International Congress on Environmental Modelling and Software

9th International Congress on Environmental Modelling and Software - Ft. Collins, Colorado, USA - June 2018

Jun 25th, 10:40 AM - 12:00 PM

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iEMSs International Congress on Environmental Modelling and Software

9th International Congress on Environmental Modelling and Software
Fort Collins, Colorado, USA, Mazdak Arabi, Olaf David, Jack Carlson, Daniel P. Ames (Eds.)
https://scholarsarchive.byu.edu/iemssconference/2018/

Hybrid Service Simulation Model for Circular Economy Implementation

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Abstract: The Circular Economy (CE) aims to redefine products and services with a reduced-waste design that relies on renewable energy sources. In Europe and the United States, many industries have implemented the circular economy in one or more of their product cycles. However, in the literature, there are no reported cases from Mexico. In this article, we review Service-Dominant Logic (SDL) and Ecosystem Services (ES) to define the value co-creation between the elements in a CE cycle. Furthermore, we model each one of these elements, their interactions and behaviors using Agent-Based Modelling (ABM) and System Dynamics (SD) aiming at the development of a simulation tool. Users of this tool will be able to make decisions, apply new policies, and visualize the advantages and consequences of applying concepts of CE before modifying the real-world scenario. In this document, we explore the literature and research frontiers concerning CE, SDL, ES, ABM, and SD, and then we propose a methodology for modeling the entities and developing the simulator as an iterative process. As future work, we will implement the proposed methodology in a case study in Mexico: the food banks in the Guadalajara Metropolitan Area.

***Keywords**:* circular economy; service-dominant logic; ecosystem services; agent-base modelling, system dynamics.

1 INTRODUCTION

In the past 50 years, there has been a generalized concern about the use and abuse of natural resources. Some authors explain the evolution of industrial processes and the way they have contributed to the depletion of the natural materials in the world (McDonough & Braungart, 2002) , (Webster, 2016). They also look at the use of unnecessary and toxic substances in final products, which damage human health and the environment where these products are discarded (i.e. water or soil).

In recent years, the circular economy concept has emerged from the need for the most efficient utilization of components and materials, from their design to their final disposal in nature. This concept distinguishes two cycles: biological and technical. In the biological cycle, the aim is to study how natural and biodegradable materials can reintegrate into nature. On the other hand, the technical cycle is designed by technical industries, which imitate the biological cycles by preserving natural capital, optimizing resources, and minimizing risks by managing renewable flows (Ellen MacArthur Foundation, 2015).

In Europe and the United States, many industries have implemented the circular economy in one or more of their product cycles (EMAF, 2017). However, in Mexico, there are no reported cases in the international literature. Furthermore, sustainability is not a primordial issue in Mexican industries. In general, it is difficult to convince stakeholders, customers, and authorities that the strategy of “waste maximization” is beneficial for the environment and sustainability (Korhonen, et al., 2018).

Industrialists’ main concern is the cost and economic benefits for the organization when a new sustainable improvement is proposed; stakeholders need information to design and implement policies that foster CE. A simulation model allows the user to gain insight into the benefits of a new policy implementation before making the decision about the real system, which in the end saves money (Edmonson, 2011).

There are two methodologies for simulating systems: Agent-Based Modelling (ABM) and System Dynamics (SD). Even though, there are a number of differences and similarities between them (Nava Guerrero, et al., 2016) , their main purpose is to explain the social system's behavior and model the reality and interactions between the system elements or actors. Both simulation systems focus on representing feedback loops, which is the main characteristic of non-linear and complex systems (Sterman, 2000). They also complement each other: whereas ABM has an inductive vision, SD has a deductive vision (Schieritz & Milling, 2003). Some authors have used both methodologies in their research work, linking several characteristics of the circular economy (such as material recovery) that can be clearly represented by a hybrid model (Swinerd & MacNaught, 2012), (Swinerd, 2014), (Ferrada & Camarinha-Matos, 2017), (Hesan & Pruyt, 2016), (Martin & M., 2015).

