A Conceptual Framework for Green Supply Chain Design

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Abstract

The increasing importance of sustainability requires efforts in every field of research and application. Supply Chain Design (SCD) as the top level of supply chain planning offers great potentials for the improvement of ecological logistics performance. The respective strategic decisions comprise the structural and conceptual design of a supply chain network including its material and information flow processes. Classic approaches consider logistics costs and performance as primary objectives, whereas modern approaches integrate ecological objectives and, thus, are considered as Green Supply Chain Design (GSCD) approaches. The goal of this paper is to identify current scientific contributions to GSCD, discuss their applicability and to identify an outline of an ideal GSCD framework. Hence an extensive academic literature research has been conducted comprising drivers, objectives and measurement systems as well as the respective models, frameworks and instruments. On this basis, relevant GSCD elements have been derived and systematised in a conceptual GSCD framework. As a result, this paper does not only provide a systematic overview of GSCD elements, but also allows outlining further research requirements. Evidently, each field of GSCD already holds valuable individual approaches. However, the appropriate interrelation of these elements into one methodology is still lacking.

Keywords: green supply chain design; supply chain management; ecology; performance measurement; framework.

1 Motivation and Research Approach

Society and politics are becoming more and more aware of the climate change and its consequences. Consequently, measures for the improvement of *ecological sustainability* are required in every field of life. The logistics sector assumes increasing responsibility: globalised business processes necessitate more transportation processes over longer distances, thus, resulting in high energy demand and growing emissions. In particular, the emission of greenhouse gases (GHG) needs to be closely observed as the climate warming is accelerated by excessive human-caused emissions (Intergovernmental Panel on Climate Change, 2001, p. 5). While GHG emissions have decreased by 2 % in the 192 countries of the UNFCCC contract (United Nations Framework Convention on Climate Change) from 1990 to 2005, the emissions of the transportation sector have increased within the same period by 43 % to 3.47 bn. t. (Kuczmierczyk, 2010). The transportation sector induces 14 % of worldwide GHG emissions (Stern, 2008, p. 197). Within OECD countries this share amounts to 30 % (International Transport Forum, 2008).

Counteractive measures can be divided into technological and organisational approaches. Technologically, energy and emissions may be saved by innovations such as hybrid engines or SkySails (the equipment of cargo ships with sails, cf. http://www.skysails.info). Organisationally, ecological objectives need to be included in logistics planning, e.g. when deciding upon transport dispositions or network locations. In order to influence logistics networks in an early stage and, therefore, to make use of the maximum potential for improvements, these activities have to start at the long-term level of Supply Chain Management (SCM), the *Supply Chain Design* (SCD). Here, classic approaches consider logistics costs and performance as primary objectives, whereas modern approaches integrate ecological objectives and, thus, are considered as Green Supply Chain Design (GSCD) approaches. The goal of this paper is to identify current scientific contributions to GSCD, discuss their applicability and determine an outline of a GSCD framework.

As a basis, an extensive academic literature research has been conducted and is presented in section 2. It comprises drivers, objectives and measurement systems as well as the respective models, frameworks and instruments. Subsequently, relevant GSCD elements have been identified and systematised. The resulting conceptual GSCD framework is presented in section 3. Section 4 concludes with a summary and an outline of further research requirements.

2 State of the Art in Green Supply Chain Design

Supply chain design determines the structure of the supply chain and its processes. It comprises long-term decisions, which are expensive to reverse (Chopra & Meindl, 2010). According to Gilbert (2001), it is necessary that a green supply chain combines the usual purchasing decisions and long-term relationships between buyer and supplier with environmental criteria and requirements. In his view, greening the supply chain can be achieved through three different approaches: environment, logistics and strategy. Another definition is given by Srivastava (2007): SCM has to include environmental thinking regarding all steps related to the life cycle of a product. This includes "design, acquisition, production, distribution, use, re-use and disposal". All these activities from the design of the product or service to the distribution and reverse logistics are covered by GSCM (Srivastava, 2007). Walker, Di Sisto, and McBain (2008) also saw all phases of the product life cycle involved, starting at the purchase of raw materials through the design until the disposal. The definition given by Davies and Hochman (2007) resembles the definition above. According to their view, GSCM is more than just putting some green practices in place: the environmental performance on all levels of the supply chain management has to be improved as well as on the shop floor levels. It is the task of GSCM to minimise all negative effects a product or service has on the environment (Rettab & Ben Brik, 2008). Sarkis, Zhu, and Lai (2011) defined GSCM as "integrating environmental concerns into the inter-organisational practices of SCM including reverse logistics."

