Norm
Food bought	*FB director*	Obligation	Get required Food	Food acquired $\leq Food required$	-	Norm
Food price	*FB director*	-	Deal the Food price	Food price < Retailer price	-	Shared Strategy
Food conditions	*FB provider*	Obligation	Separate Food	Is Food in lousy conditions?	-	Norm

which can only be accessed by flows influenced by external variables [120]. We defined the Food affordances as stocks and the flows between stocks as actions to be executed to fill or empty the stocks (see Figure 4.1).

The stock called "Produced" refers to the Food produced by the agent *producer*, and this stock is emptied by two flows: *demand* and *donation*, which refers to the market demand and Food donation, respectively. The demand flow fills the "Sold" stock, whereas the donation flow supplies the "Donated" stock. The donated Food is transported (*transport*) to the "FB Food" stock. At the same time, the "Semi processed" stock refers to perishable Food, which is "Bought" by the *FB director*

TABLE 4.5. PHYSICAL STRUCTURE

Name	**Properties**	**Type**	**Affordances**
Food	Type, Weight, Expiration date, Purchase price, Status	Public	Produced, Sold, Bought, Donated, Processed, Semi-processed, Packed, Delivered, Wasted

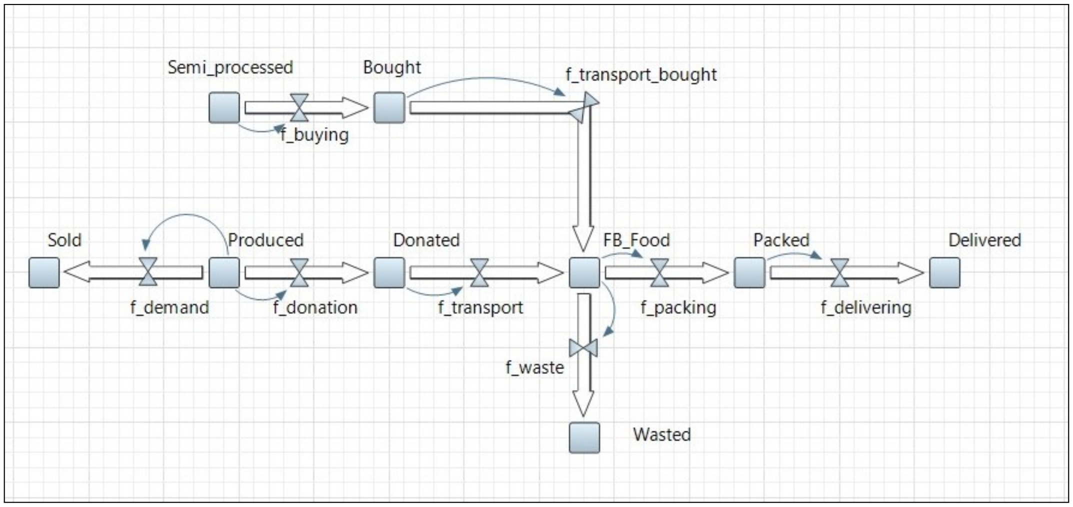


Figure 4.1: Physical structure represented as flows and stocks in a system dynamics model.

to complete the Food required to deliver to the beneficiaries. This Food bought is also transported to the FB. From the FB Food stock is emptied by two flows: *waste* and *packing*. The first supplies the “Wasted” stock, and the second supplies the “Packed” stock, which is the Food divided in bags that is “Delivered” (the last stock) to the beneficiaries.

4.2.4 Operational Structure

The operational structure describes the dynamics of the agents’ influence on the system’s state concerning time and space. It defines the order of the agents and physical components’ actions. In every time step in the simulation, each agent enters the action arena to explore the actions he may execute. The action arena is defined in each simulation by a list of action situations, which at the same time, are described by several related entity actions that take place using plan specifications. There are four plan types: atomic plan, which consists of a single entity action; sequence, which is a set of actions that will be executed in the specified order; choice, which is a set of actions from which one is selected randomly (with equal probability); and loop, which is a plan that is repeated for as long as a condition holds [49].

The action arena for our case study is described in Table 4.6. We defined six action situations. The first one, Producers Contact, which the *FB provider* performs, is a loop conformed by two entity actions: review the FB stock, which means to compare the current level of the FB stock with the Food required to attend to the beneficiaries. The second action is to review the *producer* Status if this is greater or equal to 7. This action situation will maintain until the FB stock is greater or equal to the Food required. Until the loop condition is reached, the post-conditions will be changed: increase FB stock and decrease the number of producers contacted, and the flag *FB provider* contact is set to True.

TABLE 4.6. ACTION SITUATIONS

Action situation/ Performer	**Plan type**	**Entity actions**	**Rule name**	**Loop condition**	**Post-condition**	**Institution**
Contact producers/ *FB provider*	Loop	Review the FB stock, Review *producer* Status	*producer* contact	FB stock ≥ Food required	Increase FB stock, Decrease producers, *FB provider* contact = True	-
Donate Food/ *producer*	Sequence	Review *FB provider* contact, Review Food Surplus, Review Transportation	*producer* donation	-	Donation Status = True, Update Food donation characteristics: Food type, weight, expiration date	-
Buy Food/ *FB director*	Sequence	Review FB stock, Review retailer Status	Food purchase	-	Increase FB Stock	Food Bought
Transport Food/ *FB provider*	-	Review donation Status, Review donator location, Calculate transportation expenses	Food transportation	-	Set transportation time, Transportation Status = True	-
Separate Food/ *FB provider*	Sequence	Check Food conditions	Is Food in good conditions?	FB stock is empty	Decrease FB stock, Increase packed Food stock, Increase Food waste,	-
Deliver Food/ *social worker*	Atomic	Deliver Food	FB stock = Food required	-	Increase Food delivered, Decrease Food packed	Food delivery, Food reception

The second action situation, Food Donation which the *producer* performs, is a sequence of three entity actions: (1) review if *FB provider* has called him; (2) quantify if the Food surplus exceeds 500 kg, and establish the Food expiration date; (3) review the transportation availability, i.e., if the transportation is in route at the current day, and the transportation capacity exceeds the Food surplus. The post-conditions for this action situation are: the donation Status is set True, and update the Food characteristics: Food type, weight, and expiration date.

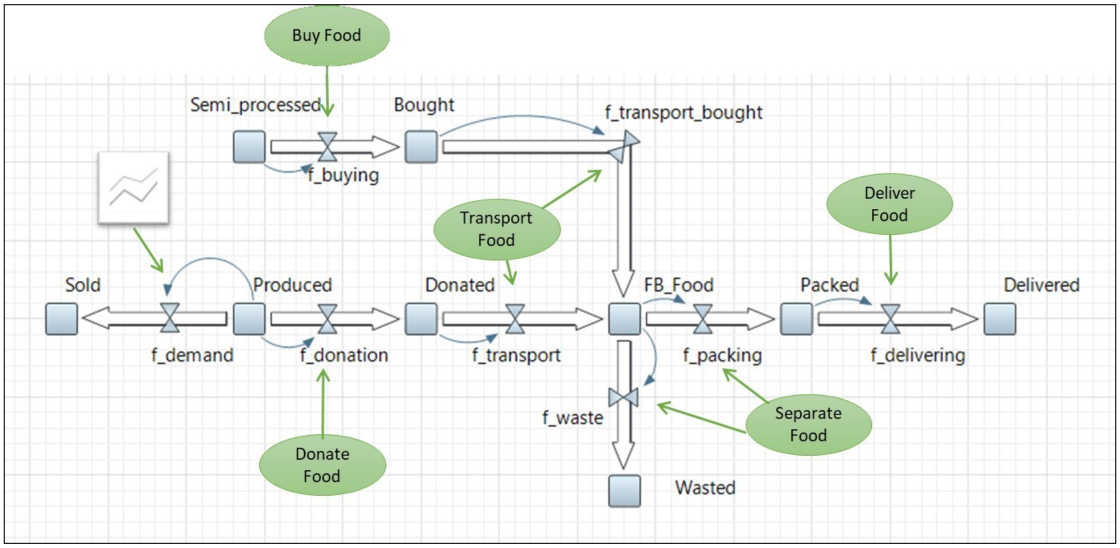


Figure 4.2: Entity actions related to the flows in the physical structure.

The third action, Food Bought, which the *FB director* performs, is a sequence that consists of two entity actions: (1) review the FB stock and (2) review the retailer Status. This sequence will be executed until the FB stock exceeds the Food required. This action situation will be regulated by the institution Food Bought. The post–condition will be to increase the FB stock. The Food Transportation, the fourth action situation performed by the *FB provider*, follows a sequence of entity actions conformed by: (1) checking donation Status, (2) reviewing donor location, and (3) calculate transportation expenses. The pre-conditions for this action situation are: the donation situation be true, i.e., that the *producer* has accepted to donate the Food; and that the *producer*'s location of the is on the Food collection route. The post-conditions are: to set the transportation time and to enable the transportation flag.

The Food Separation, the fifth action situation which the *FB provider* performs, is a loop that will be executed until the FB stock is empty. The sequence will follow two entity actions: (1) to check Food conditions, and (2) to separate Food. The Food conditions are defined with two values: good and bad conditions. The post-conditions are: to decrease FB stock, increase pacing Food, and increase Food waste. The sixth action situation is Food Delivery, which the *social worker* performs. This action is an atomic plan because it is performed just once every 15 days. The entity's action related to this situation is to deliver Food. The pre-condition is that the Food required is the same as the Food collected in the FB stock. The post-conditions are to increase the Food delivered stock and to decrease the packed stock.

This set of action situations is related to the set of flows in the physical structure (see Fig. 4.2). The Buy Food action will enable the *buying* flow. The Transport Food action will attend the flows *transport* and *transport* flows. The Donate Food action will activate the *donation* flow. The Separate Food action will regulate the *packing* and *waste* flows. Finally, the Deliver Food action will enable the *delivering* flow. The relations of each agent with their respective actions are shown in Fig. 4.3 and the relations between them.

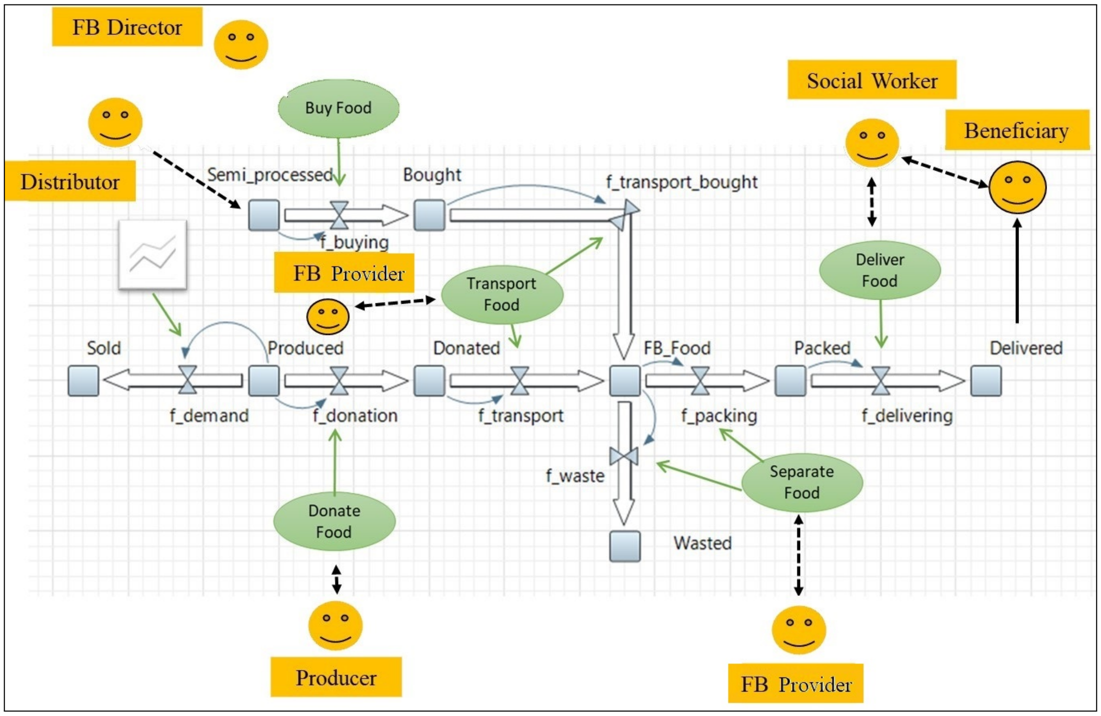


Figure 4.3: Agent interaction with their physical structure.

4.2.5 Evaluative Structure

The Evaluative Structure defines those indicators that show patterns of interaction, evaluation, and outcomes, where it is possible to observe discrepancies between simulation and reality due to software bugs or conceptualization errors. These indicators show the model validity (is it realistic?) and the model usability (can we prove policies?) The variables that review the states of the system and its performance are called problem domain variables, which sometimes are related to variables in the model. The validation variables are used for debugging and validating the model [49]. According to the case study, the scope matrix of the evaluative structure is shown in Table 4.7. The variables defined are obtained from the stocks of the Physical Structure, and in this table, these variables are related to the entity's actions influence on those variables. If the influence is direct, we will use a 'd', and an 'i' if the influence is indirect.

TABLE 4.7. SCOPE MATRIX OF EVALUATIVE STRUCTURE

Entity actions/ Problem domain variables	Review the FB stock	Review *producer* Status	Contact *producer*	Review Food surplus	Review transportation	Review retailer Status	Review donor Status	Review donor location	Calculate transportation expenses	Check Food conditions	Separate Food	Deliver Food	Review Food market demand
Kg of Food in the FB	d	i	i		i		i	i		i	d		
Kg of Food produced													d
Kg of Food sold				d									d
Kg of Food bought	d					d			d	d	d	i	
Kg of Food donated	d	d		d	d	d	d	d	d	d	i	i	d
Kg in the FB stock	d				d		i	i	i	d	d	d	
Kg of Food wasted		d					d			d	d		
Kg of Food packed										i	d	i	
Kg of Food delivered											i	d	
producers contacted	i	d	d		d		d	d	d				
Transportation time					d				d				

4.3. Conclusions

This first approximation of the agent-based model gives us a clear idea of the agent's interaction and decisions. Furthermore, how the agents interact with their environment, in this case, Food is the physical component. The MAIA Meta Model describes five structures for defining the agent attributes and performance. The FB responsible has validated this agent model, at a conceptual level. The next step is to choose and program the model. Once the model is programmed and tested, it is important to validate it in terms of replicability in the real world. Later, we will apply the Circular Economy policies and measure the circularity of the process.

5. Building the Simulation Model in Netlogo

5.1. Introduction

This chapter mainly explains how the agent-based model is translated to the software. We have chosen NetLogo software [139] to implement the case study because it is an open-source program, and it allows to design and connect a hybrid model (ABM and SD). Besides, we present the ODD (Overview, Design concepts, and Details) protocol [104] to define some qualitative characteristics of the model. Finally, we present some graphs to show the model performance. Additionally to the model simulation, we investigated some information related to the circular economy policies and how to evaluate them.

5.2. ODD Protocol

Agent models (AM) are not easy to design, and it is essential to keep in mind all the model's characteristics. There are some approaches dedicated to describing the agents' characteristics and behaviors. The ODD (Overview, Design concepts, and Details) protocol, proposed by [104], is designed to create a model description that is easy and quick to read and understand. The protocol comprises three general elements: overview, design concepts, and details; these elements group seven characteristics that every AM developer must describe.

The overview part involves three elements: (1) purpose, (2) entities, state variables, and scales, and (3) process overview and schedule. The design concept is considered the fourth element, which describes the characteristics of the model like basic principles, emergence, adaptation, objectives, learning, prediction, sensing, interaction, stochasticity, collectives, and observation. Finally, the details are shaped by (5) initialization, (6) input data, and (7) submodels [104].

5.3. Tepatitlán Food Bank ODD Protocol

Now, we describe the ODD protocol for the Tepatitlán food bank (TFB) case study. This description will be helpful for programming the AM.

5.3.1 Purpose

The purpose of the model is to evaluate, in the short and long terms, environmental decisions in the TFB case study in order to transform it from a linear supply chain to a circular one and implement a services ecosystem between agents, finding a value generation between actors.

5.3.2 Entities, State Variables, and Scales

The model includes six agents or entities: producers, *FB providers*, *FB directors*, *distributors*, *social workers*, and *beneficiaries*. *Producers* have attributes transformed in variables for food surplus, food type, food quantity, location, status, food production quantity, food expiration date, and food donated quantity. *FB providers* have attributes for location and review the status of FB stock quantity and the number of benefited families. In practice, food has been considered a physical component, and it is represented using System Dynamics, like a supply chain (see Fig. 5.1). Each stock is considered a state variable, and the agents will manipulate the flows between each stock. We also have two other state variables: families benefited and food bank money. The time step is fifteen days, which is the frequency for delivering the food bags to the families, and the food unit is kilograms.

5.3.3 Process overview and scheduling

The food bag delivered to *beneficiaries* is composed of 50% of vegetables and fruits, which are donated directly from *producers*; 30% corresponds to grains and cereals (beans, rice, sugar, and soy); and the other 20% are sanitary products and groceries donated by The National Association of Food Banks (BAMX).

The process begins with buying the percentage of food like grains and cereals; this action is performed once every fifteen days. The second action, performed by the *FB providers*, is to contact the *producers* to get the food donations. The food donation occurs if three conditions are satisfied: (i) the existence of food surplus from the *producers*' inventories; (ii) the food lifetime is enough to handle it and deliver to *beneficiaries* (greater than one week); (iii) the transportation is available. In other words, the transportation capacity is greater than the food donation, and the Producer location is on the route from other *producers*' donations.

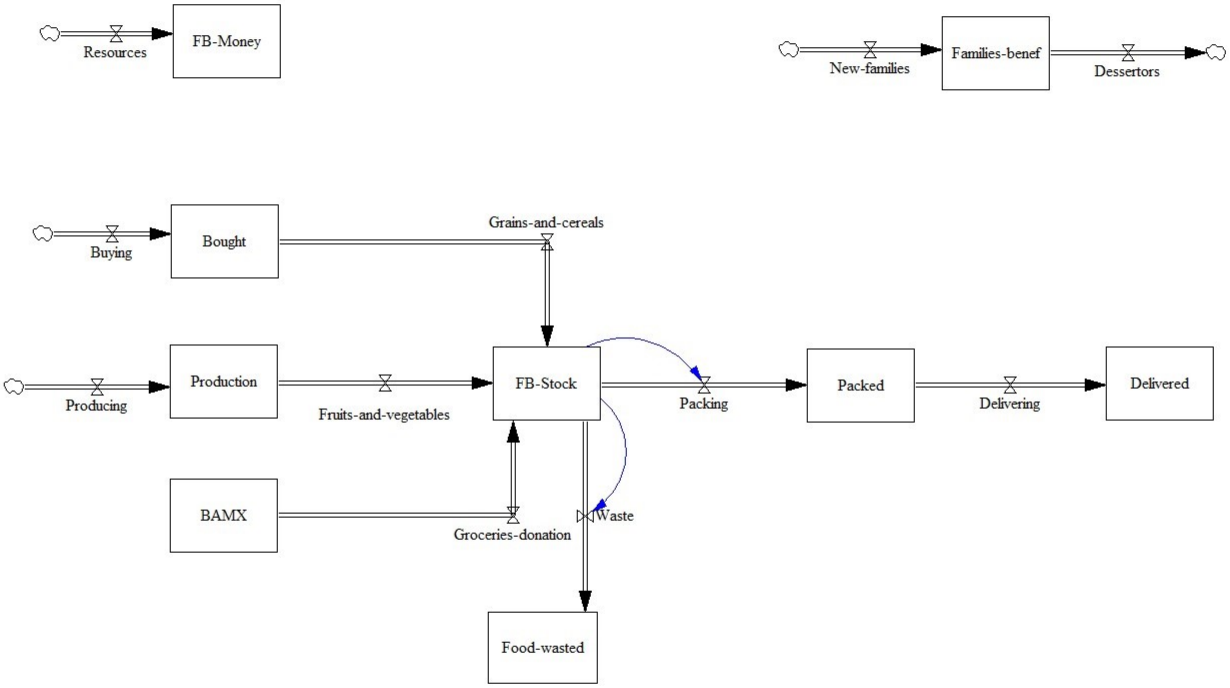


Figure 5.1: System dynamics model for Tepatitlán food bank.

