Trade-offs between Environmental and Economic Objectives in Closed-Loop Supply Chains

Oscar Fabián Velásquez Rodríguez, PhD (C)
Universidad Nacional de Colombia
Bogotá, Colombia
ofvelasquezr@unal.edu.co

Carlos Eduardo Moreno Mantilla, PhD
Systems and Industrial Engineering Department
Universidad Nacional de Colombia
Bogotá, Colombia
cemorenoma@unal.edu.co

Abstract

During the last decades, environmental management has become a matter of prime importance in business, derived from the need of responding to pressure exerted by different types of stakeholders (e.g., regulators, NGOs, or consumers). In particular, an instrumental perspective in academics has addressed the analysis of how the implementation of environmental strategies impacts the economic performance of firms. The mainstream of environmental management literature has followed the win-win paradigm, in which environmental and economic objectives can be achieved simultaneously. However, given the multifaceted and complex nature of the relationships between economic and environmental objectives under the framework of sustainable development, it is argued that trade-offs are the rule rather than the exception. Therefore, this work aims at developing a conceptual framework for the analysis of the trade-off between environmental and economic objectives in the context of closed-loop supply chains. This framework will help to understand the emergence of trade-offs between environmental and economic objectives of firms during the adoption of advanced environmental practices, such as reverse logistics. It also aims at exploring how collaboration among different agents in the supply chain can help decision makers to manage these trade-offs.

Keywords
Reverse Logistics, Environmental Collaboration, Sustainable Supply Chain Management, Modeling and Simulation.

1. Introduction

The growing importance of environmental issues in business management, derived from the intention to respond to the pressure exerted by different types of stakeholders (e.g., regulators, NGOs, or consumers), has aroused great interest in the academic field that is evidenced in the development of studies that analyze how the implementation of environmental strategies impacts the economic performance of companies. Different empirical studies have focused on analyzing how environmental strategies can be financially viable (Epstein & Roy, 2003; Hart, Milstein, & Caggiano, 2003; Orsato, 2006; Schaltegger & Figge, 2000).

This interest to study the relationship between environmental management and economic performance has led researchers and entrepreneurs to strive for establishing the so-called "Green Business Case", which postulates that strategies for making a company environmentally sustainable can generate "win-win" situations that reconcile environmental protection with financial success. Under this approach, environmental practices are viewed from the perspective of capital efficiency; that is, environmental projects are evaluated in terms of its contribution to the financial results of the firm, since environmental strategies are designed to respond to economic objectives (Figge & Hahn, 2012).

According to the above, it can be argued that the mainstream of the literature on corporate sustainability continues to emphasize the win-win paradigm, according to which economic, environmental and social sustainability objectives can be achieved simultaneously (Figge & Hahn, 2012; Hahn, Figge, Pinkse, & Preuss, 2010; Matos & Hall, 2007). In fact, corporate sustainability has often been defined by the intersection of these three areas (Elkington, 1994; Hart et al., 2003). However, given the multifaceted and complex nature of sustainable development, it is argued that trade-offs and corporate sustainability conflicts are the rule rather than the exception. Turning a blind eye to trade-offs therefore results in a limited perspective on business contributions to sustainable development (Hahn et al., 2010). Under this new approach, the study and understanding of the trade-offs that can appear between environmental and economic performance when corporate environmental strategies are developed is important and fundamental.

However, it is important to emphasize that during the last decade, a firm-based approach has been extended to a chain approach for the analysis of environmental management and environmental practices (Ding, Zhao, An, & Tang, 2016). In this regard, new concepts have emerged in the literature, such as green supply chain management (Srivastava, 2007) and sustainable supply chain management (Seuring, 2011, 2013; Seuring & Müller, 2008), which have had a growing popularity both in the academic and business communities.

The approach of modeling "green" supply chains or "sustainable" supply chains uses techniques such as equilibrium models in mathematical optimization or Multi-Criteria Models for Decision Making – MCDM, and it assumes that there are trade-offs between results in the environmental and economic dimensions of organizations (Brandenburg, Govindan, Sarkis, & Seuring, 2014; Seuring, 2013). Thus, the analysis of trade-offs becomes a critical aspect in the management of green supply chains (Seuring & Müller, 2008). For example, Chaabane, Ramudhin, & Paquet (2011) show that logistical costs and carbon emissions are two conflicting objectives.

Future research can focus on filling gaps in the still emerging intersection between supply chain management and sustainability, under the trade-offs approach (Seuring, 2013). Recent literature shows that within this perspective it is pertinent to adopt the "focal company" and its supply chain as unit of analysis, focusing on how these companies can manage the stakeholders expectations and demands according to their environmental and financial performance (Wu & Pagell, 2011). This represents a huge challenge for the company, in particular, because sometimes these objectives can be opposites, therefore, it is not possible to satisfy all stakeholders simultaneously (Curkovic, Melnyk, Handfield, & Calantone, 2000).

In doing research on the management of sustainable supply chains, empirical studies are needed to assess the nature of these trade-offs between environmental and economic objectives and the business responses of firms (focal companies) through the use of qualitative research (e. g., Winn, Pinkse, & Illge, 2012; Wu & Pagell, 2011) or quantitative methods (e. g., Fahimnia, Sarkis, & Eshragh, 2015; Ferretti, Zanoni, Zavanella, & Diana, 2007; Wang, Lai, & Shi, 2011). However, quantitative modeling and simulation of environmentally sustainable, closed-loop supply chains, depends on the previous integration of emerging actors, such as third-party logistic providers, and different types of flows (i.e., material, information or financial) into a coherent conceptual framework from which testable predictions relating managers' interventions and their impact on environmental and financial outcomes can be empirically be evaluated.