Concluding, though various authors have already dealt with Green Supply Chain Management (GSCM), it may be concluded that there is still no precise definition for Green Supply Chain Design (GSCD). In contrast, driving forces and factors behind GSCD have already been approached by a number of authors, as the next section shows.

2.1 Drivers and Factors of GSCD

Reinhardt (1998) pointed out that the government is responsible to ensure an environmental-friendly policy of high quality by manufactures. Rarely do companies take the initiative of their own accord and they are only willing to spend money on environmental issues as long as it does not threaten the overall economic output and financial goals. Therefore, the government has to establish laws to safeguard the environment.

In the context of GSCM implementation at a chip manufacturer, Trowbridge (2001) differentiated between internal and external drivers. Internal drivers refer to the collaboration between manufacturer and supplier to minimise the impact on the environment. This can be achieved by using more ecological resources and equipment. External drivers are influences and restrictions given by customers, investors and non-governmental organizations. Bowen, Cousine, Lamming, and Faruk (2001b) provided an "initial analysis of the role of supply management capabilities in green supply" and found, within their study, internal drivers for greening the supply chain. Wee and Quazi (2005) "aimed to develop and validate a set of critical factors of environmental management that could be used by managers in assessing and improving their own practices." In the end they established seven critical factors: top management commitment to environmental management, total involvement of employees, training, green product/process design, supplier management, measurement and information management. Walker et al. (2008) identified, in line with a literature review, factors which drive or hinder companies from adopting ecological measures. This research also includes a classification by internal (e.g. organizational factors) and external factors (e.g.

regulations, customers, competitors) as well as internal and external barriers for implementing GSCM: “Internal barriers include cost and lack of legitimacy, whereas external barriers include regulations, poor supplier commitment and industry specific barriers.” According to Lee (2008), the major drivers are buyer influence, government involvement and GSC readiness. A research about the different levels of greening the supply chain in the UK manufacturing sector has been accomplished by Holt and Ghobadian (2009). The authors have analysed the relationship between drivers of environmental behaviour and the management methods which followed. Hu and Hsu (2010) gathered 20 critical factors for implementing a green supply chain management in the Taiwanese electrical and electronic industry to comply with European directives. The critical factors were divided into the following four dimensions: supplier management, product recycling, organization involvement, and life cycle management.

In summary, the analysis of drivers and factors of GSCD is already at an advanced stage as a lot of research projects contributed to this subject in various contexts. Nevertheless, when deciding upon structural or process-wise alternatives, the impact of these drivers on the supply chain configuration has to be evaluated. This topic is addressed by various methods as discussed in the next section.

2.2 Methods for the Ecological Assessment

Due to the increasing relevance of environment protection activities in companies as well as in the whole supply chain, various methods for environmental management were developed. Well-known examples are risk assessment, evaluation of environmental performance (e.g. of a company), environmental audits, environmental impact assessment (EIA), and life cycle assessment (LCA) (Herzig & Schaltegger, 2009, pp. 23–24). These methods differ in criteria such as completeness, transparency, practicability, objectiveness, and, notably, purpose (Meyer, 2005, pp. 51–52).

For the ecological analysis and assessment of transportation processes in supply chains, life cycle assessment (LCA) has been approved and is widely accepted (Finkbeiner, Inaba, Tan, Christiansen, & Klüppel, 2006, p. 80; Pfohl, 2004, p. 258; Reeker, Hellingrath, & Wagenitz, 2011, p. 142). LCA allows the systematic surveying and assessment of ecological impacts of products and enterprises (Kunhenn, 1997, p. 15). The LCA procedure is standardised by the DIN ISO norm 14040/44 and consists of four phases: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. The most complex part is the data collection step of the LCI phase (Baumann & Tillman, 2009, p. 97), where process inputs (e.g. energy consumed for process) and outputs (e.g. CO_2 as an emission) have to be analysed.