When the food donated arrives at the food bank, the food in good conditions is separated from lousy conditions, considered waste. The remaining good-condition food is packed in individual bags with the grains and cereals, sanitary products, and groceries for delivery to the *beneficiaries* (see Fig. 5.1).

5.3.4 Design concepts

There are eleven different design concepts that not all the models employ. Some models are so simple that they only describe a few [104].

a) *Basic Principles*. The first concept "Basic principles" describes the general concepts, theories, and hypotheses involving the model's design. The Tepatitlán food bank describes a typical linear supply chain that involves a physical element of food for families in food insecurity. This process involves food waste that can be used as a resource for other processes to obtain some value, like biogas or composting, for benefiting families and society. The number of families will "pull" the entire process, as the food bags obtained depends directly on this quantity. In other words, if the number of families increases, the amount of needed food will increase, and it will be necessary to obtain more resources for attending to these families. These theories are better observed in a causal diagram (see Fig. 5.2)

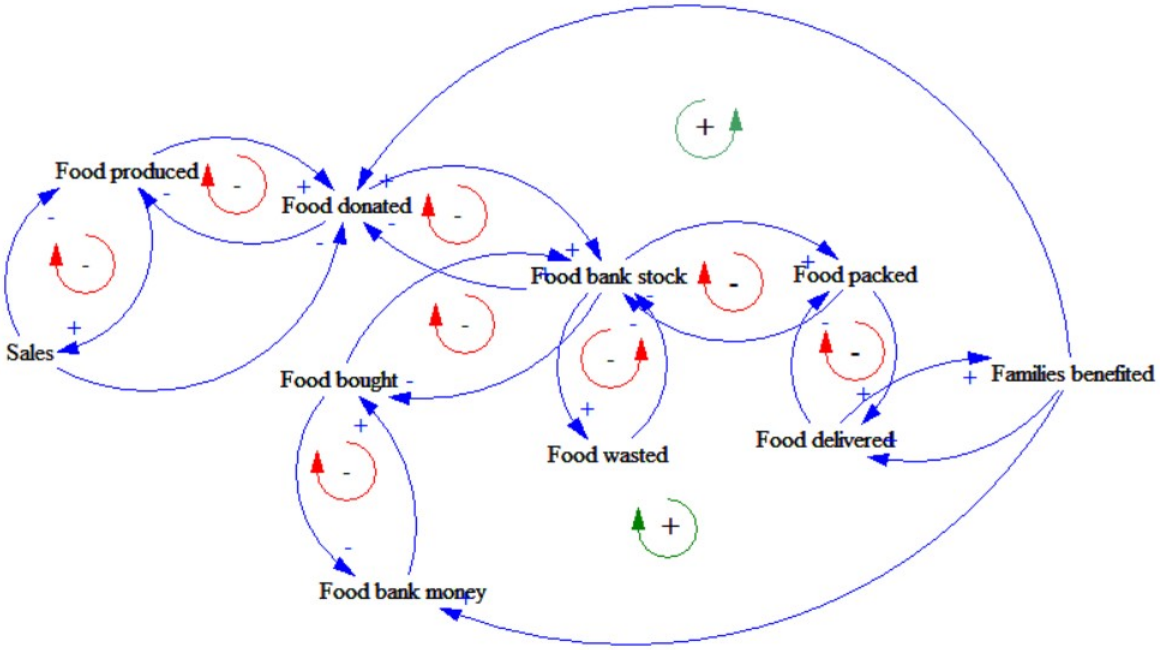


Figure 5.2: Causal diagram for Tepatitlán food bank.

b) *Adaptation*. The agents will have an adaptive behavior since they will review some conditions in the system to make decisions. For example, the *producers* need to review if they have surplus food for donation to the food bank. The food bank Producer will seek donations from *producers* to cover food goal determined by the families benefited.

c) *Objectives*. The main objective of the simulation is to get enough food for attending the families with food insecurity. However, as the food banks are non-profit organisms, they also need to get economic resources to operate the food bank and complete the food quantity. Some of these resources are obtained from selling the food bags to the families at a very low cost. Others are obtained from direct donations of money. The circular economy policies pretend to use food waste to obtain some money or other value to obtain more food and economic resources. To measure the objective achievement, we monitor some variables: food bank stock, money, families benefited, and food waste.

d) *Sensing*. The agents, especially the *FB providers*, are in charge of sensing some variables: (i) the amount of food collected, which is represented in the system dynamics model by the food bank stock (see Fig. 5.1), (ii) the *producers*' location that is available for food donations, (iii) the number of families to be attended, (iv) the food conditions donated by *producers*, and (v) the food lifetime. The *social workers* sense the families' attendance to pick up the food bags. The families evaluate their resources to gather up the food.

e) *Interaction*. The model agents interact with each other directly and indirectly (see Fig. 5.3). The *FB provider* interacts directly with *producers* and *social workers*. The *FB director* interacts with the food (grains and cereals) *distributor*. The *social worker* interacts directly with *beneficiaries* and *FB providers*. At the same time, all the agents interact directly with food as the physical component acting as flows regulators. The *FB provider* decides over the fruits and vegetables, waste, and packing flows. The *FB director* affects the grains-and cereals flow. The *social worker* determines the delivery, new families, and deserters flow. The *producers* decide the amount of production.

f) *Stochasticity*. To represent the causes of variability, we model the producer's production with random numbers. Similarly, the addition of new families and deserters is simulated with random quantities.

g) *Collectives*. Collectives represent *producers* and families. *Producers* shape a collective determined by the number-producers slider. This number will never change during the simulation. The families also are represented by a collective initially defined by Num-families slider; however, this number will be modified over the simulation execution by the new families and deserters flows.

h) *Observation*. The most critical variables to observe are food bank stock (FB-stock), food required, and food waste. The first two variables are plotted on the same graph to see if the food goal has been met. In addition, as the simulation setup is executed, we can observe the *producers*' and families' configurations.

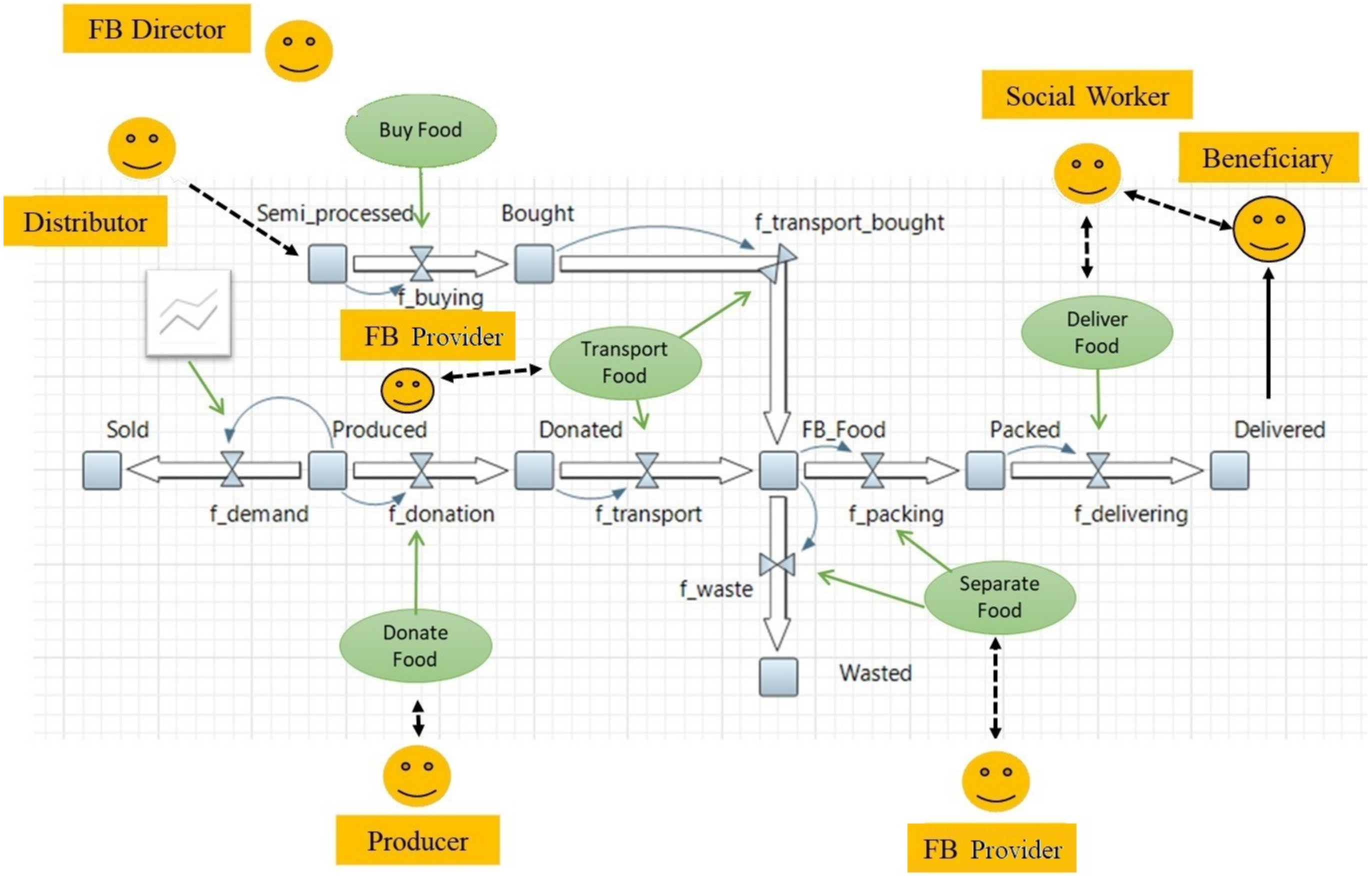


Figure 5.3: Agent interaction with their physical structure.

5.3.5 Initialization

The model initialization is divided into the system dynamics model (SDM) and the agent model (AM). The initialized variables in an SDM are the levels or stocks (see Table 5.1). The AM requires defining some particular attributes of each agent and the associated variables (see Table 5.2).

5.3.6 Input data

The input data has not been defined yet. The objective is to use information related to food production, food seasonality, population growth, household food waste, water and energy employed in the Tepatitlán community, and the food bank.

TABLE 5.1. INITIALIZATION OF SYSTEM DYNAMICS MODEL

Variable	**Value**
FB-Money	MXN $1,000,000.00
food bought	food required = food bag weight * Num families * (1 + waste index)
Production	Initial production = sum[food production] of *producers*
BAMX	1,000 tons
FB-Stock	0 tons
food-wasted	0 tons
Packed	3000 tons
Delivered	0 tons
Familes-benef	270 families

5.3.7 Submodels

NetLogo allows simulating SDM and AM. The AM is a programming language that defines all the agents' attributes and submodels. It is essential to define the main function, called "go", where all the processes will be executed. Based on the MAIA meta-model [49], in the chapter 4 we defined the Action arena, which is the core of the "go" function. In the following paragraphs, we describe the processes and how they were codified.

SDM execution. The SD model is considered a submodel, and it is executed every step time because the conditions are constantly changing; in [139] is possible to find the instructions to execute it.

Calculate the food required. The food required (foodr) depends directly on the number of families (numfam), the food bag weight (fbagw), and the waste index (wasteidx). These three variables can be modified on the user interface; then we can say that the food required is determined by the

TABLE 5.2. INITIALIZATION OF AGENT-BASED MODEL

Agent	Quantity	Shape	Color	Size	Position	Own variables
Producers	Number of *producers*	Plant	Green	1.5	Random	food production = Normal(5000, 1000); food sales = Normal(4000, 500); food lifetime = Poisson(3); Location route = false; Status = Poisson(8)
FBproviders	1	Person	White	2	Center (0,0)	-
FBdirectors	1	Person	Blue	2	-	Money collected = 100,000
Families	100	House	White	1	Random	Miss attendance = 0; Family status = Normal(0.7, 0.1); food access freq = Poisson(3); food bag transport = True; Delivery dist = Normal(1, 0.1); Money for food = Poisson(300)

user indirectly:

$$foodr = numfam * fbagw * (1 + wasteidx) \tag{5.1}$$

Buy. In this sub-process, the grains and cereals are bought. The quantity of bought food (foodb) depends directly on the food required (eq. 5.1), and corresponds to the 30% of this quantity defined by the food bank. As this action is executed once a month, and the time step is 15 days, the formula calculates the food required for two deliveries in one month (eq. 5.2). This food quantity is stored in the Bought stock in the SDM (see Fig. 5.1).

$$foodb = 2 * 0.3 * foodr \tag{5.2}$$

Donate food. When this process is executed, it initially sets false the food available and transportation available variables. The second step is to establish the location of the *producers* running the "locate" sub-process, which will be explained below. The third step is to review the three conditions required for the food donation from *producers* (see chapter 4). The first condition is related to the producer status, determined by previous donations. If this status is greater than 7, the producer contact is true. The second condition will evaluate the producer food for donation. There are two attributes to evaluate the food surplus and the food lifetime. The food surplus is calculated by subtracting from the amount of food production minus food sales (eq. 5.3).

$$food\ surplus = food\, production - food\ sales \tag{5.3}$$

The food lifetime is a characteristic established by the producer. If the food lifetime is longer than seven days and the food surplus exceeds 500 kg, the available food variable is true. The third condition to evaluate is food transportation, and the FB has its trucks for transporting the food. The only condition to evaluate is that if the producer location is on route for food collecting with other *producers*, the available transportation variable is true. Then when the three variables: producer contact, food available, and transportation available, are true, the donation amount is equal to the food surplus of the producer. Then the amount of food production for each producer is recalculated (eq. 5.4).

$$food\, production = food\, production - food\ sales - food\ surplus \tag{5.4}$$

When all the *producers*' donations are available according to the conditions mentioned above, it is important to sum up all the individual *producers*' donations. The ”need completing variable” is false if this sum is greater than the food required for vegetables and fruits, corresponding to 50% of the food required. This variable will be evaluated later in the Grain and Cereal sub-model. Before closing the Donate food process, we randomly program the food production from *producers* for the next step, and the Producing flow from SDM will be updated.

Locate. This sub-process will evaluate a location route among the close enough *producers* for picking up the food. NetLogo allows asking for the nearest agents in a certain radius. If these nearest neighbors (near-neigh) are greater or equal to 2, then the variable location-route is true.

Grain and Cereal. In this process, the ”need completing” boolean variable is evaluated. If if this is true, it means that the fruit and vegetables donated by *producers* are not enough, and the food that is missing will be completed by the grains and cereals. To calculate the percentage of the missing food (completing-index), we divide the number of fruits and vegetable donation (f-v-donation) between the food required (foodr), and it is subtracted from the 50% that the fruits and vegetables would cover (eq. 5.5). Then the flow of grains and cereals is recalculated as shown in equation 5.6. Otherwise, the grains and cereals are calculated with the 30% previously defined.

$$Completing\ index = 0.5 - (fv\ donation)/foodr \tag{5.5}$$

$$Grains\ and\ cereals = (Completing\ index + 0.3) * foodr \tag{5.6}$$

Groceries donation. This amount corresponds to 20% of the food bag composition (eq. 5.7).The national food bank association BAMX directly donates the groceries. The type of groceries generally are cleaning products, food cans, and soda.

$$Groc\ donation = 0.2 * foodr \tag{5.7}$$

Family submodel. The families are modeled every step with specific attributes: (i) the number of times that the family misses a food bag delivery, (ii) the status of the family according to the socio-economic study, (iii) food access frequency, (iv) if they have transportation for carrying the food bag, the distance from their homes to the delivery place, (v) and if they have enough money for paying the food bag. In this submodel, there are two sub-processes: ”add family” and ”remove family”. The first process creates ten families each time step, review if their status is less than 0.5 and the food access frequency is less than 2, then the family is added to the families benefited stock in the SDM through the ”new families” flow; otherwise, they are eliminated. The ”remove family” process only reviews if the family has missed two food bags deliveries consecutively. Then the deserters flow from the SDM model is modified with the number of families that comply with this condition and are also eliminated.

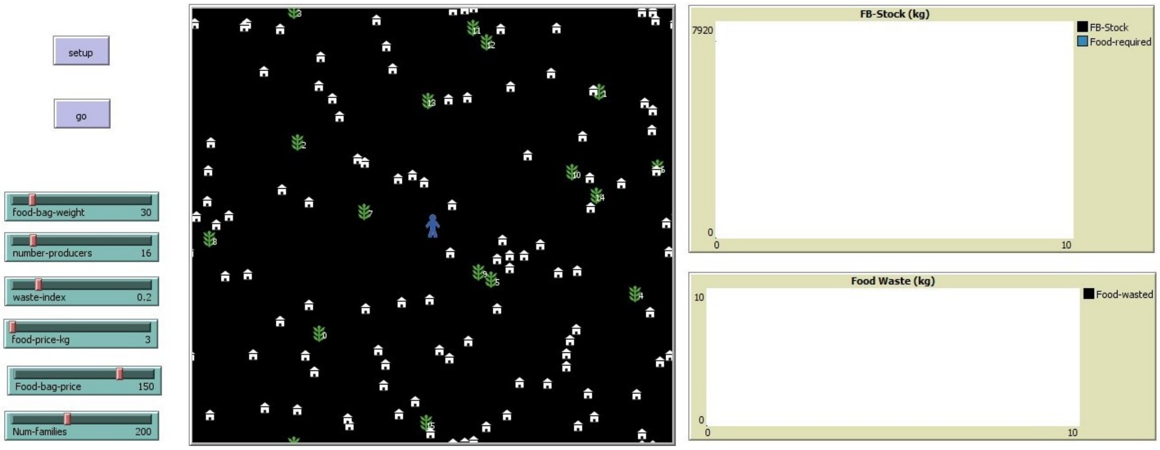
Deliver. When this process is executed, the food bag has been delivered and paid to the *social workers*. This money is collected in the FB-Money stock, and later this money will be used for paying the food bank operating costs.

Do plot. This process automatically updates the graphs according to the actual values of the variables each time step.