2. Literature review

2.1 Win-Win situations vs. Trade-offs in corporate environmental management

Within the literature related to corporate sustainability, there are two approaches to the relationship between environmental and economic objectives. On the one hand, some authors argue that firms can generate win-win situations between environmental and economic goals (Epstein & Young, 1998; Florida, 1996; González-Benito & González-Benito, 2008; Hart et al., 2003; King & Lenox, 2001; Moreno-Mantilla & Reyes-Rodríguez, 2013; Orsato, 2006; Salzmann, Ionescu-somers, & Steger, 2005; Schaltegger & Figge, 2000). This is achieved, for example, through efficient use of resources (energy, water, or raw materials), improvement of processes, and introduction of environmentally differentiated products into new markets. Under this same view, it is established that the interaction of green practices and a production system based on the lean philosophy can generate synergies to produce win-win outcomes. Integration of Lean and Green into operations management would allow companies to obtain benefits both economically and environmentally (Florida, 1996; K. Green, Morton, & New, 1998; Hanson, Melnyk, & Calantone, 2004; King & Lenox, 2001; Kleindorfer, Singhal, & Wassenhove, 2005; Larson & Greenwood, 2004; Leguízamo-Díaz & Moreno-Mantilla, 2014; Linton, Klassen, & Jayaraman, 2007).

On the other hand, the literature emphasizes the existence of trade-offs between environmental and the economic objectives. This school of thought points out that companies with proactive environmental measures may acquire an economic burden that competitors do not have (Wu & Pagell, 2011) . In the particular case of the relationship between lean objectives and green practices, according to Fahimnia et al., (2015), such trade-offs are inevitable. This is comprehensible because the main objective of the lean manufacturing philosophy is to improve the efficiency and effectiveness of the firms productive system with a purely economic approach, while the reason to be of the green practices is to improve environmental performance without necessarily being subordinated to the organization economic interests.

Despite the discussion in literature about the relationship between the environmental and financial performance of the firms, it should be noted that the majority of studies on corporate sustainability follow the win-win paradigm, either from a conceptual approach (Ambec & Lanoie, 2008; Molina -Azorín, Claver- 2009; Orsato, 2006; Porter, 1991; Porter & der Linde, 1995) or in empirical research (Álvarez Gil, Burgos Jiménez, & Céspedes Lorente, 2001; Green, Zelbst, Meacham, & Bhadauria, 2012; Rao & Holt, 2005).

According to the win-win paradigm, business contributions to sustainable development are achieved only in the intersection of the three principles of environmental integrity, social equity and economic prosperity. Although there is increasing evidence that win-win situations may exist under certain conditions, it is argued that assuming a harmonic relationship among these three principles is rather simplistic, given the complex and multifaceted nature of sustainable development. Therefore, the omission of the existing trade-offs among the social, environmental and economic objectives of the companies leads to a limited perspective (Hahn et al., 2010).

From a conceptual point of view, the win-win paradigm has two major limitations. First, this paradigm limits the scope of possible corporate responses and approaches to sustainable development, because it does not take into account all the potential positive contributions that companies can made to generate sustainable development. For example, Hahn & Figge, (2011) put forward a corporate sustainability measure that weighs environmental, economic and social performance to measure company operation. They conclude that, under this approach, a company can achieve a better performance when relevance is given to environmental and social axes, even at the expense of economic performance. The second limitation is that this paradigm leads to a partial analytical perspective on corporate sustainability, initiatives and strategies, as they are ultimately judged through the lens of maximizing profits rather than as ends in themselves (Figge & Hahn, 2012; Hahn et al., 2010).

2.2 Reverse Logistics and Closed-loop supply chain

Traditionally, logistics was focused on bringing the product from the manufacturer to the customer. However, during the last decades, aspects such as after-sales service and the creation of long-term relationships with customers have begun to be considered. This brought the need of implementing new activities aimed at recovering defective products and bringing them back to the factory, giving way to what we know today as reverse logistics.

Although the concept of reverse logistics has been extensively discussed in recent years, there is not a generalized and widely accepted definition since the multiple aspects of this concept encompass activities, products, points of origin / destination in the supply chain, actors and objectives (Fernández-Quesada, 2004).

One of the most frequently cited definitions of reverse logistics was stated by Rogers & Tibben-Lembke (1999), who argue that this is *"the process of planning, implementing, and controlling the efficient, cost-effective process for the flow of raw materials, in-process inventory, finished products and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal"*. Reverse logistics focuses on the movement of used goods from the point of consumption to the point of origin with the purpose of reusing or recycling used goods.

A term that emerges from the integration of traditional logistics –forward logistics- and reverse logistics, is that of "closed-loop supply chain". A closed-loop supply chain has been defined in the literature as a supply chain where, in addition to the traditional flows of forward logistics, the backward flows from consumers to producers are considered to take the products at the end of their useful life back (Ferguson & Souza, 2010). This includes activities such as collection, remanufacturing, reconditioning and sale in primary and secondary markets (Souza, 2013).

2.3 Environmental Collaboration

Environmental collaboration can be defined as the interaction of a company with its customers or suppliers in order to involve them in the planning of its environmental policies and solutions (Vachon & Klassen, 2008). Within the context of environmental collaboration, consumers, suppliers and stakeholders develop jointly with producers the plans to reduce the environmental impact of processes and products. Under this approach, environmental collaboration can be seen as a key relational capability to facilitate the strategic formulation and implementation of the greening of a supply chain. The development of this capacity requires the creation of close relationships with stakeholders, such as consumers and suppliers, generating complementary resources that are difficult to copy and therefore constitute a source of competitive advantage (Chacón-Vargas & Moreno-Mantilla, 2014).

