Improving strategic decision processes for sustainable supply chain management
– Multimethodological and transdisciplinary approaches –

Cumulative Dissertation at the Faculty of Business and Economics of the University of Augsburg submitted in fulfillment of the requirements for the degree of Doctor of Economic Sciences (Dr. rer. pol.)

submitted by
Dipl.-Kfm. Dennis Stindt, MBA

First reviewer: Prof. Dr. Axel Tuma
Second reviewer: Prof. Dr. Armin Reller
Chairman of oral exam: Prof. Dr. Hans Ulrich Buhl
Date of oral exam: 8th July 2016
List of Scientific Contributions

The following published and submitted scientific contributions are presented within this doctoral dissertation. The articles are sorted in accordance to their order of appearance in this dissertation. Rankings relate to the VHB-JOURQUAL3, a journal rating that has been published by the German Academic Association for Business Research (VHB).

Contribution C1 (under review at a journal ranked B)
Stindt, D. (submitted). A generic planning approach for sustainable supply chain management - How to integrate concepts and methods to address the issues of sustainability?. Submitted to: Journal of Cleaner Production.

Contribution C2 (published in a journal ranked B)

Contribution C3 (published in a journal ranked A)

Contribution C4 (published in a journal ranked B)

Contribution C5 (published in a journal ranked B)
Contribution C6 (published in a journal ranked B)


Contribution C7 (published in proceedings not ranked)


Contribution C8 (published in a journal ranked B)

**Table of Contents**

List of Scientific Contributions........................................................................................................ III

Table of Contents ............................................................................................................................... V

1. **Introduction** ............................................................................................................................. 1

2. A generic planning approach for sustainable supply chain management – How to integrate concepts and methods to address the issues of sustainability.............. 13
   1. Introduction ................................................................................................................................. 15
   2. Sustainable Supply Chain Management ................................................................................... 16
   3. Methodological approach ......................................................................................................... 18
   4. Literature analysis ...................................................................................................................... 20
   5. A framework for SSCM decision-making ................................................................................. 25
   6. Discussion & Conclusion .......................................................................................................... 42

References ........................................................................................................................................ 47

3. Review of research on closed loop supply chain management in the process industry ................................................................................................................................. 61

4. On the Attractiveness of Product Recovery: The Forces that Shape Reverse Markets ................................................................................................................................. 63

5. The Reverse Supply Chain Planning Matrix: A Classification Scheme for Planning Problems in Reverse Logistics ................................................................................................. 65

6. Transdisciplinary Research in Sustainable Operations – An Application to Closed-Loop Supply Chains ................................................................................................................................. 67


8. Analysis of European Closed-loop Supply Chain Network for WEEE – An OEM Perspective ............................................................................................................................................. 71

9. Eine quantitative Analyse europäischer Richtlinien und Verordnungen zur Abfall- und Kreislaufwirtschaft am Beispiel der Elektro- und Elektronikindustrie ........................................ 73

10. Conclusion and Research Outlook ............................................................................................. 75

General References .......................................................................................................................... 78

*Note:* References for sections 2 to 9 are listed at the end of the respective section. General references for sections 1 and 10 are provided at the end of this doctoral dissertation (p. 76).
1 Introduction

The paradigm of sustainability altered the way corporate and private actors’ actions are perceived and how society evaluates the effectiveness and efficiency of both production and consumption. Companies encounter pressures from legislation, competition and consumers that force them to incorporate aspects of environmental and social performance into decision-making. Hence, corporate sustainability, which describes the adaption of the sustainability paradigm into the realm of businesses, became a guiding principle for executives and raises interest among practitioners and academia alike. The operationalization of corporate sustainability induces a totally new set of challenges non-existent in traditional decision-making. Problems of sustainability are highly complex due to a large number of interacting elements and system properties that are hard to identify (Hall et al., 2012). Indeed, questions regarding the assessment and evaluation of environmental and social performance arise as well as the balancing of various aspects of sustainability within qualitative and quantitative decision-support models. Therefore, this research sets out to provide comprehensive guidelines and planning models within a subset of corporate sustainability management, namely sustainable supply chain management (SSCM). Focusing on this particular but still broad topic, the contributions compiled in this thesis address the following research questions guiding the overall research project:

Q1: How can the field of SSCM research be structured and which subproblems can be identified?

Q2: How can complex and ill-defined problems of SSCM be encountered addressing problems of data definition, data acquisition and data processing?

Q3: How can quantitative decision-support models be adapted taking into account the specific characteristics of sustainability?
This doctoral thesis encompasses an introductory section that structures the research project and delineates some general characteristics of SSCM research. A total of eight scientific publications addressing the research questions constitute sections 2 to 9. Finally, a summarizing discussion is given and promising fields for future research are proposed.

1.1 Sustainable Supply Chain Management

This section elaborates on basic definitions as well as general characteristics of the research field. Common theories explaining SSCM actions are presented followed by a description of research fields within the academic discourse on SSCM.

1.1.1 Corporate Sustainability and SSCM

SSCM can be defined as the “management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements” (Seuring and Müller, 2008, p.1700). In line with the triple bottom line approach (Elkington, 2002) and its three pillars of sustainability (Profit, planet, people) traditional economic evaluations of business actions are supplemented by considerations of ecological sustainability and social sustainability.

Epistemic object of the former is the analysis of interrelationships between the technosphere and the ecosphere. Ecological sustainability in a strict sense can be reached by meeting the following principles (Roth and Kaberger 2002): First, materials taken from the lithosphere must not accumulate in the ecosphere. Second, substances produced within anthroposphere and technosphere must not accumulate in the ecosphere. Third, the services provided by the ecosphere must not be deteriorated in a systematic manner. Schaltegger and Burritt (2014) distinguish three approaches to realize ecological sustainability:

- Efficiency approach, e.g., by generation of a given output with lower negative impact on the environment.
- Consistency approach, e.g., by substitution of toxic materials with harmless substances.
- Sufficiency approach, e.g., by changing patterns of consumption leading to a reduction of industrial output.
Introduction

The people part of sustainability, often referred to as corporate social responsibility (CSR), deals with the interaction of a company with humans and society both internal and external to the organization. Areas of interest comprise physical and mental well-being of workforce, human rights issues as well as societal and ethical issues. A thorough discussion of ecological and social objectives as well as respective indicators is given in Stindt (submitted, C1).

Companies implement SSCM practices to mitigate social and environmental risks which may eventually deteriorate the corporation’s legal or social legitimacy to operate. Moreover, SSCM may also serve as a means for generating competitive advantage. It can be operationalized by implementing product- or process-based strategies (Bowen et al. 2001). In C1 various SSCM concepts that can be implemented along the supply chain processes are identified: Sustainable Product Design, Sustainable Supply Chain Design, Product Stewardship, Sustainable Procurement, Eco-efficient Manufacturing, Human-oriented Manufacturing, Sustainable Warehousing & Inventory Management, Industrial Symbiosis, and Sustainable Logistics.

1.1.2 Theoretical foundation of SSCM

Research on SSCM is commonly grounded on well-acknowledged theories from economics and management research. A review of relevant theories is given by Touboulic and Walker (2015). They concede a dominance of six theoretical lenses: the resource-based view, the natural resource-based view, the resource dependence theory, the stakeholder theory, the institutional theory as well as the transaction cost theory. Other theoretical constructs such as the agency theory or the social network theory are less frequently used. In the following, the prevailing theories and its relevance for SSCM are briefly described.

The resource-based view and the natural resource-based view explain organizations’ competitive advantage as a result of unique and hardly imitable resources. The resource-based view in the context of SSCM deals with “the ability of firms to adopt sustainable practices resulting from internal capabilities/resources” (Meixell and Luoma 2015, p. 76). Resources represent assets and capabilities, including knowledge and information, enabling an organization to implement strategies that improve the sustainability performance. The theory assumes that supply chains properly addressing social and environmental concerns are hard to imitate, generate a long-term competitive edge and, thus, secure economic sustainability (Carter and Rogers, 2008). Consequently, the theory suggests that a company proactively embarking into sustainable business practice may make use of opportunities opened up by changes in
technology, legislation, and general market forces (Bansal, 2005). Explicitly positioned in the field of ecological sustainability, the natural resource-based view of a firm developed by Hart (1995) extends the resource-based view. It links competitive advantages to the company’s relationship with the environment building on the observation that natural limits are constraining business operations. Therefore, companies that efficiently and effectively control and use natural resources benefit economically in the long-term. Similarly, the resource dependence theory proposes to embark into SSCM in order to secure the access to crucial resources and natural sinks whose availability is threatened by scarcity, excessive consumption, or pollution (Wolf, 2014). It assumes that the survival of the organization at hand is connected to the long-term supply with external resources in a reliable and cost-efficient manner.

Stakeholder theory introduces societal values and ethical perceptions into corporate decision-making (Freeman et al., 2004). Companies’ actions are embedded into its social environment and the resulting effects on its stakeholders (Touboulic and Walker, 2014). Vice versa, stakeholders exert pressure forcing companies to consider sustainability aspects (Varsei et al., 2014). From a practitioners’ perspective, this theory encourages stakeholder dialogue and involvement of selected stakeholders within decision-making processes. Institutional theory explains the adoption of corporate sustainability practices focusing on pressure from institutional stakeholders such as governments, media and public associations (Meixell and Luoma, 2015; Varsei et al., 2014). In this way, institutional theory explains SSCM initiatives induced by legislation and by issues of social legitimacy as well as failures to conform to written or unwritten norms (Bansal, 2005). Transaction cost theory lays the ground for investigating the cooperation, coordination and governance of SSCM initiatives among various supply chain actors as well as the impact of transaction costs on the diffusion of SSCM across a supply chain (Touboulic and Walker, 2014).

1.1.3 Research fields in SSCM

Reviewing the scientific literature on SSCM (e.g., Stindt, submitted, C1; Stindt and Sahamie, 2014, C2) four major fields of research have been revealed: theory development, performance measurement, qualitative decision-support, and quantitative decision-support.

Contributions on theory development investigate relationships between variables, develop system understanding and eventually predict dependent phenomena within a selected field (Wacker, 1998). Commonly, these studies hypothesize causal relationships in SSCM and test them against reality (Chopra and Wu, 2016). Existing
theories, such the ones described in the preceding section, are either extended or taken as a starting point for hypothesizing relationships between investigated variables. Identifying drivers and barriers that influence corporate SSCM initiatives is a frequent epistemic object. This stream of research evaluates types of stakeholder pressure and barriers that hinder companies embarking into SSCM practices (Mitra and Datta, 2014; Meixell and Luoma, 2014; Walker et al., 2008; Wolf, 2014). Moore and Manring (2009) as well as Foerstel et al. (2015) focus on forces that act between supply chain actors. Vurro et al. (2009) extend stakeholder network theory to explain relative power to enforce SSCM initiatives between supply chain actors based on centrality. Internal drivers and barriers connected to executives and organizational structure, like executive’s personal orientation and managerial philosophy, are focused by Formentini and Taticchi (2016), Gavronski et al. (2011), Grosvold et al. (2014), and Signori et al. (2015). The influence of variables on the specific approach selected for embarking into SSCM is content of another stream within theory development (Leppelt et al., 2013; Walker and Jones, 2012). Pagell et al. (2010) inductively enhance purchasing theory to fit the practice of sustainability leaders. Morali and Searcy (2013) and Tate et al. (2010) conduct a review of 100 sustainability reports each investigating the actual implementation of SSCM practices and the importance of these practices in corporate communication respectively. An integration of SSCM and further corporate functions, such as marketing, is another area of discussion (de Sousa Jabbour et al., 2014; Liu et al., 2012).