This formulation in ODD format allows us to describe the agent-based model of the Tepatitlán food bank. It is helpful, and the authors employ NetLogo in their publications for showing examples using this format [104].

5.4. First Results of Model Execution

As we have described before, we are calculating some variables' values as random distributions for preliminary tests. The user interface is divided into four parts: controlling buttons, variables sliders, the world sight, and the output variables graphs (see Fig. 5.4). There are two controlling buttons: setup and go. The setup button corresponds to the initialization element of the ODD protocol. And the go button executes all the sub-models described in the previous section.

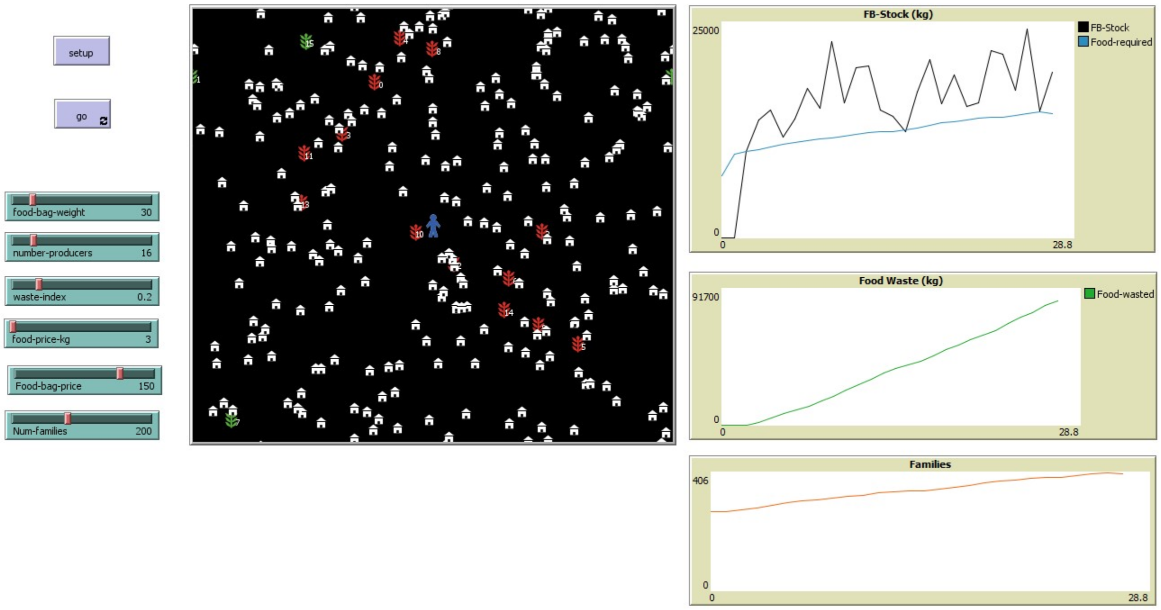


food-bag-weight 30
number-producers 16
waste-index 0.2
food-price-kg 3
Food-bag-price 150
Num-families 200

Figure 5.4: Tepatitlán food bank simulation setup.

First, the model must be initialized using the setup button to execute the simulation. The agent model creates the agents with their attributes, and the SDM is prepared with the initial values for stocks. The user can modify the variables sliders or leave them with the previously programmed values.

When the go button is pressed, the simulation begins until the go button is pressed again to stop the simulation. The graphs are updated each step time, and as we can observe (see Fig. 5.5), the food requirement (blue) grows as the number of families grows (orange), the food collected by the food bank (black) is bigger than the food requirement. Finally, the food waste (green) is accumulated in a continuously growing stock. According to the causal diagram (see Fig. 5.2), the positive or reinforcement loop generated from the families benefited is replicated in the simulation model.



food-bag-weight 30
number-producers 16
waste-index 0.2
food-price-kg 3
Food-bag-price 150
Num-families 200

Figure 5.5: Tepatitlán food bank simulation execution.

5.5. Conclusions

This chapter describes the hybrid model designed in the chapter 4 using the ODD protocol and checks if the model is complete. We programmed the MAIA meta-model described by the ODD protocol in NetLogo, and we found that it is possible to combine SD and ABM in a hybrid model, which allows us to understand and separate the agents (people) from the artifacts like food (physical elements). In the preliminary results, we showed the first assumption: the number of families will make the food bank stock also grows (reinforcement loop) by analyzing the cause and effect diagram (see Fig. 5.2) and programming the hybrid model (SDM and AM) in the NetLogo software. However, the data required from the food bank is still missing, and it is necessary to get it for the model validation, which corresponds to step eight of our methodology. After model validation and analyzing the information delivered by the model, we will pass to step 9: "Formulate and evaluate policies." The constraint for this last step is that the policies must be obtained from circular proposals, satisfying the circular economy principles. Circularity indicators must be defined depending on the validation model proofs and the case study objectives to measure this objective. The circular policies proposed will be implemented in the simulation model as future scenarios, and their economic, environmental, and social impacts will be quantified in the short and long term. As we continue applying the methodology, we have found its viability for creating a simulation model for implementing circular economy principles in Mexican industries.

6. Model Validation

6.1. Introduction

In previous chapters, we explained the pertinence of circular economy in the Mexican linear processes and the importance of developing a tool like a simulator to prove some policies before implanting them in the real world. Furthermore, we visualized the tools and concepts to develop the simulator like service-dominant logic, ecosystem services, agent-based modeling (ABM), and system dynamics (SD). Then, we proposed a new methodology to design and implement a simulation model from a linear process and analyzed the case study: Jalisco without hunger. Next, we described the first attempt at methodology implementation and the concepts for representing the chosen case study: the Tepatitlán food bank. Finally, we designed the agent model applying the MAIA Meta Model and defined the agents involved in the model. Besides, we proposed the food as a physical component represented by stocks and flows like a system dynamics representation.

This chapter describes the next step for the methodology that corresponds to the eighth step: "Determine and execute performance tests." We understand that this step also refers to the model validation. In the following two sections, we will explain some tests to be performed in the model and how to validate them.

6.2. Model Evaluation

Several tests for evaluating the model include boundary adequacy, structure assessment, dimensional consistency, parameter assessment, extreme conditions, integration error, behavior reproduction, behavior anomaly, family member, surprise behavior, sensitivity analysis, and system improvement [120].

6.2.1 Boundary adequacy test

Boundary Adequacy tests assess the appropriateness of the model boundary. We constructed a causal diagram to explain the model boundary (see Fig. 6.1). This diagram can observe the exogenous variables: food baskets per family, number of families, food bag weight, food waste index, number of producers, transportation available, and status desired. On the other hand, the model's endogenous variables are food required, food bought, food donation, food packed, and food waste.

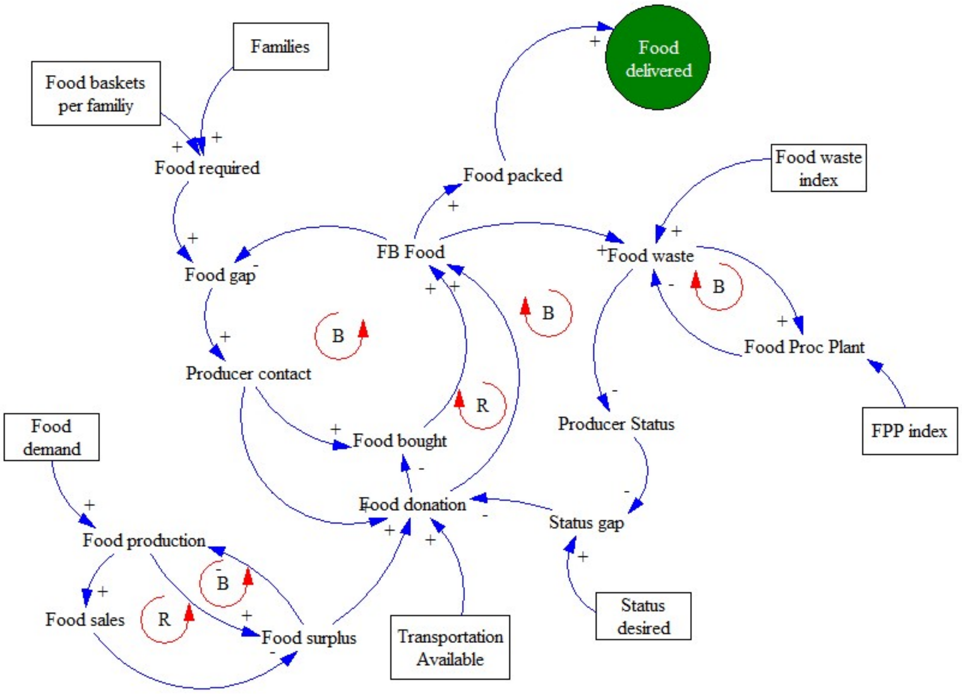


Figure 6.1: Causal diagram for defining the model boundary of the Tepatitlan Food Bank.

6.2.2 Structure assessment test

Structure assessment tests ask whether the model is consistent with knowledge of the actual system relevant to the purpose. The model structure has been developed using the MAIA Meta-Model for agent-based modeling (ABM) [49]. This model allowed us to evaluate and define the different agents' decisions and behaviors, validated by the food bank contact. According to conservation laws, food is the only physical component; the agents manipulate and transform it during the entire process (see Fig. 5.3).

6.2.3 Dimensional consistency

This test inspects the variables' units, mainly if their dimension corresponds to the model meaning and if the equations are consistent with the model logic. For our simulator model, the units' analysis is described in Table 6.1.

6.2.4 Parameter assessment

The parameter assessment seeks the real-life meaning of each estimation. The relationship modeled by the equations must be justified by statistical or judgmental methods [120].

Monthly, registers collected from the food bank obtained some data, and other information were average estimations given by employees or food bank director, and we plotted their historical behavior (see Fig. 6.2). We analyzed the data obtained, which is summarized in Table 6.2. This table describes each variable from the causal diagram: input or output, dimensional units, sample frequency, the period that the data is available, data type, and the distribution they should follow according to the variables' nature.

6.3. Model Validation

Validation determines whether the simulation model is an acceptable representation of the actual system, given the purpose of the simulation model. There are different statistical tools for validating a model depending on the available data quantity. Kleijen considers three cases: (i) no real data available, (ii) only output data, and (iii) input and output availability [69].

In the first case, if data is not available, strong validations are impossible. At least a Sensitivity Analysis (SA) should be performed. SA is an investigation of the reaction of the simulation responses to extreme values of the model's structure. Besides, SA shows which factors are essential and how to change them in the real system if they are controllable [69].

In practice, the SA is done through a Design of Experiments (DOE). The DOE's central problem is how to select a limited set of combinations of factor levels to be observed. Next, the resulting data of the simulation experiment are analyzed by applying ANOVA or regression analysis (RA). This analysis estimates the importance of the individual factors, and the result of the RA is a model called a meta model. Typically, this meta model uses a polynomial approximation. The main objective of the SA is to find out whether the simulation model contradicts qualitative or expert knowledge. If the simulation's behavior violates this knowledge, the model should be seriously evaluated for programming and conceptual errors [69].

In the second case, the ideal simulation model would have a statistical distribution function for its output that is identical to the distribution for the real system. In practice, the manager is interested in the particular characteristics of the distribution, like the system's mean and variances [69].

In the third assumption, with accurate input and output data after running the simulation program, analysts compare the simulated output with the real historical output, and a regression model is obtained that should validate the simulation model [69].

6.4. Conclusions

This chapter describes the eighth step of the proposed methodology, which consists in "Determine and execute performance tests." We developed four tests from twelve that Sterman suggests. These tests have helped us debug the simulation model related to the mathematical equations and general performance, observing the state variables and the output.

On the other hand, validating the simulation model is aligned to specific standards found in the concerning literature. The lack of enough data from the TFB has made us search for other alternatives to validate the simulation model. We have found that sensitivity analysis can be an option to validate the simulation model by developing a design of experiments to find the most important factors or inputs of the simulation model. Once these results are obtained, we will continue with the ninth step, "Formulate and evaluate policies," which proposes circular economy policies to implement in the simulation model and evaluate future scenarios for the case study

TABLE 6.1. VARIABLES DIMENSION

Variables/Equations	**Units**
Number of Families	Families
Food bag weight	Kilograms
Food waste index	Dimensionless
Number of producers	Producers
Food baskets per family	baskets/family
Food required	Kilograms
Food bought	Kilograms
Food donation	Kilograms
Food packed	Kilograms
Food waste	Kilograms
Food production	Kilograms
Food sold	Kilograms
Food surplus	Kilograms
Food lifetime	Days
Grain and cereal food	Kilograms
Food access frequency	Times/day
Delivery distance	Kilometers
Money for food	MXN Pesos
Food bag price	MXN Pesos/basket
Missattendance	Times/month
Completing food index	Dimensionless

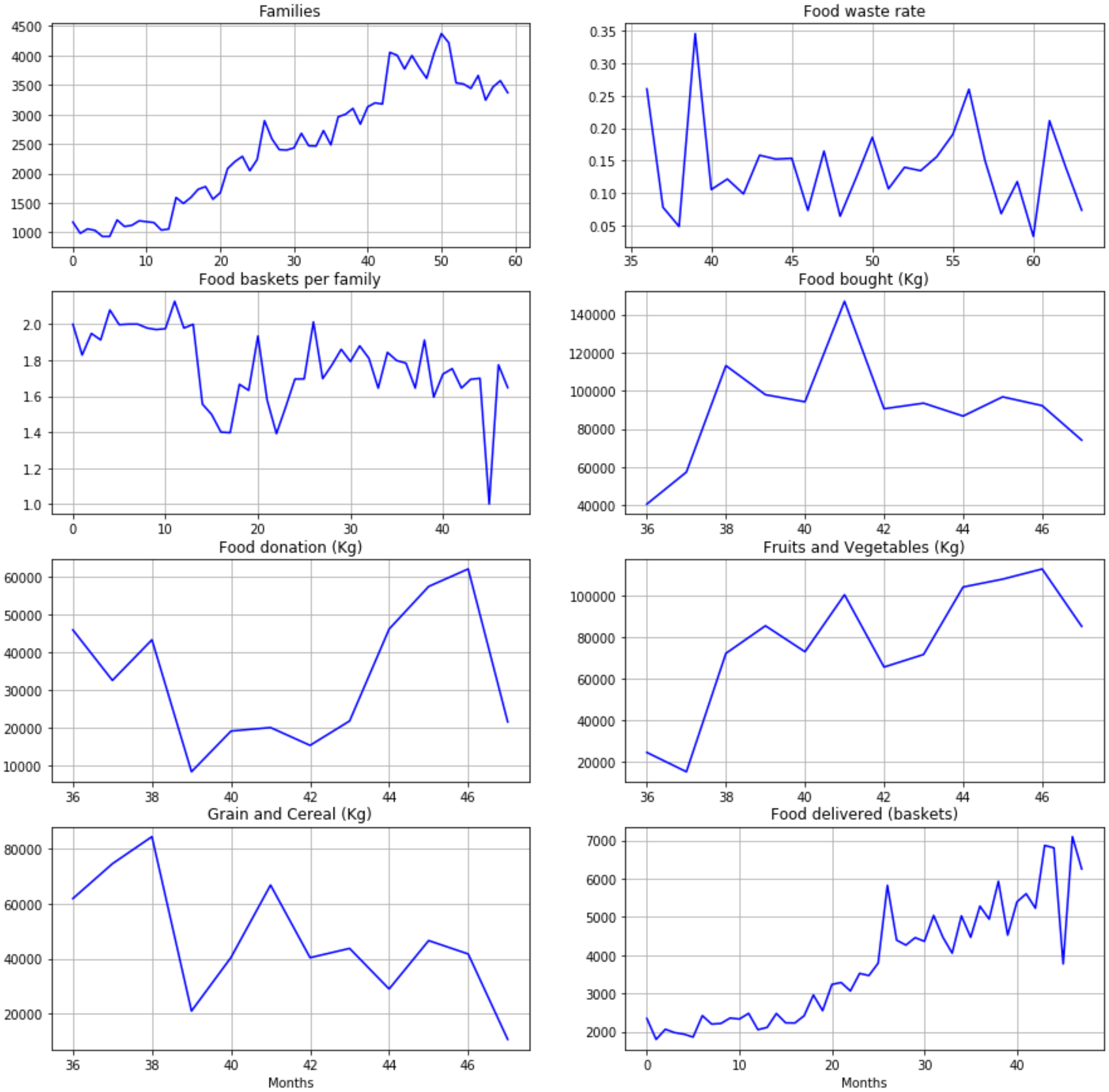


Figure 6.2: Data collected from Tepatitlán Food Bank.

TABLE 6.2. PARAMETER ESTIMATION

Variable	**Input / Output**	**Units**	**Sample Freq**	**Begin**	**End**	**Data type**	**Distribution**
No. Families	Input	families	Monthly	Jan-14	Dec-18	Discrete	Poisson
Food bag weight	Input	kilograms	-	-	-	Continuous	Normal
Food waste rate	Input	%	Monthly	Jan-17	Apr-19	Discrete	Binomial
No. Producers	Input	producers	-	-	-	Discrete	Poisson
Production qty.	Input	kilograms	-	-	-	Continuous	Normal
Food type	Input	-	-	-	-	Categorical	-
Food baskets	Input	baskets	Monthly	Jan-14	Dec-17	Discrete	Poisson
Food bought	Input	kilograms	Monthly	Jan-17	Dec-17	Continuous	Normal
Food donation	Input	kilograms	Monthly	Jan-17	Dec-17	Continuous	Normal
Fruits and vegetables	Input	kilograms	Monthly	Jan-14	Apr-19	Continuous	Normal
Food lifetime	Input	days	-	-	-	Continuous	Log Normal
Grains and cereals	Input	kilograms	Monthly	Jan-17	Dec-17	Continuous	Normal
Food delivered	Output	baskets	Monthly	Jan-17	Dec-17	Discrete	Poisson

7. Second Case Study: Confectionery Factory

7.1. Introduction

The methodology proposed for implementing the hybrid service simulation model has been designed to be applied in any company organized through a value chain. Ellen MacArthur Foundation [33] proposes a classification of this value chain: biological cycle and technical cycle. Both cycles are composed of a traditional supply chain and extra loops that close the loops and convert the linear supply chain to a circular one. The methodology proposed in this thesis consists of nine steps based on four perspectives: service-dominant logic, ecosystems services, agent-based modeling, and system dynamics. As a case study, we implemented this approach in a food bank located in Jalisco, México. Seven of the nine steps were implemented successfully, and for reasons out of our concern, the two final steps were not implemented, which are related to model validation and proposals for implementing circular economy strategies. Consequently, and to validate the methodology proposed ultimately, we applied this methodology to a second case study: a confectionery factory in Jalisco, México. This chapter will present an overview of the food industry, the new case study, and the first step of implementing our methodology, 'Select interacting parts of the value chain (entities)' [56].

7.2. Food industry

The 2030 Agenda for Sustainable Development resolved to end hunger, achieve food security as a matter of priority, and end all forms of malnutrition [92]. Food security is defined as the state in which all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food than meets their dietary needs and food preferences for a healthy and active life [129].