Regarding transportation processes, the norm DIN prEN 16258 provides precise rules for the data acquisition and the allocation of emissions to load units. Nevertheless, this norm is still under development. For the whole logistics sector, a number of software tools and databases provide average values or ulteriorly aggregated data sets. Some of the most prominent tools are according to Hellingrath & Schürrer (2009, p. 21) EcoTransIT (http://www.ecotransit.org/), GaBi (http://www.gabi-software.com), Umberto (http://www.umberto.de), ProBas (http://www.probas.umweltbundesamt.de), SimaPro (http://www.simapro.de), and sirAdos (http://www.sirados.de/). Well-known databases are ecoinvent (http://www.ecoinvent.ch/), Gemis (http://www.gemis.de/), the U.S. Life Cycle Inventory Database (http://www.nrel.gov/lci/), and the European Life Cycle Database (ELCD, http://lca.jrc.ec.europa.eu/lcainfohub/). These databases may be particularly easy and inexpensive to integrate into existing logistics systems. In the context of GSCD, these databases are suitable to provide the necessary input data for the LCI of newly planned supply chain structures and processes.

According to the LCA methodology, the LCI analysis is followed by the LCIA. Typical assessment objectives are acidity, damages to the ozone layer, or effects on the biodiversity (Baumann et al., 2009, p. 129). The LCIA aims at aggregating the results of the LCI for better understanding and easier communicability. The LCIA results are typically classified in the categories “resource demand”, “human health”, and “ecological impacts”.

The systematic presentation of the results of the LCI as well as of the LCIA requires proper methods to structure and aggregate the identified information and data. For this purpose, various performance measurement systems have been developed.

2.3 Performance Measurement Systems for GSCD

According to Neely, Gregory, and Platts (2005), performance measures are metrics which are used to quantify the efficiency and effectiveness of a particular action. The benefit of measuring performance is to stabilise the green supply chain design process and to identify potential for additional improvements (Bond, 1999).

There are various types of performance measurement to evaluate green supply chains. Chaabane, Ramudhin, and Paquet (2010) referred to a number of approaches combining environmental and economic performance to compromise between these two dimensions (e.g. Nagurney & Toyasaki, 2003; Sheu & Chou, 2005; Frota Neto & Bloemhof-Ruwaard, 2008). Typically, the economic dimension is covered by the consideration of costs and profits in the net present value (Hugo & Pistikopoulos, 2005). In order to measure the impact on the environment, several performance metrics have been developed. They measure, for instance, the quantities of greenhouse gases (e.g. CO_2, CFC and NO_x) related to processes, products, or activities (Luo & Wirojanagud, 2001) as well as waste generation, energy efficiency and material recycling.

An early approach which is still established today is the CML method, developed in 1992 by the "Centruum voor Milieukunde" (CML) in the Netherlands. Along the life cycle of a product, all emissions having an identical effect are considered and aggregated to an index known as the effect indicator (Heijungs, Guinée, Huppes, Lankreijer, & Udo Haes, 1992). The integration of noise emissions is also possible (Althaus, Haan, & Scholz, 2009).

The "Eco-indicator 95" has been developed by the National Reuse of Waste Research Program and Pre Consultants of the Netherlands (Goedkoop, 1998). This method classifies environmental impacts based on their effects in order to provide an environmental profile with standardised effect scores. The effects are evaluated and aggregated to a single Eco-indicator value. The "Eco-indicator 99" is an updated extension to this methodology. It introduces damage models for human health, ecosystem quality and resource depletion (Goedkoop & Spriensma, 2000). The Association of German Engineers (VDI) developed the Cumulative Energy Demand (KEA) method to measure the total demand in the phases of a life cycle of a product to compare possible products and services (VDI guideline 4600, 1997). Wackernagel et al. (1999) developed the concept of the "Ecological Footprint". This framework considers human consumption of resources as well as industrial and commercial usage. The natural capital requirement of a company, region or population is represented by the Ecological Footprint.