Service-Dominant Logic (SDL) (Vargo & Lusch, 2004) is a framework that allows us to see sustainability in the sense that every element of the circular economy process interacts with other elements or agents, co-creating value and exchanging services for preserving natural resources and creating value. This perspective provides us with new insights to model complex systems of this kind.

In our research, we are proposing a tool to test policies and help decision making among stakeholders and customers to adopt the circular economy principles: a model and a simulation system software. The simulation system software helps to understand the relationship between the elements of the system, visualize feedback loops, and implement policies in order to predict behaviors without risking the real system. This report shows the proposal based on the four perspectives that we propose to address this complex system: CE, ABM, SDL and SD. To achieve this, we present a literature review related to the perspectives; we also propose a theory-based methodology to address the problem and we show a case that could provide an ideal scenario for the implementation of a circular economy simulator. Finally, we propose the next steps in this or other related research.

1.1 Circular Economy

The Circular economy (CE) is a concept recently used by the European Union as an alternative for producing products and services (Korhonen, et al., 2018). Instead of using the traditional industrial scheme of "make-use-dispose," CE proposes imitating nature's way of using resources and renewing the waste produced by nature's processes. Whereas the industrial processes commonly use energy from non-renewable resources, nature uses only solar energy to accomplish its processes. The waste generated through these processes is reintegrated into the soil, and when living beings reach the end of their life, serve as food for other microorganisms.

According to Webster (2016) the circular economy rests on five principles:

P1. Design out waste. Waste does not exist when the biological and technical components (or 'materials') of a product are designed by intention to fit within a biological or technical materials cycle, designed for disassembly and re-purposing.

P2. Build resilience through diversity. Diverse systems with many connections and scales are more resilient in the face of external shocks than systems built simply for efficiency – throughput maximization driven to the extreme results in fragility.

P3. 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.

P4. Think in 'systems'. The ability to understand how parts influence on another within a whole, and the relationship of the whole to the parts, is crucial.

P5. Think in cascades. For biological materials, the essence of value creation lies in the opportunity to extract additional value from products and materials by cascading them through other applications.

The main objective of the Ellen MacArthur Foudation (EMAF, 2015) is to provide the tools needed to implement CE. These tools are books, handbooks, and methodologies to make the transition from a linear to a circular supply chain. The EMAF is formed by European stakeholders who have contributed to the implementation of the concept of CE in some industries.

Beyond these concepts, the implementation of CE in a real system depends on several factors and it is necessary to take into account the limitations of CE, as Korhonen (2018) recently did. In his article, he suggests six limitations according to the impact of CE implementation in three aspects: environmental, economic, and social. One of the most important limitations that justifies our research project deals with the fifth one: intra-organizational vs. inter-organizational strategies and management. In this aspect, the authors discuss the willingness of the participants or actors to change to a circular working mode with the key 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? (Korhonen, et al., 2018).

1.2 Service-Dominant Logic

We now explore another concept concerning service ecosystems. Vargo & Lusch (2004) stated that “marketing activity (and economic activity in general) is best understood in terms of service-for-service exchange, rather than 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 provide for themselves and others (i.e., service, applied abilities), not the goods. Value is co-created by several actors and subsequently delivered.

Vargo & Lusch (2016) identified 11 foundational premises and five of them have become axioms. These axioms serve as the foundation of Service-Dominant Logic (SDL). Furthermore, these authors have publicized other inputs to this research line. In one of their most recent articles, they present future research concerning SDL from different perspectives (Vargo & Lusch, 2017). In this article, the need to find a meta-theory that explains the use of SDL is assessed. Among other perspectives, system and ecosystem theory is explained from its roots, which are in “natural” science and attributed to Tansley (1935) as “the basic unit of nature.” In a figurative sense, the term ecosystem is used in the business environment as “networked constellations of firms, often centered on a central actor” (Vargo & Lusch, 2008).