The current food industry seems insufficient for the global population; there are alterations in overall nutritional needs and rising economic incomes [128]. Besides, there are remarkable challenges to transforming a food system into a healthy, nutritious, and environmentally sustainable

[88], for example, water scarcity, energy use, and land availability [130], [42].

Ellen MacArthur Foundation (EMAF) published a report on the food systems and their performance in big cities. In this document, the authors explain why the current feeding systems are no longer sustainable. Some of these reasons are: the generation of large amounts of food waste generated by large cities, the way food is currently produced is harmful to human health, and the distance between cities and rural areas where food is grown is too far. Addressing this problem, EMAF proposes three ambitions that cities can realize to catalyze a circular economy for food: (1) source food grown regeneratively and locally where appropriate, (2) make the most of food, and (3) design and market healthier food products [32].

The confectionery sector is not the exception, and these challenges are essential in connecting nutrition, health, and environmental issues [88]. For example, México is second place in confectionery consumption in Latin America and sixth place globally. The estimated consumption per capita is around 4.5 kg per year [31]. On the nutritional side, in recent years, undernourishment has decreased, in contrast with obesity increase, due to factors like food consumption rich in fat, salt, and sugar. México and USA have the highest index of adult obesity, and México occupies fourth place globally in childhood obesity [72]. Moreover, the increasing consumption of confectionery products is pressuring the global supply chains. For example, cocoa and palm oil are grown in only certain places [88].

As the diversity of products, the confectionery supply chains are complex: the raw material, specialized equipment, different formulation for creating nutritious and tasty recipes, and several strategies to sell products. A system-view approach is required across the confectionery supply chain (from raw material to disposal: cradle to grave) to attend to the transition towards environmental sustainability [88]. For this reason, it is crucial to evaluate the circularity performance of the organization to assess the correct part of the system.

7.3. Circular economy analysis

The impact of CE implementation in an industry is difficult to quantify and visualize. According to [114], the circularity performance monitoring is difficult to assess as CE has a dynamic nature. In the literature, several instruments evaluate and quantify engagement and product performance concerning CE principles [17, 39, 80, 102, 113, 137]. These instruments involve the several stages of a supply chain like design, materials, manufacturing, packing, delivery, and final user. We chose the Circular Economy Indicator Prototype (CEIP) [17] to evaluate the circularity performance of our case study. This instrument contains fifteen questions to evaluate five cycle stages of a circular supply chain: design, manufacturing, commercialization, in use, and end of use. Each question associates a measurable variable with a CE principle using a weighted score.

In the Design stage, CEIP evaluates principles like material selection, cascades thinking, and material identification. The material selection principle assesses the use of reused or recycled material that reduces waste. Also, this principle refers to dematerialization; in other words, circular design demands less material for the same performance and quality. Material identification refers to a complete bill of materials and substances in product manufacturing. CEIP uses the principles of energy identification and waste management to evaluate the circularity in the manufacturing stage. The energy identification principle evaluates the presence of a bill of energy, which provides the information required to plan for energy consumption and efficiency manufacturing processes and contributes to using more renewable energy sources. The waste management principle establishes that waste must be avoided and treated as raw material for other processes.

CEIP evaluates the cascades thinking principle in product packing and product life extension during commercialization. Besides acquisition, the diversity principle assesses the rental schemes to access higher quality products and materials without purchasing the product themselves.

‘In use’ circular stage assesses the cascade thinking and waste reduction principles. In the cascade thinking principle, it is essential to identify the usage status of the product that contributes to planning maintenance actions before a malfunction happens, extending the lifetime of the product. Besides, this principle identifies the importance of reusing product options enabling waste reduction. The ‘end of use’ stage appraises the thinking of cascades materials and waste through the availability of take-back schemes and product materials reintroduction [17].

7.4. Case Study: Confectionery Factory

We selected the confectionery factory for three important reasons: (1) it is a Mexican small and medium enterprise (SME) with around 200 employees [16], (2) its business model is a value chain configuration [100], and (3) there is available data to be used in the simulator model. This organization has ethical values like reliability, respect, honesty, and responsibility. Unfortunately, its mission and vision do not include the sustainability, environment, or green organizations concepts. However, a confectionery recycling process is used to reuse the waste obtained from the manufacturing process, called neutral carbon filtration.

In the first chapter, we considered that our hybrid simulator methodology is oriented to companies whose environmental theme is less important than the economy because the environmental impact cannot be easily visualized [56]. In this sense, some authors question how it is possible to convince stakeholders to adopt circular economy (CE) principles in an organization [70], [138].

According to [33], confectionery manufacturing is classified as a biological cycle because the primary raw material is sugar, and the final product is edible. As CE considers the entire supply chain from the raw materials production and final disposal, we compared the supply chain of our company to that explained by [88], who established six main stages to be considered: raw materials, pre-processing (only for chocolate-based products), manufacturing, distribution and retail, consumption, and disposal. The latter two stages belong to the final user, and the other four to the confectionery manufacturer. Regarding raw materials, there are two categories: ingredients and packaging, which are inputs to the pre-processing and manufacturing processes. From this comparison, we apply the CEIP instrument described before to our case study (see Table 7.1).

We adjusted the instrument according to the product's nature. The confectionery factory only covered three of the five life cycle stages that CEIP evaluates: designing, manufacture, and commercialization. Within these elements, there are two questions that we did not consider for the evaluation: (i) "Q2: Is the product lighter than its previous version?" and (ii) "Q8: Is there a rental option for the product?". So, we eliminated their contribution in the final score, and it was calculated as shown in Table 7.1. The product rating was 52%, which corresponds to a "good" product ranking according to the CEIP scale. In the following paragraphs, we will explain how we implemented the first step of the methodology: 'Select the interacting parts of the value chain (entities)' [54].

TABLE 7.1. CEIP INSTRUMENT APPLIED TO THE CONFECTIONERY FACTORY

Life cycle	**Question**	**Answer**	**Scored**	**Rating**
Design/Redesign	Q1: Is the product made from recycled or reused material? (20p)	10%	1	$6/25 = 24\%$
	Q2: Is the product lighter than its previous version? (2p)	-	-	
	Q3: Is there a complete bill of materials and substances for the product? (5p)	Yes	5	
Manufacture	Q4: Is there a complete bill of energy for the manufacturing process? (10p)	Yes	10	$25/25 = 100\%$
	Q5: Is there a complete bill of solid waste for the manufacturing process? (15p)	Yes	15	
Commercialisation	Q6: What packaging is being used? (5p)	Recyclable	1	$3/15 = 20\%$
	Q7: What is the product's warranty? (10p)	2-3 years	1	
	Q8: Is there a rental option for the product? (15p)	-	-	

7.5. Step 1: Select interacting parts of the value chain

Analyzing the stages that the CEIP instrument proposes, the innovation process is not frequent in the Design/redesign section, and there is not much information to be analyzed. In Manufacturing, the confectionery factory manages the confectionery waste obtained along the supply chain. We selected this stage because of the confectionery waste's recycling process, mainly composed of sugar-based products like pops and candies with their plastic packing. This recycling process is already installed in the company, and there is available data to use in the simulator model. According to [67], who analyzed the resource flows through a value chain in a circular economy, we chose the stages involved in the confectionery waste recycling process. These parts of the value chain are manufacturing, remanufacturing, recycling and recovery, materials sourcing, and design (see Fig. 7.1).

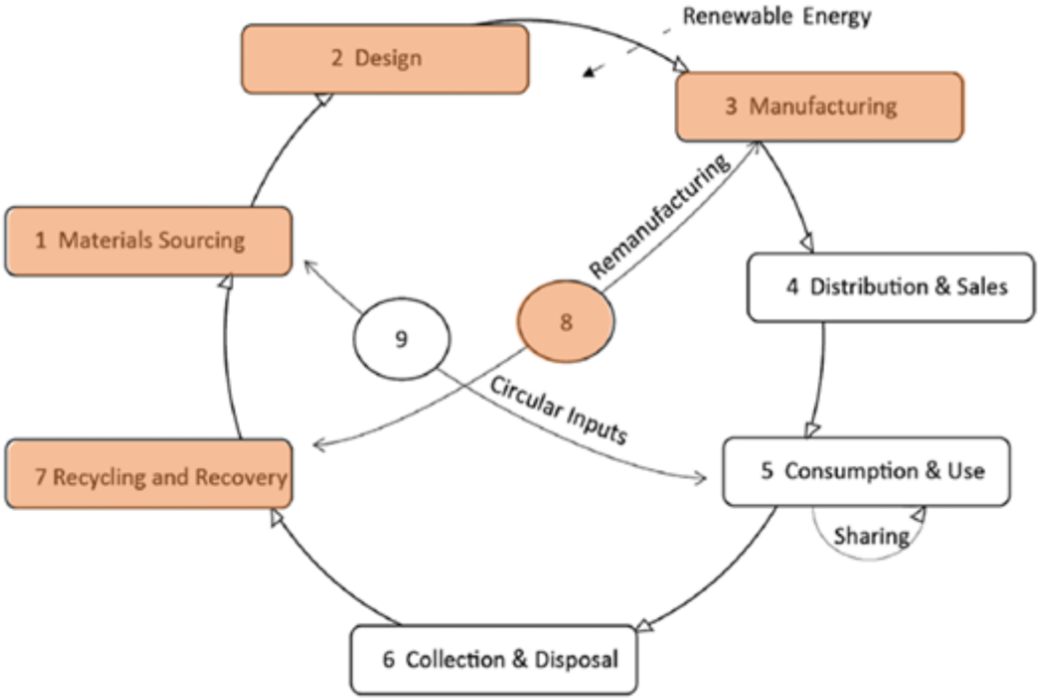


Figure 7.1: Value chain parts involved in the confectionery waste recycling process (adapted from [67])

7.6. Conclusions

This chapter presented the literature review concerning the confectionery industry in the world and México. Furthermore, we analyzed some results related to sustainability in confectionery organizations. Regarding the case study addressing, we evaluate some CE maturity frameworks. We adopted the CEIP model for measuring the current CE state of the case study. When we applied the CEIP questionnaire, we realized that questions related to commercialization, in use, and end-of-use stages, were not suitable for the food industry. Thus we found an area of opportunity for developing a CE maturity model appropriate for this sector.

According to the results obtained from this instrument and the data availability of the case study, we selected the manufacturing stage and defined the related processes according to the CE value chain. This procedure belongs to the first step of our proposed methodology, and the next steps depend directly or indirectly on this step. In the second step, we will analyze the CE strategies to find a connection between them and select those critical for the simulator's objective and the case study.

8. Methodology Implementation in the Confectionery Factory

8.1. Introduction

This chapter explains the next steps for implementing the proposed methodology. We explain the eight steps remaining for obtaining the simulation model. In chapter 7, we performed the first step, where we selected the stages involved in the confectionery recycling process. In the following paragraphs, we will explain the subsequent steps.

8.2. Step 2. Analyze the CE strategy for each part or entity

We analyzed all the strategies [67] proposed for each stage in this step. Next, we selected those related to the food industry that the confectionery fabric had implemented.

Mainly, we observed the high-quality recycling strategy, which refers to the recovery of materials in pure form without contamination and belongs to the material sourcing stage. In the case study, glucose is recycled from the confectionery waste generated in the manufacturing process.

The second strategy observed is material productivity which refers to the economic value generated by a unit of material input or material consumption. This strategy belongs to the manufacturing process, and it is related to high-quality recycling because the recycled glucose obtained from this process is used in the manufacturing process for completing the glucose ingredient of the confectionery product.

The resulting stages selected were materials sourcing and manufacturing, which correspond to stages 1 and 3, respectively, according to [67].

From the strategies analyzed in the second step, the indicators used in the simulation model are those which explain the strategy. For the first strategy, high-quality recycling, we propose as indicators: confectionery waste, recycled material, and cost of recycled material, all in kilograms per day. For the second strategy, material productivity, we propose the same indicator, material productivity (MP) measured in cost per kilogram, calculated as [93]:

$$MP = \frac{Production\ cost}{Material\ used} \tag{8.1}$$

The raw material used in this context is measured as the sum of virgin material (water, glucose, and sugar) and recycled material (syrup).

8.3. Step 3. Define the entities' attributes according to the CE strategies

In this step, we first defined the inputs and outputs of the stages selected in the previous step. Next, we observed the variables related to the strategies selected. Then, we defined the units of measurement in conjunction with the people involved in the industry. Finally, we obtained a list of the variables from each process: manufacturing and confectionery recycling (see Figure 8.1). These variables will be used in step seven when the simulation model is programmed [55].

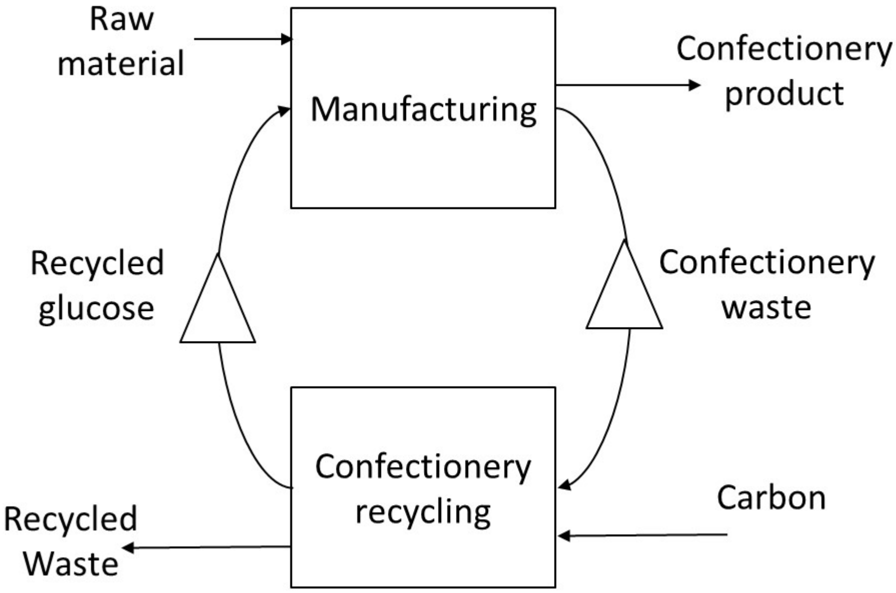


Figure 8.1: Processes connected with I/O variables.

8.4. Step 4. Define the agent-based model for selected entities

The fourth step is to define the agent-based model related to the entities or processes selected using the Modeling Agent systems based on the Institutional Analysis (MAIA) meta-model [49]. In this context, we found the MAIA model helps define the agent model and their actions in different structures, like physical and institutional. In the case study, we analyzed three agents: *quality inspector*, *product engineer*, and *operations director*. Each one makes different decisions concerning the selected processes, and these decisions affect the processes' performance and, consequently, the variables defined in the previous step.

It is essential to define the physical component agents make decisions [49]. In this case study, the physical component refers to the confectionery product.

8.5. Step 5. Define the dynamic behavior or a mathematical model of the environment variables

This step defines the dynamic behavior using a causal diagram (see Figure 8.2). We observe two reinforcement (R1 and R2) and two balance (B1 and B2) loops. The R1 loop involves manufacturing and recycling, which both increase their production if one of them rises. The R2 loop refers to the use of coal. If the production of recycled glucose grows, it will be necessary to use more coal. In the B1 loop, the use of glucose is affected by recycled glucose, and if the recycled glucose rises, less average glucose is used as raw material. Finally, the B2 loop associates the cost of the coal necessary to produce recycled glucose. If the cost of coal increases, so does the cost of the recycling process, which will cause a decline in the production of recycled glucose.

8.6. Step 6. Map a diagram connecting the entities or agents with the environment

It is crucial to locate the agents' actions in the physical structure; this step will facilitate programming the model in the software [49, 55]. We defined three agents in step 4: the *quality inspector*, *product engineer*, and *operations director*. The *quality inspector* will decide the waste quantity according to the quality yield of the confectionery product. The *product engineer* will determine

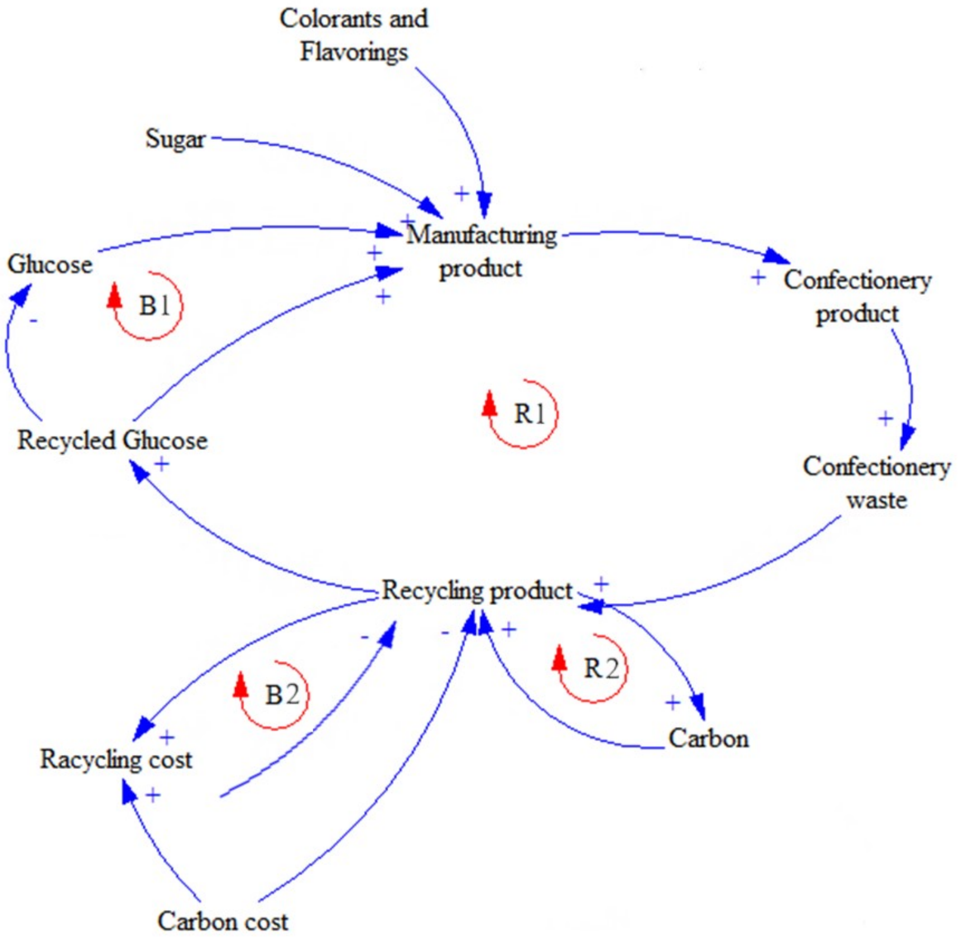


Figure 8.2: Dynamic behavior of the confectionery case study.

the quantity of recycled glucose used in the confectionery manufacturing. The *operations director* will decide when to recycle glucose taking into consideration the cost of raw materials like sugar, glucose, and coal.

