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SUSTAINABILITY OF FOOD SUPPLY CHAINS – MAPPING FOOD WASTE AND BY-PRODUCT SYNERGIES

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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 organisations 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 Organisation of the United Nations (Gustavson *et al*., 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.

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-organisational processes within specific production areas, but also the relationships and integration of inter-organisational processes that take into account the flow of food waste and related by-products across the supply chain. Accordingly, this paper presents 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.

We draw from industrial ecology and other relevant 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. We conclude the paper by highlighting potential contributions of the framework and areas for future research.

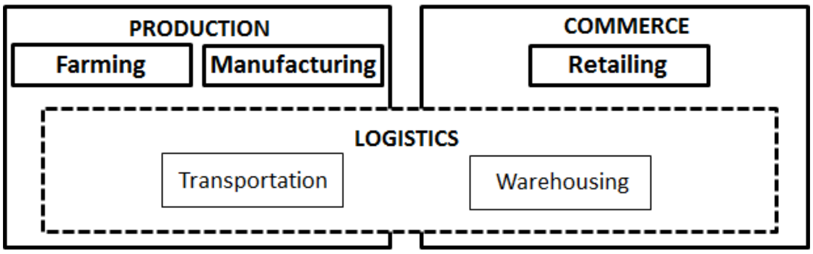
Relevant industries in food supply chains

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 organisations 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 organisations' 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 *et al*., 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. Deriving food waste scenarios and potential by-product synergies from the context above depicted 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 organisations and sectors in the chain are likely to fail (Cellura *et al*., 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.

Analyzing food waste and by-product synergies

Before specifying 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.

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 Organisation (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. 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.

A framework for analysis of food waste and by-product synergies

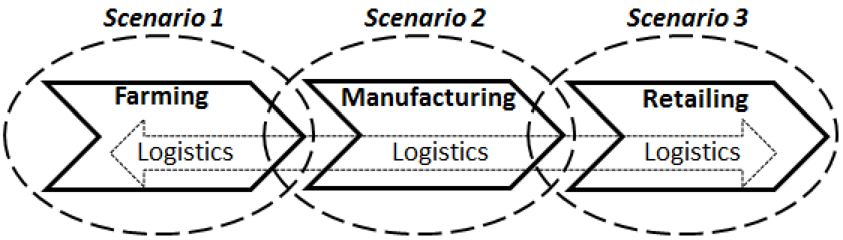
The environmental impact of food supply chains and related issues concerning waste minimization have been widely researched over the years, with LCA being the predominant methodological framework of analysis adopted by most of the studies. The application of LCA methods focused on the supply-side of supply chains is also known as “cradle to gate” analysis (ISO, 2006). 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 analyzing food waste scenarios. The key difference is that rather than focusing only on the flow of food products and related environmental impacts, we focus mainly upon the flows of food waste and related by-products across the organisations in a supply chain and between organisations in the supply chain and organisations outside the supply chain being analyzed.

While LCA analysis is mainly centered on the lifetime of a product flowing through a supply chain, 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 organisations operating in proximate regions (Mangan & Olivetti, 2008; Cimren *et al*., 2011).

A fundamental practice of BPS is the matching of by-product outputs from one facility with input streams into other facilities, which may involve exchange of materials, energy and water (Mangan & Olivetti, 2008). This refers to an essential aspect of industrial linkages at inter-firm 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 framework of analysis developed 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 applied by Ardente *et al*. (2009), in which LCA-driven analysis is applied with the purpose of defining industrial ecology strategies for the development of 'eco-industrial clusters'. We build upon this approach by combining it with the waste model for the food sector proposed by Darlington *et al*. (2009) to classify the inventory of food waste and by-products 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, 2000; 2007). Figure 2 shows the scope of the different Industrial Ecology scenarios that emerge from the analysis applied in different stages of the supply chain. The specified scenarios are the main outcomes of the analysis process and they ultimately describe potential food waste and by-product synergies not only between core industrial activities in the supply chain being studied, but also potential industrial linkages with organisations outside the supply chain. The key steps to be followed in the analytical framework proposed are presented next.

Figure 2 – IE-based scenarios of industrial linkages



Methodological phases of the proposed analysis

Phase 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 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 organisations 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 farming, manufacturing, retail and related logistics companies. Finally, the external environment represents the specific region comprising the external organisations surrounding the system-in-focus (the core organisations) in each stage of the supply chain. In other words, it comprises organisations 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. Then, for each stage of the supply chain 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.

c. *Analysis of industrial processes*: General characterization of core productive processes of the companies 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 organisations in a specific region and their related resources. According to Chertow (2012) 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.