Environmental collaboration includes topics such as the exchange of technical information and the readiness to learn from other links in the chain. The aim is to develop joint objectives that allow a better environmental performance and the implementation of activities that minimize the environmental impact of the materials flow within the supply chain (K. W. Green et al., 2012).

In particular, the exchange of information has a leading role in environmental collaboration with customers, since it allows communication during the development and introduction of a new product to the market, and collecting data from them about product use and market expectations (e.g., environmental performance and new requirements). This helps to identify business and environmental opportunities as well as to inform, educate and engage clients in various environmental protection activities. Environmental collaboration with the customer is an integral part of producer extended responsibility, which facilitates customer participation in the end-of-life product return process (Wong, Lai, Lun, & Cheng, 2016).

3. Proposed Framework

3.1 Hypotheses Development

According to Govindan, Soleimani, & Kannan (2015), during the last decades, the concepts of reverse logistics and closed-loop supply chain have acquired great importance due to a growing concern about the negative impacts generated by the different end-of-life products. This is why new regulations have been developed in different countries, which make producers responsible for the management of their products at the end of their useful life. For example, the Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96 /EU became a European law in 2003 that establishes mandatory collection, recycling and recovery requirements for all types of electrical products. Similar laws for WEEE were introduced in Canada, Japan, China and many states in the United States. In the Colombian context, Law 1672 was issued in 2003 that establishes the guidelines for WEEE in the country. This kind of legislation enforces reverse logistics activities by firms for the management of this type of waste so negative environmental impacts are avoided or reduced.

However, the implementation of reverse logistics activities requires a huge initial investment to establish the necessary infrastructure (Jayaraman, Ross, & Agarwal, 2008). Besides, reverse logistics brings costs inherent to its operation (Mihi-Ramírez & Morales-García, 2014). For example, it is necessary to develop activities such as localization, inspection, pre-processing and distribution, which result in high costs for the firm. Thus, firms require allocation of financial resources and other types of resources to be capable of deploying reverse logistics activities. Information systems require strong capital investments, but the tracking, localization and return of products, for the development of reuse, remanufacturing, recycling, etc., is not possible without them (Ravi & Shankar, 2005; Sharma, Panda, Mahapatra, & Sahu, 2011). Likewise, it is necessary to train the personnel involved in both the management and the activities of reverse logistics (Sharma et al., 2011), because an inadequate implementation can generate very high costs allocated to product return flows.

On the other hand, e-waste management could be highly complex due to the high number of components and elements that this type of products has, requiring a skilled labor force that can add costs. This inherent complexity and uncertainty in collecting end-of-life products (Guide, Jayaraman, Srivastava, & Benton, 2000; van Hillegersberg, Zuidwijk, van Nunen, & van Eijk, 2001) make this process technically difficult and costly (Jayaraman et al., 2008; Mihi-Ramírez & Morales-García, 2014). In addition, quantity and variability in the quality of the take-back products can also make the evaluation and classification process expensive and prone to errors (Jayaraman et al., 2008).

According to this, it can be established that the implementation of reverse logistics can generate the emergence of trade-offs between economic and environmental objectives. While improving environmental performance, because its objective is to generate improvement in the firm's environmental performance, reverse logistics entails high implementation and execution costs that can generate a negative impact on firms economic performance.

Based on this statement, the following research question is proposed: Q1 - What is the reason for the appearance of trade-offs between environmental and economic objectives within the adoption of reverse logistics for the management of end-of-life Electronic and Electrical Equipment (EEE)? As a research hypothesis associated with this question, to be empirically tested in the Colombian context, it is proposed: H1 - The implementation of reverse logistics practices, in the framework of the management of end-of-life EEE in Colombia, will give rise to trade-offs between environmental and economic objectives in supply chain management.

Literature calls for conducting further research on advanced greening practices in the supply chain that allow decision makers to better manage trade-offs between environmental and economic objectives, and even to transform these compromising situations in win-win situations (Hahn et al., 2010). Some authors (e.g., O'Rourke, 2014; Pagell & Shevchenko, 2014; Vachon & Klassen, 2006, 2008) have argued that environmental collaboration is a key factor in green supply chain management. For example, Vachon & Klassen (2008) affirm that the implementation of advanced environmental practices, such as reverse logistics and product stewardship, requires varying degrees of interaction with both suppliers and consumers. Likewise, collaboration with stakeholders outside firm is considered a key factor for the success of sustainability management (Albino, Dangelico, & Pontrandolfo, 2012).

In addition, several authors have argued that collaborative relationships are a way of producing substantial improvements in supply chain performance (Arshinder, Kanda, & Deshmukh, 2008; Cao & Zhang, 2011; Mentzer, Foggin, & Golicic, 2000; Sheu, Rebecca Yen, & Chae, 2006). Collaboration helps members of the supply chain to share risks, access complementary resources, improve their technological capabilities, reduce transaction costs, improve productivity and increase profits (Arshinder et al., 2008; Cao & Zhang, 2011).

Similarly, Olorunniwo & Li (2010) establish that sharing information improves the visibility of the supply chain, which can lead to better coordination and build a solid basis for collaboration, developing efficient operations, reducing costs and improving customer service. Consequently, collaboration is a determining factor in the performance of the closed cycle supply chain.