8.7. Step 7. Build the simulation model in a software

To program the model, we used version 7.1 of Vensim for Windows. We built the model from the previous steps. We modeled a system using flow and level variables as System Dynamics theory suggests [46, 120]. We identified four stocks in the model: manufacturing, confectionery waste, recycling production, and recycled glucose. The input flows in the manufacturing stock are raw materials like glucose, sugar, packing, colorants, flavorings, and recycled glucose. The manufacturing's output flows are the confectionery product and the confectionery waste (i.e., the product that does not meet the quality standards).

In our case study factory, there is a stock where the confectionery waste is stored until the recycling process requires it. Once obtained, the recycled glucose is stored until the manufacturing process requests some glucose to produce confectionery. In the recycling process, some waste is represented as an output flow (see Figure 8.3).

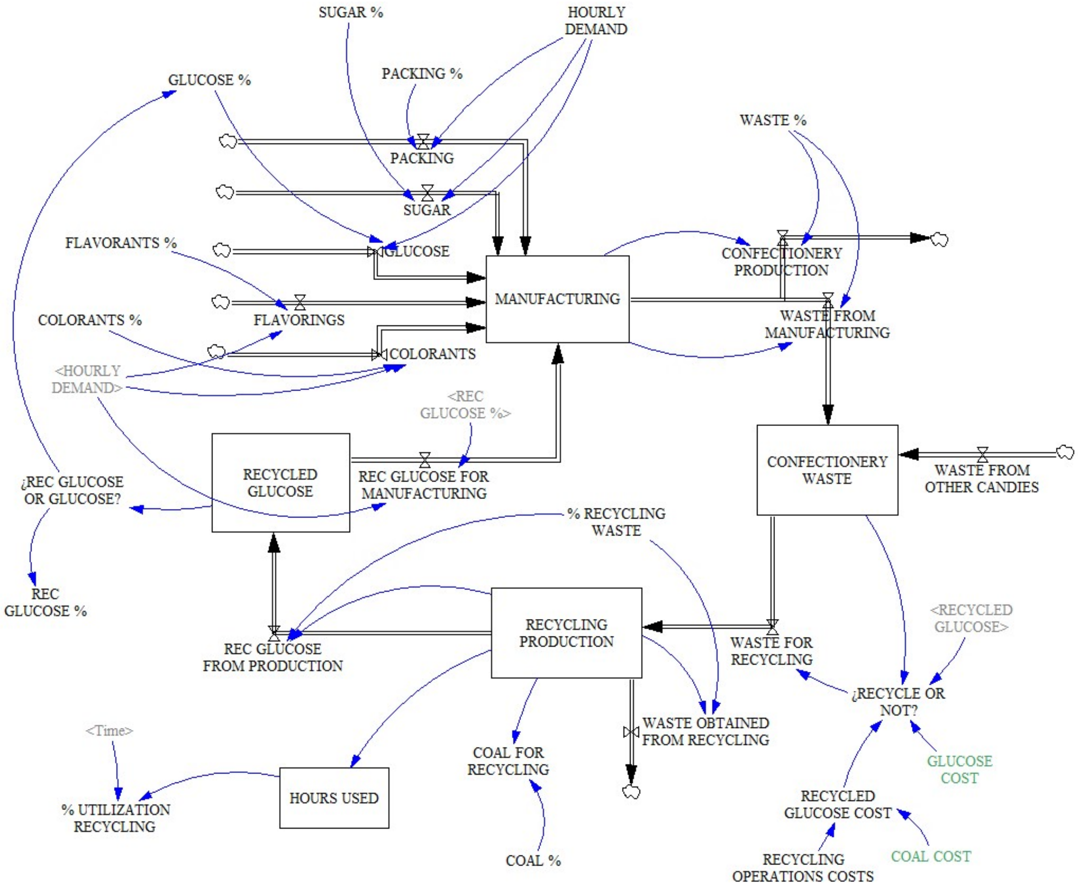


Figure 8.3: Simulation model of the confectionery case study.

8.8. Step 8. Define and execute performance tests

We executed the performance tests defined by [120] to calibrate the model. The manufacturing process is pulled by demand, around 400 kg/hr. As the confectionery waste is a portion of the production (around 4%), its behavior is proportional. The recycling process is not always on because its execution depends on three variables to be observed: (1) if there is enough confectionery waste to load the recycling machine, (2) if the recycled glucose cost is less than the average glucose, and (3) if there is not recycled glucose in stock. These conditions oscillate the system behavior, and the recycling production works at only 20% of its capacity (see Figures 8.4 and 8.5).

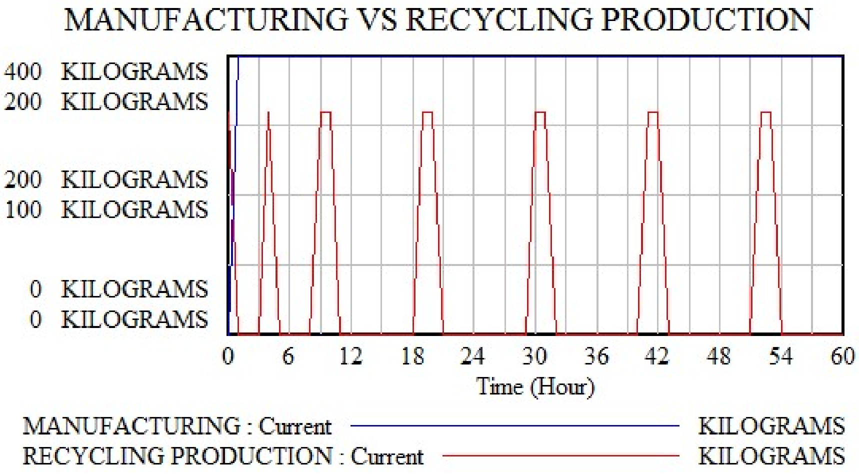


Figure 8.4: The behavior of the confectionery manufacturing and recycling production

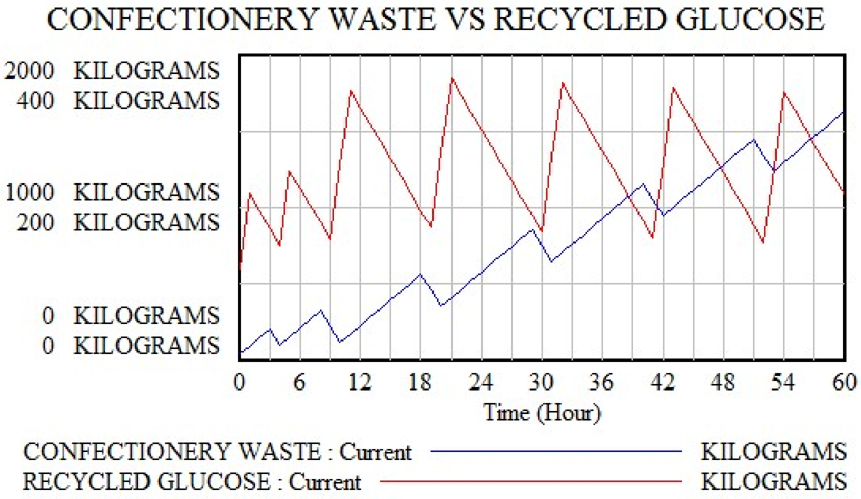


Figure 8.5: The behavior of confectionery waste vs recycled glucose stocks.

8.9. Step 9. Formulate and evaluate policies

According to the four perspectives proposed for assessing CE, we employ service-dominant logic (SDL) and ecosystem services (ES) to formulate policies that comply with the CE policies.

We proposed some policies described in the following paragraphs to evaluate the strategies analyzed in step 1 and the results obtained in step 8.

a) Policy 1: Marketing the recycled glucose

Since the confectionery production uses a low amount of recycled glucose, this is accumulated in stock, and the utilization of recycling production is around 20%. If half of this recycled glucose were sold to other industries, the stock would decrease sometimes, and the utilization percentage will increase to 35% (see Figure 8.6). According to CE principles, the impact of this policy must be analyzed in several approaches (economic, social, and environmental). Furthermore, the implementation of this policy requires an analysis of service logistics and marketing to take advantage of the recycling process.

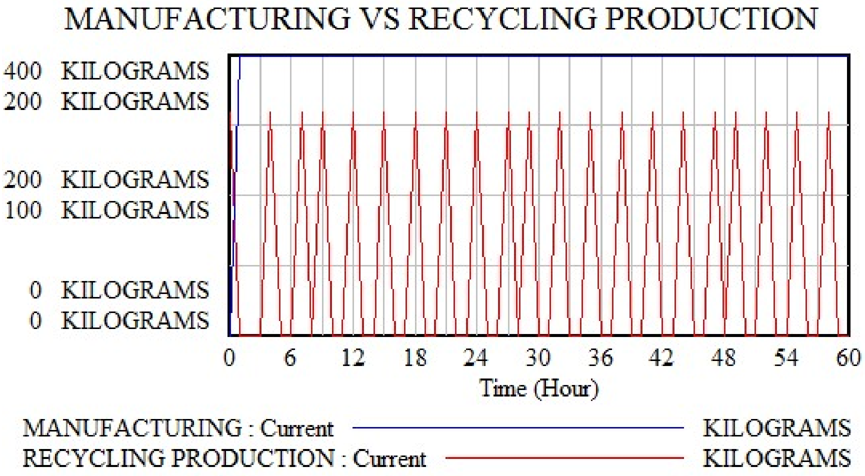


Figure 8.6: The behavior of recycling production when this is sold to other industries.

b) Policy 2: Obtain confectionery waste from other industries

We propose a second policy where confectionery waste from other industries is recycled to increase recycling production. If we obtain 40 kilograms/hr of waste, the utilization percentage increases to 60% (see Figure 8.7).

These policies' economic, social, and environmental impacts must be evaluated, contrasting the organization's current situation. This analysis is out of the scope of this research. However, the simulation of these impacts is possible using system dynamics and agent-based modeling.

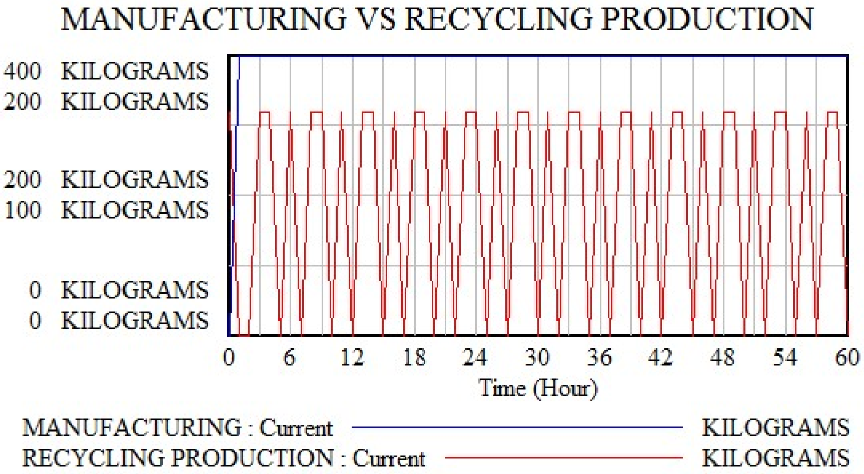


Figure 8.7: The behavior of recycling production when waste from other industries is recycled.

8.10. Conclusions

This chapter briefly presented the steps from two to nine of the methodology proposed and analyzed the food industry in the Mexico context. In chapter 7, we evaluated the circularity of our case study using the CEIP tool as the first step of our methodology. The results obtained were used to define the stages to be analyzed in the value chain. Then as a second step, we analyzed the strategies related to each stage and defined the entities' attributes involved.

We continued implementing each step to obtain the simulation model. We found that the recycling production oscillates due to the decisions made regarding the existence of confectionery waste, raw material costs, and operational resources. For the confectionery management, it was essential to know the utilization percentage of the recycling production process, then we considered it as our output variable. The value of the utilization changed according to the policies proposed.

9. Circular Economy Measurements

9.1. Introduction

Circular economy (CE) mainly promotes virgin material minimization and clean technologies. While CE also encourages the elimination of waste from the value chain as a benefit of reducing material cost and resource dependence, there are no specific guidelines to sectors on how to implement CE. Besides, CE omits the feature of semi-recyclability when choosing a raw material for the production process [115].

Attending this situation, in [56], we explained the pertinence of circular economy in México's linear processes and the importance of developing a simulation tool to prove some policies before implanting them in the real world: a hybrid service simulation model (HSSM). We visualized the tools and concepts to design the simulator like service-dominant logic, ecosystem services, agent-based modeling, and system dynamics. Furthermore, we proposed a methodology that consists of nine steps to follow for developing the HSSM based on circular economy strategies. These approaches allowed us to model a three-dimensional system (social, physical, and ecological) and visualize some future consequences. We prove the methodology in a first case study, where we implemented the first steps of the methodology: a food bank located in Jalisco, Mexico [55].

From the reviews obtained in the former publication [55], we implemented the methodology in a second case study, a confectionery factory in Jalisco, México. This confectionery factory recycles the caramel waste obtained from manufacturing. They use a process where the caramel is filtered, producing a syrup ready to use in the main process.

Modeling the HSSM in the confectionery factory has involved customer participation. They are operations manager, operations supervisor, recycling operator, quality manager, and costs manager in this case. There was an active contribution of all participants, which guarantees the real-world abstraction of the model. CE was a new concept for them, including the circular indicators like circularity index (CI) [25], material circularity indicator MCI [64], and circular economy indicator prototype (CEIP) [17]. For this reason, we proposed calculating the break-even point of their recycling process as an economic measure of the recycling process viability, considering that stakeholders were familiar with this term.

Besides, we chose circularity index (CI) using the web tool called C-indicators advisor developed by [112]. It uses circular characteristics like implementation level, CE loops, CE perspective, and CE performance to propose those circular indicators suited for the particular problem attended [112]. This document describes CI and break-even point calculus, and we present the results obtained.

9.2. CE measures

In a pure sense, CE is a future in which waste no longer exists, where material loops are closed, and products are recycled indefinitely. In the actual world, that is impossible; every loop needs the energy to overcome the dissipative losses (in quantity and quality) generated in every stage of the circular stage [25].

The Ellen MacArthur Foundation describes the CE as a ”new economic model which seeks to ultimately decouple global economic development from finite resource consumption” [82]. From this vision, there are two implicit premises: (1) transforming from a linear economic system to a circular one will significantly reduce the environmental impacts associated with resource use, and (2) these reductions will facilitate economic growth without environmental impacts of resource depletion [25].

From these two premises, we propose the circularity index (CI) and Breakeven-point (BP) as two simple measures to assess a circular economy implementation in a linear supply chain. We will explain these indicators in the following paragraphs.

9.2.1 Circularity index

CI is a scale ranging from linear at one end to circular at the other. This scale considers the loss of material quantity and material quality.

a) Material quantity

Conserving the material quantity means that everything that goes into the economy must equal what comes out, and there is no material loss during transformation in a perfect CE. In practice, materials are leaked from recycling loops and require the addition of new material to maintain circularity [25].

There are two specific concerns related to material losses: material stock dynamics and dissipative material losses. The first refers to product lifetimes creating a lag between production and disposal and it takes several decades to recover material outputs that match input demands. The second explains the quantity of material recovered from product waste [25, 57]. A simple ratio (α) describes the effects of these two issues. An α value of 1 describes a perfect circularity of material quantity [25].

$$\alpha = \frac{\text{recovered end-of-life material}}{\text{total material demand}} \tag{9.1}$$

b) Material quality

Many recycling processes degrade and destroy the material structure, requiring energy to restore material quality. A simple ratio, β, can quantify the energy needed for material recovery relative to the energy required for primary material production from virgin resources [25].

$$\beta = 1 - \frac{\text{energy required to recover material}}{\text{energy required for primary production}} \tag{9.2}$$

A value of 1 for β would describe perfect circularity of material quality, an economy in which no loss of material quality occurs with each recovery cycle.

These ratios are then multiplied to obtain the circularity index (CI). Which CI = 1 refers to a theoretical circularity.

$$CI = \alpha\beta \tag{9.3}$$

9.2.2 Break-even point

The break-even point is an essential reference to the business's long-term planning, and it is helpful to know it for sales, production, operations, and investment recovery. In this sense, the break-even is when the total entry of the organization is equal to the total expenses. This mean that at the break-even point, there is no profit, or this is zero [87].

To calculate the break-even point, we use the terms: unit sale price (P) is the final value of the products or services to be sold. Variable costs (VC) are the costs that tend to vary according to the business activity level. Total fixed costs (TFC) are the costs in a period, and they are not affected by the fluctuations in the business activity levels. Turnover (Q) is the number of products produced or sold by an organization, while Contribution margin (CM) is the unit sale price less variable costs. The Break-even point (Q_e) is the product sales volume when the utility is zero [87].

$$Q_e = \frac{TFC}{P - VC} = \frac{TFC}{CM} \tag{9.4}$$

According to the confectionery case study, we explain the calculus of these indicators in the next paragraphs.

9.3. Case study: confectionery factory

We consider the recycling process a separate business unit of the confectionery factory; even the own managers consider this unit part of the business. To obtain the variables described by the indicators, first, we calculate the costs per kilogram of caramel recycled. Then we calculate the break-even point and the circularity index. We contemplate all the prices and costs in Mexican pesos (MXN).

9.3.1 Circularity index

We count four indicators to determine the circularity index: recovered end-of-life material, total material demand, the energy required to recover the material, and energy required for primary production. The first two indicators are required for α calculus and the other two for β. In our case study, as the caramel is a biological product, the first indicator, recovered EOL material, is the waste generated by the confectionery production, which is the 4%. On the other hand, the total material demand for caramel is around 890 kg per hour, then $\alpha = 0.04$, which measures the circularity of material quantity.

The circularity of material quality refers to the energy employed in the production and recycling process. The confectionery process absorbs the energy required to recycle material. The energy consumed by the recycling process is around 1% of the total energy in the factory; thus, $\beta = 0.99$. In this sense, $CI = 0.0396$, is a low value; if the factory could get more caramel scrap from other industries, the CI would increase, as shown in Fig. 9.1.