Studies on **performance measurement** are devoted to development and evaluation of sustainability indicators as well as metrics and measurement tools which are supposed to quantify the effectiveness and efficiency of sustainability efforts (Beske-Janssen et al., 2015). The multidimensional nature of polystructured data and information comprising economic, environmental as well as social aspects of supply chain performance makes this area challenging but – at the same time – critical for the overall research field as difficulties in quantifying the (positive) effects of SSCM initiatives pose a major impediment for implementation (Wolf, 2011). The development of generic performance indicators is perceived as a pressing issue by corporations, especially the proliferation of a common measurement methodology that enables benchmarking (Morali and Searcy, 2013). The research in this field is divided into articles that identify and evaluate potential metrics for sustainable performance measurement (Erol et al., 2011; Hassini et al., 2012; Nikolau et al., 2013; Veleva and Ellenbecker, 2001) and those that investigate the impact of improvements on the environmental or the social performance on traditional measures (Chopra and
Qualitative decision-support comprises frameworks mainly meant to ease the selection and implementation of sustainability initiatives in corporations. Hereby, we can differentiate between two different foci either providing guiding implementation principles (e.g., best practices) or frameworks raising awareness to specific factors that should be considered when dealing with SSCM. An enumeration of potential sustainable business practices can help executives to recognize the breadth of levers available to introduce sustainability within their organization. For instance, Svensson (2007) as well as Ansari and Qureshi (2015) list concepts such as sustainable supply chain design, green purchasing, environmental marketing, and reverse logistics. Seuring (2004) describes best practices for integrated chain management referring to companies in the textile industry. Tsoulfas and Pappis (2006) mention 25 principles for sustainability initiatives along the supply chain. In order to identify those areas with significant potential, Lake et al. (2015) propose a four-step framework incorporating an LCA-based methodology. Another example of a framework utilizing LCAs is proposed by Matos and Hall (2007). A process model for generation of economic, ecological and social input parameters for subsequent mathematical analysis is given by Varsei et al. (2014). Schrettle et al. (2014) delineate how to select decision alternatives depending on the drivers that motivate SSCM. Fabbe-Costes (2014) suggests an environmental scanning framework to create appropriate pathways to sustainability. Based on the observation of operationalization of sustainability initiatives at British Aerospace, Gopalakrishnan et al. (2012) develops a generic roadmap for actually implementing and steering such actions. Turning to tools addressing issues of awareness, Schaltegger and Burrit (2014) distinguish between risk-oriented and opportunity-oriented SSCM. They propose a set of tools for each orientation focusing on environmental aspects and social audits. Risk management emanating from stakeholder requirements is considered by Giannakis and Papadopoulos (2016).

Quantitative decision-support is provided by means of normative mathematical models comprising optimization and simulation techniques, methods of multi-criteria decision making as well as analytical models. A closer look reveals that the environmental and, a fortiori, the social dimension is often rudimentary treated within these models due to problems with data acquisition. A detailed discussion of quantitative decision-support models in SSCM is given in Stindt (submitted, C1).
1.2 The research project at a glance

This section presents the research gap tackled by this research project and gives an overview of the contributions compiled in this doctoral thesis. Each contribution is briefly described and positioned within the research project.

1.2.1 Research gap

Overall, this research aims on providing methodologies, tools and processes that ease the evaluation and implementation of corporate SSCM initiatives. More precisely, shortcomings in this research field are addressed.

First, we could observe a lack of guidelines that steer corporate planning and decision-making on SSCM issues. To facilitate corporate decision-making, Stindt et al. (*accepted, C3*) and Nuss et al. (2015, *C4*) develop intuitive managerial tools that support corporate planning and decision-making by qualitatively structuring the challenges executives face when dealing with sustainability.

Second, decision-support by means of quantitative models is crucial for translating SSCM into the realm of companies. Unfortunately, a number of problems hinder the proper application and utilization of operations research models within this context. In a nutshell, modeling SSCM problems is “complex and challenging, as a very large number of parameters, decision variables and constraints are involved along with a large number of estimation requirements [...] associated with each decision” (Srivastava 2007, p. 71). Hence, abstracting the relevant system and determining involved interdependencies is not an easy task. These characteristics represent a major challenge within quantitative modeling in SSCM contexts and, thus, hinder the actual implementation and control of SSCM initiatives. To tackle this complex and ill-defined issue, transdisciplinary approaches seem to be compulsory (Pimenta and Ball, 2015) to overcome compartmentalized research in disciplinary silos (Srivastava, 2007) and to advance SSCM developing truly sustainable supply chains (Pagell and Shevchenko 2014). A detailed discussion on the problems operations researchers encounter when dealing with SSCM and how these challenges can be addresses by means of transdisciplinary collaboration is given in Stindt (*submitted, C1*), Sahamie et al. (*2013, C5*), and Stindt et al. (*accepted, C6*).

As delineated in Stindt (*submitted, C1*) the field of SSCM research is rather wide and comprises various topics such as Sustainable Product Design, Sustainable Manufacturing, and Sustainable Logistics. In order to thoroughly tackle the issues described above, a specific focus needs to be chosen within the research project. Closed-loop supply chain management (CLSCM) is attracting significant attention
among practitioners and researchers due to highly complex processes needed to implement product recovery systems, increasing legislative pressures, and economic rationale open to questions in many cases. However, the implementation of CLSCs is seen as a major contributor to sustainable business practice. Advances in CLSCM clearly contribute to sustainable development and the insights generated in this field are likely to be transferable to other issues of SSCM in many cases (Sahamie et al., 2013, C5). Therefore, out of the manifold topics relevant in SSCM, the main body of this work focuses on CLSCM.

1.2.2 Contribution
Summing up and acknowledging that a wide range of further issues in SSCM exists, the doctoral thesis advances quantitative decision-support in the field of CLSCM. Figure 1 depicts and relates the contributions compiled in this work. Overall, this doctoral thesis contributes to research in line with the research questions stated above:

- Structuring the research field and identifying definable and manageable subproblems within the struggle for SSCM (C1, C2, C3, C4).
- Developing reference processes facilitating transdisciplinarity in SSCM and, in this way, easing the development system understanding as well as the specification of data (C5, C6).
- Developing approaches enabling comprehensive decision-support by means of proper data acquisition and quantitative modeling (C1, C5, C6, C7, C8).

SSCM is a broad field comprising various concepts as means to operationalize sustainability along the supply chain. In Stindt (submitted, C1), eight SSCM concepts are identified and interrelated within a comprehensive planning approach: Sustainable Product Design, Sustainable Supply Chain Design, Sustainable Procurement, Sustainable Manufacturing, Sustainable Warehousing & Inventory Management, Industrial Symbiosis, Product Stewardship, and Sustainable Logistics. The proposed planning framework delineates three consecutive phases that steer decision-making and suggests methodologies enabling executives to evaluate decision alternatives when embarking into SSCM initiatives. As argumented in the preceding section, the remaining part of the doctoral thesis is narrowed to issues being part of product stewardship or, to be more precise, of closed-loop supply chain management (CLSCM).
Stindt and Sahamie (2014, C2) describe the main characteristics of a closed-loop supply chain system and emphasize the specific circumstances of material and product recovery in the process industry. The collected products may be reprocessed by means of reuse, remanufacturing, refurbishing, retrieval, or recycling and are eventually used as secondary input or traded on a secondary market. The article gives a structured review of quantitative decision-support models applied to problems within CLSCs classifying the literature in line with the primary planning problem that has been addressed. Although a number of planning problems is described, a structured and integrated framework for planning and guiding decision-making is missing. This void is tackled in Stindt et al. (accepted, C3) and Nuss et al. (2015, C4).

The decisive question executives have to ask themselves is how to position their company in a focal market. For traditional markets decision-makers may rely on market analysis models like Porter Five Forces. A comparable tool that considers the specific characteristics of markets for recoverable goods, called reverse markets, does not exist. To remedy this shortcoming, a qualitative decision-support model proposed in Stindt et al. (accepted, C3) enables holistic assessment of a reverse market based on forces that drive its attractiveness: Access to recoverable products, Threat of market entry of independent recovery companies, Rivalry for recoverable products, Adverse effects on core business, and Remarketing opportunities. By consulting the ‘Reverse Five Forces Model’ practitioners can generate an in-depth understanding of
a focal reverse market and, thus, can thoroughly assess the viability of product recovery and prepare decisions on market entry and positioning.

When setting up and operating a CLSC a number of unique planning problems arise. These planning problems are identified, defined and interconnected in Nuss et al. (2015, C4). A conceptual framework for reverse supply chain planning that provides a structured overview of planning problems along the supply chain is developed. The ‘Reverse Supply Chain Planning Matrix’ depicts relevant planning problems along the processes of Product Returns Management, Reprocessing Operations, Remarketing/Reintegration and distinguishes three planning horizons: Strategic planning, tactical planning, and operational planning. This hierarchical structure reveals interdependencies between distinct planning tasks and provides practitioners with a complete set of challenges encountered within the management of a product recovery system.

Planning problems, especially those on the strategic level, are commonly analyzed using methods of operations research. These methods abstract the real-world problem by mathematical formulation. Here, two major sources of failures may occur, especially in the context of complex and ill-defined problems of sustainability. First, the assumptions made within the abstraction may not appropriately represent the system under assessment. Second, the results of the mathematical model depend on the quality of the data input. To mitigate the risk of according shortcomings this doctoral thesis proposes several measures. While Stindt (submitted, C1) proposes several data acquisition methods (e.g., Life Cycle Assessment, Ecological footprinting), Sahamie et al. (2013, C5) and Stindt et al. (accepted, C6) suggest the implementation of transdisciplinary research settings to adequately define system characteristics, interdependencies within a system and relevant data. Sahamie et al. (2013, C5) identify the current lack of transdisciplinarity in research on CLSCM and carve out potential benefits that may be induced by such research settings. Specific attention is paid to the expertise that may be contributed by disciplinary experts from engineering, management and natural sciences as well as representatives from industry and society. Finally, different degrees of transdisciplinary collaboration are depicted and the resulting benefits and challenges are described. Building on these insights, Stindt et al. (accepted, C6) develops a reference process for facilitating collaboration by means of transdisciplinarity. The collaborative research setting is embedded into a research cycle explicitly aiming at the development of mathematical models for tackling problems of SSCM. The reference process is exemplified by two demonstration cases: Strategic resource management for sustainable energy systems and assessment of a CLSC in the plastics & polymer industry. A prototypical
mathematical model is derived to show the value and contribution of each involved competency.

