# Optimising Sustainable Supply Chains: A Summarised View of Current and Future Perspectives

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**Abstract** Sustainable supply chain (SSC) research is recognised as being an emerging field where both academics and industry communities have an important role to play. At the organizations level, companies should not only be managed towards a profitability goal but also their contribution towards a sustainable society needs to be part of their decisions. For academic's sustainable supply chains although being an area that has been the focus of several studies is still far from being consensual. On the optimization of supply chains different perspectives have been adopted but much further has to be done. Along this chapter the concept of sustainable supply chains and some of the important publications in the area are analysed. A particular focus is given to the construction of tools based on optimization that may help the decision process in such systems while improving the efficiency and responsiveness of SSC. The chapter concludes with a recap of the published work while identifying key aspects that should be pursued so as to build optimized sustainable supply chains.

**Keywords** Sustainability · Sustainable supply chain · Optimization · Closed-loop supply chains · Design · Planning

## 1 Introduction

Supply chains activities have evolved over time and similarly has their definition. Now a days some convergence exists on how to define such systems. As stated by Christopher (2012) a supply chain can be defined as a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products or services delivered to the ultimate consumer. Sustainability in such systems has been a recent focus but the

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concept of sustainable supply chains is still undefined and some misperception of it exists. While sustainable development describes a global view of people and nature, efforts to achieve this in practice provoke questions on how this concept could be meaningfully interpreted and operationalized for smaller systems, such as supply chains. A close-systems view tries to apply the concept of sustainability just to a specific enterprise itself, while an open-systems view focuses on how the organization contributes to sustainable development of a wider society (Figge and Han 2004). Both perspectives have their inherent strengths and neither one should be readily discarded. This must be reflected in the way the sustainability concept is applied at the supply chain level. Successful sustainability-driven supply chain should contribute positively to the sustainable development of the larger social-ecological system of which it is part (Parrish 2009).

The first step towards understanding how sustainable supply chains are shaped and how they evolve over time implies getting more deeply involved with the phenomenon called "sustainability". Using the definition of the World Commission on Environment and Development, sustainability can be viewed as the use of resources to meet needs of the present without comprising the ability of future generations to meet their own needs (WCED 1987). Thus, sustainability definitely influences organizations and it certainly influences the shape of current and future supply chains. Combining this with the fact that production is increasingly fragmented across geographic spaces and between companies, the need to develop a more profound comprehension of the interaction between these elements within the supply chain is demanding. In particular, the need to seriously explore the concept of sustainable supply chains within a collaborative perspective should be further explored and taken as a goal of any organization. This would help companies' revenue growth, costumer's recognition and their contribution to society and to the planet (Kleindorfer et al. 2005). To respond to this challenge companies must invest on the design, planning and operation of their supply chains while considering the minimization of their global energy consumption (Barbosa-Póvoa 2009). On way of helping such goal is through the usage of optimization tools that will support the supply chains decision process (Grossmann 2004; Suring 2013).

In this chapter the analysis on how the concept of sustainability should be incorporated into supply chains is explored. Then and having in mind that tools are required to help the decision making process of sustainable supply chains that are complex systems a focus is given to the use of optimization to build such tools. Finally the chapter concludes with the identification of future challenges in the area of sustainable supply chains optimization.

## 2 The Extended Supply Chains Concept

Sustainable Supply Chains Management has its roots in both Sustainability and Supply Chain Management literature and involves a broadened approach of the supply chain management. The concept of sustainable supply chains is now

