Conference or Workshop Item

Title: Industrial ecology perspectives of food supply chains: a framework of analysis

Creators: Batista, L., Saes, S., Fouto, N. and Fassam, L.

Industrial ecology perspectives of food supply chains – a framework of analysis

Luciano Batista[1], Sylvia Saes[2], Nuno Fouto[3], Liam Fassam[1]

[1]CELAS - Centre for Excellence in Logistics and Supply Chain, University of Northampton, UK
[2]CORS - Centre for Organizational Studies, University of Sao Paulo, Brazil
[3]PROVAR - Centre for Retail Management Studies, University of Sao Paulo, Brazil

Abstract

This paper introduces the theoretical and methodological basis of an analytical framework conceived with the purpose of bringing industrial ecology perspectives into the core of the underlying disciplines supporting analyses in studies concerned with environmental sustainability aspects beyond the product cycle in a supply chain. Given the pressing challenges faced by the food sector, the framework focuses upon waste minimization through industrial linkages in food supply chains. The combination of industrial ecology practice with basic LCA elements, the waste hierarchy model, and the spatial scale of industrial symbiosis allows the standardization of qualitative analyses and associated outcomes. Such standardization enables comparative analysis not only between different stages of a supply chain, but also between different supply chains. The analytical approach proposed contributes more coherently to the wider circular economy aspiration of optimizing the flow of goods to get the most out of raw materials and cuts wastes to a minimum.

Key words: food supply chain, industrial ecology, industrial symbiosis, by-product synergy

I. Introduction

The environmental sustainability of the food industry and its supply chain activities is a complex issue calling for innovative sustainable practices that can be effectively achievable by the organizations operating in food value chains. The food sector as a whole faces considerable challenges imposed by the limited availability of arable land and natural resources for food production on one hand, and the continuous increase of food consumption dictated by the rapid growth of populations and livestock on the other hand.

In this context, food waste represents a major problem that remains to be comprehensively addressed. A recent study by the Food and Agriculture Organization of the United Nations (Gustavson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011) has acknowledged that a substantial amount of food, roughly a third of the global annual production, ends up in landfill as waste. An aggravating problem is that all the resources used in the production of food that is wasted are used in vain and the related carbon emissions generated in the process are for no good reason. There is also considerable loss of food inefficiently used to feed livestock (Tscharntke et al., 2012).

Despite the increasing awareness of the environmental impact of food waste and the positive consequences of reducing waste in the sector as a key means of addressing both food and water security concerns (Parfitt, Barthel, & Macnaughton, 2010; Reisinger et al., 2011), the National Resources Defense Council in the US has recently pointed out that the amount of food that gets wasted has increased by around 50% over the last four decades (Sharma-Sindhar, 2014). Even though such increase of food waste is relative to an increase in the volume of food production over the years, the amount of food waste generated in the sector can be seen as an ascending significant problem.

In order to improve its accountability and responsibility towards new expectations of customers and the society, the food sector needs innovative ways of developing concerted actions and collaboration initiatives that improve not only intra-organizational processes within specific production areas, but also the relationships and integration of inter-organizational processes that take into account the flow of food waste and related by-products across the supply chain.

The environmental sustainability of supply chains is a complex issue that involves interdependent organizations from different industries, sectors and geographical areas. The adoption of sustainable practices in supply chains is therefore a daunting task. To improve sustainability in a supply chain system as a whole it is imperative to understand the role that players in a supply system can play to develop sustainable practices at local as well as at wider regional levels. Moreover, the ecological paradigm for supply chain management demands extended integration of sustainability values, where responsible management is a key function (de Brito, Carbone, & Blanquart, 2008).

When exploring conceptual frameworks for sustainable supply chain management, Svensson (2007) has identified a number of reasonably independent, but to a certain extent replicated or overlapping, knowledge fields that strive to address issues concerning sustainability in the area, namely: green purchasing strategy; green supply chain; environmental management; sustainable supply network management; life cycle analysis; and so forth. By bringing Industrial Ecology perspectives into this context, this paper provides a valuable and innovative contribution to the wider debate on how supply chains meet the challenges of sustainability.

Specifically, the paper aims to develop a conceptual framework that is based upon knowledge areas that provide a more coherent eco narrative and innovative perspective for the analysis of waste and by-product synergies in supply chains. Food supply chains are the particular context of interest for the framework here developed, given the major challenges currently faced by the sector. We draw from industrial ecology and other relevant knowledge areas theoretical and practical aspects that support the specification of an analytical method for the diagnosis of waste minimization synergies across a food supply chain. In the following section we define the scope of the key industries in a food supply chain the paper focuses on. In the sequence, we present the core theoretical aspects underlying the proposed framework of analysis. Finally, we highlight potential applications of the framework and conclude the paper by pointing out limitations and issues for future research.