Environmental Management Systems (EMS) provide companies with a structural approach for implementing environmental performance and protection measures. However, EMS do not comprise instructions for the achievement of environmental targets. Companies are constrained to determine their processes and develop a solution to manage their impacts. Typical EMS are ISO 14001 (Borken, Patyk, & Reinhardt, 1999) and EMAS (Eco-Audit Management Scheme).

Lucent Technologies developed, in cooperation with the Multi-lifecycle Engineering Research Center (MERC) at the New Jersey Institute of Technology, the universal environmental metric EcoPro. Luo et al. (2001) refer to this system as universal because it contains various necessary attributes "including applicability to the entire product lifecycle, compatibility with LCA methods and databases, and means for communicating with both suppliers and customers."

Cirullies, Klingebiel and Scavarda (2011) presented a target system "combining ecological objectives with the established objectives of economy and logistics performance." The authors chose the German industrial guidelines 4400 "logistic indicators" (VDI guideline 4400, 2002) and extended the indicator system by a definition of logistics efficiency and respective ecological target values and according measures.

All performance measurement systems presented above are suitable scientific approaches that can be applied on the LCI or LCIA level for GSCD. Certain PMS – such as the one developed by Cirullies et al. (2011) – already integrate logistic and environmental targets. Four basic methods are well-established to determine relevant logistic indicators and will be presented now.

2.4 Evaluation methods of Green Supply Chain Design Options

Appropriate methods for the development of structural or process-wise green supply chain options are brainstorming, mind-mapping, and morphological matrices (Nöllke, 2010, pp. 33–110). The creation of supply chain design alternatives also makes use of methods like product, region, customer, or competition segmentation (Beckmann, 2004, p. 33). This form of clustering allows for a reduction of complexity and, thus, decreases the effort required for further evaluation of the identified alternatives.

Current research contributions suggest a two-stage SCD assessment approach applying two different modelling methods (Kuhn, Wagenitz & Klingebiel, 2010; Klingebiel & Seidel, 2007). The first phase makes use of static methods that are – depending on the detail level – rather easy to apply. Suitable methods are *material flow calculation* and *mathematical optimization*. The static phase results in a reduced set of potential solutions that represent the input for the second phase. This level introduces the consideration of uncertain and dynamic behaviour within the supply chain. As proven in many studies, *discrete event simulation* is an appropriate and widely accepted approach to analyse these dynamics occurring in logistics networks (Tako & Robinson, 2011; Wagenitz, 2007). Each method must be supported by respective IT tools and "green" modelling approaches.

Suitable *IT tools* for the static analysis phase include LogiChain and Microsoft Excel. Whereas LogiChain was developed explicitly for logistics processes (Fuchs, 2004), Excel is a general – however acceptable – tool as it is known by most users. Both static modelling approaches – material flow calculation and mathematical optimization – can be implemented in Excel. In addition, this tool allows the attachment of ecological datasets. Established tools for the simulation-based design and planning of supply chains are OTD-NET, WITNESS, Arena, ProSim, and Extend (Pierreval, Bruniaux, & Caux, 2007, p. 187; Reeker et al., 2011, pp. 149–150). Notably, OTD-NET combines information and material flow in a unique way. This feature is particularly relevant in the automotive sector, which necessitates a complicated long term planning process. OTD-NET has proven its suitability in various logistics research and industry projects. The new version OTD-NET^{eco} comes with an ecological assessment module based on the ELCD datasets that can be easily customised (see for example Cirullies et al., 2011).