The relationship with consumers is very important for reverse logistics implementation, since it is the gateway for products to be collected for proper management (Jayaraman et al., 2008; Wong et al., 2016). For example, uncertainty in product collection processes can be managed through customer cooperation agreements (Mihi-Ramírez & Morales-García, 2014) and the high costs involved in reverse logistics can be mitigated through the use of effective information systems and collaboration with supply chain partners (Jayaraman et al., 2008).

According to the above, it can be concluded that collaboration can improve the economic performance of reverse logistics practices (Leuschner, Rogers, & Charvet, 2013; Mihi-Ramírez & Morales-García, 2014; Olorunniwo & Li, 2010). Therefore, the previous research question is complemented with the following: Q2 - How does the environmental collaboration with clients affect the trade-offs between environmental and economic objectives within reverse logistics adoption for end-of-life WEEE management? And, for the purpose of empirical testing, two additional research hypotheses are stated: H2a - Environmental collaboration contributes to close the gap between environmental and economic performance in the management of end-of-life WEEE in Colombia; and, H2b - Environmental collaboration generates win-win situations between environmental and economic objectives in the management of end-of-life WEEE in Colombia.

3.2 Proposed Methodology

In order to address the above questions, a simulation model is proposed, since it combines the clarity and generality of mathematical models, with more realistic models and statistical analysis (Davis, Eisenhardt, & Bingham, 2007; Größler & Schieritz, 2005). A simulation model is a simplified representation of a real system. From a practical point of view, Kelton, Sadowski, & Swets (2010) describe the simulation as the process of designing and creating a computational model of a real system, with the purpose of carrying out a series of virtual experiments to obtain a better understanding of the system behavior. It can be very useful for the study of complex problems derived from the analysis of relationships among the members of a supply chain.

Within the different simulation approaches, discrete event simulation and system dynamics have been widely used in the field of supply chain management. However, these two approaches have shown limitations when representing the dynamics of relationships among supply chain members (Dorigatti, Guarnaschelli, Chiotti, & Salomone, 2016). Therefore, agent-based simulation has gained a leading role in supply chain research over the last decade (Long & Zhang, 2014).

For this reason, agent-based simulation (ABS) is proposed here as the preferred approach to model interactions in a closed-loop supply chain. ABS is a computational method that allows a researcher to create, analyze and experiment with models composed of agents that interact within an environment (Gilbert, 2007). In multi-agent systems, agents interact with each other in order to carry out tasks through cooperation, coordination and negotiation (Wooldridge & Jennings, 1995). Thus, a supply chain can be seen as a network of autonomous agents aimed at the acquisition, manufacture and distribution of related products or services.

During the last decade several supply chain studies using agent-based simulation have been developed, which show the importance that this methodology has acquired in the field of study. Some authors have developed simulation models based on supply chain agents for decision making (e.g.,Julka, Karimi, & Srinivasan, 2002; Julka, Srinivasan, & Karimi, 2002; Labarthe, Espinasse, Ferrarini, & Montreuil, 2007; Méndez Fajardo, 2016; M. Wang, Wang, Vogel, Kumar, & Chiu, 2009). Other authors have tried to model the benefits of implementing some mechanisms of collaboration in the supply chain, including coordination (e.g., Xue, Li, Shen, & Wang, 2005), exchange of information (e.g., Zhu (David), 2008), cooperation (e.g., Albino, Carbonara, & Giannoccaro, 2007) and level of integration (e.g., Kwon, Im, & Lee, 2007). Finally, some authors have modeled greening practices in the supply chain, including reverse logistics (e.g., Haiyan & Min, 2010; Ravi Sankara Pandian, 2015).

Agent-based simulation is relevant for supply chain research, because it allows the analysis of the autonomous behavior of each member of the chain, as well as of the interactions that exist among them, which explains the emergence of a global behavior for the chain. This type of simulation uses an agent or a group of agents to represent supply chain members, and the interactions between agents to represent communication and coordination among these members. According to their objectives, resources and knowledge, agents make decisions by themselves and interact with other agents to achieve the overall objective of the multi-agent system. Consequently, agent-based simulation has an unprecedented advantage over discrete event simulation and system dynamics, since it is fully consistent with supply chain realities (Long & Zhang, 2014).

3.1 Agent-based Conceptual Model

The purpose of this model is to allow analyzing the emergence and management of trade-offs between environmental and economic performance due to the implementation of reverse logistics at the end-of-life stage of refrigerators' life cycle. This model is grounded on the post-consumer refrigerator management program in Colombia, called "Red Verde". In order to achieve the described objective, the present model focuses on the actors involved in the logistics system and proposes four agents: Consumer Agent (client), Third-party logistics Agent, Coordinator Agent, and Producer Agent. The following assignment of tasks among agents is proposed based on the process approach:

- Producer Agent: It is in charge of providing the financial funds for the operation of the whole system, as well as the guidelines for the management.
- Coordinator Agent (Red Verde): It is responsible for managing the financial resources of the system, to achieve the best possible results in terms of the objectives of reverse logistics, including costs minimization and improvement of environmental performance. It is also responsible for complying with and enforcing the system guidelines given by the Producer Agent.
- Third-party logistics Agent: It is responsible for collecting and selecting refrigerators returned by the consumer agent.
- Customer Agent: It is the entry point to the reverse logistics system, returning the refrigerators at the end of their useful life.