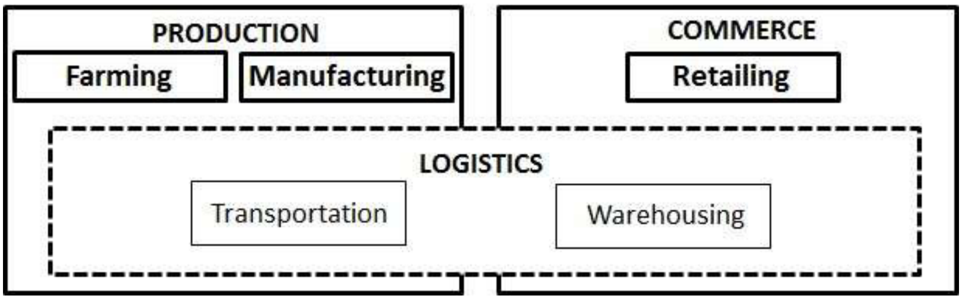
II. Relevant industries in food supply chains

The food industry is one of the largest industrial sectors in the world. The sector as a whole mobilises key industrial activities of many economies, such as agriculture, transport, manufacturing and service. Several organizations in these sectors are involved in innumerable food supply networks providing for the demand of many markets worldwide at local, national and international levels.

The market context of a supply chain can be generally sub-divided into two main perspectives: the supply-side and the demand-side. These perspectives refer respectively to the suppliers and customers in organizations' supply chains. Many studies concerned with the sustainability of food supply chains focus on demand-side aspects such as sustainable consumption and end-consumer behaviours in terms of food selection, physical flows and waste generation at household as well as hospitality industry levels (Duchin, 2008; Sloan, Legrand, & Chen, 2013; Harder et al., 2014). In this paper, we are particularly interested in addressing sustainability aspects concerning the supply-side of food supply chains, which involves major industrial activities providing for the demand-side of food markets.

More specifically, we are interested in mapping food waste scenarios and potential by-product synergies in relation to three major industrial areas on the supply-side of food supply chains: Food production, logistics and retailing. Figure 1 presents a structured view of these industries and the related key sectors they involve.

Figure 1 – Relevant industrial activities on the supply-side of food chains



Key sectors in the food production industry usually involve farming and manufacturing (processing) of food. These are typical starting points of many food supply chains, although in many cases food production involves only farming (e.g. fresh fruits and vegetables). The main outcomes from the production industry reach the retail sector through the logistics industry, where companies provide specialised food transportation and warehousing services. Finally, the retail industry makes food available for consumption through the commercialisation of food to end-consumers (individuals and businesses) on the demand-side of the supply chain.

The structured perspective shown in Figure 1 is a simplified overview of the key industrial sectors of food supply chains. The real context in which those industries operate is actually much more complex. In a large-scale context of a commodity supply chain, like coffee for example, transportation and warehousing activities also take place within farming and manufacturing processes, as well as within retail processes downstream the supply chain. Farming and manufacturing sites in the food production industry are not necessarily situated in the same geographical areas. Very commonly, manufacturers of processed coffee in the US and Europe source their coffee beans from farms in Africa or Latin America. To improve the range of their offers, retailers all over the world source a variety of coffee categories such as organic, fair trade, gourmet, and so forth, from a multitude of producers worldwide. Linking this complex network of producers and retailers around the world, global logistics activities involving transportation by rail, ship and truck, as well as large warehousing operations, take place. In addition, all major industrial activities involved in the cycle of food production, logistics and retailing mobilise key supporting industries that provide essential inputs such as packaging, fertilisers, fuel, water, gas and electricity necessary for food production, handling, flow and storage within and between the industrial sectors in the supply chain.

Deriving food waste scenarios and potential by-product synergies from the context above described is not a straightforward task. Previous studies have pointed out that approaches to analyse and mitigate the environmental impact of food supply chains without proper consideration of the dependencies that exist between processes intra and inter organizations and sectors in the chain are likely to fail (Cellura, Ardente, & Longo, 2012). To deal with the environmental complexity of food supply chains, it is necessary to have the support of analytical framework methods that take into account the array of industries involved as well as their geographical configurations and potential cross-industry linkages in different regions across the supply chain. Based upon these premises, in the next section we introduce an innovative framework for the analysis of food waste and potential by-product synergies in food supply chains. The framework synthesises best practices and approaches from established knowledge areas and frameworks into a more practical analytical method. Specifically, the theoretical basis underlying the framework proposed comprises fundamental principles of industrial ecology and related industrial symbiosis area combined with core elements of the classic Life Cycle Assessment (LCA) method and the EU waste hierarchy framework.

III. Analyzing food waste and by-product synergies

Before developing a framework for the analysis of food waste and by-product synergy scenarios across industries in a food supply chain, it is important to address the concepts of "food waste" and "by-product" the framework takes into account. A first aspect to consider is that food waste does not necessarily mean food that is not proper for consumption, i.e. inedible. In many food supply chains edible food is considered a disposable commodity, and therefore seen as "waste", because it does not fulfill aesthetic requisites of adequate shape, size, weight, visual presentation, etc. specified by major retailers around the world (Stuart, 2009). Moreover, it is not uncommon to find food production scenarios, specifically in farming, where a surplus of food that meets commerce specifications is produced beyond demand needs as a measure to safeguard against unpredictable weather conditions. Papargyropoulou *et al*. (2014) make a distinction between food waste and food surplus by considering food waste as food unfit for human consumption while food surplus comprises food fit for human consumption. From this point of view, the instant food surplus becomes unfit for human consumption it becomes food waste.