*Stindt and Nuss (2014, C7)* as well as *Nuss et al. (2016, C8)* round off the research project by presenting optimization models for reverse network design which represents a strategic planning problem in CLSCM. The models are developed to analyze the viability of recovery of information technology equipment from B2B customers in Europe. Both the problem structure and the input data are derived from a collaborative project conducted with an industry partner. Apart from economic parameters the model is designed to account for relevant legislative influences, like the Waste of Electrical and Electronic Equipment Directive and the Regulation on Shipments of Waste. Scenarios are calculated to analyze the influence of these legislative constraints on the economic viability of product recovery and respective recovery quotas. Recommendations for practitioners as well as for politics are derived from this analysis.
A generic planning approach for sustainable supply chain management – How to integrate concepts and methods to address the issues of sustainability

Contribution C1

Title: A generic planning approach for sustainable supply chain management – How to integrate concepts and methods to address the issues of sustainability

Authors: Dennis Stindt (University of Augsburg)

Submitted to: Flexible Services and Manufacturing Journal

Abstract: Corporate sustainability is seen as a major enabler for realizing sustainable patterns of economic development. Forced by competitive, legislative and customers’ pressures, corporate executives are supposed to consider environmental and social aspects of value creation inducing a totally new set of challenges within decision-making. Unfortunately, guidelines supporting comprehensive decision-making in this context, especially concerning the evaluation of environmental and social performance of decision alternatives, are missing, eventually hindering the advancements in corporate sustainability. Further questions arise on how to measure and balance respective indicators with traditional economic objectives. To fill this void, this research sets out to develop an intuitive and holistic planning framework for advancing sustainability along supply chains. In a first step, we identify sustainability issues and indicators as well as decision-support methods by scrutinizing literature on sustainable supply chain management (SSCM). Based on this, we develop a planning framework that supports executives in evaluating and deciding upon corporate sustainability initiatives. The framework comprises three consecutive phases of planning: ‘Problem definition’, ‘Assessment of alternatives’, and ‘Decision analysis’. For each phase we propose appropriate tools distinguishing
concepts of SSCM (e.g., Sustainable Logistics or Sustainable Manufacturing), methods for measuring the ecological and social efficiency of decision alternatives, and quantitative decision-support techniques able to balance trade-offs between the three dimensions of the triple bottom line. As a result, this article presents a framework for guiding corporate decision-processes in SSCM. From the academic angle, the article contributes to the research field by providing a structured integration of SSCM concepts and methods utilizable in the pursuit of ecological and social improvements along the value chain.

**Keywords:** Green Supply Chain Management; Sustainable Development; Sustainable Operations; Operations Research; Decision-making
1. **Introduction**

A fast growing population combined with increasing living standards, climate change, depletion of finite natural resources, and humanitarianism conceptions make sustainable business practices compulsory. Societal and competitive pressures as well as legislation elevate the attention companies pay to environmental and social effects of their supply chain activities (Kleindorfer et al., 2005; Meixell and Luoma, 2015). According business practice, known as sustainable supply chain management (SSCM), mitigates risks (Giannakis and Papadopoulos, 2016), but may also act as a differentiator (Jain, 2012). Media reports on unsocial labor practice, as observed at Foxconn, the Rana Plaza in Bangladesh, or incidents of child labor at Nike’s supply chain exemplify the risks (Meixell and Luoma, 2015; Sancha et al., 2015; Wolf, 2014). Companies like Subaru and Toyota aim for zero-waste facilities (Hassini et al., 2012) and follow the idea of zero-emission warehouses (Dekker et al., 2012) to differentiate themselves from competition. Favoring a pro-active strategy, sustainable business practice is even considered to be a basic requirement for market participation (Pagell and Wu, 2009; Wolf, 2014) and a critical success factor for the future (Kushwaha and Shama, 2015). Undisputably, the integration of sustainability “is one of the most important subjects in the modern study of operations management” (Jabbour and de Sousa Jabbour, 2016, p. 1827).

Corporate sustainability contributes to the overarching goal of “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987), a goal postulated almost three decades ago. Since, the academic research on SSCM is on the rise (Ashby et al., 2012). Deduced from two observations, we formulate guiding research questions. First, the degree of the integration of sustainability aspects into supply chain management is controversially discussed in academia. Beske and Seuring (2014) assume that sustainability issues in SCM are overstretched, while others point out huge potentials remaining in the young research field (Ageron et al., 2012; Brandenburg et al., 2014) and observe a lack of integration between the paradigm of sustainability and the discipline of SCM (de Brito and van der Laan, 2010). Hence, the first research question arises:

**Q1:** To which extent did the paradigm of sustainability diffuse into SCM research?

Second, complaints about a “persistent gap between the diffusion of sustainability discourse and its practical application” are articulated (Ashby et al., 2012, p. 509). Indeed, “sustainability remains an extremely confused and complex issue” for practitioners (Ageron et al. 2012, p. 172) as sustainability practices in SCM are hard to understand (Pimenta and Ball, 2015). This shortcoming may be largely attributed
to a lack of guidelines on how to pursue and actually implement SSCM within business practice (Keating et al., 2008; Fabbe-Costes et al., 2014). Reviewing extant literature, we confirm Schaltegger and Burritt (2014) who concede a need for a structured framework that depicts concepts and methods corporate decision-makers can use to progress sustainability within their supply chain. To fill this void, two research questions are formulated:

Q2: Which concepts and methods for facilitating the design and implementation of sustainable supply chains are presented in the academic discourse?

Q3: How do these concepts and methods interact and how can they be integrated supporting the development of sustainable supply chains?

Overall, the motivation of this study is to develop an intuitive and holistic framework that may benefit practitioners to detect potential fields for corporate sustainability initiatives and to provide them with a proper methodological toolset. This way, we hope to take another step to bring "notions of sustainability [...] into the boardrooms of companies" (Schaltegger and Burritt, 2005, p. 187) by easing the integration of sustainability aspects into corporate decision-making processes. From an academic angle, the framework opens new pathways in research on SSCM by presenting various concepts and methods in a structured and integrated manner. To do so, this research is scrutinizing literature positioned in the field of SSCM, identifies existing concepts and methodologies that facilitate the actual implementation of this paradigm and provides a framework for identification and evaluation of SSCM initiatives along the value chain.

2. Sustainable Supply Chain Management

SSCM is a key enabler for advancing sustainable development in the industrial sector (Taticchi et al., 2015). The research paradigm itself is, at least under this term, quite new. Carter and Rogers (2008) claim to have taken the first steps applying sustainability to SCM. Since, an increasing interest in SSCM is well documented by a rise in research contributions (Brandenburg and Rebs, 2015) and numerous special issues recently published in mainstream journals, such as Computers & Operations Research (Govindan and Cheng, 2015), European Management Journal (Choi et al., 2014), and Journal of Cleaner Production (Tseng et al., 2013). The paradigm of SSCM is directly deduced from the triple bottom line advising companies to consider the three pillars of sustainability: People, planet, and profit (Elkington, 2002). In many cases the boundaries between SSCM and adjacent paradigms, such as Green SCM (GSCM) and Corporate Social Responsibility (CSR) are blurry (Ahi and Searcy, 2013).
Both can be seen as a subset of SSCM. While GSCM is located on the interface between lithosphere, technosphere and biosphere, SSCM also incorporates socioeconomic interrelations. The ambiguities in relation to CSR are twofold. On the one hand, it is understood as a paradigm for corporate business practice incorporating the triple bottom line used interchangeably with the paradigm of corporate sustainability (Boukherroub et al., 2015; Gimenez and Tachizawa, 2012). On the other hand, it represents the social dimension of sustainable business practice (Kuo et al., 2010; Gopalakrishnan et al., 2012). For the purpose of this article, we follow the latter interpretation.

Up to now, a consistent definition of SSCM is missing. Ahi and Searcy (2013) list twelve definitions used in contemporary publications. Formerly, the understanding of SSCM is narrowed down to supplier issues (Handfield et al., 2005). In recent times, the scope was broadened covering manufacturing and after-sales processes. Close to the definition of sustainability, Ansari and Qureshi (2015, p. 26) describe the SSCM paradigm as “maintaining a balance among social responsibility, environmental stewardship and economic viability along the entire supply chain, improving the long-term economic performance of an individual and the company and also meeting the customers’ need competitively throughout the life cycle of goods and services”. A very broad understanding of SSCM is provided by Schaltegger and Burritt (2014) who define SSCM as the creation of economic value “with lower negative social and environmental impacts”. Directly deduced from the triple bottom line approach, Kleindorfer et al. (2005) describe SSCM as “integrating profit, people and the planet into the culture, strategy, and operations of companies”. Inspired by the definition of SCM (Mentzer et al., 2001) and the definitions given above, we interpret SSCM in a broad sense as planning, execution and control of corporate value creation processes by integrated consideration of economic, ecological and social aspects for the purpose of improving the long-term performance of an individual company and the supply chain as a whole. In line with this, the proposed framework targets an influential company that governs the supply chain, initiates sustainability activities, can force upstream companies to engage with sustainability initiatives and is decisive in designing the final product (Beske und Seuring, 2014). Concerning the valuation of sustainability gains, we follow the efficiency approach (Schaltegger and Burritt, 2014).

A meta-study of recent reviews suggest that the young and, in both research (Ashby et al., 2012) and industry practice (Varsei et al., 2014), still evolving field of SCCM can be described as fragmented (Gopalakrishnan et al., 2012) or – as Srivastava (2007, p. 68) coins it – “compartmentalized” with frequently discussed concepts such as
management of closed-loop supply chains (Stindt and Sahamie, 2014), sustainable supply chain design (Eskandarapour et al., 2015), green procurement (Pimenta and Ball, 2015), socially responsible sourcing (Zorzini et al., 2015), green logistics (Dekker et al., 2012), sustainable manufacturing (Gahm et al., 2016), integrated chain management (Seuring and Müller, 2007), sustainable mining (Pimentel et al., 2015), performance measurement (Beske-Janssen et al., 2015) or information technology as an enabler for SSCM (Thöni and Tjoa, 2015). Attempts to map the field with a broader scope are confined to certain methodologies as quantitative modelling (Brandenburg et al., 2014; Brandenburg and Rebs, 2015; Seuring, 2013; Tang and Zhou, 2012), and empirical studies (Carter and Easton, 2011), or are limited to environmental issues (Gupta and Palsule-Desai, 2011; Srivastava, 2007). Although each of these articles extensively summarizes its epistemic field, none provides a holistic synopsis of concepts and methods for implementing sustainability in corporate supply chains. Closest to research at hand is Jaehn (2016) developing a taxonomy of sustainable operations by synthesizing relevant research fields. He gives a broad overview of sustainability practices applicable by private corporations, public institutions and non-governmental organizations. Hereby, the author focuses on methods of operations research. Although these articles show certain overlaps, our article provides unique insights (i) by developing a planning approach tailored for private sector companies, (ii) by proposing methods exceeding those being part of operations research, and (iii) by eventually integrating these concepts and methods within a structured planning framework applicable to plan, steer and advance sustainability within corporate environments.