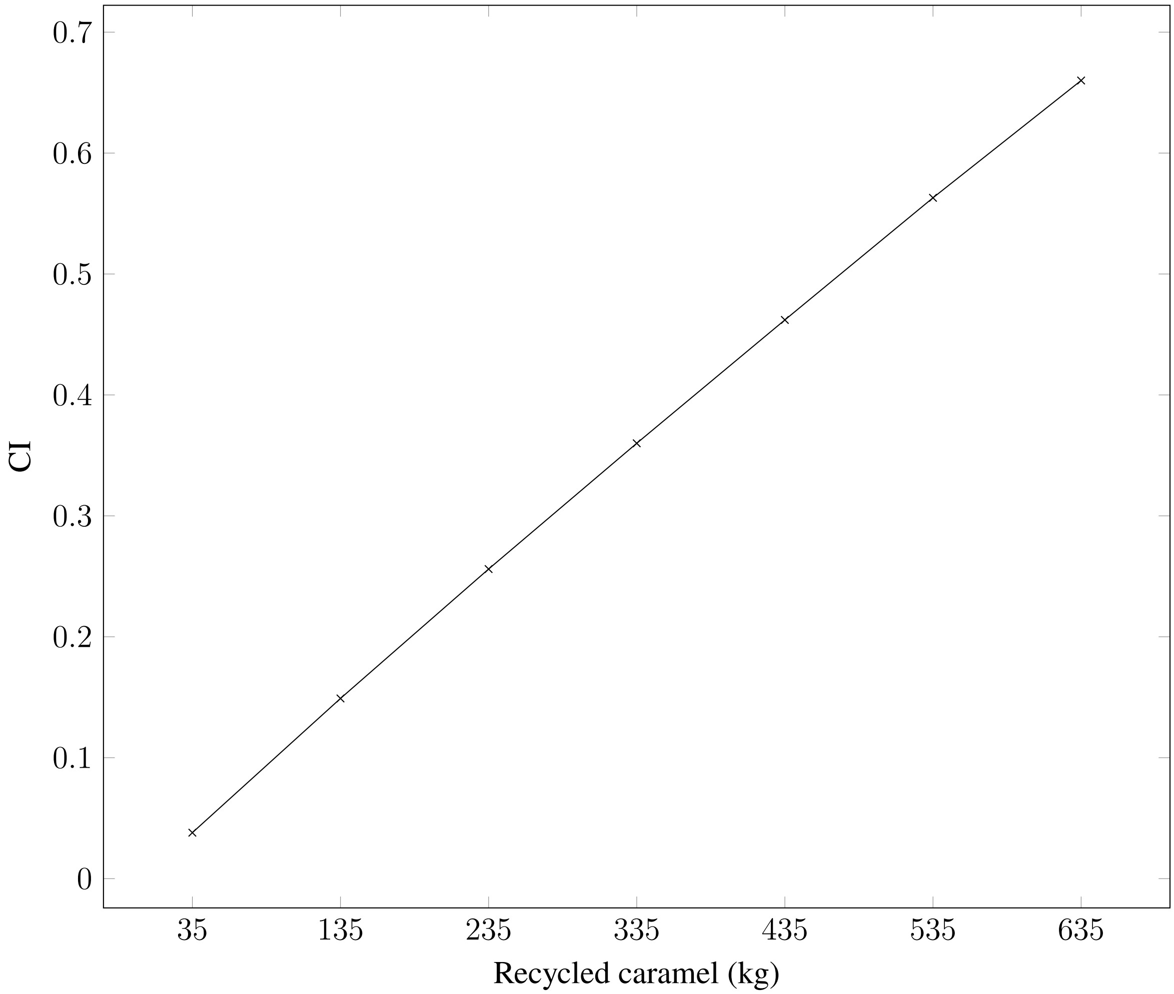


Figure 9.1: Circularity index in the caramel recycling process.

9.3.2 Break-even point

To calculate the recycling process's break-even point (Q_e), we analyzed their inputs like water, caramel scrap, activated carbon, sodium bicarbonate, filter helper, and paper filters. We consider the caramel scrap price the same as it is sold for other industries, like cattle breeders or beekeepers, around \$4.00. These materials, excluding caramel scrap, are around \$1.73 per kilogram. We considered the fixed costs as \$20,000.00. The sale price (P) is \$14.70, which is the cost of the raw material for confectionery production. Then Q_e value under these conditions is 2,229.65 kg (see Table 9.1). In Fig. 9.2, we can observe four different sales scenarios in kg and break-even points. The caramel production process uses around 4,500 kg of recycled syrup per week; then, the BP is overtaken. It is important to study the total fixed costs to calculate the recycling process BP more accurately.

TABLE 9.1. CALCULUS OF BREAK-EVEN POINT

Variable	Value
Sale price (P)	\$14.70
Variable costs (VC)	\$5.73
Total Fixed costs (TFC)	\$20,000.00
Break-even point (Q_e)	2,229.65 kg
Sales Q_e	\$32,775.92

9.4. Conclusions

There are many circularity indicators; however, not all of them can be used in every implementation. According to the case study, choosing those that meet specific characteristics is relevant. In the confectionery case study, the reasons for adopting the circularity index and break-even point were the kind of available data and the customer's requirements to measure the Q_e of the recycling process. We calculated these indicators in the confectionery factory's present conditions and extrapolations.

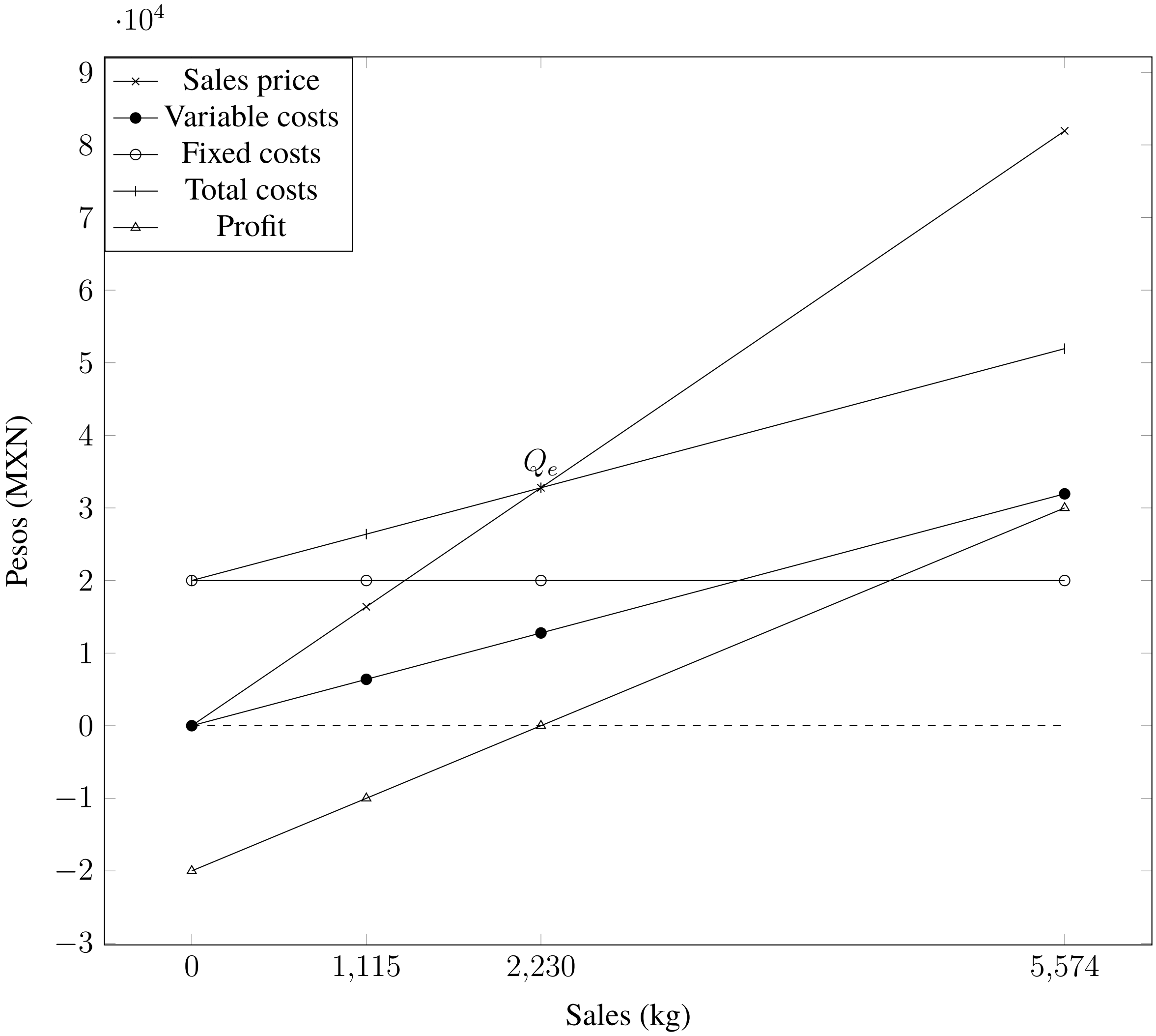
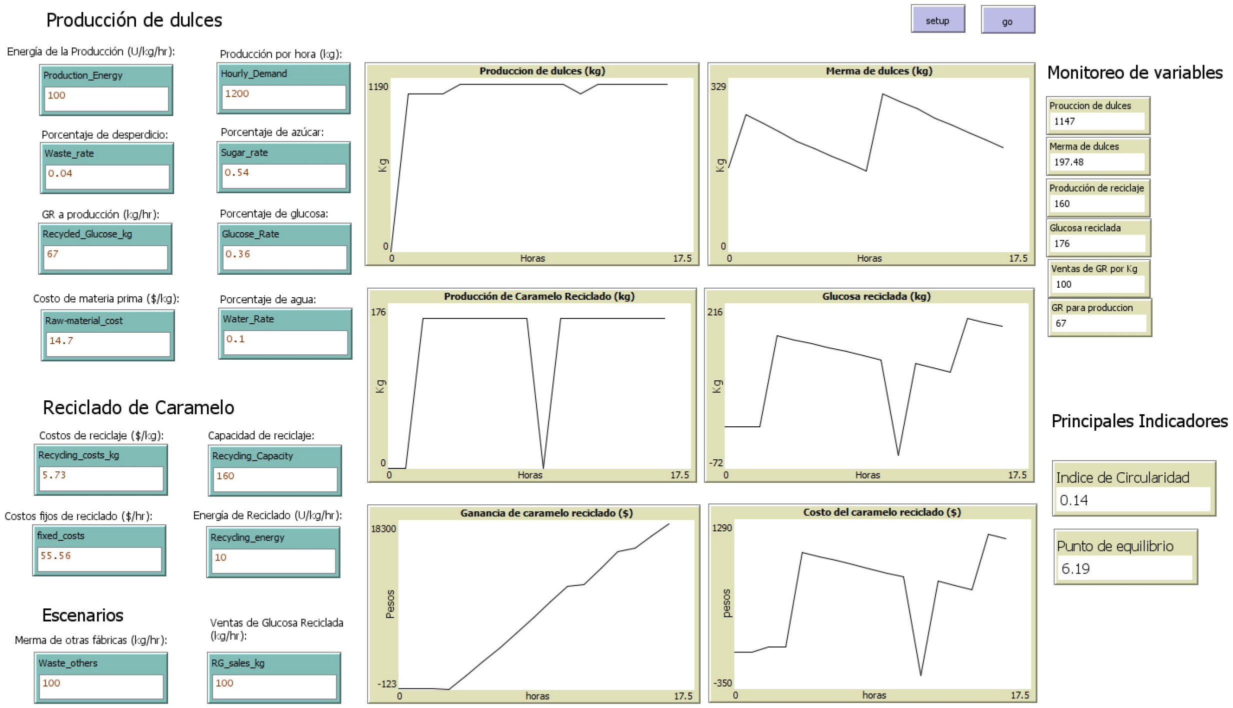


Figure 9.2: Break-even point in recycling caramel process.

10. Scenario Analysis

10.1. Introduction

Due to confectionery products being diverse, the entire supply chain of confectionery products is complex: raw material supply, specialized equipment acquisition, tasty and nutritious recipe design, product packing, commercialization strategies, and the final disposal of confectionery products. A system-view approach across the confectionery supply chain is required from raw material use to the final disposal, considering a cradle to grave assessment to attend to the transition towards environmental sustainability [88]. We found significant growth in the confectionery waste valorization in the European Union. For example, the production of bioethanol and biogas as bioenergy products and bio-based and biodegradable polymers [58].



Producción de dulces

Energía de la Producción (U/kg/hr): Production_Energy 100

Producción por hora (kg): Hourly_Demand 1200

Porcentaje de desperdicio: Waste_rate 0.04

Porcentaje de azúcar: Sugar_rate 0.54

GR a producción (kg/hr): Recycled_Glucose_kg 67

Porcentaje de glucosa: Glucose_Rate 0.36

Costo de materia prima ($/kg): Raw-material_cost 14.7

Porcentaje de agua: Water_Rate 0.1

Reciclado de Caramelo

Costos de reciclaje ($/kg): Recycling_costs_kg 5.73

Capacidad de reciclaje: Recycling_Capacity 160

Costos fijos de reciclado ($/hr): fixed_costs 55.56

Energía de Reciclado (U/kg/hr): Recycling_energy 10

Escenarios

Merma de otras fábricas (kg/hr): Waste_others 100

Ventas de Glucosa Reciclada (kg/hr): RG_sales_kg 100

Monitoreo de variables

Prouccion de dulces 1147

Merma de dulces 197.48

Producción de reciclaje 160

Glucosa reciclada 176

Ventas de GR por Kg 100

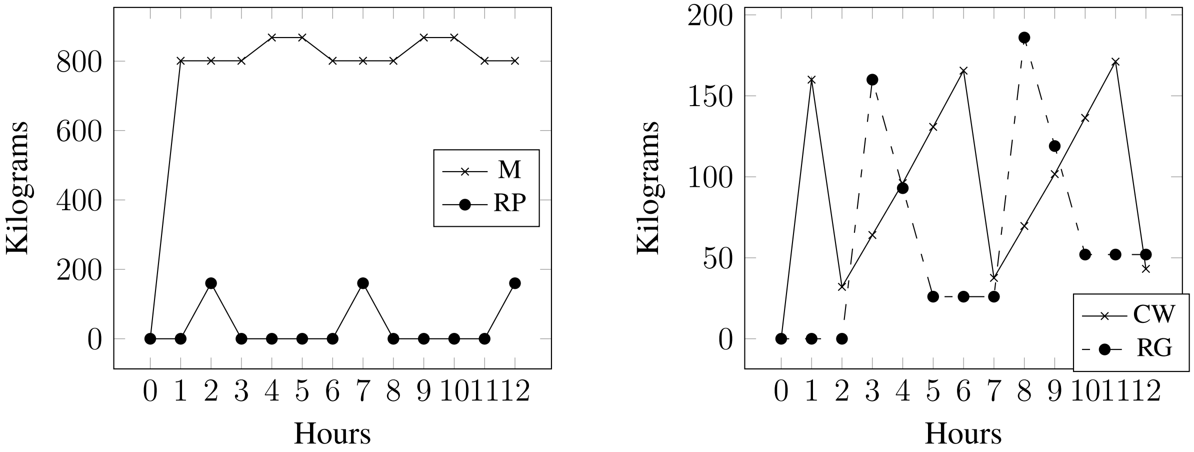
GR para produccion 67

Principales Indicadores

Indice de Circularidad 0.14

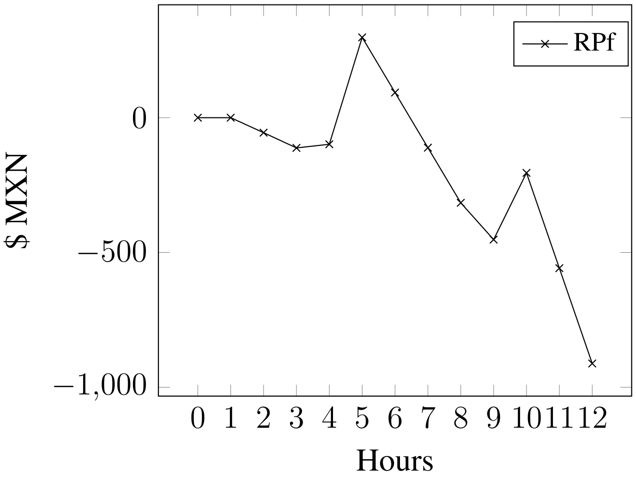
Punto de equilibrio 6.19

Figure 10.1: Confectionery simulator implemented in NetLogo.



(a) Manufacturing (M) vs. Recycling production (RP) processes

(b) Confectionery waste (CW) vs. recycled glucose (RG) stocks



(c) Recycling profit (RPf)

Figure 10.2: Performance of primary variables in the hybrid simulation model.

10.2. Step 8: Performance Test Execution

For the scenario analysis, we implemented the simulator in Netlogo [139] (see Fig. 10.1). Next, we executed the performance tests defined by [120] and [104] to calibrate the model. The manufacturing process is pulled by demand, around 400 kg/hr. As the confectionery waste is a portion of the production (around 4%), its behavior is proportional. The recycling process is not operating all the time because its execution depends on three variables: (1) if there is enough confectionery waste to load the recycling machine, (2) if the recycled glucose cost is less than average glucose, and (3) if there is no recycled glucose in stock. These conditions oscillate the system behavior, and recycling production can operate only to 25% capacity (Figure 10.2). Graph 10.2a shows that when recycled glucose is produced, manufacturing production increases. Next, graph 10.2b shows the behavior of confectionery waste and recycled glucose stocks. Finally, graph 10.2c describes the profit calculated from the raw material price and recycling total costs.

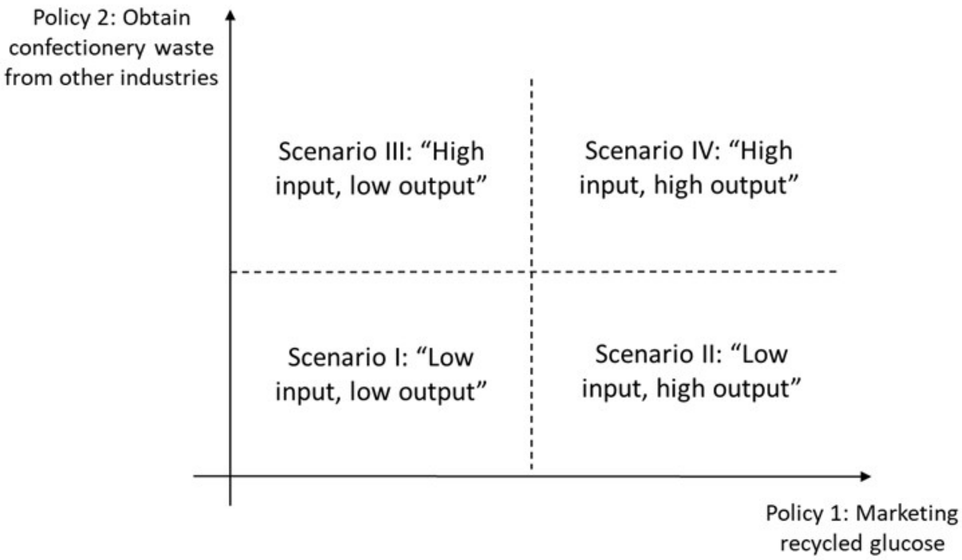


Figure 10.3: Four scenarios are proposed from two policies.

10.3. Step 9: Policy Formulation and Evaluation

According to the four perspectives proposed for assessing CE in chapter 2, we formulated policies that comply with CE principles based on service-dominant logic (SDL) [131] and ecosystem services (ES) [86] theories. Evaluating the strategies analyzed in step one and the results obtained in step eight, we proposed two policies: (i) marketing the recycled glucose; and (ii) obtaining confectionery waste from other industries to increase the recycling production. We evaluated both policies in four scenarios according to the utilization rate of the recycling process. The first scenario, entitled ”low input, low output,” supposed that there was a low amount of waste from other factories and a low sale of recycled glucose. The second scenario, ”low input, high output,” presumed that the waste acquired from other industries was low, but the recycled glucose sales were high. The third scenario, entitled ”high input, low output,” estimated that the waste received was low, but the sales of recycled glucose were high. Finally, the fourth scenario, called ”high input, high output,” estimated that the acquisition of waste and recycled glucose sales were high (Figure 10.3).