Given that not any food supply chain presents a food surplus scenario, for the purpose of this study food waste is not linked to the issue of whether it is edible or not. From our framework of analysis, food waste is all food that for any reason is taken out of the supply chain it was originally linked to. This perspective fits the general definition of food waste provided by the Food and Agriculture Organization (FAO) of the United Nations, which defines food waste as any edible material intended for human consumption that at any point in the supply chain is discarded, degraded, lost, spoiled or consumed by pests (FAO, 1981).

The other important element we consider in our eco-analysis of food supply chains is by-product, which is a form of product residue. According to the European Commission Waste Framework Directive (DG-Environment, 2012), a product residue is all material that is not deliberately produced in a production process. A product residue may be a by-product or a waste, and to be characterized as a by-product the material has to satisfy conditions such as: The material can be lawfully used in other production processes; it can be used directly without any further processing other than normal industrial practice; and its use will not lead to adverse human health and environmental impact.

In general, food waste and related by-products are non-desired outcomes of a food supply chain. These outcomes however may be valuable resources (feedstock) to other processes inside or outside the supply chain where they were originally generated. With this fundamental premise in mind, key questions concerning the framework here developed are: What are the food waste and by-products materials generated throughout the industrial activities in a food supply chain? Can they be minimized in the generation processes? Can they be absorbed (re-used) by the industrial activities they were generated from or by other industrial activities they can connect to? The different answers to these questions depict the distinct scenarios of food waste and by-product synergies one can potentially find across the major industrial activities taking place in different stages of a food supply chain.

III.1. An Industrial Ecology (IE)-based framework for analysis of food waste and by-product synergies

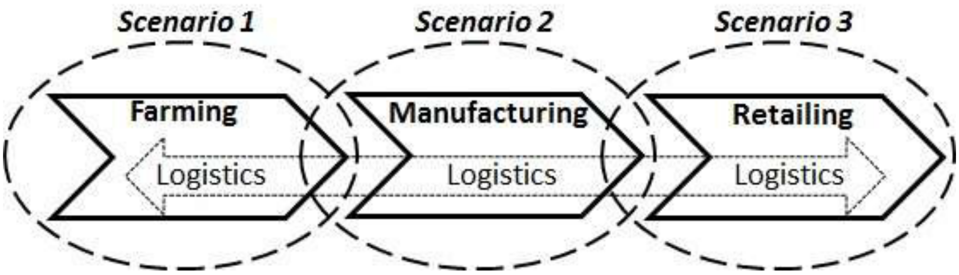
The environmental impact of food supply chains and related issues concerning waste minimization have been widely researched over the years, with LCA being the predominant methodological framework of analysis adopted by most of the studies. Also known as "cradle to grave" analysis, LCA is a well-established and widespread standardized methodology to assess the environmental impact of products and associated industrial processes throughout their life cycle, including raw material production, manufacture, distribution, use and disposal (ISO, 2006). The application of LCA methods focused on the supply-side of supply chains is also known as "cradle to gate" analysis. Thus, by focusing on the analysis of the supply-side of food supply chains we are in practice taking a "cradle to gate" approach to analyze food waste. The key difference is that rather than focusing mainly upon the flow of food products and related environmental impacts, we focus mainly upon the flows of food waste and related by-products across the supply chain stages as well as from the organizations in the supply to organizations outside the supply chain.

More specifically, while LCA analysis is mainly centered on the lifetime of a product flowing through a supply chain, i.e. the life cycle of a product and consequent environmental impacts throughout its lifetime, the focus of other analytical methods is mainly upon the waste and by-products generated from industrial activities. In such studies the investigative viewpoint shifts from a linear approach to a network perspective of analysis involving the assessment of potential by-product synergy (BPS) networks comprising cross-sector organizations operating in proximate regions (see for example the works of Mangan & Olivetti (2008) and Cimren et al. (2011)). An important aspect of the BPS approach is that it does not depend on the co-location of industries within same industrial parks. Rather, it takes into account potential network linkages among companies that are not necessarily located within the boundaries of a specific industrial park (Cimren et al., 2011).

A fundamental practice of BPS is the matching of by-product outputs from one facility with input streams to other facilities, which may involve exchange of materials, energy, water and/or byproducts (Mangan & Olivetti, 2008). This refers to an essential aspect of industrial linkages at interfirm level considered by the Industrial Ecology (IE) theory, which takes into account the utilization of by-products as feedstock for other industrial processes (Chertow, 2000). Industrial connections of this nature are crucial in a 'closed-loop' or circular economy, where input/output systems are complemented by further input/output connections in which undesired outputs are transferred to entities able to use them as inputs into their productive systems (Sterr & Ott, 2004). Such industrial connections are a fundamental principle of the IE-based framework of analysis we develop in this paper. Ultimately, the methodological framework proposed aims at identifying potential exchanges of food waste and by-products across the industrial activities taking place in a food supply chain, pointing out scenarios of waste and by-product outputs linked to prospective input alternatives across the supply chain.