Vargo and Lusch propose several aspects for continuing the study of SDL’s impact on the future. One of them is related to dynamic strategy development and implementation, where 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” with an emphasis on: (1) taking into account the ecosystem diversity where the organization is located, and (2) the collaboration among other actors and beating the competition. This issue is summarized in the 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?” (Vargo & Lusch, 2017).

Another aspect is related to complexity economics, which studies economic and social actors under more 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 markets and the economy?” (Vargo & Lusch, 2017).

The third subject we consider important for our study is environmental sustainability. Vargo and Lusch (2017) establish that SDL, with its focus on service ecosystem viability and resiliency, can be used as an informative and robust framework for environmental sustainability. The salient research question with respect to this theme is: “How can SDL and ecosystem service(s) be used to advance environmental sustainability?” (Vargo & Lusch, 2017).

1.3 Ecosystem services

Regarding environmental sustainability, Matthies et al. (2016) compare Ecosystem Services (ES) with the service system. ES refers to the benefits that 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 (Vargo & Lusch, 2008). Thus, the ES approach is potentially an extension of service sciences.

The value creation by one service system is a non-linear interactive and dynamic process, and results in a potential value that can be utilized, missed, or destroyed by various other actors, processes, and resources that are part of a service system’s value network (i.e., a forest). From this definition, Matthies et al. (2016) indicate 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. The natural ecosystems are shown as the largest entity, which contains the societal and economic dimensions. ES is related to three dimensions and the value creation cascade is operating across all of them.

Matthies et al. (2016) 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, ES can be considered as a service system where the actors are living beings in themselves (i.e., a forest or a lake), which provide offerings with a potential value that human beings are capable of creating or destroying. To find a clear explanation of the relations and behaviors between actors and operand resources in an ES is not an easy task. In recent years, there have been many contributions in the form of computing systems, such as System Dynamics (SD) and Agent-Based Modelling (ABM), to help to understand the behavior of economic and social systems.

1.4 System Dynamics and Agent-based Modeling

Today, it is possible to observe different complexity levels everywhere: macro systems like economic, social, and environmental systems; meta systems 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 at the same or a different level.

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

“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” (System Dynamics Society, 1999). Forrester published in 1961 the book *Industrial Dynamics*, where he proposed the notion of this methodology. He introduced the concepts of flows and levels to explain complex systems’ behaviors, how the variables interacted with each other, and the importance of feedback loops.

On the other hand, “Agent-Based Modelling (ABM) has been used to study socio-technical systems. In ABM a socio-technical system is modeled by decomposing a system into heterogeneous entities called agents, which continuously interact with each other and with their surrounding environment. The global behavior of these systems is the result of interaction between agents and environment” (Hezan, 2007). Wooldridge (2009) defines an agent as “a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its delegated objectives.” An intelligent agent must have balanced capabilities like reactivity, proactiveness, and social ability. “Agent interactions are defined by a set of decision-making rules to interact with each other and the environment" (Swinerd & MacNaught, 2012).

Schieritz & Milling (2003) compared both methodologies, and concluded that "an integrated approach possibly has the potential to help decision makers develop the capacity of thinking at one and the same time of both, the forest and the trees". In other words, by integrating both methodologies it is possible to simulate complex systems at several levels. Simultaneously, Swinerd and MacNaught (2012) have used both methodologies to design and implement hybrid models. They have proposed different schemes for connecting the SD and ABM blocks depending on the abstraction level and system hierarchy.

2 METHODOLOGY

The CE principles proposed by Webster are the basis for organizing the concepts (see Figure 1). We have assigned SDL to principles 1 and 5 due to the theory of service innovation and value co-creation concerning the way waste is utilized by different actors during its life. Building resilience through diversity (principle 2) can be assessed using ABM, since each actor can be considered as an individual agent within the organization with its own characteristics, and the interactions between actors can be defined in an agent-based model. The third principle: "work towards using energy from renewable sources" is related to ecosystem services, since in Matthies' explanation the ecosystem is seen 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 can be 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. According the assignment of the five concepts, we defined six connections to analyze the relevant literature (see Table 1).