TABLE 10.1. VARIABLES OBSERVED IN THE PROPOSED SCENARIOS.

	Scenarios			
	I. LI, LO	**II. LI, HO**	**III. HI, LO**	**IV. HI, HO**
Confectionery waste	83.16 kg	91.2 kg	4,773.88 kg	4,773.88 kg
Recycled glucose	800 kg	800 kg	1760 kg	1760 kg
Recycling utilization	42%	42%	100%	100%
Cost recycled glucose	\$6,448.29	\$8,081.34	\$26,079.27	\$19,489.77
Benefits	\$2,432.22	\$449.34	-\$9,024.9	-\$372.3

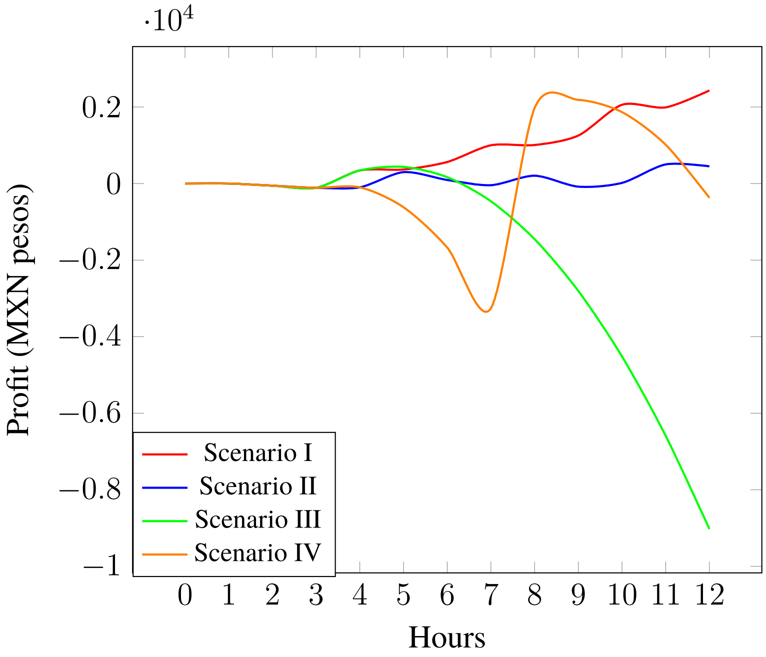


Figure 10.4: Profit performance from the four scenarios related to the two policies: marketing recycled glucose and obtaining confectionery waste.

Several variables were proposed to evaluate the feasibility of the recycling operation as a separate business unit from the primary process. These variables are confectionery waste, recycling glucose production, cost of recycled glucose, break-even point (Q_e), recycling process utilization, and benefits. We compared these variables in the scenarios proposed (Table 10.1).

Thus, the first scenario had the highest benefits due to the cost of recycling glucose, and the recycling process utilization was 42% capacity. On the other hand, the third scenario had the lowest benefits and the highest cost of recycled glucose due to the high confectionery waste quantity received from other industries and low sales, causing the recycling utilization to be at maximum capacity (100%) (Figure 10.4). The user determines the recycled glucose price. In the simulation results shown in Figure 10.4, we considered the recycled glucose price equal to the cost of raw material so that the use of recycled caramel could be viable. If the sale price of recycled glucose increases, the benefits of the four scenarios also increase.

10.4. Model Validation

Finally, we performed a series of interviews with recycling process decision-makers (operation manager, recycled-process owner, and quality manager) during the methodology implementation. At the end of the procedure, a questionnaire was presented, and their feedback was recorded. Key elements from the questionnaire were:

- Model purpose: the model allowed participants to understand the process behavior and their interactions. Furthermore, they identified the variables and factors that influence the entire process and how they are related.

- Model results: the model lets shareholders know the recycling process costs more precisely because the calculus was based on activity costing and not only on average costs.

- Circular economy view: the operational manager attempted to minimize the usage of the recycling process before the simulator implementation. However, after evaluating the results obtained, like costs and utilization, he decided to review the recycling process operation.

- User interface: the user interface was redesigned to be more friendly and understandable for the process owners to facilitate access to the input and output variables.

- Simulator usage: the shareholders considered outsourcing the model design service with a more straightforward user interface for daily planning during the operational process, measuring the economy's circular impact and other business variables.

10.5. Conclusions

As SDL and ES suggest, the methodology was designed to find a co-creation value between the main actors (i.e., stakeholders and environment) involved in the ecosystem. The case study implementation demonstrated through the four-scenario analysis that an economic benefit for the stakeholders could exist if the recycled glucose were commercialized. The caramel waste disposed of in landfills could be reduced regarding the environment. The process owner decided to evaluate the results shown in the simulator and consider the recycled syrup commercialization as a future project.

In the simulator, we implemented the CI and Q_e calculus. These indicators depend only on primary production, and for these reasons, they stayed constant during the scenario simulation: (Q_e) = 6.19, and CI = 0.14.

We found that in addition to evaluating circular economy strategies, the simulator allowed partners to understand the operation of the recycling process and visualize all the variables involved in the system. The reason is that the simulation model was developed using ABM and SD simulation methods, and understanding the system's behavior and performance is one of their main objectives.

11. Literature Review Update

11.1. Introduction

Systems modeling has been widely used to analyze and understand the behavior of complex systems. There are several methodologies and tools to obtain a dynamic model or a partial representation of a system to evaluate the consequences of some decisions before implementing them in the real world. The model is designed and computationally implemented depending on the system's scope and limitations. We can find as many systems in the world as we can observe around us. A system is ”a collection of possibly interacting, related components that exhibits emergence.” [119] The scientific community has developed several methodologies and theories to study systems from different points of view, depending on their application.

In this research, we applied the system theory to study the implementation of the Circular Economy (CE) concept in the real world, considering other four concepts derived from system theory: service-dominant logic (SDL), ecosystem services (ES), agent-based modeling (ABM), and system dynamics (SD). The conjunction of these tools allowed us to design a methodology for developing a simulation model for any small and medium enterprise (SME) that wanted to analyze CE strategies inside their organizations [56].

At the beginning of the Ph.D. program (2017), we did a literature review concerning these tools and concepts. After four years, we decided to do a second review to complement the former and visualize the future work regarding the methodology proposed. The following paragraphs describe the most recent research related to the tools. Furthermore, we compare the methodology proposed with a similar framework in section 11.7. Finally, we conclude with the most relevant findings and the future work associated with the research.

11.2. Circular Economy

Ellen MacArthur Foundation (EMF), launched in 2010, generates original research related to a circular economy (CE) that can contribute to solving climate change and biodiversity problems by focusing on the circular economy principles implementation into practice [82]. Four years ago, when we analyzed the literature review concerning the circular economy, we found that EMF had published different reports related to this topic. In the last years, they have reported research related to artificial intelligence, electronics consumption, the future of plastics and textiles, food chain redesign, packaging, and policies, among others. [81].

The circular economy has been well adopted in the European Union (EU) by governments and private industry through the report named 'A new Circular Economy Action Plan For a cleaner and more competitive Europe' [22] published on November 3rd, 2020. However, in Latin America, there is an absence of regulations and institutions that allow circular economy implementation in the long term [9].

In Mexico, there are circumstances to analyze and deal with to implement a circular economy in the productive processes of the country. Dieleman and Martinez established some elements to explore: market and trend conditions; competitiveness and productivity; the political and regulatory framework; education, training, knowledge transfer; and learning culture [28]. Similarly, Cantú et al. identified nine categories of barriers and enablers in a literature review for a CE's successful implementation in Mexico: (1) user behavior, (2) regulatory, (3) infrastructure, (4) economy and competitive markets, (5) supply chain, (6) knowledge, (7) financial, (8) organizational, and (9) product and material characteristics [15].

Particularly, last August, Jalisco's government announced a new model for solid waste management based on CE principles, where one of their initiatives is the implementation of Integral Centers of Circular Economy (CIEC in spanish) around the state. These centers will receive urban solid waste in order to separate, treat and value it for reuse [37].

On the other hand, in 2019, an agency was created to attend to the sustainability problems in Mexico: Maken Sustanability. The organization headquarters are in Guadalajara. Its mission is "to help stakeholders make the best decisions, through international methodologies and road maps that help the company integrate social, environmental and good governance aspects to ensure sustainability [83]."

11.3. Service-dominant logic (S-D Logic)

S-D Logic has emerged as a framework that describes service as the fundamental basis of economic and social exchange [135]. Vargo et al. published a paper (2020) that summarizes the five axioms of S-D logic and discusses the conceptualization of S-D logic and other perspectives like service logic, customer-dominant logic, service science, and goods-dominant logic (see Fig. 11.1).

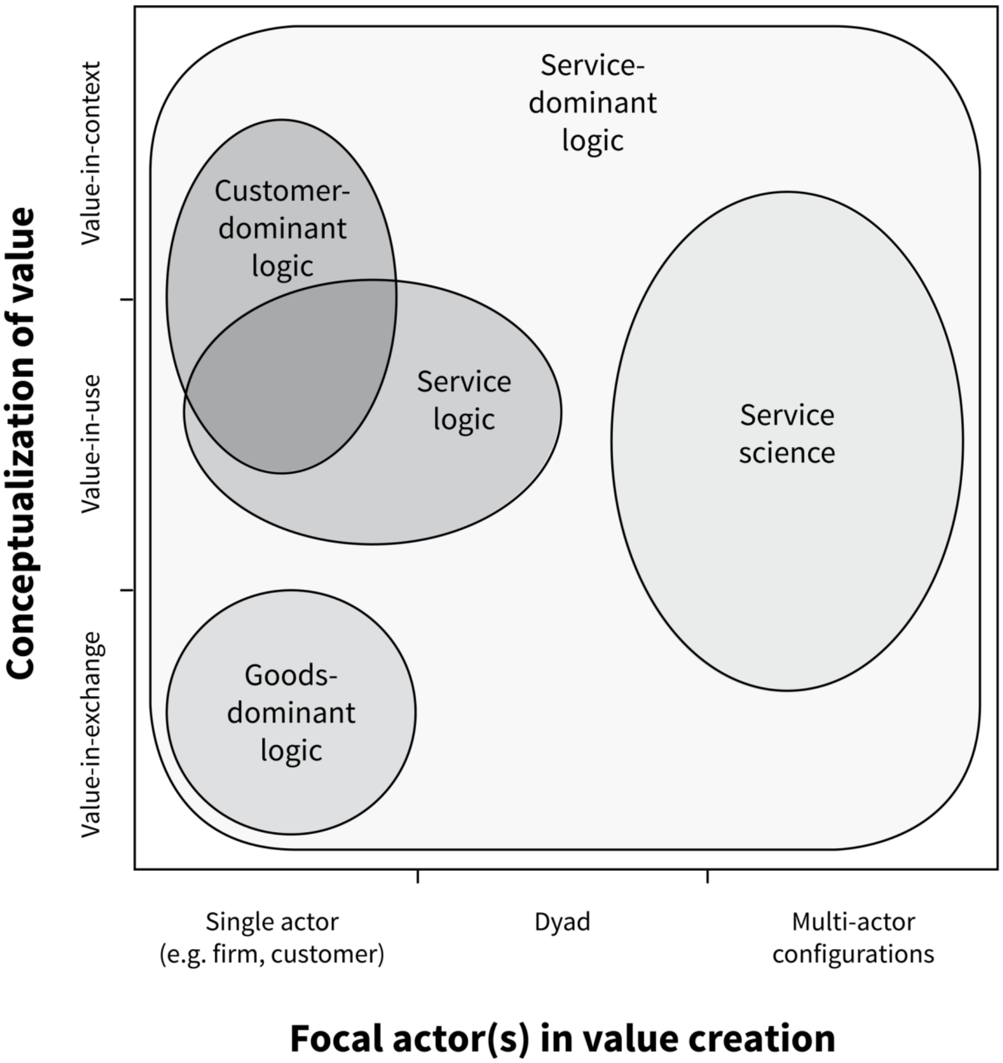


Figure 11.1: Comparing the conceptualization of value and focal actors of S-D logic and related perspectives (taken from [132]).

Besides, in this paper, they identified the applications of S-D logic they call ”vectors of diffusion in diverse disciplines” (see Fig. 11.2), where we can find the ecosystem services [86]. They conclude this discussion with the implications of applying SD-logic: transcendence, accommodation, and transformation. They emphasize these implications in the ecosystem services point of view, sustainability as ”the well-being and the viability or survivability of the system”, and the governance regulations that S-D logic facilitates [132].

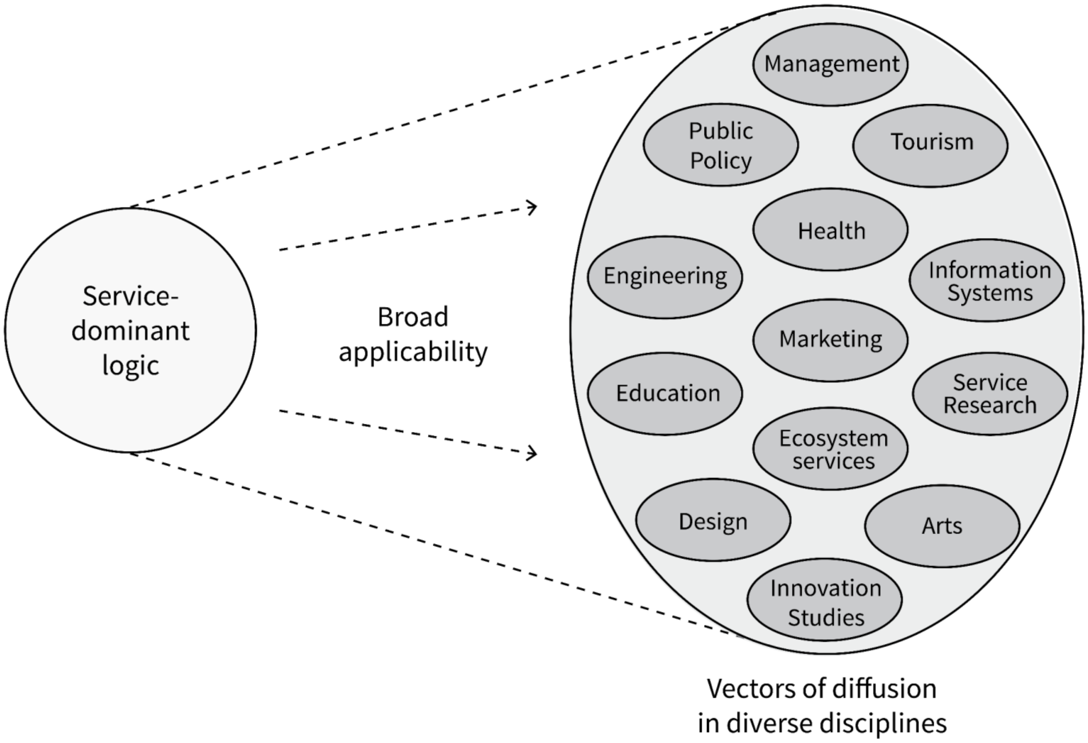


Figure 11.2: The broad applicability of S-D logic and existing diffusion vectors in diverse disciplines. (taken from [132]).

Regarding circular economy (CE), this year (2022), Vargo published an opinion paper comparing the goods-dominant logic, that CE proposes for the reuse of products versus service-dominant logic, where the value is obtained through the application of resources in a service-for-service exchange called a service ecosystem. These ecosystems need to be regulated by institutions to grant value co-creation [131].

Some authors have published innovation frameworks to implement the circular economy in business models using the S-D logic ([107, 118, 124]). Moreover, [50] proposes a qualitative evaluation method of service-dominant business models.

11.4. Ecosystem Services

As a discipline derived from S-D logic, Ecosystem Services (ES) has conceived nature as an actor in a service ecosystem (a forest or a lake), where it co-creates value for other actors (humans). As nature delivers services, according to the S-D logic, it needs to obtain services from the others [86].

The Consumer-Driven Business Ecosystem Research and Development (CD-BERD) model for new product and service innovations in the forest sector adopts the classical "technology-push and demand-pull" innovation model. It considers consumer values, enabling resources and dominant logic, and information flow during each phase of the research and development process leading toward new consumer-driven solutions [61].

Regarding regulations and institutions, [1] identifies and visualizes the nexuses between urban challenges (UC), ecosystem services (ES), and nature-based solutions (NBS) in order to support the mainstreaming of NBS in urban policies and sustainable and resilient urban planning interventions and strategies.

On the other hand, [18] made a literature review of ES frameworks and found that very little of the ES literature includes valuation of biophysical change (2.4%), despite many biophysical studies of services (24%). They propose as future research the integrative biophysical-social research that characterizes ES change and is coupled with multi-metric and qualitative valuation and context-appropriate decision-making.

11.5. Agent-based modeling

Agent-based modeling (ABM) has been used to explain the system behavior by observing the individual performance of the agents involved in the system. We found some research related to natural ecosystems that use ABM; for example, [97] presents a model that couples individual epiphytes' dispersal, growth, and mortality. They use substrate dynamics, obtained from a three-dimensional functional–structural forest model, allowing the study of forest–epiphyte interactions. Similarly, in [66] have designed an agent-based model to study the cultural evolution of sustainable behaviors. Besides, [91] presents a Bottom-up building stock model (BSM) based on an agent-based modeling approach (ABM) that models stock development in terms of new construction, retrofit, and replacement by modeling individual decisions on the building level.

Furthermore, [141] adopts an enterprise input-output model providing a cost–benefit analysis of industrial symbiosis (IS) integrated into an agent-based model to simulate how companies share the total economic benefits stemming from IS.

One of the most widely used tools for describing Individual ABM is the Overview, Design concepts, and Detalis (ODD) protocol [52]. Recently, the authors published a paper in which they discuss its limitations: the limited availability of guidance on how to use ODD; the length of ODD documents; limitations of ODD for highly complex models; lack of sufficient details of many ODDs to enable reimplementation without access to the model code; and the lack of provision for sections in the document structure covering model design rationale, the model's underlying narrative, and how the model's fitness for a purpose is evaluated [51].

11.6. System Dynamics

System Dynamics (SD) emerged from Philosophy, Mathematics, Logic, Biology, and Social Sciences theories. In [117], the author describes of the system theory evolution from its origins until the last findings, passing through three important threads: Dynamic and Evolutionary Systems thread, Cybernetics thread, and Soft Systems (interpretative) thread. The application fields of system theory vary from operations research, engineering and computing, economics, sociology, organization and management, political science, pedagogy, anthropology, ethics, aesthetics, semiotics, ecology, biology, medicine, psychology and psychiatry, and cognitive science (see Fig. 11.3).

The use of system dynamics (SD) in urban sustainability can be observed in [4], in which a summary of the simulation models based on SD is presented. Sustainability theories like energy, waste management, and transport are applied to design a simulation model for urban sustainability (SUSTAIN), integrating subsystems like industries, services, transport, population, and land use.

Diverse applications have been found using SD. For example, [40] presents the research ideas and conceptualization of a framework to determine the factors that influence the effectiveness of a personal healthcare response monitoring system from a systems engineering perspective. The Systems Dyanmics Society (SDS) has collected several case studies, which can be found in [123].