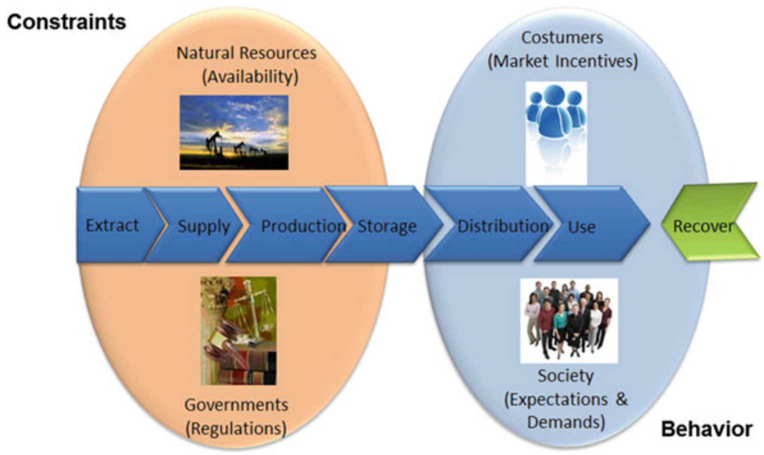


**Fig. 1** Extended Supply Chains

emerging (Suering and Muller 2008; Barbosa-Póvoa 2009; Meckenstock et al. 2015) and it is now clear that supply chains need to be defined as operational structures that are able to manage raw materials and services from suppliers to manufacturers/service providers and back while guaranteeing costumers satisfaction and contributing positively to society and to the planet. An extended supply chains view must then be adopted as depicted in Fig. 1. Here an external supply chain view is considered where supply chain activities are integrated and forward and reverse flows are managed not in an isolated form but simultaneously while surrounded by an extended context that includes costumers and marketing incentives, natural resources availability, governments and regulations constraints and society expectations and demand.

Furthermore, and considering an internal supply chains view a new understand should be given to the well-known supply chains activities as stated by Linton et al. (2007). These include product design, production, distribution, and the management of end of life products. Such activities should be managed considering their contribution to the economic goal but also environmental and societal objectives should be assimilated (Barbosa-Póvoa 2009).

The integration between the extended external and internal views of the supply chains is mandatory as the basis to construct sustainable supply chains. Efforts on both sides will support the goal of responsible care as stated by Grossmann (2004), but require support on the decision process. The development of systematic methods and tools that guarantee the design of environmental benign products and processes while creating economic and societal optimized conditions are an end to be accomplished.

## 3 Optimising Supply Chains Towards Sustainability

The incorporation of the sustainability concept into the supply chain management implies considering simultaneously economic, environmental as well social aspects into the supply chain decision process. This meaning increasing the engagement of all the supply chain activities into the triple bottom line (3BL), the threes P's, people, profit, planet (Elkington 2004; Kleindorfer et al. 2005). At the company level the need of seriously exploring this new concept is now a reality and it is starting to be seen as an opportunity as it can contribute to improve companies' revenue growth and costumers recognition (Barbosa-Póvoa 2009; UNGC 2013). However, the complexity associated with this new supply chains paradigm calls for academic research investment on the development of methods and tools that may help to understand sustainable supply chains fostering companies decision making process support.

Different approaches have been followed by the academics when addressing sustainability in supply chains. Some authors have looked only to the forward supply chains while others have explored the reverse logistics as a way to deal with the environmental and social pressures. The closed-loop supply chain concept has materialized where both flows, forward and reverse, are considered simultaneously. As referred by Guide and Van Wassenhove (2002) the companies that have been most successful with their reverse supply chains are those that closely coordinate them with the forward supply chains, creating the closed-loop supply chain (CLSC). These companies have a positive contribution to the sustainable development by defining and operating the right systems that guarantee a reduction of resources consumption by recycling and recovering end of life products back into the chain. Such systems have been studied since 1999 by academia and in 2007 as stated by Salema et al. (2007) the literature on closed-loop supply chains was already been slowly building. Nowadays and as shown by Cardoso et al. (2013) closed loop supply chains are a reality and some effort has been done by academia on the development of optimization tools.

Jayaraman et al. (1999) developed a mixed integer programming formulation to model a closed-loop supply chain. The model was tested on a set of problems based on the parameters of an existing electronic equipment remanufacture firm. Fleischmann et al. (2000) proposed a model for the location of logistic facilities. Their work was the first to propose a general model formulation (Mixed Integer Linear Programming Model, MILP) that simultaneously optimizes the reverse and the forward networks. Two case studies were used to explore the model application. Krikke et al. (2003) also proposed a MILP model for the design of a closed-loop supply chain where both location-allocation decisions and product design were considered. The objective function included both supply chain costs and environmental impacts using a performance indicator (based on LCA approach). As product design was involved, an assembly and disassembly of products was explicitly modelled. Beamon and Fernandes (2004) presented a model for a single product closed-loop supply chain design. Fandel and Stammen (2004) propose a strategic model for the supply chain design. Salema et al. (2006, 2007, 2009, 2010) studied the problem of designing simultaneously the forward and reverse networks. In such works the models evolved along time and different aspects of the closed-loop supply chains have been considered. The proposed models are fairly general as incorporate facility capacity limits, multi-product flows and uncertainty. Strategic versus tactical decisions were considered. Quarasigui Frota Neto et al. (2008) developed a framework for the design of logistics structures in which profitability and environmental impacts are balanced. Zeballos et al. (2012) introduced a two-stage scenario-based modelling approach in order to deal with the design and planning decisions in multi-period, multi-product CLSCs subject to uncertain conditions. Uncertainty is associated to the quantity and quality of the flow of products of the reverse network.