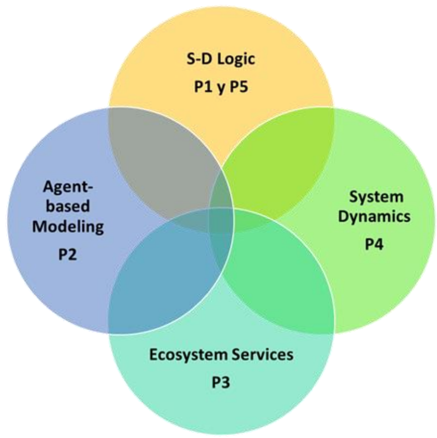

Figure 1 The adoption of the circular economy, with its five principles assigned to the methodologies studied.

Table 1. Literature related to the intersections between concepts.

	Author	Main contribution
SDL and ES	(Matthies, et al., 2016)	Value codestruction and potential value.
SDL and ABM	(Lusch & Tay, 2004) (Rajapakse & Terano, 2013), (Rajapakse & Terano, 2014), (Rajapakse & Terano, 2015)	ABM in a service industry. ABM using ISPAR, NKCS, customer engagement model.
ABM and SD	(Schieritz & Milling, 2003), (Cherif & Davidsson, 2009), (Borshchev & Filippov, 2004), (Nava Guerrero, et al., 2016)	Comparison between ABM and DS
	(Teose, et al., 2011)	ABM and DS for CAS
	(Lektauers, et al., 2011), (Ferrada & Camarinha-Matos, 2017), (Martin & M., 2015)	Examples using ABM and DS
	(Hesan & Pruyt, 2016), (Swinerd & MacNaught, 2012), (Swinerd, 2014)	Hybrid models
ABM and ES	(Sun & Müller, 2013)	ABM with BBN and ODM for land-use decisions
	(Brady, et al., 2012)	ABM with AgroPoliS software
	(Filatova, et al., 2013)	ABM for SES
	(Bagstad, et al., 2013)	ABM for representing ES flows.
ES and SD	(Boumans, et al., 2002)	GUMBO model
	(Boumans, et al., 2015)	MIMES framework
	(Arbault, et al., 2014)	LCA on GUMBO model
SDL and SD	(Qiu, 2009)	Dynamic model of a service system

Considering the literature review we summarized that the methodology proposed is based on:

(i) CE flows through a value chain (see Figure 2). This configuration proposed by Kalmykova et al., (2017) 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.

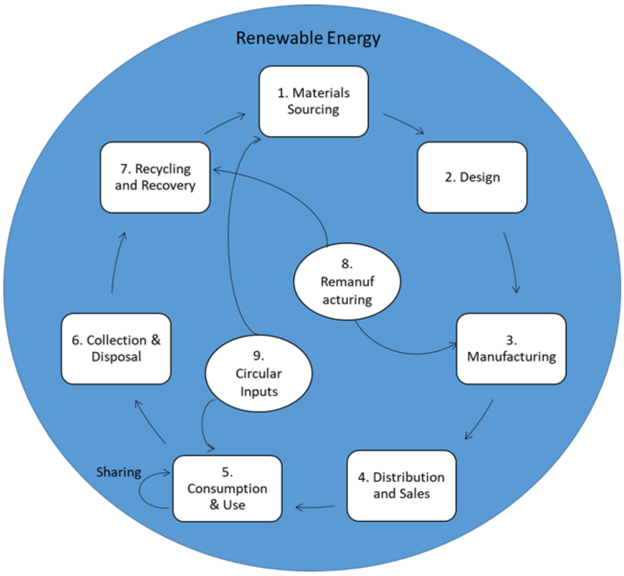

Figure 2. Circular economy resource flows through a value chain (taken from Kalmykova, et al., 2017).