Modelling approaches for mathematical optimisation include ecological objectives either by transforming the indicator into the existing target dimension (mono-criterion), e.g. costs, or developing a multi-criteria optimisation model. The latter involve LCA for the aggregation of environmental impacts. Seuring and Muller (2008) pointed out that LCA has already been successfully included in the design of new products to minimise the impact on the environment. However, not much work has been done to include LCA and supply chain management principles in integrated decision making models (Seuring et al., 2008). One mathematical programming-based approach which includes LCA for strategic decisions in the supply chain design was developed by Hugo and Pistikopoulos (2005). Guillen-Gosalbez (2001) introduced a model for supply chain design which also considers environmental aspects. The model provides a plan to maximise the net present value and to minimise the impacts on the environment. Bowen, Cousine, Lamming, and Faruk (2001a) tried to explain and resolve the conflictive situation in which the desirability of greening the supply chain is high, but the implementation in practice is slow. Within the process of their research they recognised certain implementation patterns. Another approach was provided by Nagurney et al. (2003). They developed a supply chain model comprising a manufacturer that produces homogenous goods in different plants with different impacts on the environment (Nagurney & Liu, 2006). A similar approach considering the effects on the environment was introduced by Frota Neto et al. (2008) who developed a framework for designing and evaluating logistic networks.

Besides LCA-based approaches, there are studies which include external control mechanisms in terms of statutory provisions and carbon taxes. Johnson and Heinen (2004) considered the growing carbon trading market. An extensive mathematical generic model, which helps decision makers in the design and planning of supply chains, was developed by Chaabane, Ramudhin and Paquet (2010). By linking with the emission trading scheme, sustainability objectives are evaluated in a cost-effective manner (Chaabane et al., 2010, p. 3). Ramudhin, Chaabane, Kharoune, and Paquet (2008) introduced a mixed integer mathematical model for the green supply chain network design where the influences of the carbon market trading are considered. This extension helps to understand the trade-offs between total logistics costs and the impact of reductions in greenhouse gas emissions (Ramudhin et al., 2008). Chaabane et al. (2010) built on this model and extended it by including LCA.

An early simulative approach was developed by the LOCOMOTIVE project in the nineties. This project combines conventional goals like costs, delivery time, and customer service with environmental compatibility in a simulative model (Hirsch, Kuhlmann, & Schumacher, 1996) for the inexpensive verification of environment-friendly production. Within the Austrian project MOVE, a recent simulation approach for the "optimisation of transport logistics systems considering aspects of sustainability" excluding air traffic was introduced (Baumgartner, Matyus, & Haunschmied, 2006). Another research work was introduced by Reeker et al. (2011) who evaluated the ecological design of logistic systems in the peripheral area of automotive production facilities.

The review of existing methods for the design of supply chains as well as according models and tools clearly shows that the potential for a "green" supply chain is far from being fully tapped as planning methods integrate the ecological aspect insufficiently. Evidently, research lacks a holistic framework that includes all relevant elements of GSCD and illustrates the cause-effect relationship between these components. Furthermore, GSCD research misses a planning methodology that provides detailed but generally applicable instructions for logistics network design.

As the development of a framework represents a first step towards such a design methodology, the succeeding section presents the concept of a framework for GSCD.

3 Concept of an Integrative Framework

A concept of an integrative GSCD framework has been constructed which arranges all elements identified in the literature review as well as the relations between them. The framework is based on the typical SCD process as it is applied in the procedure models developed by Klingebiel (2009), Winkler (2009, p. 115), or Straube, Doch, Nagel, Ouyeder, and Wuttke (2011).

The starting point is represented by *drivers* which influence the logistics network or may do so in case no according action takes place such as re-designing the network ("*zero base alternative*"). The continuous monitoring of these drivers triggers the GSCD process which starts with the *development of design alternatives*. This phase starts with the precise definition of the design scope depending on the effecting drivers and design objectives. The definition of the scope also involves the supply chain segmentation according to products, regions, or customers. These steps help to reduce the complexity and limit the number of potential alternatives. The succeeding development of design alternatives is often supported by informal methods such as creativity techniques.

Subsequently, the alternatives are *evaluated* by the use of analysis methods which integrate a "green" performance measurement system (PMS). This integration requires the combination of logistics assessment and LCA methods as well as the availability of a suitable software tool. Thus, the choice of an appropriate method is strongly case-depending as the scope of the use-case determines the degree of complexity, the need to consider stochastic effects, i.e. uncertainties, risks and dynamics, and the acceptable modelling and computation effort, for instance. The evaluation phase usually ends with a recommendation for action.