To develop the framework, we draw from a methodological approach developed by Ardente et al. (2009), in which LCA-driven analysis is applied to the study of industrial activities in a specific region with the purpose of defining industrial ecology strategies for the development of 'eco-industrial clusters'. We expand on this approach by combining it with the waste model for the food sector proposed by Darlington, Staikos, & Rahimifard (2009) to classify the inventory of food waste and byproducts generated in different stages of the supply chain. Finally, food waste and by-product synergy scenarios are considered with basis on the European waste hierarchy model (EU Comission, 2008) and basic industrial symbiosis concepts (Chertow, 2007; 2000). A diagram of the methodological process is illustrated in Figure 2, which shows that different Industrial Ecology scenarios emerge from the analysis applied in different industrial stages of the supply chain. The scenarios are the main outcomes of the analysis process and they ultimately describe potential food waste and by-product synergies not only within and between core industrial activities of the supply chain being studied, but also potential industrial linkages with organizations outside the supply chain that are nonetheless located in areas adjacent to the core industries in the supply chain stage being analyzed. The key steps to be followed in the analytical framework proposed are presented next.

Figure 2 – IE-based scenarios of industrial linkages



III.2. Methodological phases of the proposed analysis

III.2.1. Goals and scope definition

The initial phase of the analysis corresponds to the starting phase of the LCA method, where the 'systems boundaries' are specified (ISO, 2006). More specifically, in this phase we specify the unit of analysis, the systems-in-focus and the scope of the external environment that are going to be investigated. The unit of analysis refers to the underlying case for the study. That is, the specific food product being analyzed and its supply chain of reference from which food waste and by-product synergy scenarios are going to be drawn. The systems-in-focus comprise the core organizations in each of the supply chain stages being analyzed. As illustrated in Figure 2, the typical system-in-focus in each stage of a specific food supply chain are the farming and related logistics organizations in the initial productive stage, the manufacturing and related logistics organizations in the food processing stage, and the retailer companies and related logistics organizations operating at the interface between the supply-side and demand-side of the food supply chain under study. Finally, the external environment represents the specific region comprising the external organizations surrounding the system-in-focus (the core organizations) in each stage of the supply chain. In other words, it comprises organizations external to the supply chain of reference that might be involved in potential food waste and by-product synergies in particular stages of the supply chain.

Building upon the method suggested by Ardente et al. (2009), we have specified the following core activities for this phase:

a. *Specification of the unit of analysis*: Characterization of the specific food supply chain to be investigated. In practice, this represents the overall specification of a specific supply chain that represents the underlying case for study, the productive supply chain stages it comprises and the geographical regions being considered. Then, for each supply chain stage the activities below should be developed.

b. *Characterization of systems boundaries*: Characterization of the companies within the regional scope being considered in the particular supply chain stage under analysis. It involves specification of the production activities, related industrial sectors and area occupied by the companies participating directly in the supply chain being investigated (the systems-in-focus) as well as the surrounding organizations in the specific region being analyzed.

c. *Analysis of industrial processes*: General characterization of core productive processes of the companies identified in the previous activity in terms of input resources such as raw materials, production materials, water and energy, as well as output flows such as the core outcome product and related food waste and by-products outputs.

From an industrial ecology perspective, steps b. and c. above refer to the 'industrial inventory' process of the analysis. Industrial inventory in practice comprises the identification of local organizations in a specific region and their related resources. According to Chertow (2012) due to confidentiality issues involving private organizations, in this phase data concerning the inputs and outputs of relevant industrial processes are collected generically to form a base analysis from which further assessments can be developed.

III.2.2. Inventory of waste outputs

Differently from traditional LCA approaches, in this phase of the analysis we focus particularly upon the classification of the waste outputs identified in the previous phase. For this, we apply the waste model for the food sector defined by Darlington et al. (2009) as a basis to classify, in a standardized way, the food waste and related by-product outputs previously identified. We slightly adapt the model to specify a clearer differentiation among the five general types of waste in the food sector, namely:

1) *Processing waste*: This category of waste includes all inedible materials generated from the production process such as stems, leaves, bones, excess animal fat, spoiled food, spillages, contaminated products due to poor handling or processing failure, and debris generated by washing processes.

2) *Wastewater*: This category of waste refers to water at the end of food processing or cleaning processes, which usually carries dirt or debris. According to Darlington et al. (2009), in some cases it might be possible to recycle water after filtration processes; however, in most cases waste water is disposed of after bulk debris are filtered.

3) *Packaging waste*: Packaging is a critical element in the food industry, as it is widely used in several points of the food supply chain to prevent contamination or spoilage as well as to facilitate transportation, storage and handling processes. When flowing through the supply

chain, food is usually packed and re-packed in different sorts of packages that may involve materials such as plastic, paper, cardboards, wood, fabrics, styrofoam, etc. Many of these materials are disposed from packaging and re-packaging processes along the way.

4) *Non-conformity waste*: We place in this category all edible products generated in the production process that have not achieved conformity with specifications of quality, consistency, flavour, aroma, size, shape, and so forth, predetermined by organizations taking the products into their operations downstream the supply chain.