(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 service ecosystem, there is a strong focus on collaborative processes (Lusch, 2011).

(iii) ABM design applied to ES, as Murray-Rust et al. (2011) implemented for a complex system related to land use.

(iv) The Sterman's SD modelling process, which is iterative. At every step, it is necessary to redefine some features related to other steps (Sterman, 2000).

The methodology steps are shown in Figure 3. The first four stages are considered as previous work, and the next five steps are those proposed by Sterman's (2000) modeling process:

1. Choose two interacting parts of the value chain (entities) from Figure 2.
2. Analyze the CE strategies proposed by Kalmykova (2017) for each part or entity.
3. Define the entities' attributes according the CE strategies.
4. Define the agent-based model for the selected entities.
5. Define the dynamic behavior or a mathematical model of the environmental variables.
6. Map a diagram connecting the entities or agents with the environment.
7. Build the simulation model in software.
8. Define and execute performances tests.
9. Formulate and evaluate policies.

Each step has its own process. We propose, from step five to step nine, that the modeling process be iterative, in all senses. For example, in the moment of building the simulation model in software (step 7), if we find an inconsistency, it will be necessary to review a prior step. To validate our methodology, we have chosen a case study developed in our community: "Jalisco Without Hunger". This project addresses food insecurity in the Guadalajara Metropolitan Area.

3 CASE STUDY: "JALISCO WITHOUT HUNGER"

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

i. To form competitive, free and engaged professionals, willing to put their being and their professional practice at the service of society.

ii. To extend the frontiers of knowledge and culture by means of an ongoing search for truth.
iii. To propose and develop, in a dialogue with different social organizations, viable and pertinent solutions for the transformation of systems and institutions (ITESO, 2003).

From this mission, ITESO has implemented many social projects with a relevant impact on the environment, society, and vulnerable sectors of society.

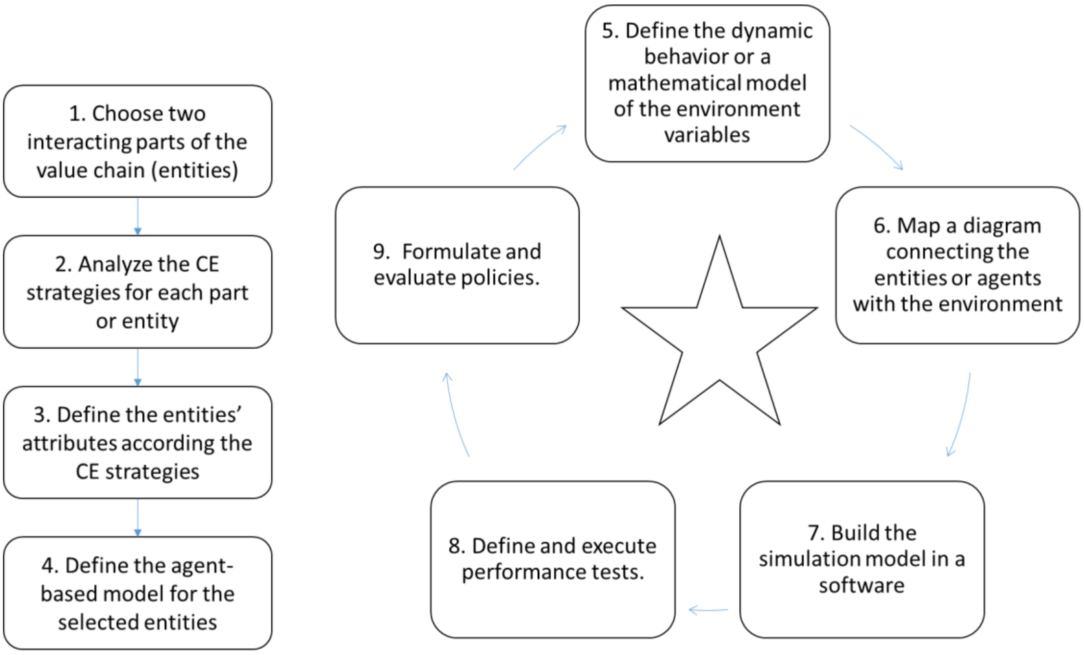

Figure 3. Methodology proposal for implementing a hybrid-service simulation model for CE.