Interaction protocols are established according to Swaminathan, Smith, & Sadeh (1998), who recognize three broad categories of messages, each associated with the simulation of a specific type of flow across the supply chain:

- Material flows: Messages in this category refer to the delivery of goods from one agent to another. In the present model, these messages establish the return of a refrigerator by the Consumer Agent to the Third-party Logistics Agent.
- Information flows: This category of messages shows the exchange of information between agents in the supply chain.
- Cash flows: The final category of messages refers to the movement of capital among the players in the reverse logistics system. This category includes a message sending the financial resources given by the Producer Agent to the Coordinator Agent for the operation of the system and the payment to the Third-party Logistics Agent for the services rendered to the Coordinator Agent. Moreover, in the case of shared-savings contracts, there are two additional messages that represent the capital flow from the Third-party Logistics Agent to the Coordinator Agent and from the Coordinator Agent to the Producer Agent for distributing the capital savings achieved during the operation of the reverse logistics system among these agents.

Figure 1 shows a representation of the agent-based conceptual model of the reverse logistics system for the management of end-of-life refrigerators in Colombia, focusing on the interactions between agents through the mapping of the physical, information and financial flows.

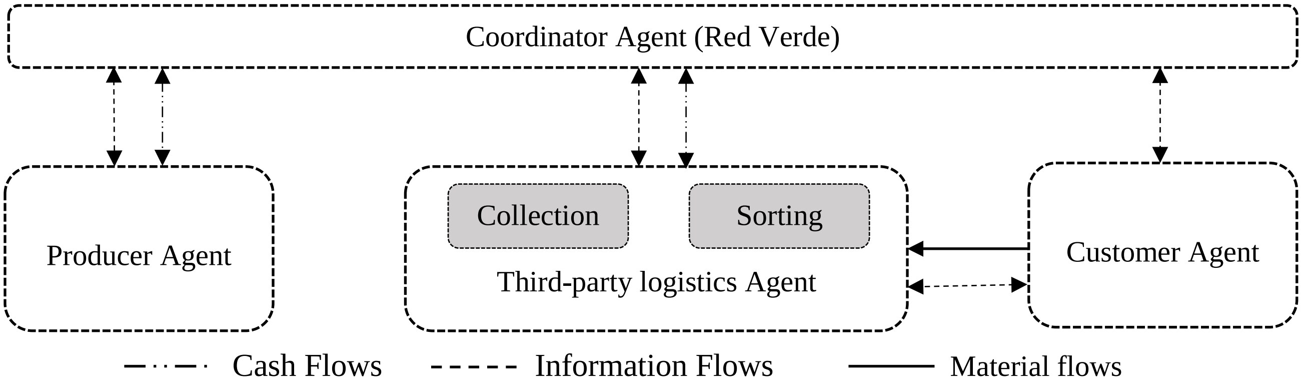

Figure 1. Agent-Based Conceptual Model of Reverse Logistics

4. Conclusions

Based on the literature review, it can be established that the implementation of advanced environmental practices along the supply chain, such as reverse logistics, can generate conflicts between environmental and economic objectives, allowing the emergence of trade-offs. On the other hand, it is established that the trade-offs approach between environmental and economic objectives has not been much studied and therefore calls for the development of qualitative and quantitative work to understand the nature of these trade-offs and the response by companies to them.

In addition, during the last decade, simulation has acquired importance in research on logistics, supply chain and reverse logistics. The agent-based simulation approach shows the greatest projection to address these issues since it allows capturing the behavior of the chain members as well as their interactions, being consistent with the reality of a supply chain.

This paper illustrates the preliminary research stage for the development of an agent-based system that could be implemented to study the emergence of trade-offs between environmental and economic performance due to the implementation of a reverse logistics system, as well as to study the role of collaboration in the management of these trade-offs. The next steps of the research will include the development of a case study about the reverse logistics system of end-of-life refrigerators in Colombia, the design of the communication structure, the control structure between the agents, and the design of collaboration mechanisms.

An exploratory case study will help to study the current phenomena in a real-world context, which will allow characterizing the post-consumer management program for refrigerators in Colombia "Red Verde", studying the behavior of each of the actors and the mechanisms of interaction among them. This will enrich the conceptual model proposed here for the development of the agent-based computational model.

Likewise, during the development of the case study, the collaboration mechanisms that exist among the different agents will be identified. Also, it will be verifying if there are the conditions for the implementation of collaboration mechanisms suggested by the literature, such as information sharing and shared-savings contracts.

Computer simulation can be seen as an experimental technique for hypothesis testing and scenario analysis, which can be used in a complementary way and in combination with experiments in real life. For this reason, the hypotheses can be tested through the development of sensitivity analysis to validate both the emergence of trade-offs between environmental and economic objectives, as well as, the role of environmental collaboration in the management of these trade-offs.

The agent-based simulation model will contribute to a better comprehension about the generation and post-consumption management of WEEE in Colombia. It will also enable decision makers in the EEE logistics chain to understand better the interactions between environmental and economic objectives, as well as the relationship between the adoption of reverse logistics practices and the impact of these strategies on performance, both economic and environmental.

References

Albino, V., Carbonara, N., & Giannoccaro, I., Supply chain cooperation in industrial districts: A simulation analysis. *European Journal of Operational Research*, vol. 177, no.1, pp. 261–280, 2007.

Albino, V., Dangelico, R. M., & Pontrandolfo, P., Do inter-organizational collaborations enhance a firm's environmental performance? a study of the largest U.S. companies. *Journal of Cleaner Production*, vol. 37, pp. 304–315, 2012.

Álvarez Gil, M. ., Burgos Jiménez, J., & Céspedes Lorente, J., An analysis of environmental management, organizational context and performance of Spanish hotels. *Omega*, vol. *29,* no. 6, pp.457–471, 2001.