Ilgin and Gupta (2010) offer a description of the main type of modelling techniques and topics addressed in close-loop supply chain research. Stindt and Sahamie (2014) analyse close-loop supply chain research in different sectors of the process industry.

Dekker et al. (2012) state that most papers focused on close-loop supply chain do not explicitly deal with the supply chain environmental impacts, and draw attention to the need for new models to support environment related decision making.

Recently, Cardoso et al. (2013), proposed a detailed dynamic model for the design and planning of supply chains where reverse logistics activities are considered simultaneously with forward supply chain activities. Supply chain dynamics are incorporated through capacity expansion and dynamic entities links along the planning horizon. Uncertainty in products demands is considered, justified by markets' volatility. Also, Zebalos et al. (2014) addressed uncertainty in CLSC. A Mixed Integer Linear Programming (MILP) multi-stage stochastic model is proposed to deal with the design and planning problem of multi-period multi-product closed-loop supply chains. The MILP formulation is proposed for addressing general CLSCs, structured as a 10-layer network (5 forward plus 5 reverse flows), with uncertain levels in the amount of raw material and customer demands. The effects of uncertain demand and supply on the network are considered by means of scenarios. The goal is to minimize the expected cost of facilities, purchasing, storage, transport and emissions, minus the expected revenue due to returned products. To show the application of the mathematical formulation, several instances of an example proposed in the literature are examined.

The above works focused essentially on the strategic and at most on the planning contexts. At the operational level fewer works appeared that dealt with the closed-loop supply chains. Amaro and Barbosa-Póvoa (2008a) looked into the detailed scheduling of supply chains with reverse flows where different product recovery policies are analysed. A real case-study of the pharmaceutical industry was solved. Later on, the same authors Amaro and Barbosa-Póvoa (2008b) presented a generic approach where the integration between the planning and the scheduling level was proposed. The model also contemplated the reverse flows where the management of non-conform and end-of-life products was considered.

On the reverse logistic structures several works have also been reported. A review, on the characteristics of the research on reverse logistics, is presented by Rubio et al. (2008). Ammons et al. (2000) developed a MILP model for the design and planning of reverse production systems. The State-Task Network (STN) was used as representation methodology. The model was applied to the recycling of a network router from an Original Equipment Manufacturer. The same problem was addressed by Realff et al. (2000) through a different approach where a robust optimization framework was used. Duque et al. (2007), using the maximal State-Task Network proposed an optimization model for the design and operation of a recovery route for residual industrial products with uncertain demands. The final model is able to suggest the optimal processing and transport routes, while optimizing a given objective function and meeting design and environmental constraints. This work was extended in Duque et al. (2009) where the eco-indicator 99 (Pré consultants 2001) was used to quantify the environmental and social impact of the chain. In the same year, Quarisiguai Frota Neto et al. (2009) studied the eco-efficiency methodology and proposed a multi-objective linear problem with three objectives: minimize costs, cumulative energy demand and waste in a reverse logistics network. Gomes et al. (2011) addressed the design and planning of reverse chains and proposed a generic MILP model where the best locations for collection and sorting centres are chosen simultaneously with the definition of a tactical network planning. The model was applied to a real case on the collection of waste electric and electronics equipment (WEEE) products.

On the forward chains the sustainability concept has been mainly associated with the quantification of environmental impacts. Zhou et al. (2000) developed a goal programming model to account for sustainability aspects on the supply chains of continuous processes. Hagelaae et al. (2002) explored the concept of Life Cycle Analysis (LCA) when applied to a supply chain context and concluded that no guidelines exist for an integration of these two strategies. Turkay et al. (2004) studied the problem of multi-company collaborative supply chain management where not only economical goals where considered but also environmental aspects where incorporated. Hugo and Pistikopoulos (2005) looked into the supply chains planning problem where environmental concerns were accounted for. A mathematical formulation was developed which was applied to a bulk chemicals supply chain. In 2006, Soylu et al. (2006) analysed the synergies that may exist on a collaborative supply chain of energy systems. Matos and Hall (2007) analysed the integration of sustainable development concepts into the supply chains and build up a framework that should guide the utilization of LCA methods into the supply chains. Two case studies were studied, oil sand refining and agriculture biotechnology. Bojarski et al. (2009) also studied the design and planning of forward supply chains considering economic and environmental aspects. Guillén-Gosalbez and Grossmann (2010) addressed the design and planning of forward chemical supply chains where environmental concerns are modelled in the presence of uncertainty in the life cycle inventory of the supply chain operation. More recently, Pinto-Varela et al. (2012), presented a MILP formulation for the design of supply chains with reverse flows where environmental aspects were incorporated, and

Amin and Zhang (2012) proposed a MILP to optimize a closed-loop supply chain based on product life cycle.