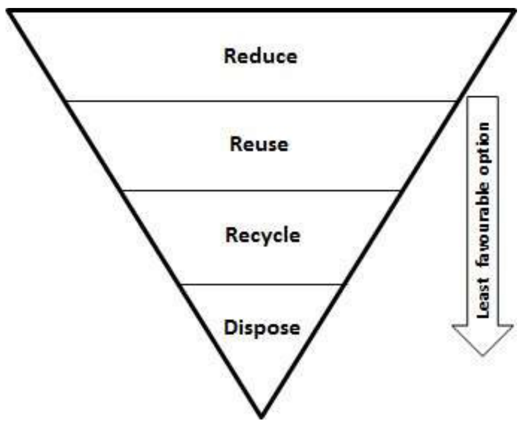
5) *Overproduction waste (OPW)*: The OPW category refers to food that meets industry specifications but has to be scrapped because it no-longer has a consumer. This is a common situation for own-label food manufacturers that fulfil their customer orders but cannot redirect their spare production to other customers due to contractual agreements.

III.2.3. Scenarios specification

After the categorical classification of waste outputs in the previous phase, the analysis moves on to the scenarios specification phase, which is mainly concerned with the systematic description of waste destination patterns in each of the regions related to the supply chain stages being analyzed. The regional scenarios specified for each stage of the food supply chain have two time-related perspectives, one portraying the current status of waste destination processes taking place in the regions and the other portraying future waste destination scenarios with innovative industrial activity linkages that can potentially take place if industrial ecology practices are implemented.

Ultimately, the future scenarios are specified with the purpose of improving the environmental sustainability of food supply chains by pointing out potential alternatives to divert food waste and by-product flows from disposal processes. Based upon the EU waste hierarchy model developed by the European Commission (EU Comission, 2008), we have specified a hierarchy model that better fits the food sector context. The food waste hierarchy framework proposed (Figure 3) is the referential basis to classify in a standardized way the different alternatives of waste destination one can find in present and future scenarios.

Figure 3 – The food waste hierarchy



According to the food waste hierarchy model in Figure 3, the alternatives to divert food waste and by-product flow from disposal are reduction, reuse or recycling of waste, with reduction being the most favourable option and disposal the least favourable one. Indeed, from an environmental sustainability perspective reducing waste generation is logically the best option to protect the environment and preserve resources. That is why the waste hierarchy pyramid is classically drawn upside down, suggesting that most industrial activities should target waste reduction in the first place. On the other extreme, the disposal of food waste, especially in edible state, should be seen as a last resort to be considered. In the food sector context, the 'reuse' alternative in the waste hierarchy model can be seen as the reuse of surplus food proper for human consumption, through redistribution networks and food banks for example, and the 'recycle' alternative can be seen as recycling of food waste into animal feed or composting processes for example (Papargyropoulou et al., 2014).

In practice, the hierarchy model indicates an order of preference for actions we target when looking for better alternatives for food waste and by-product disposal processes. Based upon the present scenario specified in the analysis process, we specify future waste destination scenarios showing potential industrial activity connections that move current waste flows up the food waste hierarchy pyramid, and most importantly out of the disposal cycle. This is done by matching food waste and by-product streams from one organization with inputs at other facilities inside or outside the supply chain under analysis. From an industrial ecology perspective, such input-output matching refers to industrial linkages that transform 'open-loop' systems into 'closed-loop' systems where waste becomes the inputs for other processes (Chertow, 2007). In this sense, waste and by-product destination processes flowing to landfill (disposal) can be seen as open-loop systems, whereas waste and by-product destinations into recycle and reuse processes are closed-loop systems. In general the 'reduce', 'recycle' and 'reuse' alternatives for waste can be achieved through the optimization of internal productive processes of organizations (Gunasekaran & Spalanzani, 2012). Further recycle and reuse alternatives can be potentially achieved through industrial linkages (synergies) with other organizations (Chertow, 2012) in the region being analyzed.

To extend the standardized characterization of 'closed-loop' scenarios involving industrial linkages in the region, the different configurations of materials exchange identified are further categorized in terms of the spatial dimension of the linkages. For this we adopt the typology defined by Chertow (2000) for categorizing the spatial scale of industrial symbiosis initiatives. Industrial symbiosis is a specific area of the industrial ecology field that is concerned with the flow of materials through networks of traditionally separate industries engaged in physical exchanges of waste, by-products, water and energy (Chertow, 2007). Such initiatives are expected to boost the environmental integrity and economic prosperity of communities and regions (Bansal & McKnight, 2009). From a spatial perspective, the general types of materials exchange through industrial activity connections are (Chertow, 2000):

- *Type 1 – Through waste exchanges*: Refers to materials exchange involving third-party brokers or dealers (e.g. scrap dealers) that create trading opportunities for waste and byproducts.

- *Type 2 – Within a facility, firm or organization*: Refers to exchanges that occur inside the scope of one organization, without involving outside parties. For instance, between departments or productive areas of the same organization.