3. Methodological approach

This research is set out to investigate the dissemination of sustainability within SCM as well as to synthesize concepts and methods provided by academia for the purpose of easing sustainability-oriented decision-making in corporate environments. To thoroughly answer the stated research questions, a structured research process is applied (see Figure 1) inspired by the procedures used in Gahm et al. (2016) as well as Khalid et al. (2015) extended by guidelines for content analysis in SCM (Seuring and Gold, 2012). For the purpose of advancement, verification and validity, the research was discussed numerous times in master courses, at academic conferences as well as with knowledgeable colleagues at various stages of development.
Figure 1: Research process (inspired by Gahm et al., 2016; Khalid et al., 2015)

The initial conceptualization of the epistemic object was informed by review articles within the field of SSCM supplemented by insights from intensive discussions with fellow researchers in SCM and disciplines like geography, physics, engineering science and resource strategy. For the purpose of material collection we employed common principles for literature search (vom Brocke et al., 2009). Reviews in the SSCM arena either use a broad set of search terms in a limited number of journals (Carter and Easton, 2011; Brandenburg and Rebs, 2015) or apply a specific search string to comprehensive databases (Ashby, 2012). As we like to reveal the academic understanding of SSCM in particular and the concepts and methodologies explicitly applied to this field, we follow the latter proceeding searching comprehensive databases, namely EBSCO and ScienceDirect, and limiting the search string to “Sustainable Supply Chain”. Within the databases we cover peer-reviewed journals published in English, except journals that are located in remote disciplines, like medicine. A limitation with regard to the date of publication is not applied. Studies on food and agricultural supply chains (Ene et al., 2013), public waste management (Blengini and Garbarino, 2010), sustainable tourism (Font et al., 2008), green marketing and green accounting (Jasch, 2006; Schaltegger and Csutora, 2012) as well as studies taking a macro-economically perspective (Foran et al., 2005; Liao et al., 2015; Yu et al., 2010) are excluded. Editorials (Choi et al., 2014; Jain, 2012; Tseng et al., 2013; Govindan and Cheng, 2015) are also not considered. The material evaluation encompassed a total of 602 articles produced by the search query (EBSCO: 295; ScienceDirect: 307). The restriction to peer-reviewed journals reduced the number of articles to 394. Four articles are published in a language other than English. Further constraints with regard to relevant disciplines left 314 articles in total, which are furtherly filtered by reviewing title and abstract reducing the number to 177. After deletion of 23 redundancies 154 articles are considered in a full text
content analysis. Eventually, 133 articles are incorporated into the analysis. The analytical categories used for categorization and synthesis are initially identified deductively from the sources used for the conceptualization. In the iterative process the categories are furtherly adapted, especially referring to conceptual frameworks that provide classification schemes for concepts and methods common in SSCM (Chardine-Baumann and Botta-Genoulaz, 2014; Diabat et al., 2014). As some concepts and methods which are potentially valuable for SSCM are only discussed rudimentary within publications or only brought up throughout discussion with fellow researchers, a deeper understanding was generated by adding specific but randomly selected literature pertaining to these topics. These domain-specific enhancements are especially required in the context of the social dimension (e.g., Social LCA) or specific domains of the environmental dimension (e.g., industrial symbiosis). These enhancements are added afterwards, but before embarking to the actual development of the SSCM framework because we do not want to dilute the results from the SSCM-centered literature review (Step I.-IV.). The concepts and methods are mutually interrelated and positioned building a SSCM framework for corporate decision-making. For this purpose, we build on generic reference models for SC planning presented in Adam (1997) and Klein and Scholl (2004).

4. Literature analysis

In this section we elaborate on the literature reviewed and analyzed within the iterative part of the research process (Step II. to IV.). We present a descriptive overview of the quantifiable statistics and key characteristics of the research field focusing on decision-support in SSCM.

4.1. Frequency analysis and descriptive statistics

The analysis confirms the rising interest on SSCM (see Figure 2). In addition to the publication frequency, we extracted the paradigmatic background of each study. Within the sample 77% of all studies are explicitly located in the context of SSCM. This means that the authors refer to SSCM for motivating their research or prominently introduce the paradigm. One tenth of all studies are embedded in GSCM (e.g., Bloemhof-Ruwaard et al., 1995; Maxwell and van der Vorst, 2003), while two are built on CSR (Amini and Bienstock, 2014; Nikolaou et al., 2013) and 13 studies do not mention any paradigm. In the temporal context, we see the SSCM paradigm appearing in the academic discourse in 2004 and gaining momentum by 2007. We observe a significant culmination of SSCM research in a limited number of journals.

Table 1 shows the distribution of the publications across five research domains: Quantitative decision-support, qualitative decision-support, theory development, performance analysis, and articles summarizing the state-of-the-art. This categorization provides advantages for the upcoming framework development: First, it gives a hint concerning the orientation of the articles by means of being more academia-oriented or practitioner-oriented. Moreover, it helps identifying articles beneficial for decision-support in SSCM (for a detailed overview on the reviewed articles and the categorization see appendices). Table 1 also suggests that the vast majority of contributions at least address the economic and ecological dimension, with a significant fraction tackling the triple bottom line as a whole. In the next section we provide an in-depth analysis of the sustainability indicators used. Here, we focus on quantitative decision-support as these studies need to explicitly define and operationalize these indicators.
<table>
<thead>
<tr>
<th></th>
<th>Quantitative decision-support</th>
<th>Qualitative decision-support</th>
<th>Theory development</th>
<th>Performance analysis</th>
<th>State-of-the-art</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Ecological</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Social</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Economic &amp; Ecological</td>
<td>18</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>49</td>
</tr>
<tr>
<td>Economic &amp; Social</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ecological &amp; Social</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Triple bottom line</td>
<td>14</td>
<td>12</td>
<td>17</td>
<td>6</td>
<td>11</td>
<td>57</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>36</strong></td>
<td><strong>25</strong></td>
<td><strong>39</strong></td>
<td><strong>12</strong></td>
<td><strong>21</strong></td>
<td><strong>133</strong></td>
</tr>
</tbody>
</table>

Table 1: Distribution of articles across sustainability dimensions and research domains

4.2. Sustainability issues and shortcomings of decision-support

Decision-support in SSCM is provided by means of normative mathematical models comprising optimization and simulation techniques, methods of multi-criteria decision making (MCDM) as well as analytical models. To provide adequate insights and to appropriately guide corporate SSCM initiatives, these models are required to cover multiple dimensions of sustainability (Matos and Hall, 2007). For better understanding the ability of the reviewed models to suffice this requirement, we screw into the addressed issues and parameters. Therefore, Table 2 gives an overview of the ecological and social issues tackled in quantitative research. These categories are adapted from the Sustainability Reporting Guidelines of the Global Reporting Initiative (GRI, 2012), which are well accepted by academia (Varsei et al., 2014; Eskandarpour et al., 2015) and are widely coherent with indicator sets proposed by other organisations and institutions, like the OECD, NIST, Guidelines of social accountability 8000, or the standards promoted by the International Labor Organisation. Please be aware that the figures in Table 2 do not add up. On the one hand, several articles address more than a single issue. On the other hand, in some cases the authors do not refer to a specific issue but to an impact category in general.
<table>
<thead>
<tr>
<th>Impact category</th>
<th># of articles</th>
<th>Sustainability issue</th>
<th># of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource saving</td>
<td>21</td>
<td>Material intensity</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recyclability of product</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of secondary input</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy efficiency</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integration of renewable energy systems</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land use &amp; Biodiversity</td>
<td>4</td>
</tr>
<tr>
<td>Mitigation of adverse environmental</td>
<td>31</td>
<td>Use/Release of toxic substances</td>
<td>7</td>
</tr>
<tr>
<td>effects</td>
<td></td>
<td>Reduction of emissions (e.g., CO₂)</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of solid wastes</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of water consumption</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental management system (e.g., ISO 14000)</td>
<td>3</td>
</tr>
<tr>
<td>Labor practice and decent work</td>
<td>13</td>
<td>Employment effects and employee turnover</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Occupational health and safety</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Employee development</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversity among workforce</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exploitative hiring policies</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social standards (e.g., SA8000)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive working hours</td>
<td>0</td>
</tr>
<tr>
<td>Human rights</td>
<td>4</td>
<td>Discrimination</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freedom of Association</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Child and forced labor</td>
<td>0</td>
</tr>
<tr>
<td>Society</td>
<td>7</td>
<td>Indigenous rights</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on local community and economy</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corruption</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anti-competitive behavior</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Animal treatment</td>
<td>0</td>
</tr>
<tr>
<td>Product responsibility</td>
<td>2</td>
<td>Socially undesirable products</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Customer Health and Safety</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Environmental and Social Indicators applied to quantitative decision-support models

Ecological initiatives pursue improvements of the input-output ratio by simultaneously reducing resource consumption and adverse impacts on the ecosystem, such as climate change, smog, acidification, or eutrophication (Bloemhof-Ruwaard, 1995; Tang and Zhou, 2012). Strategies for saving resources can be realized by designing less material intensive products (Tajbakhsh and Hassini, 2015) or products not containing depleted resources (Borchardt et al., 2011). Other authors concentrate on increasing the fraction of secondary input (Alinoviy et al., 2012; Devika et al., 2014; Li, 2013). Energy efficiency, the leading issue for realizing resource savings, is either implemented by minimizing energy consumption during processing (Rager et al., 2015) or by designing products to be less energy intensive throughout usage (Kuo et al., 2010). Models that prefer energy sourced from renewable sources (e.g. scheduling of operations considering supply peaks from renewable energy systems) could not be identified. The effects of supply chain...
activities on biodiversity and land change, a topic often quoted in qualitative literature (Beske-Janssen et al., 2015; Chardine-Baumann and Botta-Genoulaz, 2014; Schaltegger and Burrit, 2014), are widely neglected in modeling. Being unaware of effects concerning land use change and biodiversity can bear significant economic risks as experienced by sectors publicly criticized for deforestation connected to production of leather and palm oil (Vurro et al., 2009; Wolf, 2014). Especially in the mining sector, the impact on land and land rehabilitation upon closure of sites represents a decisive issue (Pimentel et al., 2015). Parameters representing adverse eco-effects mostly emphasize greenhouse gases emissions, either referring to total emissions (Chaabane et al., 2012), to the carbon footprint (Jakhar, 2015) or to emission intensity (Boukherroub et al., 2015). Further objectives comprise the reduction of wastes and unwanted by-products as well as water consumption (Geldermann et al., 2007) or the utilization of toxic substances (Kuo et al., 2010). Despite certain problems concerning the determination of precise ecological impacts, these indicators are mostly measurable at a cardinal level easing the integration into quantitative decision-making models.

The social dimension is measured nominally in many cases (Schaltegger and Burrit, 2014). In consequence, the incorporation of social indicators is less elaborated. In many cases, singular indicators, such as employment (Jakhar, 2015), employment stability (Boukherroub et al., 2015), injury rates (Bouchery et al., 2012) as well as job creation in less developed regions (Mota et al., 2015) are taken into account. Impact on local communities can be operationalized in terms of donations, community projects or cultural services provided by the focal company (Govindan et al., 2013; Su et al., 2015). Table 2 shows a number of issues not addressed at all. Some authors argue that an improvement of the environmental performance is an implicit contribution to the social dimension (Ashby et al., 2012; Schrettle et al., 2014). The approach presented by Tseng and Hung (2014) can be regarded as an application of this understanding calculating a social cost rate for damages to human beings induced by carbon emissions.