Phase 2 - Inventory of waste outputs:

Differently from traditional LCA approaches, in this phase we focus particularly upon the classification of the waste and by-product 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 outputs identified. We slightly adapt the model to specify a clearer differentiation among the five general types of waste in the food sector, namely:

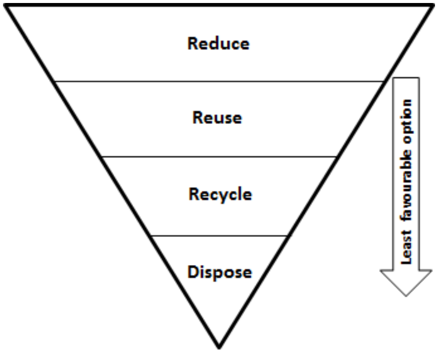
1) *Processing waste*: All inedible materials generated from the production process such as stems, leaves, bones, excess animal fat, spoiled food, spillages, contaminated products due to poor handling or processing failure.
2) *Wastewater*: Water at the end of food processing or cleaning processes, which usually carries dirt or debris.
3) *Packaging waste*: 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, etc. that may be disposed along the way.
4) *Non-conformity waste*: 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 organisations downstream the supply chain.
5) *Overproduction waste (OPW)*: 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.

Phase 3 - Scenarios specification:

After the categorical classification of waste and by-product outputs in the previous phase, the analysis moves on to the scenarios specification phase, which is mainly concerned with the 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 (2008), we have specified a hierarchy model for the framework. The model (Figure 3) is the referential basis to classify in a standardized way the different waste and by-product destination flows 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. Based upon the present scenarios specified in the analysis process, we specify future scenarios showing potential industrial linkages that move current waste flows up the hierarchy pyramid, and most importantly out of the disposal cycle. This is done by matching food waste and by-product streams from one organisation 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).

To extend the standardized characterization of ‘closed-loop’ scenarios involving innovative industrial linkages, 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. From a spatial perspective, the general types of materials exchange through industrial activity connections are (Chertow, 2000):

Type 1 – Through waste exchanges: Materials exchange involving third-party brokers or dealers (e.g. scrap dealers) that create trading opportunities for waste and by-products

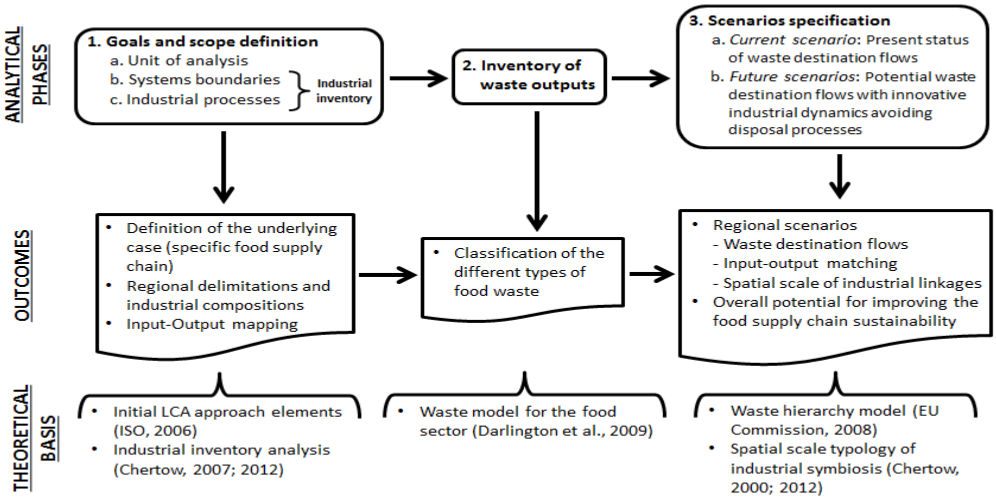
Type 2 – Within a facility, firm or organisation: Exchanges that occur inside the scope of one organisation, without involving outside parties

Type 3 – Among firms colocated in a defined industrial park: Exchanges involving organisations located within a determined industrial park

Type 4 – Among local firms that are not colocated: Exchanges involving organisations that are not 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: Exchanges involving organisations that are not necessarily in geographical proximity; however, they can get engaged in materials exchange initiatives in a wider regional scale through existing logistics systems

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



To analyze a food supply chain with basis on the 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. 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.

Conclusion

This conceptual paper introduces the theoretical and methodological basis of an analytical framework conceived with the purpose of mapping food waste and by-product synergy scenarios in studies concerned with environmental sustainability aspects beyond the product cycle in food supply chains. 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 studied, but also through flows going outside the supply chains. To establish synergistic collaborations where waste and by-products can be exchanged, sold or transferred, 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 EFOS framework here presented 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 stream 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.

In terms of practical contributions, the proposed framework facilitates an initial exploratory analysis of industrial linkages and related waste and by-product flow configurations in a food supply chain. This allows a helpful structuration of potential disposal problems, unveiling waste flows and industrial dynamics that can be used as focal points for eco innovations. 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 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 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.

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