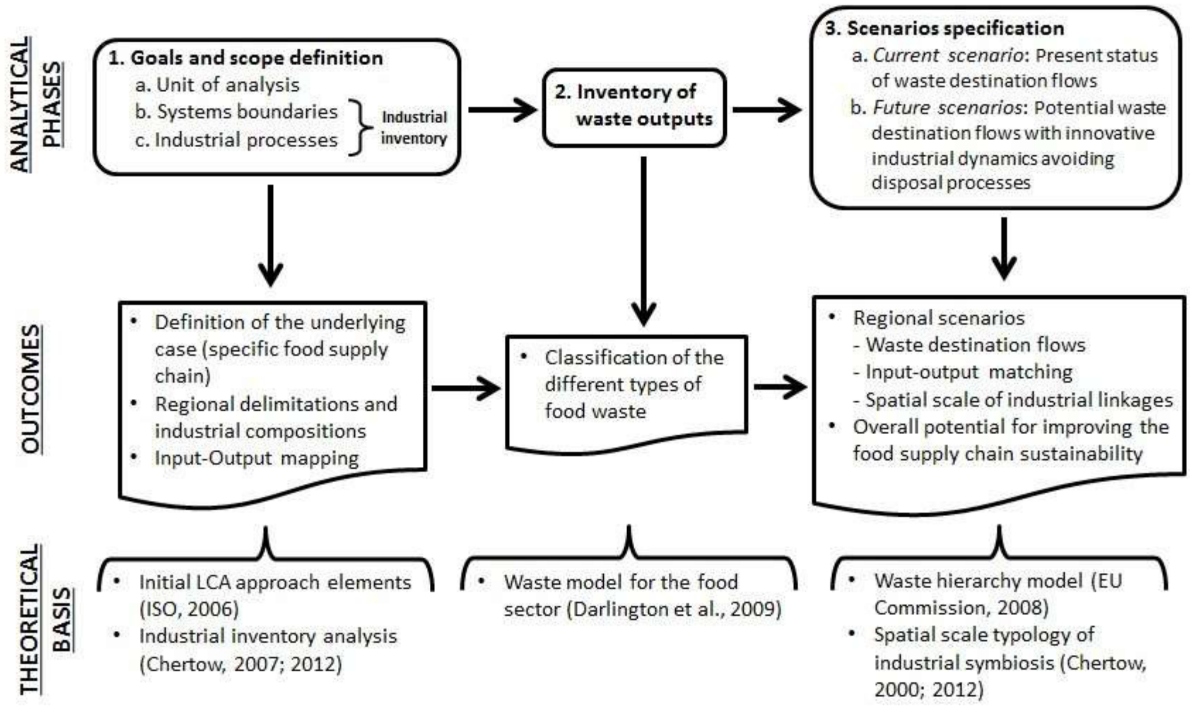
- *Type 3 – Among firms colocated in a defined industrial park*: Refers to exchanges involving organizations located within a determined industrial park.

- *Type 4 – Among local firms that are not colocated*: Refers to exchanges involving organizations that are not necessarily in the same industrial park; however, they are located in physical proximity within a specific geographic region.

- *Type 5 – Among firms organized across a broader region*: Refers to exchanges involving organizations that are not necessarily in geographical proximity; however, they can get engaged in materials exchange initiatives in a wider regional scale by capitalizing on existing logistics systems.

To analyze a food supply chain with basis on the methodological framework above described, a case study approach should be taken, where a qualitative characterization of food waste and by-product synergies scenarios is developed for each region comprising the different stages of a food supply chain. In conformity with qualitative research strategies (Bryman, 2012), a variety of techniques such as field observation, analysis of texts and documents, and interviews involving recording/transcribing activities should be developed. The use of multiple techniques allows a comprehensive understanding of the industrial linkage configurations and related regional contexts. Figure 4 presents a summary of the methodological framework with its phases, main outcomes and theoretical basis. As the framework ultimately points out alternatives for eco-friendly scenarios in food supply chains, we termed it EFOS (Eco Food Supply Chain) framework to facilitate future references.

Figure 4 – The EFOS (Eco Food Supply Chain) framework for food supply chain analysis



IV. Discussion

The EFOS framework specified in the previous section makes valuable methodological and practical contributions to studies concerned with the sustainability of food supply chains. On the methodology side, it brings core industrial ecology (and related industrial symbiosis) concepts and principles into the core of underlying theories and methods supporting waste analysis in the context of supply chains. This enables the development of more authentic eco narratives to address sustainability issues. This is because the method gives more emphasis on wider industrial dynamics taking place in different stages of food supply chains. By depicting current industrial linkages and pointing out potential industrial connections that can take place in the future in order to minimize waste disposal processes, the method paves the way for eco-innovation across the supply chain.

The combination of industrial ecology perspectives with basic LCA elements, the waste model for the food sector (Darlington et al., 2009), the waste hierarchy model (EU Comission, 2008), and the spatial scale typology of industrial symbiosis (Chertow, 2012) allows the standardization of qualitative analyses and associated outcomes. Such standardization enables comparative analysis not only between different stages (regions) in a supply chain, but also between different supply chains. Moreover, it also allows comparative analysis between past and current scenarios, as studies are replicated over time.