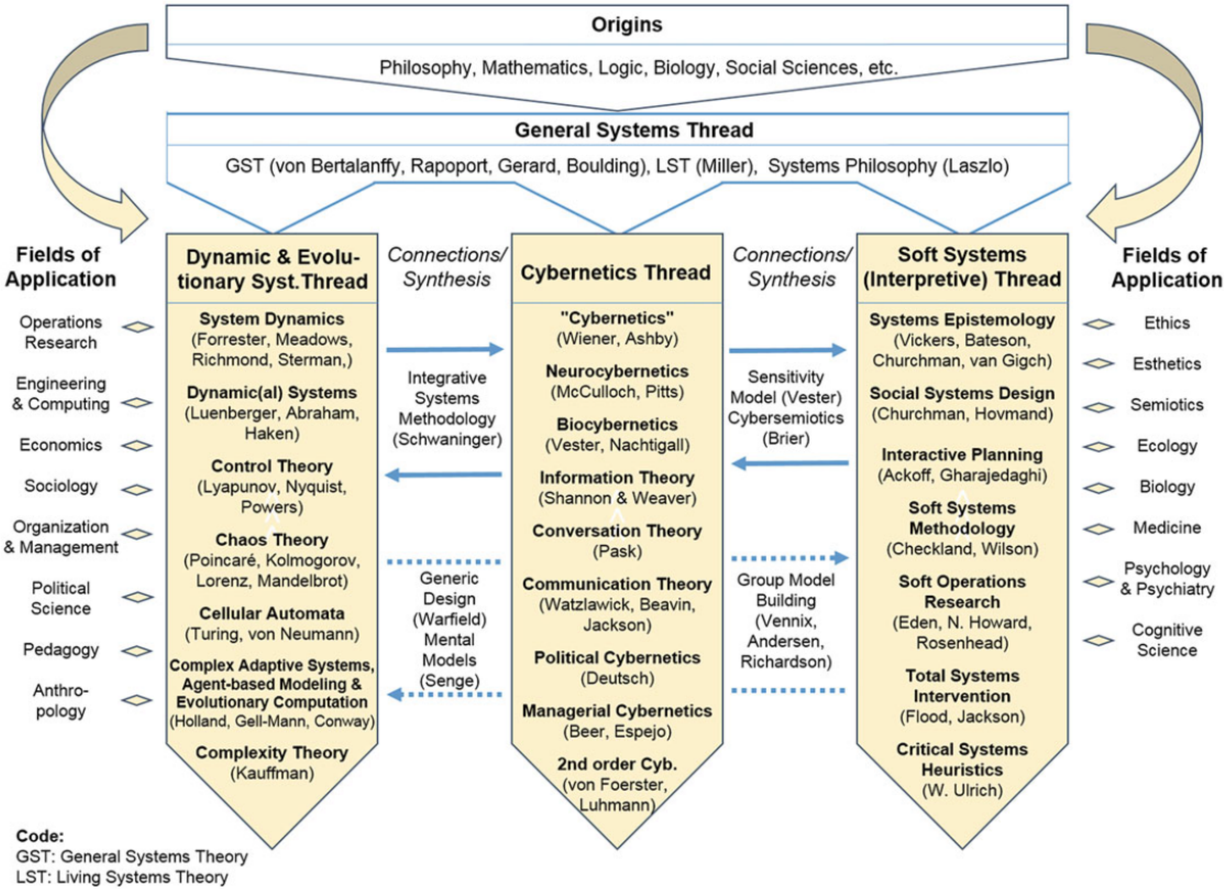


Figure 11.3: System Dynamics in the evolution of systems approach (taken from [117]).

11.7. Hybrid Modeling

"Modeling is essential to characterize and explore complex societal and environmental issues systematically and collaboratively. Socio-environmental systems (SES) modeling integrates knowledge and perspectives into conceptual and computational tools that explicitly recognize how human decisions affect the environment [35]." In this sense, eight challenges need to be overcome to accelerate the development and adaptation of SES modeling: bridging epistemologies across disciplines; multi-dimensional uncertainty assessment and management; scales and scaling issues; combining qualitative and quantitative methods and data; furthering the adoption and impacts of SES modeling on policy; capturing structural changes; representing human dimensions in SES; and leveraging new data types and sources [35].

Regarding ecological modeling, [78] proposes a framework for the business ecosystem modeling, including three parts and nine stages (shown in Tables 11.1 and 11.2). This framework combines business ecosystem modeling, system engineering, and ecology theories, including agent-based modeling and system dynamics.

TABLE 11.1. THE BUSINESS ECOSYSTEM MODELING WITH THE INTEGRATION OF SYSTEM MODELING AND ECOSYSTEM THEORY

Business ecosystem modeling	**Business ecosystem**	**System engineering**	**Ecology**
Part I–Stage 1 Identify the boundary of a selected ecosystem	Domain oriented business ecosystem. Innovation ecosystem. Digital ecosystem.	Ontology development. System architecture	Types of ecosystem. Ecosystem hierarchy
Part I–Stage 2 Identify actors and their roles in the ecosystem.	Stakeholders. Business models.	Domain ontology. System standards.	Categories of organisms [74] (producers, consumers, decomposers.) Types of keystone species [89] (predators, mutualists, engineers.)
Part I–Stage 3 Identify actors' value propositions and business models.	Business model [142], value creation [21]	Business services. Value stream.	Ecosystem function and biodiversity [29]
Part I–Stage 4 Identify interaction between actors (different types of interactions.)	Value co-creation. Value flows [86] (monetary, product, information and intangible.) Social network analysis [5]	Flows (e.g., information exchange.) Associations (in UML diagram.) Service-oriented architecture (in TOGAF.)	Intra-specific and inter-specific ecological interaction. Ecosystem services Matter, energy and information flows.

Comparing this framework with our methodology named Hybrid Service Simulation Model (HSSM) [56], we can find some similarities in Table 11.3. The main difference is that the HSSM does not include the ecosystem reconfiguration, which belongs to Part III - Stages 2 and 3, implementing the new proposals for the business model.

11.8. Conclusions

Four years ago, Circular Economy (CE) concept emerged recently, and there was no related research in international journals in Mexico. After this second literature review, we find some proposals presented in Mexico. This concept is essential to develop and innovate products and services through value co-creation and exchange, as Vargo suggests in a new opinion paper [131] related to

TABLE 11.2. THE BUSINESS ECOSYSTEM MODELING WITH THE INTEGRATION OF SYSTEM MODELING AND ECOSYSTEM THEORY (CONT.)

Business ecosystem modeling	Business ecosystem	System engineering	Ecology
Part II–Stage 1 Investigate influential factors and their impact on the elements in the ecosystem (actors, roles, and interaction.)	-	Motivation and strategy (in ArchiMate.) System thinking [110] Machine logic [99]	Assessment and indicator of ecosystem conditions.
Part II–Stage 2 Investigate potential changes in the ecosystem.	Emergence and coevolution [96]	Risk management/assessment [111].	Ecosystem change [34]
Part III–Stage 1 Multi-agent based ecosystem simulation to identify ecosystem reaction towards the potential changes.	Multi-agent-based models [75]	System dynamics [68]	System dynamics, Multi-agent based modeling.
Part III–Stage 2 Ecosystem reconfiguration (including reconfiguration of actors, roles, and interaction) due to changes.	Business ecosystem lifecycle [108]	System lifecycle management [111]	Evolution of ecosystems [6]

service-dominant logic (SDL). The value exchange can be given among actors like government, users, and organizations and the natural ecosystems like a forest, a lake, or the land. It is important to visualize the ecosystem services and their value delivered to the human. Agent-based modeling (ABM) has been widely used to explain and visualize the elements' interactions of a system, defining their actions and analyzing their effects on the whole system. On the other hand, system dynamics (SD) is used to observe the causal explanation in a system by analyzing its state variables.

In ecological modeling, the conjunction of these concepts, especially ABM and SD, has been widely used in recent years, as we did in our research. The analysis level obtained from these tools allowed us to design our nine-step methodology to create a simulation model which involves the scenario visualization according to the CE strategies analyzed at the beginning of the methodology. The main characteristic of this simulation model is that the final users and stakeholders can make decisions related to CE in their organization. Applying these decisions in the real world depends on several variables that are out of the scope of our methodology. However, SDL is suitable for designing the CE strategies implementation.

For future work, first, we propose a statistical studio of the organizations that have adopted CE in Jalisco. Secondly, The validation of the methodology in other case studies to generalize its implementation. Third, design a general simulation model that would be easy to evaluate for SMEs. Finally, the design of the service ecosystem to exchange knowledge of the best practices and services that contribute to the community growth and waste minimization.

TABLE 11.3. SIMILARITIES BETWEEN HYBRID SERVICE SIMULATION MODEL (HSSM) AND BUSINESS ECOSYSTEM MODELING FRAMEWORK

HSSM	**Business ecosystem modeling**
Step 1: Select interacting parts of the value chain	Part I–Stage 1 Identify the boundary of a selected ecosystem
Step 2: Analyze the CE strategies for each part or entity	Part I–Stage 3 Identify actors' value propositions and business models.
Step 3: Define and identify entities' attributes according CE strategies	Part I–Stage 2 Identify actors and their roles in the ecosystem.
Step 4: Define the agent-based model for the selected entities	Part III–Stage 1 Multi-agent based ecosystem simulation to identify ecosystem reaction towards the potential changes.
Step 5: Define the dynamic behavior or a mathematical model of the environmental variables	Part III–Stage 1
Step 6: Make a diagram connecting the entities or agents with the environment	Part I–Stage 4 Identify interaction between actors
Step 7: Build the simulation model in software	Part III–Stage 1
Step 8: Define and execute performance tests	Part III–Stage 1
Step 9: Formulate and evaluate policies	Part II–Stage 1 Investigate influential factors and their impact on the elements in the ecosystem. Part II–Stage 2 Investigate potential changes in the ecosystem.

General Conclusions

This research project was registered in the Doctoral Program in Engineering Sciences at ITESO university. The main contribution to this area is the conjunction of diverse perspectives related to Services Engineering, Computing Sciences, Systems Thinking, and Environmental and Economic Sciences, which we integrated into a nine-step methodology proposal for obtaining a simulation model to allow users to make decisions concerning circular economy (CE) strategies in their processes. This work presents the design and implementation of this methodology based on four perspectives: service-dominant logic, ecosystem services, agent-based modeling, and system dynamics.

Service-dominant logic (SDL) perspective allowed us to understand the value co-creation concept around a service ecosystem. As a CE seeks to create value from waste, SDL concepts can be applied as a guide for CE business innovation. Ecosystem services (ES) is derived from SDL as an alternate concept considering nature as another actor in a service ecosystem, providing services to people.

From these approaches, we observed the need to create a simulation model for implementing CE in the Mexican industry due to the lack of environmental impact visualization around stakeholders. The use of agent-based modeling (ABM) and system dynamics (SD) allowed us to define and design the nine-step methodology for creating a dynamic simulation model according to a specific case study.

As we found in the literature review, there is a similar framework for designing and implementing CE strategies using a multi-agent simulation. The main difference is that our methodology is focused on visualizing different scenarios in the simulator according to the strategies adopted. There is no other simulation methodology or framework for implementing CE policies in SMEs in Mexico.

This methodology was implemented in two case studies in Guadalajara, Mexico: a food bank and a confectionery factory. In both cases, a specific dynamic simulation model was developed to understand the organization's performance and to evaluate future scenarios as possible CE policies that could modify or enhance the waste used in the business processes. During the methodology development, interviews were conducted to acquire the qualitative and quantitative data needed for the simulation model. The final product delivered to the organizations' stakeholders was a dashboard where they could modify some variables and observe the state variables' performance. The model validation was conducted through a questionnaire to the stakeholders where they evaluated five characteristics of the simulation model: model purpose, model results, CE view, user interface, and simulator usage.

Regarding the CE implementation in the case studies, stakeholders were convinced that CE is essential in the actual processes. However, a financial study must evaluate the viability of its implementation. Thus, until the end of this study, CE was not implemented in the case studies' processes.

The recent literature review showed similar research regarding simulation methodologies with some differences in the case studies' implementation. Besides, the use of SDL in CE scope increases the cooperation of different actors to change the linear to circular supply chains.

In future work, the methodology can be implemented in other case studies to generalize its adoption and develop a standard simulation model for evaluating CE scenarios. This model will facilitate the CE implementation in the industries, not only to the stakeholders but also to the owners of the services related to waste and energy management, creating a service ecosystem in the metropolitan area of Guadalajara.

Conclusiones Generales

Este proyecto de investigación fue registrado en el Programa de Doctorado en Ciencias de la Ingeniería de la universidad ITESO. La principal contribución a esta área es la conjunción de diversas perspectivas relacionadas con la Ingeniería de Servicios, las Ciencias de la Computación, el Pensamiento de Sistemas y las Ciencias Ambientales y Económicas, que integramos en una propuesta metodológica de nueve pasos para obtener un modelo de simulación que permita a los usuarios tomar decisiones sobre estrategias de economía circular (EC) en sus procesos. Este trabajo presenta el diseño e implementación de esta metodología basada en cuatro perspectivas: la lógica dominante del servicio, los servicios de los ecosistemas, el modelado basado en agentes y la dinámica de sistemas.

La perspectiva de la lógica dominante del Servicio (LDS) nos permitió comprender el concepto de creación conjunta de valor en torno a un ecosistema de servicios. Dado que la EC busca crear valor a partir de los residuos, los conceptos de SDL se pueden aplicar como guía para la innovación empresarial de EC. Los servicios de los ecosistemas (ES) se derivan de LDS como un concepto alternativo que considera a la naturaleza como otro actor en un ecosistema de servicios, brindando servicios a las personas.

A partir de estos planteamientos, observamos la necesidad de crear un modelo de simulación para la implementación de EC en la industria mexicana debido a la falta de visualización del impacto ambiental en torno a los stakeholders. El uso de modelado basado en agentes (MBA) y dinámica de sistemas (DS) nos permitió definir y diseñar la metodología de nueve pasos para crear un modelo de simulación dinámica de acuerdo con un caso de estudio específico.

Como encontramos en la revisión de la literatura, existe un marco similar para diseñar e implementar estrategias de EC utilizando una simulación de múltiples agentes. La principal diferencia es que nuestra metodología se centra en visualizar diferentes escenarios en el simulador según las estrategias adoptadas. No existe otra metodología o marco de simulación para la implementación de políticas de EC en las PYMES en México.

Esta metodología se implementó en dos casos de estudio en Guadalajara, México: un banco de alimentos y una fábrica de dulces. En ambos casos, se desarrolló un modelo de simulación dinámica específico para entender el desempeño de la organización y evaluar escenarios futuros como posibles políticas de EC que pudieran modificar o potenciar los residuos utilizados en los procesos de negocio. Durante el desarrollo de la metodología, se realizaron entrevistas para adquirir los datos cualitativos y cuantitativos necesarios para el modelo de simulación. El producto final entregado a los stakeholders de las organizaciones fue un tablero donde podían modificar algunas variables y observar el desempeño de las variables de estado. La validación del modelo se realizó a través de un cuestionario a las partes interesadas donde evaluaron cinco características del modelo de simulación: propósito del modelo, resultados del modelo, vista EC, interfaz de usuario y uso del simulador.

Con respecto a la implementación de la EC en los estudios de caso, las partes interesadas estaban convencidas de que la EC es esencial en los procesos reales. Sin embargo, un estudio financiero debe evaluar la viabilidad de su implementación. Así, hasta el final de este estudio, el EC no fue implementado en los procesos de los estudios de caso.

La reciente revisión de la literatura mostró investigaciones similares con respecto a las metodologías de simulación con algunas diferencias en la implementación de los estudios de casos. Además, el uso de LDS en el ámbito de la EC aumenta la cooperación de diferentes actores para cambiar las cadenas de suministro lineales a circulares.

En trabajos futuros, la metodología puede implementarse en otros casos de estudio para generalizar su adopción y desarrollar un modelo de simulación estándar para evaluar escenarios de EC. Este modelo facilitará la implementación de la EC en las industrias, no solo a los stakeholders sino también a los titulares de los servicios relacionados con la gestión de residuos y energía, creando un ecosistema de servicios en la Zona Metropolitana de Guadalajara.

Appendix

A. List of Internal Research Reports

- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “Hybrid simulation model for circular economy implementation: Literature review” Internal Report PhDEngScITESO-17-43-R, ITESO, Tlaquepaque, Mexico, Dec. 2017.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “Hybrid service simulation model for circular economy implementation: Case study and methodology proposal,” Internal Report PhDEngScITESO-18-15-R, ITESO, Tlaquepaque, Mexico, May 2018.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “Hybrid service simulation model for circular economy implementation: Tepatitlán food bank,” Internal Report PhDEngScITESO-18-48-R, ITESO, Tlaquepaque, Mexico, Dec 2018.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Agent-based modeling,” Internal Report PhDEngScITESO-18-59-R, ITESO, Tlaquepaque, Mexico, Dec 2018.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Building the simulation model in NetLego,” Internal Report PhDEngScITESO-19-44-R, ITESO, Tlaquepaque, Mexico, May. 2019.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Model validation,” Internal Report PhDEngScITESO-19-45-R, ITESO, Tlaquepaque, Mexico, Dec. 2019.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Second case study,” Internal Report PhDEngScITESO-20-25-R, ITESO, Tlaquepaque, Mexico, May. 2020.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation in the confectionery factory,” Internal Report PhDEngScITESO-20-26-R, ITESO, Tlaquepaque, Mexico, Jul. 2020.

- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Circular economy measurement,” Internal Report PhDEngScITESO-20-27-R, ITESO, Tlaquepaque, Mexico, Dec. 2020.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Scenario analysis,” Internal Report PhDEngScITESO-21-23-R, ITESO, Tlaquepaque, Mexico, May. 2021.
- E. L. Guevara-Rivera, R. Osorno-Hinojosa, and V. H. Zaldívar-Carrillo, “A simulation methodology for circular economy implementation: Literature review update,” Internal Report PhDEngScITESO-21-24-R, ITESO, Tlaquepaque, Mexico, Nov. 2021.

B. List of Publications

- E. Guevara-Rivera, R. Osorno-Hinojosa and V. H. Zaldívar-Carrillo, ”Hybrid service simulation model for circular economy implementation,” 9th International Congress on Environmental Modelling and Software, Fort Collins, 2018, 66. `https://scholarsarchive.byu.edu/iemssconference/2018/Stream-C/66/`
- E. Guevara-Rivera, R. Osorno-Hinojosa and V. H. Zaldívar-Carrillo, ”A Simulation Methodology for Circular Economy Implementation,” IEEE 10th International Conference on Advanced Computer Information Technologies (ACIT), Deggendorf, 2020, DOI: `10.1109/ACIT49673.2020.9208839`
- E. Guevara-Rivera, R. Osorno-Hinojosa, V. H. Zaldívar-Carrillo and H. Perez-Ortiz, ”Dynamic simulation methodology for implementing circular economy: A new case study,” Journal of Industrial Engineering and Management, vol. 14, no. 4, December 2021, DOI: `http://dx.doi.org/10.3926/jiem.3609`

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