Ambec, S., & Lanoie, P., Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, vol. 22, no. 4, pp.45–62, 2008.

Arshinder, Kanda, A., & Deshmukh, S. G., Supply chain coordination: Perspectives, empirical studies and research directions. *International Journal of Production Economics*, vol. 115, no. 2, pp. 316–335, 2008.

Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, S., Quantitative models for sustainable supply chain management: Developments and directions. *European Journal of Operational Research*, vol.233, no.2, pp. 299–312, 2014.

Cao, M., & Zhang, Q., Supply chain collaboration: Impact on collaborative advantage and firm performance. *Journal of Operations Management*, vol. 29, no. 3, pp. 163–180, 2011.

Chaabane, A., Ramudhin, A., & Paquet, M., Designing supply chains with sustainability considerations. *Production Planning & Control*, vol. 22, no. 8, pp. 727–741, 2011.

Chacón-Vargas, J. R., & Moreno-Mantilla, C. E., Sustainable supply chain management capabilities: a review from the resource-based view, the dynamic capabilities and stakeholder theories. *Latin American J. of Management for Sustainable Development*, vol. 1, no. 4, pp. 323–343, 2014.

Curkovic, S., Melnyk, S. A., Handfield, R. B., & Calantone, R., Investigating the linkage between total quality management and environmentally responsible manufacturing. *IEEE Transactions on Engineering Management*, vol. 47, no. 4, pp. 444–464, 2000.

Davis, J. P., Eisenhardt, K. M., & Bingham, C. B., Developing theory through simulation methods. *Academy of Management Review*, vol. 32, no. 2, pp. 480–499, 2007.

Ding, H., Zhao, Q., An, Z., & Tang, O., Collaborative mechanism of a sustainable supply chain with environmental constraints and carbon caps. *International Journal of Production Economics*, vol. 181, pp. 191–207, 2016.

Dorigatti, M., Guarnaschelli, A., Chiotti, O., & Salomone, H. E., A service-oriented framework for agent-based simulations of collaborative supply chains. *Computers in Industry*, vol. 83, pp. 92–107, 2016.

Elkington, J., Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development. *California Management Review*, vol. 36, no. 2, pp. 90–100, 1994.

Epstein, M. J., & Roy, M.-J., Making the Business Case for Sustainability: Linking Social and Environmental Actions to Financial Performance. *The Journal of Corporate Citizenship*, vol. 9, pp. 79–96, 2003.

Epstein, M. J., & Young, S. D., Improving corporate environmental performance through economic value added. *Environmental Quality Management*, vol. 7, no. 4, pp. 1–7, 1998.

Fahimnia, B., Sarkis, J., & Eshragh, A., A tradeoff model for green supply chain planning:A leanness-versus-greenness analysis. *Omega*, vol. 54, pp. 173–190, 2015.

Ferguson, M., & Souza, G. C.. *Closed-loop supply chains : new developments to improve the sustainability of business practices*. CRC Press, 2010.

Fernández-Quesada, M. I., *Análisis de la logística inversa en el entorno empresarial. Una aproximación cualitativa*. Universidad de Oviedo, 2004.

Ferretti, I., Zanoni, S., Zavanella, L., & Diana, A., Greening the aluminium supply chain. *International Journal of Production Economics*, vol. 108, pp. 236–245, 2007.

Figge, F., & Hahn, T., Is green and profitable sustainable? Assessing the trade-off between economic and environmental aspects. *International Journal of Production Economics*, vol. 140, no. 1, pp. 92–102, 2012.

Florida, R., Lean and Green: The Move to Environmentally Conscious Manufacturing. *California Management Review*, vol. 39, no.1, 80–105. 1996.

Gilbert, G. N., *Agent-based models*. London: Sage Publications, 2007.

González-Benito, J., & González-Benito, Ó., Operations management practices linked to the adoption of ISO 14001: An empirical analysis of Spanish manufacturers. *International Journal of Production Economics*, vol. 113, no. 1, pp. 60–73, 2008.

Govindan, K., Soleimani, H., & Kannan, D. Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, vol. 240 no. 3, pp. 603–626, 2015.

Green, K., Morton, B., & New, S., Green purchasing and supply policies: do they improve companies' environmental performance? *Supply Chain Management: An International Journal*, vol, 3, no.2, pp. 89–95, 1998.

Green, K. W., Zelbst, P. J., Meacham, J., & Bhadauria, V. S. (2012). Green supply chain management practices: impact on performance. *Supply Chain Management: An International Journal*, vol. 17, no.3, pp. 290–305, 2012.

Größler, A., & Schieritz, N., Of Stocks, Flows, Agents and Rules - ``Strategic'' Simulations in Supply Chain Research. In H. Kotzab, S. Seuring, M. Müller, & G. Reiner (Eds.), *Research Methodologies in Supply Chain Management: In Collaboration with Magnus Westhaus* (pp. 445–460). Heidelberg: Physica-Verlag HD., 2005.

Guide, V. D. R., Jayaraman, V., Srivastava, R., & Benton, W. C., Supply-Chain Management for Recoverable Manufacturing Systems. *Interfaces*, vol. 30, no.3, pp. 125–142, 2000.

Hahn, T., & Figge, F., Beyond the Bounded Instrumentality in Current Corporate Sustainability Research: Toward an Inclusive Notion of Profitability. *Journal of Business Ethics*, vol. 104, no.3, pp.325–345, 2011.