Regarding practical contributions, the qualitative approach adopted by the proposed framework facilitates the initial analysis of industrial linkages and related waste flow configurations in a food supply chain. By 'initial analysis' we mean that the standardized qualitative description of waste flow scenarios and their industrial contexts provides a helpful structuration of the problem, unveiling waste flows and industrial dynamics that can be used as a basis in further studies undertaking deeper quantitative analysis in which specific aspects of the initial qualitative scenarios are measured and quantitatively analyzed. The EFOS method was in practice designed with the ultimate purpose of complementing rather than replacing current methods. The gap addressed by EFOS is that many of the existing methods for analyzing the environmental impact of an industrial process or product require quantitative approaches that usually involve considerable efforts of data acquisition and modeling that are complex, time consuming and cost demanding.

The qualitative approach in the framework here proposed provides a relatively low-cost and less complex method to investigate sustainability issues concerning supply chains. Building upon the strengths of established methods and tools, the framework combines best methodological practices that provide a solid and simple approach for exploratory assessments whose structured outcomes serve as a valuable diagnostic basis to inform and influence strategic choices and decision-making processes for producers, businesses, and policy-makers. It also establishes a benchmarking structure for future data collection, facilitating the development of studies involving quantitative analysis and simulations.

Finally, the framework takes industrial symbiosis aspects into account. The applicability of industrial symbiosis concepts and practices in supply chain studies is particularly useful for supporting the development of eco-innovative approaches to improve the environmental sustainability of supply chains, for it allows better comparative analysis of regional perspectives where the different types of materials exchanges are characterized according to their spatial scale and organizational elements.

The potential industrial symbiosis scenarios provided by the framework point out alternatives for sustainable regional developments. In practice, the different scenarios represent Industrial Ecology options highlighting potential cross-sector linkages involving key industrial activities in specific stages of the supply chain. These industrial connections actually represent latent value chains that can emerge from food waste and by-product outputs in food supply chains. Such valuable insights can be used to support policy making and planned industrial symbiosis initiatives.

V. Conclusion

This conceptual paper introduces the theoretical and methodological basis of an analytical framework conceived with the purpose of bringing industrial ecology perspectives into the core of the underlying disciplines supporting analyses in studies concerned with environmental sustainability aspects beyond the product cycle in a supply chain. Given the pressing challenges faced by the food sector, the framework focuses upon waste minimization via innovative industrial collaboration dynamics in food supply chains. By pointing out potential alternatives to divert food waste flows from disposal processes, the framework termed EFOS (Eco Food Supply Chains) provides evidencebased scenarios to reduce the generation of waste and increase the level of reuse and recycling flows. In this sense, the approach proposed by EFOS coherently contributes to the wider circular economy aspiration of optimizing the flow of goods and services to get the most out of raw materials and cuts waste to the absolute minimum (Preston, 2012).

Currently, there are several methods and tools to measure the environmental impact of supply chains in general. However, before measuring impacts it is necessary to understand properly the dynamics of waste and by-product flows not only through the supply chain being studies, but also through flows going outside the supply chain. To establish synergistic collaborations where waste and by-products can be exchanged, sold or transferred free of charge, it is crucial to determine how industries can work together and develop potential applications of unwanted materials (Cimren et al., 2011). This is the key issue the EFOS framework addresses. The framework provides a systematic and standardized way to determine such industrial linkages and applications. Specifically, the overall implications addressed by the analysis method here developed consider how organizations involved in a food supply chain system can get engaged in symbiotic relationships that can potentially improve not only their own environmental sustainability performance, but also the performance of the supply chain systems they are part of.

The framework also provides a helpful basis for the development of future research. For instance, it is claimed that the overall food losses and waste are higher in developed countries than those in developing countries (Gustavson et al., 2011; Papargyropoulou et al., 2014). The standardized outcomes provided by the EFOS framework allows comparative analysis of how the distribution of food losses and waste varies between developed and developing countries, as well as between different regional production contexts.

Additionally, the framework can be associated with quantitative techniques in future research. For example, the different contexts of waste hierarchy processes, categories of food waste, and types of industrial symbiosis linkages can all be numerically scored. Depending on the availability and access to data from the organizations being analysed, this can be combined with figures related to cost reduction and revenue enhancement enabled by potential exchanges of materials that can take place in the future. Such research approach can be applied to facilitate comparative analysis and as a quantitative basis to support simulation applications showing how emergent industrial ecosystems influence the potential costs and revenues of the organizations involved.

References

Ardente, F., Cellura, M., Lo Brano, V., & Mistretta, M. (2009). Life cycle assessment-driven selection of industrial ecology strategies. *Integrated Environmental Assessment and Management*, *6*(1), 52–60. doi:10.1897/IEAM_2008-065.1

Bansal, P., & McKnight, B. (2009). Looking forward, pushing back and peering sideways: Analyzing the sustainability of industrial symbiosis. *Journal of Supply Chain Management*, *45*(4), 26–37. doi:10.1111/j.1745-493X.2009.03174.x

Bryman, A. (2012). *Social Research Methods* (4th ed., p. 766). Oxford: Oxford University Press.