In addition to the insights specific to each sustainability dimension, we observe common patterns between them. Measures of sustainability commonly refer to top level concepts, like human rights (Kuo et al., 2010), or apply rather abstract indicators, like CSR performance (Hsueh, 2015) or sustainability degree (Li and Li, 2016), staying vague about the practical meaning (Bouchery et al., 2012). Moreover, quasi-economic objectives are used as ecological goals, e.g. minimization of perishable left-overs (Choi and Chiu, 2012; Soysal et al., 2015) and eco-design costs (Azadi et al., 2015), or as social objectives respectively, e.g., corporate reputation and
customer satisfaction (Tajbakhsh and Hassini, 2015). Environmental (e.g., ISO 14000, AA1000) and social certifications (e.g., SA8000, OHSAS 18001, ISO 26000) or codes of conduct are not directly used as metrics but are frequently used to signal a desired behavior or are seen as minimum criteria (Morali and Searcy, 2013).

The content analysis reveals that the first conclusion suggested in Table 1 is misleading as the environmental and, a fortiori, the social dimension is often only rudimentary treated. Concluding, shortcomings pertaining to the comprehensive integration of sustainability factors within quantitative decision-support models outlast, leading to the fact that comprehensive transition of sustainability considerations into quantitative decision-support is rare. We believe that the structured approach synthesizing relevant concepts and methods within the proposed framework helps to overcome these shortcomings and, thus, contributes to the development of more realistic and holistic decision-support models.

5. A framework for SSCM decision-making

In this section, we elaborate on the framework for guiding decision-processes in SSCM (Figure 3). The central contribution is the structured integration of paradigms, concepts, and methods utilizable in the pursuit of ecological and social improvements along the value chain. The framework builds on the generic phases of planning comprising three consecutive steps (Adam, 1997; Klein and Scholl, 2004) and is inspired by the transposition framework presented by Boukherroub et al. (2015).

- Phase I: In the first phase the characteristics of the problem are defined and a qualitative goal is derived (e.g., reducing carbon emissions). Executives may select one of the concepts proposed in section 5.1 that (i) fit the strategic goals and business concept of the focal company and (ii) address the sustainability goal at hand. The qualitative definition of goals, the description of the problem at hand, and the information requirements can be narrowed by concept selection.

- Phase II: The second phase is dedicated to the identification and assessment of potential decision alternatives. Potential alternatives, including investments, process changes, and product changes, can be identified in a creative process and are specified by measurement and assessment of each alternative. Methods capable to capture relevant parameters (see section 4.2) are proposed in section 5.2. In this way, the quantitative parameters for each alternative and
the decision variables are determined. Based on the decisive data for each alternative, a quantified goal can be formulated.

- Phase III: Depending on the size and complexity of the problem a decision-support method is applied and fed with the parameters determined in the preceding phase. This may happen using simple decision rules or sophisticated methods such as the ones described in section 5.3. A crucial issue at this point is the handling of (competing) objectives reflecting the sustainability dimensions. Eventually, the selected decision alternative is carried out either by means of investments, process changes or product changes.

Before describing each phase in detail in the upcoming sections, we like to clarify basic terms which are defined by consultation of the Oxford Dictionary (2015) and Merriam Webster (2015). A ‘paradigm’ encompasses selected concepts that reflect a world view determining patterns about the way something should be thought about. SSCM as well as its subsets GSCM and CSR are paradigms as they changed the view business practice is perceived by stakeholders. To move from paradigm to something more concrete, ‘concepts’ represent general principles that are connected to something abstract. In this sense, Green Logistics, Sustainable Procurement and alike are classified as concepts. Finally, ‘methods’ help operationalizing a concept by means of systematic procedures. In order to provide a comprehensive picture of concepts and methods this section also relies on domain-specific literature (Step VI of the research process).
5.1. Concepts of SSCM
In total we identify nine high-level concepts for improving sustainability along the value chain. Commonly, a distinction between those concepts targeting a product and those associated with processes is made (Bowen et al., 2001). Following this understanding, the concepts of Sustainable Product Design takes a product perspective, whereas, Sustainable Supply Chain Design, Sustainable Procurement, Eco-efficient Manufacturing, Human-oriented Manufacturing, Sustainable Warehousing, Industrial Symbiosis, Green Logistics, and Product Stewardship introduce triple bottom line thinking into processes. Each of the concepts is connected to value chain processes, which are defined following the Supply Chain Planning Matrix (Stadtler and Kilger, 2008), the SCOR model (Ntabe et al., 2015), the Reverse Supply Chain Planning Matrix (Nuss et al., 2015) and further
publications that depict relevant processes (Ansari and Qureshi, 2015; Kleindorfer et al., 2005; Pagell and Wu, 2009). These processes constitute a supply chain covering all phases along which SSCM practices can be implemented: Raw Material Mining, Sourcing & Supply Chain Coordination, Production, Distribution, Use, and Return (Figure 4). We introduce each of the concepts in the following.

**Sustainable Product Design**: Traditionally, companies’ strive for developing products of a certain quality with least costs. Nowadays, the environmental and social performance of products over the whole lifecycle has to be considered. From the ecological perspective, the product design should result in products that are characterized by decreased material intensity, less toxic inputs, biodegradability, durability, ease of recovery and low energy consumption over lifetime (Leigh and Li, 2015). The design process is crucial within the struggle for SSCM. A majority of impacts generated during value creation is determined at this stage with options for material input, manufacturing processes, impacts during use, and end-of-life treatment being set to a great extent (Seuring, 2004). Addressing the variety of issues, we differentiate four broad categories of Sustainable Product Design: First, product design may target a reduction of the quantity or quality of input materials build into the product by decreasing the material intensity, increasing the fraction of secondary inputs or limiting the use of toxic substances (Pimenta and Ball, 2015). Such design objectives result in resource conservation and less impact on both the environment and human beings (‘Design for Material Efficiency’) as mining processes are a major source of emissions and damages to surrounding landscape and biodiversity are often inevitable (Hassini et al., 2012). Moreover, certain sectors of the mining industry are notorious for social risks, like forced and child labor. Secondly, considerations may be given to the impacts during the product’s
production (‘Design for Sustainable Production’), such as reducing the amount of production wastes, including by-products, water consumption and auxiliary materials. From the social perspective, the product design may influence the ease of handling during production as well as the risk of occupational injuries induced by certain assembly steps or by noxious materials impacting the workforce. Third, focusing on the use phase (‘Design for Sustainable Usage’), consumer risks associated with the product are to be considered. In a broad understanding, decisions may also comprise product portfolio issues leading to a phase-out of products that are perceived as socially undesirable. Environmental factors within the use phase mostly pertain to energy efficiency and length of product life-cycles (Handfield et al., 2005). A fourth category deals with the influence of product design on recoverability. Products especially designed for recovery (‘Design for Recovery’), e.g., implemented by modular assembly, open up a broad set of recovery options, ranging from recycling to remanufacturing (Bansal, 2005; Kleindorfer et al., 2005; Veleva and Ellenbecker, 2001).

**Sustainable Supply Chain Design:** Supply chain design is a cross-cutting planning problem embracing all value chain processes of the focal company with interfaces to (raw material) suppliers and customers representing sources and sinks of material flows. As being highly strategic, decisions on the supply chain design delimit the degrees of freedom within almost every other planning problem of the company’s operations (Nuss et al., 2015). Common decisions deal with the localization of production sites and distribution facilities framed by the geographical dispersion of supply sources and customer demand. Viewed from a meta-level, supply chains can be designed decentralized with lots of facilities close to customers or centralized with long transportation distances between few producing plants and the regions of demand. Apart from the location problem, decisions on site-specific capacities, technology choices and flows between the entities are often interwoven. The environmental factors typically considered within this type of problem deal with emissions. The impact of land development on the biosphere, which would be of special interest in ‘greenfield’ problems, is widely ignored. The social lens is even less developed. Some authors merely give advantage for creating jobs in less developed regions.

**Sustainable Procurement:** Irresponsible behavior by one member affects the image of the supply chain as a whole (Mitra and Datta, 2014). Synonymously termed as responsible purchasing or ethical sourcing, Sustainable Procurement integrates environmental and social aspects into sourcing decisions (Ciliberti et al., 2008; Koplin et al., 2007; Pagell et al., 2010; Zorzini et al., 2015). In this way, the
sustainability orientation of the focal company is passed to upstream supply chain actors by exertion of purchasing power. First attempts to integrate aspects of sustainability into procurement date back more than two decades ago (Drumwright, 1994). Nevertheless, traditional decision parameters, like price and quality, are still dominating in industry practice (Wolf and Seuring, 2010). Sustainable Procurement can be realized by setting requirements concerning the sustainability impact of the sourced inputs (e.g., conflict-free materials) or by insisting on suppliers’ adherence to ecological and social standards within their processes. Concerning latter, Seuring (2013) distinguishes between supplier assessment & selection and collaborative development of supply chain partners. Assessments may comprise auditing and monitoring of suppliers encompassing site visits, in-depth analysis of suppliers’ business model and supplier surveys. Such practices generate reliable data, but are costly at the same time. Instead, many corporations rely on external certifications, verifiable processes such as environmental management systems in line with ISO 14001, or supplier’s commitment to a code of conduct (Morali and Searcy, 2013; Turker and Altuntas, 2014). In contrast to supplier selection, collaborative approaches for supplier development imply intensive relationship management with suppliers involving supplier education programs and interorganizational working groups (Leigh and Li, 2015; Leppelt et al., 2013; Pagell et al., 2010). Such strategic collaboration is supposed to be superior concerning the success of sustainability initiatives compared to approaches that purely rely on supplier assessments (Gimenez and Tachizawa, 2012; Sancha et al., 2015; Vachon and Klassen, 2006). A number of sustainability indicators is specific to procurement comprising factors like the fraction of orders placed with suppliers that are either located nearby, also known as local sourcing, are under control of minorities (e.g. indigenous people), or are located in developing countries in order to strengthen the regional economy (Hassini et al., 2012; Pagell and Wu, 2009; Zorzini et al., 2015). Sustainable buyers should also guarantee that their sourcing practice does not discriminate certain supplier types, such as small entities, driving them out of business (Hall et al., 2012). As a downturn, most studies on supplier management target first tier suppliers, while proactive firms are supposed to implement direct (interorganizational collaboration) or indirect (e.g., list of prohibited substances, certification requirements) governance mechanisms pushing sustainable behavior further upstream (Tachizawa and Wong, 2014).

**Sustainable Manufacturing:** Sustainable Manufacturing is considered as a cornerstone of sustainable development (Garetti and Taisch, 2012). Within this analysis, we differentiate between two concepts: Eco-efficient Manufacturing and Human-oriented Manufacturing. Specifically dedicating a concept to social issues is
suggested because social factors considered in manufacturing considerably deviate from those commonly addressed in other SSCM concepts.