From above it can be seen that the sustainability concept has been studied but not yet fully addressed in an integrated form. The integration of the tree pillars of sustainability is still to be explored. The social component has not yet been analysed. Hassini et al. (2012) corroborate this conclusion claiming that none of the measures described in their review have been designed to be used in a supply chain context. A recent work by Carvalho and Barbosa-Póvoa (2011) developed an analysis of possible social indicators that can be used to evaluate the social responsibility performance in global supply chains. You et al. (2012) determine the social benefit of a cellulosic biofuel supply chain, measured through full-time equivalent yearly jobs created. Mota et al. (2015) presented a detailed multi-objective optimization methodology that accounts for economic, environmental and social concerns in a supply chain with reverse flows. Environmental impact assessment is considered through the use of ReCIPe 2008 (Goedkoop et al. 2009). A social benefit indicator is developed where the creation of employment in less developed regions is preferred. The multi-objective approach is used to reach a solution of compromise between the three sustainability pillars. The model is applied to a case study developed in collaboration with a Portuguese company, leader in battery production.

The above literature analysis clearly shows that the field on sustainable supply chain optimization is still in its infancy but important ideas have already been explored. However a clear consensus on the analysis of such systems and more detailed forms of looking into the integration of the three sustainability pillars within the supply chains optimization should be further explored.

## 4 Conclusions and Future Research Agenda

Along this chapter it was shown that an increased concern with sustainability at the supply chain level exists. Sustainable supply chains have become important not only within the academic community but also at the industrial level. Within this context the development of tools that can support the decision process of these emergent complex systems—sustainable supply chains, has been recognised as mandatory. Several works have been published on the topic but it is also clear that much is still to be done.

Sustainability in the supply chains has been addressed in different forms. This range from the explicit consideration of environmental issues into forward supply chains, to the modelling of the simultaneous forward and reverse flows where collection, recycling and remanufacturing of non-conforms and/or end-of-life products, have been well thought-out. Moreover, the simultaneous consideration of closed-loop supply chains and environmental impacts was at the same time considered with the integration of detailed process activities into the supply chain. But further work is still required to fully address the optimization of sustainable supply chains where the different aspects of sustainability become adequately modelled. To achieve such target the research community has to look into a set of key aspects and some answers are to be given:

1. How to measure in an appropriate form sustainability into the supply chains? Further work needs to be done on the environmental impacts measures and its consequences in the social wellbeing of the population. The incorporation of social concerns into the supply chains is still an area unexplored and almost no measures exist to quantify properly this component.
2. How to define or redesign the supply chains to facilitate collection, refurbishment, recycling or disposal or returned products? The optimization of the supply chains structures to easily incorporate the end-of-life products is required. Although, several studies appeared on the closed-loop supply chain, general models are still scarce and its application to a large number of real supply chains has yet to been done.
3. How to trade-off the profit, people and planet of the 3BL into the supply chains management? Multi-objectives approaches need to be explored, which encompass all the above aspects.
4. How to deal with uncertainty? Uncertainty influences the sustainable supply chains both at the supply chain structure definition as well as at the associated planning and scheduling activities. Does a detailed form of dealing with uncertainty is required.
5. How to minimize risk when building and operating sustainable supply chain structures? Different decisions lead to different levels of risk that need to be defined so as to take the right decision. The need of identifying the appropriate risk measures that will help the establishment of proper trade-offs between profit and risk, amongst others objectives is a challenge to attain.
6. How to incorporate responsiveness and resilience into sustainable supply chains? At a qualitative level supply chain risk management strategies dealing with redundancy and flexibility have been proposed in the literature but these strategies have not yet been considered explicitly into the optimization models. The need of quantifying resilience and responsiveness in supply chains requires further investment.

The study of the above points will help to expand the scope and nature of sustainable supply chains optimization and contribute to effectively solve real-world industrial problems.

Concluding, following the above sketched research lines should aim to build holistic models that will support sustainable supply chains management decisions while accounting for the three pillars of sustainability (economic, environmental and social) under an increasing uncertain context.

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