Hahn, T., Figge, F., Pinkse, J., & Preuss, L., Trade-offs in corporate sustainability: you can't have your cake and eat it. *Business Strategy and the Environment*, vol. 19, no.4, pp. 217–229, 2010.

Haiyan, W., & Min, T. Reverse Logistics Outsourcing Model Based on Principal-Agent Theory. In *2010 International Conference on Optoelectronics and Image Processing* (pp. 335–338). IEEE, 2010.

Hanson, J. D., Melnyk, S. A., & Calantone, R. J., Core values and environmental management: A strong inference approach. *Greener Management International*, vol. 46, pp. 29–40, 2004.

Hart, S. L., Milstein, M. B., & Caggiano, J., Creating sustainable value. *Academy of Management Executive*, vol. 17, no. 2, pp. 56–69, 2003.

Jayaraman, V., Ross, A., & Agarwal, A., Role of information technology and collaboration in reverse logistics supply chains. *International Journal of Logistics Research and Applications*, vol. 11, no. 6, pp. 409–425, 2008.

Julka, N., Karimi, I., & Srinivasan, R., Agent-based supply chain management—2: a refinery application. *Computers & Chemical Engineering*, vol. 26, no. 12, pp. 1771–1781, 2002.

Julka, N., Srinivasan, R., & Karimi, I., Agent-based supply chain management—1: framework. *Computers & Chemical Engineering*, vol. 26, no. 12, pp. 1755–1769, 2002.

Kelton, W. D., Sadowski, R. P., & Swets, N. B., *Simulation with Arena*. McGraw-Hill Higher Education, 2010.

King, A. A., & Lenox, M. J., Lean and Green? An empirical examination of the relationship betwee lean production and environmental performance. *Production and Operations Management*, vol. 10, no. 3, 244–256, 2001.

Kleindorfer, P. R., Singhal, K., & Wassenhove, L. N., Sustainable Operations Management. *Production and Operations Management*, vol. 14, no. 4, 482–492, 2005.

Kwon, O., Im, G., & Lee, K., MACE-SCM: A multi-agent and case-based reasoning collaboration mechanism for supply chain management under supply and demand uncertainties. *Expert Systems with Applications*, vol. 33, no.3, pp. 690–705, 2007.

Labarthe, O., Espinasse, B., Ferrarini, A., & Montreuil, B., Toward a methodological framework for agent-based modelling and simulation of supply chains in a mass customization context. *Simulation Modelling Practice and Theory*, vol. 15, no. 2, pp.113–136, 2007.

Larson, T., & Greenwood, R., Perfect complements: Synergies between lean production and eco-sustainability initiatives. *Environmental Quality Management*, vol. 13, no. 4, pp. 27–36, 2004.

Leguízamo-Díaz, T. P., & Moreno-Mantilla, C. E., Effect of competitive priorities on the greening of the supply chain with TQM as a mediator. *DYNA*, vol. 81, no. 187, pp. 240–248, 2014.

Leuschner, R., Rogers, D. S., & Charvet, F. F., A Meta-Analysis of Supply Chain Integration and Firm Performance. *Journal of Supply Chain Management*, vol. 49, no. 2, pp. 34–57, 2013.

Linton, J., Klassen, R., & Jayaraman, V., Sustainable supply chains: An introduction. *Journal of Operations Management*, vol. 25, no. 6, pp. 1075–1082, 2007.

Long, Q., & Zhang, W., An integrated framework for agent based inventory–production–transportation modeling and distributed simulation of supply chains. *Information Sciences*, vol. 277, pp. 567–581, 2014.

Matos, S., & Hall, J., Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology. *Journal of Operations Management*, vol. 25, no. 6, pp. 1083–1102, 2007.

Méndez Fajardo, S., *Systemic decisions for more sustainable weee (waste electrical and electronic equipment) management in developing countries*. Pontificia Universidad Javeriana, 2016.

Mentzer, J. T., Foggin, J. H., & Golicic, S. L., Collaboration: the enablers, impediments, and benefits. *Supply Chain Management Review*, vol 4, pp. 52–57, 2000.

Mihi-Ramírez, A., & Morales-García, V. J., Improving organisational performance through reverse logistics. *Journal of the Operational Research Society*, vol. 65, no. 6, pp. 954–962, 2014.