**Eco-efficient Manufacturing** encompasses technological and organizational measures that result in ecologically benign production processes that are less-polluting, energy efficient, and emit a minimum of unwanted substances exceeding traditional makespan-, throughput-, or capacity-oriented objectives (Tang and Zhou, 2012). On a strategic level, investing in innovative eco-friendly equipment is seen as a major driving force for advancing ecological production (Schrettle et al., 2014). For existing machinery, re-configurations can induce environmental benefits. Majozi (2005) shows that alterations of layout design can generate situations where profit is improved and resource consumption is reduced at the same time. Another option for cleaning the production process is to equip production plants with state-of-the-art end-of-pipe technologies (Garetti and Taisch, 2012). Organizational measures on the tactical and operational level can substantially improve the environmental performance of a process without necessitating high investments. Rules of thumb regulating the shut-down of idle machinery instead of standby (Pach et al., 2014) or simple measures like eliminating leakages, optimizing drives, saving of solvents and lubricants, and recovery of by-products can also contribute to greening (Duflou et al., 2012; Giret et al., 2015; Haapala et al., 2013). More sophisticated approaches encompass optimization of production schedules, cutting processes, and maintenance cycles. Scheduling approaches are mostly input-oriented with energy-efficient production planning representing a growing field of research (Gahm et al., 2016), while output, e.g. wastewater reduction (Majozi, 2005), is less focused (Giret et al., 2015). The breadth of energy saving strategies in production environments is compiled in Abdelaziz et al. (2011). Cutting optimization contributes to the reduction of wastes and by-products (Dyckhoff 1990, Wäscher et al. 2007). Although being well elaborated, cutting problems have not been associated with SSCM so far. Improved maintenance cycles benefit sustainability by extending the equipment’s lifetime, by eliminating leakages, and by reducing the fraction of rejected products (Garetti and Taisch 2012). Potentials neglected in Eco-efficient Manufacturing pertain to the integration of renewable energy systems, e.g., by developing production plans in line with supply patterns from renewables or by analyzing the viability of energy storages build into production processes.

**Human-oriented Manufacturing** mainly deals with measures for employee safety and working conditions. This is in contrast to strategic social issues (e.g., wage level, conforming human rights) which are focused else. The risk of major accidents during occupational work is influenceable by decisions on all planning horizons. For
instance, investments into safe machinery, tactical decision on packaging easing handling, and ergonomic planning of operational tasks may positively influence the frequency and severity of injuries. Sarshar et al. (2016) and Bautista et al. (2016) give an overview of planning issues that impact the risk of major accidents and propose countermeasures. In contrast to these acute incidents, long-term and more subtle effects on the workers well-being, like musculoskeletal disorders caused by repetitive work are barely discussed. For instance, ergonomic considerations of the working place and material handling are missing in SSCM models (Grosse et al., 2015; Pagell and Shevchenko, 2014). Fabbro and Santarossa (2016) may help to exploit this topic. Moreover, contemporary production planning assumes employees to be interchangeable, emotionless and deterministic (Boudreu et al., 2003). Therefore, the workforces’ behavior and their individual skills are ignored in decision-making models (Grosse et al., 2015). The product recovery operations of a major electronics manufacturer, which we could observe within action research, illustrate the importance of these aspects. In line with the common heuristics for production planning, the manually conducted disassembly tasks were organized as batches of similar products. This organization ended up in decreased productivity. Eventually, employees were given the freedom to decide on the sequence of tasks on their own which resulted in increased motivation, a higher level of satisfaction and increased productivity. The motivational effect of having control over a task is long known within research on human resources management (Hackman, 1978) but did not trickle into SCM. We concede interdisciplinary collaboration with behavioral research and experts in human resources management may yield significant benefits for employee’s satisfaction, their well-being and the economic bottom line at the same time. Likewise, issues pertaining to employee training, corporate culture and reward structures are also missing (Jabbour and de Sousa Jabbour, 2016). Another topic of interest from a social perspective is the adaption of planning models considering the specific requirements of disabled people. Decision-support in this area would help to remove executives’ concerns and may facilitate the inclusion of minorities.

**Sustainable Warehousing & Inventory Management:** Empirical studies show issues of Sustainable Warehousing are widely neglected (Ciliberti et al., 2008; Pagell and Wu, 2009). Problems of warehousing traditionally deal with equipment choices within the warehouse as well as optimization of order quantities and order frequency. High energy demand and according emissions for storing products that need temperature control imply significant impacts on the environment (Dekker et al., 2012). Intelligent warehousing may also contribute to waste prevention by minimizing the amount of perishable left-overs. The social issues tackled in
sustainable warehousing correspond to those described in human-oriented manufacturing. Material handling is a main task in warehousing operations and should be conducted in a way that is not physically and mentally straining. Grosse et al. (2015) names human factors within planning of order picking referring to factors like size, weight, volume, and location of the product which ease handling by employees. Multi-criterial examinations of inventory management having not been existent half a decade ago (Hassini et al., 2012) are now evolving mostly as extension of the economic order quantity (EOQ) model.

**Industrial symbiosis:** Manufacturing concepts focus on production processes of a focal company, whereas Industrial Symbiosis deals with improvements realizable by cooperation of facilities under control by different companies. It promotes resource efficiency by establishing eco-industrial parks that are characterized by a symbiotic collaboration of the involved actors based on the exchange of resources. The concept of Industrial Symbiosis emanates from the industrial ecology paradigm and, thus, was not originally developed for SCM applications (Zhu and Cote, 2004). Up to now, Industrial Symbiosis is widely neglected by mainstream SSCM research and the overall literature on the interface between both is underdeveloped. This is unfortunate as Industrial Symbiosis may yield significant environmental and economic gains, and promising fields for application are already identified (Leigh and Li, 2015). Companies striving for more efficient management of material and energy flows within the production stage are likely to benefit (Geldermann et al., 2007) by realizing potentials for reduction of wastes from production processes and unwanted by-products (Winkler, 2011). Zhu and Cote (2004) provide an in-depth description of an eco-industrial park highlighting levers and barriers faced during the run-up and subsequent operations.

**Product Stewardship:** The research field pertaining to end-of-life management evolved from disposal management to circular approaches (Bloemhof-Ruwaard, 1995; Rubio et al., 2008). Product Stewardship aims on establishing product recovery systems and, thus, minimizing a product’s impact on human health and the environment (Ashby et al., 2012; Madu et al., 2002). Product Stewardship is strongly intertwined with closed-loop supply chain management which is perceived as “sustainable almost by definition” (Quariguasi Frota Neto et al., 2010 p. 4463). Circular economy concepts can be realized by recovery of internal by-products or by collecting products from customers after use (Stindt and Sahamie, 2014). The management of product backflows induces a totally new set of managerial problems, which are mainly caused by uncertainties regarding timing, quantity and quality of returns. Nuss et al. (2015) describe these challenges along the processes of product
returns management, reprocessing operations, and remarketing: The range of challenges is rather wide including backflow forecasting, infrastructure decisions, disassembly planning and redistribution planning to name just a few, but also comprises issues such hazard management (Diabat et al., 2014) and save disposal of harmful substances (Geldermann et al., 2007). Product recovery is supposed to reduce waste, mitigate the effects of toxic substances, and save resources in terms of materials and energy initially invested into the product. Socially, closed-loop supply chains create jobs for less-skilled workers on a regional level as recovery processes are barely automated.

**Sustainable Logistics:** Waste from means of transportation as well as emissions generated through transportation are the major source of environmental impact in logistics (Garetti and Taisch, 2012; Wolf and Seuring, 2010). Within the struggle for sustainability, corporate executives perceive savings in these areas as a powerful lever (Ageron et al., 2012). Sustainable Logistics is often limited to green issues, which are reviewed in detail by Dekker et al. (2012): Practices such as reducing the frequency and distance of transports, optimization of routing, efficient container loads, and multimodal transport are named for realizing sustainable transportation. Latter is defined as meeting “mobility needs while serving and enhancing human and ecosystem health, economic progress, and social justice” (Ciliberti et al., 2008, p. 91). Obviously, the above named issues only tackle the ecologic dimension articulated in this definition. Typical social issues within logistics deal with injuries and deaths caused by accidents, fair payment of truck drivers, avoidance of congestions, noise reduction, as well as ergonomic handling of goods (Nikolaou et al., 2013). Even less assessed is the impact of transportation on land use and biodiversity, although both is strongly influenced by the infrastructure that is required, be it roads, waterways, harbors, or airports.

### 5.2. Data acquisition for ecological and social assessment

In line with Phase II, methods utilizable for acquisition of the environmental and social data (see Section 4.2) are proposed (see Figure 5). Material flow analysis (MFA) and footprinting approaches provide structured approaches for depiction of inputs and outputs along value chain processes. Latter methods also allow making statements about the ‘degree’ of sustainability. Mechanisms for aggregation and rules for assessing the severity of impacts are described in life cycle assessments (LCA) and criticality assessments enabling ordinal comparisons of sustainability performance covering various impact categories. In the following we introduce these methods and
highlight some contributions that exemplify their application in the context of the proposed framework.

Material flow analysis is a hands-on method mapping processes emphasizing the input-output flows at every stage. Adapted versions of value stream mapping serve similar purposes. These tools produce sound knowledge and graphical depiction of material flows and waste flows identifying efficiency losses (Seuring and Müller, 2007). Apart from solid substances this methodology can be used for analyzing emission sources and according reduction potentials (Ball et al., 2009). Furthermore, it is useful for comparison of ex-ante and ex-post states. MFA is regarded as a prerequisite for improvements concerning waste generation and emissions, especially in manufacturing (Giret et al., 2015). For this purpose, Smith and Ball (2012) establish guidelines for utilization of flow modelling. Rybicka et al. (2015) demonstrate the benefits of MFA within a production system for composite materials revealing potentials for by-product recovery. More ambitiously, Ball et al. (2009) use MFA to establish zero waste and zero emission manufacturing practices within a system consisting of energy utilities and manufacturing processes.

![Figure 5: Tools for assessing SSCM alternatives and decision-making](image)

Ecological footprints compare the extent of human interaction with the capacities of nature. Human activities are perceived as sustainable when natural limits are not exceeded (Wiedmann and Barrett, 2010). Coming from a macroeconomic perspective, footprinting has been adapted to supply chain activities (Minx et al., 2009). The methodology translates ecological impacts into an aggregated single score, such as the total land area required to support the company’s resource
consumption and disposal (Barrett and Scott, 2001). Hence, a decision alternative showing the lowest value is ecologically dominating. Various inputs and outputs can be analyzed and aggregated using ecological footprinting. Within the review sample, footprinting approaches are scarcely chosen and only limited to carbon footprints. Jakhar (2015) and Bouchery et al. (2012) consider the carbon footprint to select material suppliers or to evaluate order processing and transportation activities respectively. Reviewing the literature it is striking that the term ‘carbon footprint’ is often falsely used representing the total emissions of CO2 associated with a process or a product. Hence, a more rigorous distinction between a figure representing the quantity of output and the footprint providing an aggregated score making comparisons between various inputs and outputs possible is necessary. In analogy to the ecological footprint, the social footprint is a context-based methodology for measuring social sustainability based on the needs of individuals. It gives the capability to quantitatively depict the social bottom-line of an organization using social indicators which are compartmentalized into four broad categories: Social capital, Human capital, Natural capital, and Constructed capital. The performance in each category is normalized by the so-called people feet, which represents the fraction of human resources under supervision of the company. The social footprint itself is defined as the quotient from the company’s performance within a selected sustainability category and a given target value expressing the carrying capacity of a capital category (McElroy et al., 2008). In contrast to the ecological footprint, the larger the social footprint the better. A footprint value of one or above suggests social sustainability (McElroy, 2007). An overview covering both ecological footprinting approaches and various social footprints is provided by Cucek et al. (2012). The authors also demarcate footprinting from LCA.