The 2030 Agenda for Sustainable Development resolved to end hunger, to achieve food security as a matter of priority, and to end all forms of malnutrition (United Nations, 2015). Food security is defined as the state in which all people, at all the 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 (FAO, 2003).

According to the Global Food Security Index (GSFI) in 2017, Mexico had a score of 65.8/100, occupying 43th place below Uruguay, Costa Rica, Brazil and Argentina (EIU, 2017). The CONEVAL (National Council for Evaluation of Social Development Policy) poverty index considers other indicators: per-capita income, educational backwardness, access to health services, social security, household quality, access to basic household, lack of access to food, and the degree of social cohesion. The 2016 CONEVAL poverty index indicated that there were 24.6 million people living in poverty in Mexico. Similarly, the lack of access to food index was 20.1%, and 15.4% for Jalisco (CONEVAL, 2017).

In Jalisco, there are three food banks, which operate independently of each other. They collaborate with food producers to collect food that might go to waste and deliver it to people with 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 important to reduce the number of people with food insecurity and to ensure policies to support the food banks' viability.

Jalisco Without Hunger (JWH) 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, and make them more efficient. The organization's purpose is to reduce the number of people with food insecurity in the state of 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.

The process of analysing the food banks' value chain begins with food availability from producers. They communicate with the food bank manager, indicating a possible donation. The food bank manager sends a truck to pick up the food donation. The traveling expenses are paid by the food bank. When the food donation arrives at the food bank, the food that is in good condition is separated. Later, it is classified and packed to be delivered to needy people, who pay a minimal amount. This money is utilized to cover the food bank's operating expenses.

JWH 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, the implementation of a platform to make good use of donations, and the installation of a food processing plant.

JWH is a pertinent case for applying our proposed methodology in the sense of the CE perspective, because of the opportunity to make use of the waste, in this case, food. Food banks are already installed; the simulator will focus on the first strategy to explain the organization's behavior and to find new policies for improving performance.

4 CONCLUSIONS AND RECOMMENDATIONS

In this article, we introduced the CE concept, which arises from the need to maximize waste use by recycling and reusing the waste generated from the value chain, consequently creating a circular value chain. However, the process for implementing this is not an easy task. It depends on different factors, such as the nature of the process itself, the willingness of people, institutional policies, and monetary resources, among others. Furthermore, the implementation of the circular economy in an established process or system requires an understanding of the whole system, the interactions among the elements, the complex behaviors, the non-linearities, etc. According to the CE principles, it is necessary to explore new paths to find innovative forms of maximizing the life of a product and preserve the natural ecosystems.

One of the main objectives of S-D logic is to find new forms of value co-creation to benefit the actors of a system by forming networks, and the entire system as an entity. Natural resources are seen as actors in these co-creation networks, which provide services to create value for a common benefit. Consequences from decisions taken on environmental issues are not immediate and many times, they are irreversible.

Analyzing the literature concerning CE adoption and S-D Logic, we found the need to simulate prior to implementing and changing the actual systems. ABM and SD are the most commonly-used methodologies for achieving this goal. Considering these findings, we proposed a methodology to implement a simulation model based on four perspectives – CE, SDL, ABM and SD – which will allow us to observe the entire circular value chain, apply policies and define long-term scenarios. This methodology can be implemented in phases, first by choosing only a pair of value-chain entities, and subsequently adding more elements, following the same steps.

As future work, we recommend the implementation of the proposed methodology in a case study (i.e. JWH). The main objective of the model and simulation will be to define policies that will improve food banks' performance and producers' donations, analyzing the co-creation of networks aimed at finding a common benefit.

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