Molina-Azorín, J. F., Claver-Cortés, E., López-Gamero, M. D., & Tarí, J. J., Green management and financial performance: a literature review. *Management Decision*, vol. 47, no. 7, pp. 1080–1100, 2009.
Moreno-Mantilla, C. E., & Reyes-Rodríguez, J. F., Cuadernos de administración. *Cuadernos de Administración*, vol. 26, no. 47, pp. 87–118, 2013.
O'Rourke, D., The science of sustainable supply chains. *Science*, vol. 344, no.6188, pp. 1124–1127, 2014.
Olorunniwo, F. O., & Li, X., Information sharing and collaboration practices in reverse logistics. *Supply Chain Management: An International Journal*, vol. 15, no. 6, pp. 454–462, 2010.
Orsato, R. J., Competitive environmental strategies: When does it pay to be GREEN? *California Management Review*, vol. 48, no. 2, pp.127–143, 2006.
Pagell, M., & Shevchenko, A., Why Research in Sustainable Supply Chain Management Should Have no Future. *Journal of Supply Chain Management*, vol. 50, no. 1, pp. 44–55, 2014.
Porter, M. E., America's Green Strategy. *Scientific American*, vol. 264, no. 4, pp. 168, 1991.
Porter, M. E., & der Linde, C., Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, vol. 9, no. 4, pp. 97–118, 1995.
Rao, P., & Holt, D., Do green supply chains lead to competitiveness and economic performance? *International Journal of Operations & Production Management*, vol. 25, pp. 9, pp. 898–916, 2005.
Ravi, V., & Shankar, R., Analysis of interactions among the barriers of reverse logistics. *Technological Forecasting and Social Change*, vol. 72, no. 8, pp. 1011–1029, 2005.
Ravi Sankara Pandian, G., *Performance Evaluation of a Reverse Logistics Enterprise - An Agent-Based Modelling Approach*. University of Windsor, 2015.
Rogers, D. S., & Tibben-Lembke, R. S., *Going backwards : reverse logistics trends and practices*. Reverse Logistics Executive Council, 1999.
Salzmann, O., Ionescu-somers, A., & Steger, U., The Business Case for Corporate Sustainability: *European Management Journal*, vol. 23, no. 1, pp. 27–36, 2005.
Schaltegger, S., & Figge, F., Environmental shareholder value: economic success with corporate environmental management. *Eco-Management and Auditing*, vol. 7, no. 1, pp. 29–42, 2000.
Seuring, S., Supply chain management for sustainable products - insights from research applying mixed methodologies. *Business Strategy and the Environment*, vol. 20, no. 7, pp. 471–484, 2011.
Seuring, S., A review of modeling approaches for sustainable supply chain management. *Decision Support Systems*, vol. 54, no. 4, pp. 1513–1520, 2013.
Seuring, S., & Müller, M., Core issues in sustainable supply chain management - a Delphi study. *Business Strategy and the Environment*, vol. 17, no. 8, pp. 455–466, 2008.
Sharma, S. K., Panda, B. N., Mahapatra, S. S., & Sahu, S., Analysis of Barriers for Reverse Logistics: An Indian Perspective. *International Journal of Modeling and Optimization*, vol. 1, no.2, pp.101–106, 2011.
Sheu, C., Rebecca Yen, H., & Chae, B., Determinants of supplier -retailer collabor international study. *International Journal of Operations & Production Management*, vol. 26, no. 1, pp. 24–49, 2006.
Souza, G. C., Closed-Loop Supply Chains: A Critical Review, and Future Research. *Decision Sciences*, vol. 44, no. 1, pp. 7–38, 2013.
Srivastava, S. K., Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, vol. 9, no. 1, pp 53–80, 2007.
Swaminathan, J. M., Smith, S. F., & Sadeh, N. M., Modeling Supply Chain Dynamics: A Multiagent Approach. *Decision Sciences*, vol 29, no. 3, pp, 607–632, 1998.
Vachon, S., & Klassen, R. D., Extending green practices across the supply chain. *International Journal of Operations & Production Management*, vol. 26, no. 7, pp. 795–821, 2006.
Vachon, S., & Klassen, R. D., Environmental management and manufacturing performance: The role of collaboration in the supply chain. *International Journal of Production Economics*, vol. 111, no. 2, pp. 299–315, 2008.
van Hillegersberg, J., Zuidwijk, R., van Nunen, J., & van Eijk, D., Supporting return flows in the supply chain. *Communications of the ACM*, vol. 44, no. 6, pp. 74–79, 2001.
Wang, F., Lai, X., & Shi, N., A multi-objective optimization for green supply chain network design. *Decision Support Systems*, vol. 51, no. 2, pp. 262–269, 2011.
Wang, M., Wang, H., Vogel, D., Kumar, K., & Chiu, D. K. W., Agent-based negotiation and decision making for dynamic supply chain formation. *Engineering Applications of Artificial Intelligence*, vol. 22, no. 7, pp. 1046–1055, 2009.
Winn, M., Pinkse, J., & Illge, L., Case Studies on Trade-Offs in Corporate Sustainability. *Corporate Social Responsibility and Environmental Management*, vol. 19, no. 2, pp. 63–68, 2012.

Wong, C. W. Y., Lai, K., Lun, Y. H. V., & Cheng, T. C. E., *Environmental management : the supply chain perspective*. New York: Springer, 2016.

Wooldridge, M., & Jennings, N. R., Intelligent agents: theory and practice. *The Knowledge Engineering Review*, vol. 10, no. 2, pp. 115–152, 1995.

Wu, Z., & Pagell, M., Balancing priorities: Decision-making in sustainable supply chain management. *Journal of Operations Management*, vol. 29, no. 6, pp. 577–590, 2011.

Xue, X., Li, X., Shen, Q., & Wang, Y., An agent-based framework for supply chain coordination in construction. *Automation in Construction*, vol. 14, no. 3, pp. 413–430, 2005.

Zhu (David), X., *Agent based modeling for supply chain management: examining the impact of information sharing*. Kent State University, 2008.

Biography

Oscar Fabian Velásquez Rodríguez is a PhD candidate in Engineering - Industry and Organizations at Universidad Nacional de Colombia. He earned a Bachelor of Science in Industrial Engineering from Universidad Nacional de Colombia, Bogotá, Colombia, and a Master in Industrial Engineering from Universidad Nacional de Colombia, Bogotá, Colombia.

Carlos Eduardo Moreno Mantilla is Associate Professor in the Department of Systems and Industrial Engineering, at Universidad Nacional de Colombia. He earned a Bachelor of Science in Industrial Engineering from Universidad Industrial de Santander, Bucaramanga, Colombia; he is Specialist in Environmental Engineering from Universidad Industrial de Santander, Bucaramanga, Colombia, and PhD in Environmental Sciences from State University of New York, College of Environmental Sciences and Forestry, Syracuse, New York, United States.