**Environmental Life Cycle Assessments (ELCAs)** exceed both the company’s boundaries and the focus on material flows. Depending on the perspective and the epistemic object, LCA can serve as a standalone decision-support tool (Yung et al., 2012) or as a supportive tool for subsequent analysis. Here, we follow the latter understanding. ELCA is a central tool for ecological evaluation of processes and products alike (Beske-Janssen et al., 2015; Rubin et al., 2014) measuring environmental as well as health impacts at all stages of the value chain (Mota et al., 2015; Kjaerheim, 2005). Although still evolving, LCA is scientifically accepted as being a reliable tool for environmental evaluation (Mota et al., 2015; Winkler, 2011). The reference procedure for conducting an ELCA is standardized by ISO14040. In total, ELCAs show a number of advantages: First, it covers the full breadth of environmental effects associated with business processes, ranging from CO2
emissions to resource depletion. Second, ELCAs use statistical data which are extractable from databases, like EcoInvent. This significantly eases application and reduces the costs of primary data collection. A drawback of LCAs is the variety of life cycle impact assessment methods (LCIA). Various approaches differ with regard to normalization assumptions and weighting factors (Carvalho et al., 2014). As a consequence, the results of a specific ELCA are not ultimately accepted (Lake et al., 2015). Nevertheless, ELCAs are the predominant methodology for evaluating the ecological performance of a product satisfying the requirement of life-cycle thinking in Sustainable Product Design (Kjaerheim, 2005). Haapala et al. (2013) highlight the benefits of LCAs used within decision-making on Eco-oriented Manufacturing. In this context, ELCAs are utilisable in investment decisions revealing the equipment’s environmental impact over its lifecycle, whereas, process-based ELCAs are applied to compare organizational alternatives. A detailed overview of databases and software tools supporting the application of LCAs to manufacturing environments is provided by Mani et al. (2014). Evaluations of the environmental impact of Sustainable Supply Chain Design choices are often conducted by means of LCA (Pagell and Shevchenko, 2014). A broader overview of respective applications is given by Eskandarapour et al. (2015). Examples can be found in Kostin et al. (2015), Quariguasi Frota Neto et al. (2008) as well as Chaabane et al. (2012) using the LCIA method Eco-Indicator 99 to feed their models and Mota et al. (2015) as well as Pishvaeaee et al. (2014) who refer to ReCiPe for designing a sustainable network.

A structured and comprehensive acquisition of social data is rare. An outstanding attempt to quantify social aspects is presented by Pishvaeaee et al. (2014). They calculate social parameters using Social LCA (SLCAs) following the ‘Guidelines for Social Life Cycle Assessment of Products’. Emerging from ELCAs, the research on SLCAs is in its infancy with first publications a decade ago (Dreyer et al., 2006) and can be best described as ‘under construction’. Nevertheless, it is promising to determination the social performance associated with an organization, a product or a process (Pimentel et al., 2015). SLCAs may serve two main purposes: First, the structured methodology forces to define a scope for the social analysis, a task that is often left behind in social assessments (Eskandarapour et al., 2015). Second, it generates a manageable amount of parameters condensing numerous indicators leading to computable data. Interested readers please refer to Hutchins and Sutherland (2008), Jorgensen et al (2008), and Wu et al. (2014). Former provide an example on how to apply SLCA to a supply chain, the latter two introduce the methodology and review recent developments. An extensive guideline for product-based SLCA is provided by the United Nations Environment Programme (2009).
**Criticality assessments** are originally developed for analyzing the long-term availability of functional materials based on biophysical, technical, economic, and social factors (Bensch et al., 2014). Several aggregation mechanisms, indicator sets and data sources are proposed in literature (Achzet and Helbig, 2013; Graedel et al., 2011; Bensch et al., 2015). Formerly, criticality concepts concentrate on the economic and the ecological dimension. Lately, a growing importance is given to the social impact of raw material extraction referring to indicators like human toxicity, child labor, and occupational health (Reller, 2011). Criticality assessment enables to capture impacts in a structured manner and proposes indicators as well as aggregation mechanisms. In particular, criticality assessment can bear benefits in Sustainable Product Design, especially concerning ‘Design for Material Efficiency’, and Sustainable Procurement by revealing the total costs and risks of materials. Giving transparency to the economic, ecological, and social impact of design alternatives, Bensch et al. (2015) assess design alternatives of circuit boards.

**Auditing and Surveys** aim on verifying the implementation of systematic organizational measures that allow reactive approaches for advancing sustainability within an organization. Auditing procedures often refer to standards such as ISO 14001. Auditing and surveys are commonly applied for assessing alternative suppliers in Sustainable Procurement. For these purposes Keating et al. (2008), Koplin et al. (2007) as well as Graafland (2002) provide in-depth portrays of best practices observed at a global electronics company and a German textile manufacturer respectively, describing reference processes, standard questionnaires and auditing procedures.

Summing up, depending on the scope of the problem and the focused SSCM concept the described methods facilitate the acquisition of appropriate data sets for potential decision alternatives. In this way, the fundamental data subsequently used as parameters and decision variables in normative decision-support models are accessible.

**5.3. Methods supporting quantitative decision-making in SSCM**

Basic requirements for methods supportive in SSCM decision-making are twofold. The methods have to be able to converge multiple criteria and to generate an ordinal order of the multi-attribute alternatives. Therefore, the methods have to handle conflicting objectives and have to reflect the decision-makers’ preferences. In the simplest case, the valuated alternatives are compared and, if existing, the alternative dominating across all criteria is selected. In reality such cases can hardly be found.
Then, methods generating compromise solutions or multi-attribute techniques are needed. Following the classification of Brandenburg et al. (2014), we mainly identify five types of modelling methods applied as quantitative decision-support tools: Multi-criteria decision-making (MCDM) approaches, artificial intelligence (AI), multi-objective programming methods (MOPM), simulation techniques, and analytical models. These methods mainly vary concerning the number of comparable alternatives, the required level of parameter homogeneity and the level of uncertainty.

**Methods of multi-criteria decision analysis**, including AHP, ANP, TOPSIS, and DEA, and **Artificial Intelligence**, such as artificial neural networks, fuzzy logic and rough sets, enable comparison of both qualitative and quantitative information in line with decision-makers’ preferences and can deal with incomplete information (Madu et al., 2002). Although powerful for decision-support, these methods are only applicable to a limited set of discrete decision alternatives.

Issues of Sustainable Procurement are mostly tackled by MCDM and AI methods. Govindan et al. (2013) present a fuzzy TOPSIS approach enabling the integration of qualitative information, including those describing the social dimension, for holistic evaluation of suppliers. Kuo et al. (2010) utilizes ANP to determine weights for balancing indicators in supplier selection combined with ANN. The final decision is based on DEA. Also using DEA, Azadi et al. (2015) provide a generic supplier selection model taking into account work safety and labor health. A similar proceeding might also be adopted for comparing design alternatives for products and processes. Addressing the difficulties concerning the integration of social aspect, Neumüller et al. (2015) propose an ANP based approach for locating distribution centers covering sustainability impacts during operation, build-up and phase out of facility. A combination of LCA and AHP is used by Madu et al. (2002) to combine the ecological dimension with other sustainability dimensions. Particularly tackling the issue of uncertain and partially unknown data, a hybrid methodology based on grey theory and DEMATEL is applied by Su et al. (2015). The works from Bai and Sarkis (2014) as well as Bai et al. (2012) build on grey-based rough set theory.

**Multi-objective programming** and **simulation** are applied in situations where the number of decision alternatives is virtually infinite and the specific results of each solution are unknown making an analytical enumeration of alternatives impossible. As a downside, these techniques can hardly deal with unknown measures, non-cardinal indicators and ‘soft’ facts. While optimization assumes deterministic behavior of system parameters, simulation takes stochastic processes into account. A
particular challenge in mathematical programming is how to capture and balance trade-offs between multiple objectives. In contrast to MCDM, mathematical programming approaches are not explicitly designed to simultaneously integrate multiple objectives. Acknowledging that variations and hybrid construction of approaches for integration of non-economic information exist, we distinguish three approaches: Monetarization of ecological and social effects, epsilon-constraints, and utility values. All methods strive for selection of pareto-optimal, non-inferior solutions for the problem at hand.

Monetarization of sustainability indicators is popular for environmental parameters such as costs induced by carbon emissions (Tseng and Hung, 2014; Diabat and Al-Salem, 2015), fuel consumption (Soysal et al., 2015), or waste disposal (Battini et al., 2014; Soysal et al., 2015). This conversion into monetary terms can easily be accomplished when ecological and social effects are directly attributable to operational costs, such as disposal costs or – if operations are covered by an emission trading scheme – emission costs. Apart from the fact that such market prices are hardly obtainable for other indicators of sustainability (e.g., injuries, deaths, biodiversity) it is questionable if the real or fictional market price adequately reflects the ‘natural’ and ‘social’ costs. An attempt to monetarize the social dimension is presented Azadi et al. (2015) who calculate the costs associated with safety and labor health.

Approaches implementing epsilon-constraints optimize a primary objective considering further objectives as constraints. Optimizing the economic performance, Mota et al. (2015) choose epsilon-constraints to integrate ecological and social objectives of the Sustainable Supply Chain Design problem. In a similar problem, Kostin et al. (2015) also propose epsilon-constraint methodology to reduce the complexity of a MOLP applied to supply chains of bioethanol and hydrogen production. In addition, the authors show that certain objectives are redundant and can be omitted without compromising the solution quality. Less frequent is the utilization of non-economic goals as primary objective. Rager et al. (2015) present an optimized production schedule levelling the energy demand. With this organizational measure, carbon emissions within a textile production process are decreased by 20% without compromising economic objectives. In a similar setting, Denz (2015) offers an optimization model for planning an energy supply system that operates close to its optimum operating point increasing energy efficiency based on existing production plans.
The utility value approach weights each objective converting the resulting value of the multi-objective problem into a single scalar. This approach can be found for all kinds of SSCM concepts, but especially in Sustainable Supply Chain Design problems. For instance, a weighted multi-objective linear programming approach is selected by Boukherroub et al. (2015). The authors balance the financial performance with emissions and the effects on local employment within a value chain for lumber products. Balancing the objectives pertaining to material consumption, emissions, and wastes, Geldermann et al. (2007) implement equal weight coefficients. In a more sophisticated attempt, Pishvaaee et al. (2014) propose a fuzzy linear membership function enabling the decision-maker to adapt the importance of each objective in accordance to individual preferences. Out of the sparse contributions targeting Human-oriented Manufacturing, Youssif et al. (2011) uses a weighted linear program to incorporate ergonomic factors into disassembly scheduling.

Other authors circumvent the problems of balancing the objectives by implementing a combination of decision-making methods. Validi et al. (2014) compares the feasible solutions of a bi-objective mixed integer program using TOPSIS to reflect the decision-makers’ opinion. Tajbakhsh and Hassini (2015) combine DEA with linear optimization to compare the sustainability performance of different supply chain design choices. Jakhar (2015) incorporates environmental criteria (energy consumption, level of secondary input, carbon footprint) and social criteria (Employee development, charity, contribution to community) in a procurement-network-flow problem which is solved combining of fuzzy AHP and optimization. Varsei et al. (2014) stress how the results of an AHP-based supplier selection model can be introduced into a multi-objective optimization covering all sustainability dimensions.