This recommendation constitutes the basis for the *implementation phase* which transfers the model-based planning results to practice. In parallel to this process, the continuous *monitoring* of the supply chain allows to check the expected impacts from the design process. It also acts as a sensor that enables an early reaction in case unexpected factors have an impact on the logistics network. Figure 1 summarises the context presented above.

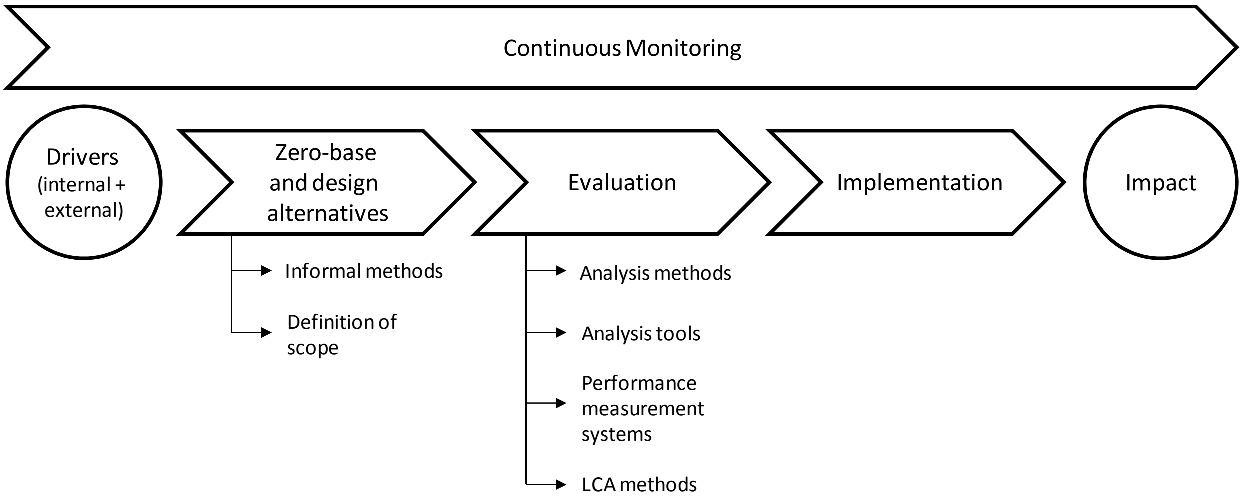

Figure 1: Integrative GSCD Framework

This integrative GSCD framework arranges all elements that were identified in the state of the art review and brings them into an overall GSCD context. It structures GSCD-relevant methods, tools, drivers, and measurement systems to indicate their mutual effects and dependencies.

4 Conclusion

Green Supply Chain Design with its relevant elements has been investigated from a supply chain design perspective. An extensive overview on the state of the art literature on GSCD has been made which gives a clear picture of the current GSCD research: On the one hand, relevant elements have been identified and many scientific contributions have been made. On the other hand, the consolidation of these elements in the context of GSCD is lacking so far.

The integrative framework presented in this paper structures and, thus, unifies the GSCD elements that were analysed in the literature review. The assignment of elements to the steps within the general GSCD procedure indicates their relation and respective dependency.

However, this framework also allows to outline further research requirements. The logical consequence of this framework is an elaborate and consistent methodology for the application in GSCD practice. The realisation of this methodology is determined by a set of requirements. These comprise the consistent integration of new environmental objectives into classic logistic targets, the coverage of the entire GCSD process (from scope definition to implementation) and the ability to handle dynamics as well as a high degree of complexity. The intensive work on such a GSCD methodology will also require a clearer definition of Green Supply Chain Design. As concluded in section 2, literature still misses this definition.

Therefore, “green” thinking has to be established as a constitutive element of the SCD process. Decision makers have to include energetic and environmental issues early, i.e when defining the scope of a network design project. Besides this influence on a company’s strategy, suitable instruments are necessary for a successful integration of green objectives in the design process. The development of an SCD methodology that is closely related to practice could provide valuable methods and tools and, thus, increase the acceptance of green issues.

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