Cellura, M., Ardente, F., & Longo, S. (2012). From the LCA of food products to the environmental assessment of protected crops districts: a case-study in the south of Italy. *Journal of Environmental Management*, *93*(1), 194–208. doi:10.1016/j.jenvman.2011.08.019

Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, *25*(1), 313–337. doi:10.1146/annurev.energy.25.1.313

Chertow, M. R. (2007). “Uncovering” Industrial Symbiosis. *Journal of Industrial Ecology*, *11*(1), 11–30. doi:10.1162/jiec.2007.1110

Chertow, M. R. (2012). *Industrial symbiosis*. *The Encyclopedia of Earth*. Retrieved October 17, 2014, from http://www.eoearth.org/view/article/153824/

Cimren, E., Fiksel, J., Posner, M. E., & Sikdar, K. (2011). Material Flow Optimization in By-product Synergy Networks. *Journal of Industrial Ecology*, *15*(2), 315–332. doi:10.1111/j.15309290.2010.00310.x

Darlington, R., Staikos, T., & Rahimifard, S. (2009). Analytical methods for waste minimisation in the convenience food industry. *Waste Management*, *29*(4), 1274–81. doi:10.1016/j.wasman.2008.08.027

De Brito, M. P., Carbone, V., & Blanquart, C. M. (2008). Towards a sustainable fashion retail supply chain in Europe: Organisation and performance. *International Journal of Production Economics*, *114*(2), 534–553. doi:10.1016/j.ijpe.2007.06.012

DG-Environment. (2012). Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste. *Directive 2008/98/EC*. European Commission. Retrieved from http://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf

Duchin, F. (2008). Sustainable Consumption of Food: A Framework for Analyzing Scenarios about Changes in Diets. *Journal of Industrial Ecology*, *9*(1-2), 99–114. doi:10.1162/1088198054084707

EU Comission (2008). Directive 2008/98/EC of the European Parliament and of the Council. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0098&from=EN

FAO. (1981). *Food Loss Prevention in Perishable Crops*. Rome. Retrieved from http://www.fao.org/docrep/s8620e/s8620e00.htm#Contents

Gunasekaran, A., & Spalanzani, A. (2012). Sustainability of manufacturing and services: Investigations for research and applications. *International Journal of Production Economics*, *140*(1), 35–47. doi:10.1016/j.ijpe.2011.05.011

Gustavson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., & Meybeck, A. (2011). *Global food losses and food waste: Extent, causes and prevention*. *Food and Agriculture Organization of the United Nations (FAO)*. Rome. Retrieved from http://www.fao.org/docrep/014/mb060e/mb060e00.pdf

Harder, R., Kalmykova, Y., Morrison, G. M., Feng, F., Mangold, M., & Dahlén, L. (2014). Quantification of Goods Purchases and Waste Generation at the Level of Individual Households. *Journal of Industrial Ecology*, *18*(2), 227–241. doi:10.1111/jiec.12111

ISO. (2006). *ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework* (p. 20).

Mangan, A., & Olivetti, E. (2008). By-product Synergy Networks, Driving Innovation through Waste Reduction and Carbon Mitigation. In *Technical Proceedings of the 2008 Clean Technology Conference and Trade Show* (pp. 554–557). Cambridge-MA. Retrieved from http://www.ctsi.org/publications/proceedings/pdf/2008/70229.pdf

Papargyropoulou, E., Lozano, R., K. Steinberger, J., Wright, N., & Ujang, Z. bin. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, *76*, 106–115. doi:10.1016/j.jclepro.2014.04.020

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: Quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *365*(1554), 3065–3081. doi:10.1098/rstb.2010.0126

Preston, F. (2012). A Global Redesign? Shaping the Circular Economy. *Energy, Environment and Resource Governance*, (March), 20. Retrieved from http://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy, Environment and Development/bp0312_preston.pdf

Reisinger, H., van Acoleyen, M., O'Connor, C., Hestin, M., Laureysens, I., Morton, G., … Vanderreydt, I. (2011). *Evolution of (bio-) waste generation/prevention and(bio-) waste prevention indicators* (pp. 1–343). Retrieved from http://ec.europa.eu/environment/waste/prevention/pdf/SR1008_FinalReport.pdf

Sharma-Sindhar, P. (2014). The entrepreneurs turning their business savvy to food waste. *Guardian Sustainable Business, Theguardian.com*. Retrieved from http://www.theguardian.com/sustainable-business/food-waste-entrepreneurs-business

Sloan, P., Legrand, W., & Chen, J. S. (2013). *Sustainability in the Hospitality Industry - Principles of Sustainable Operations* (2nd ed., p. 378). Oxon: Routledge. Retrieved from http://www.routledge.com/books/details/9780415531245/

Sterr, T., & Ott, T. (2004). The industrial region as a promising unit for eco-industrial development—reflections, practical experience and establishment of innovative instruments to support industrial ecology. *Journal of Cleaner Production*, *12*(8-10), 947–965. doi:10.1016/j.jclepro.2004.02.029

Stuart, T. (2009). *Waste: Uncovering the Global Food Scandal*. New York: W. W. Norton & Company.

Svensson, G. (2007). Aspects of sustainable supply chain management (SSCM): conceptual framework and empirical example. *Supply Chain Management: An International Journal*, *12*(4), 262–266. Retrieved from http://www.emeraldinsight.com/doi/full/10.1108/13598540710759781

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., … Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, *151*(1), 53–59. doi:10.1016/j.biocon.2012.01.068