**Analytical models**, mainly applied by means of adapted versions of the economic order quantity (EOQ) model, derive an optimum for operational problems in the context of Sustainable Warehousing and Eco-efficient Manufacturing. In the field of production planning, Alinoviy (2012) present a stochastic EOQ model in a reverse logistics environment deciding upon manufacturing and remanufacturing activities, without explicitly referring to ecological or social indicators. A SEOQ is presented by Battini et al. (2014) by incorporating monetarized impacts of emissions and waste disposal. For warehousing applications, Bouchery et al. (2012) present a multi-objective EOQ solving a trade-offs between transportation of large batches reducing the transportation-induced carbon emissions but increasing injury risks, and lengthy storing of large quantities that need cooling but expose lower injury rates. The authors implement interactive feedback loops with decision-makers, iteratively
revealing their preferences by presenting various objective values differing with regard to weighting coefficients.

6. Discussion & Conclusion

In line with the first research question this research sets out to analyze the current state of research on SSCM, especially focusing on the dissemination of the sustainability paradigm into SCM by reviewing the SSCM issues addressed in contemporary publications. Furthermore, we develop a framework mainly serving two purposes: On the one hand, the structured presentation of concepts and various methods reveals shortcomings of SSCM research as well as avenues for advancing the research field. On the other hand, the framework eases the integration of sustainability into the realm of supply chain management practice. In the following we delineate key benefits for both academia and practitioners.

Insights for researchers

The literature evaluated in section 4 provides a number of answers concerning the first research question (Q1): The academic interest on SSCM is on the rise with a growing number of publications explicitly positioned within the research field. The research field significantly evolved since the review compiled by Ashby (2012) indicated by an increased fraction of publications presenting quantitative models. This underlines that the research field is gradually moving to a mature level. Nevertheless, we identified manifold potentials for advancing respective research. First of all, we echo recent publications, such as Brandenburg et al. (2014) and Mota et al. (2015), conceding a dearth of quantitative decision-support comprehensively integrating the social dimension. Indeed, we show that such indicators are only rudimentary treated, if treated at all. Thus, we have to affirm an observation made a decade ago: “The people part is notably absent from OM [Operations Management] research” (Kleindorfer et al., 2005, p. 490). Advancements in Social LCA may yield significant advancements concerning this issue. Secondly, LCAs are frequently named as one of the most common techniques for generation of input parameters in mathematical models and a number of papers are combining LCA and multi-objective optimization. Nevertheless, we concede potential in this symbiosis. Third, concepts well elaborated in adjacent disciplines did not fully disseminate into SSCM. Further benefits can be realized by integration of concepts like Industrial Symbiosis and by interdisciplinary collaboration with disciplines such as human resource management or environmental management. This article contributes to SSCM research by clarifying basic definitions. In the academic discourse, concepts and
methods for operationalization of SSCM are frequently intermingled. For instance, Taticchi et al. (2015) lists issues on sustainable scheduling, facility location and supplier selection as well as optimization, AHP, and LCA without differentiating. Although discussable, this article introduces a distinction between the paradigm of SSCM, relevant concepts, and methods and relates these elements to each other within a hierarchical order. To the best of our knowledge such a structured understanding does not exist hitherto. Concluding, the proposed framework may serve academia as a starting point for advancing SSCM research covering all aspects of sustainability.

*Insights for practitioners*

The structured framework steering decision-making within the area of SSCM benefits corporate executives in numerous ways. Answering the research questions Q2 and Q3, the present study extends previous works by providing a holistic and integrated depiction of concepts and methods that facilitate operationalizing the sustainability paradigm spanning major supply chain activities. In this way, we remove blind spots decision-makers may encounter in the sustainability challenge and ease decision-making in this complex problem area. Apart from a reference process, the framework provides practitioners with a necessary toolkit to prepare decisions in a structured and comprehensive manner. Moreover, we expect considerable advancements with regard to the data acquisition methods further driving corporate sustainability initiatives. Overall, the framework guides executives towards sustainable business practice and, thus, represents a gradual step heading to a sustainable economy.

*Limitations and conclusion*

An inherent critique of research based on extant literature may be the question on the completeness of the literature basis. Although following a rigor research process, both the selection and the categorization of the literature as well as structuring of the decision-making framework remains a subjective decision of the authors. In order to mitigate the bias of the author, the research was extensively discussed with master students in classroom sessions, with fellow researchers and practitioners. Summing up, this research investigates the dissemination of sustainability within SCM. The respective research question Q1 is tackled in section 4. In line with Q2 and Q3, we synthesize concepts and methods for the purpose of easing sustainability-oriented decision-making in corporate environments in section 5. As a result, we present a comprehensive framework for guiding decision-processes in SSCM contributing to the research field by providing a structured integration of concepts and methods utilizable in the pursuit of ecological and social improvements along the value chain.
### Appendix A – Articles on quantitative decision-support

<table>
<thead>
<tr>
<th>Article providing quantitative decision-support</th>
<th>Sustainability Dimension</th>
<th>Focused paradigm</th>
<th>Used modelling technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alinoviy et al. (2012)</td>
<td>x</td>
<td>GSCM</td>
<td>Analytical model (EOQ)</td>
</tr>
<tr>
<td>Azadi et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>DEA</td>
</tr>
<tr>
<td>Battini et al. (2014)</td>
<td>x x</td>
<td>None</td>
<td>LCA + Analytical model (EOQ)</td>
</tr>
<tr>
<td>Besiou (2012)</td>
<td>x x x</td>
<td>CLSC</td>
<td>Single objective Simulation</td>
</tr>
<tr>
<td>Borchardt et al. (2011)</td>
<td>x x</td>
<td>None</td>
<td>Ecological Footprinting + Input-Output-Analysis</td>
</tr>
<tr>
<td>Bouchery et al. (2012)</td>
<td>x x x</td>
<td>SSCM</td>
<td>Carbon Footprinting + Analytical model (EOQ)</td>
</tr>
<tr>
<td>Boukherroub et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MOLP</td>
</tr>
<tr>
<td>Chaabane et al. (2012)</td>
<td>x x</td>
<td>SSCM</td>
<td>LCA + MOLP (Optimization)</td>
</tr>
<tr>
<td>Choi and Chiu (2012)</td>
<td>x x</td>
<td>SSCM</td>
<td>Single objective Analytical model (Newsvendor)</td>
</tr>
<tr>
<td>Devika et al. (2014)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MOLP (Optimization)</td>
</tr>
<tr>
<td>Diabat and Al-Salem (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>SOLP</td>
</tr>
<tr>
<td>Geldermann et al. (2007)</td>
<td>x x</td>
<td>SSCM</td>
<td>MFA + MCDM (Pinch Analysis)</td>
</tr>
<tr>
<td>Govindan et al. (2013)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MCDM (TOPSIS)</td>
</tr>
<tr>
<td>Govindan et al. (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>MOLP (Optimization)</td>
</tr>
<tr>
<td>Hsueh (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MOLP (Variational Inequality)</td>
</tr>
<tr>
<td>Huang et al. (2009)</td>
<td>x</td>
<td>SSCM</td>
<td>Simulation</td>
</tr>
<tr>
<td>Jakhar (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>Carbon Footprinting + AHP + MOLP (Optimization)</td>
</tr>
<tr>
<td>Ji et al. (2015)</td>
<td>x x</td>
<td>GSCM</td>
<td>Single-objective Analytical model (Game theory)</td>
</tr>
<tr>
<td>Kostin et al. (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>LCA + MOLP (Optimization)</td>
</tr>
<tr>
<td>Kuo et al. (2010)</td>
<td>x x x</td>
<td>GSCM</td>
<td>AI (ANN) + MCDM (DEA + ANP)</td>
</tr>
<tr>
<td>Li (2013)</td>
<td>x x</td>
<td>SSCM</td>
<td>MOLP (Optimization)</td>
</tr>
<tr>
<td>Li and Li (2016)</td>
<td>x x</td>
<td>SSCM</td>
<td>Analytical model (Game theory)</td>
</tr>
<tr>
<td>Mazhar and Kaebernick (2007)</td>
<td>x</td>
<td>SSCM</td>
<td>AI (ANN)</td>
</tr>
<tr>
<td>Mota et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>LCA + MOLP</td>
</tr>
<tr>
<td>Nagurney and Yu (2012)</td>
<td>x x</td>
<td>SSCM</td>
<td>Analytical model (Game theory)</td>
</tr>
<tr>
<td>Neumüller et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MCDM (ANP)</td>
</tr>
<tr>
<td>Pishvaea et al. (2014)</td>
<td>x x x</td>
<td>SSCM</td>
<td>LCA + MOLP (Optimization)</td>
</tr>
<tr>
<td>Rager et al. (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>MOLP (Optimization)</td>
</tr>
<tr>
<td>Rybicka et al. (2015)</td>
<td>x x</td>
<td>None</td>
<td>MFA</td>
</tr>
<tr>
<td>Sitek and Wikarek (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>SOLP</td>
</tr>
<tr>
<td>Soysal et al. (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>SOLP</td>
</tr>
<tr>
<td>Su et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>AI (Grey theory) + MCDM (DEMATEL)</td>
</tr>
<tr>
<td>Tajbakhsh and Hassini (2015)</td>
<td>x x x</td>
<td>SSCM</td>
<td>MCDM (DEA) + SOLP (Optimization)</td>
</tr>
<tr>
<td>Tseng and Hung (2014)</td>
<td>x x x</td>
<td>SSCM</td>
<td>SOLP</td>
</tr>
<tr>
<td>Validi et al. (2015)</td>
<td>x x</td>
<td>SSCM</td>
<td>MOLP (Optimization) + MCDM (TOPSIS)</td>
</tr>
<tr>
<td>Yung et al. (2012)</td>
<td>x</td>
<td>None</td>
<td>LCA</td>
</tr>
</tbody>
</table>

Notes: SOLP = Single-objective linear program; MOLP = Mixed-objective linear program
## Appendix B – Articles on qualitative decision-support

<table>
<thead>
<tr>
<th>Article providing qualitative decision-support</th>
<th>Sustainability Dimension</th>
<th>Focused paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbasi and Nilsson (2012)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Ageron et al. (2012)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Amini and Bienstock (2014)</td>
<td>x x x</td>
<td>CSR</td>
</tr>
<tr>
<td>Azevedo et al. (2012)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Beske and Seuring (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Fabbe-Costes et al. (2014)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Fresner and Engelhardt (2004)</td>
<td>x x</td>
<td>None</td>
</tr>
<tr>
<td>Giannakis and Papadopoulos (2016)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Gopalakrishnan et al. (2012)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Jabbour and de Sousa Jabbour (2016)</td>
<td>x x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Keating et al. (2008)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Kjaerheim (2005)</td>
<td>x</td>
<td>Cleaner Production</td>
</tr>
<tr>
<td>Koplin et al. (2007)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Lake et al. (2015)</td>
<td>x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Leigh and Li (2015)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Matos and Hall (2007)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Maxwell and van der Vorst (2003)</td>
<td>x x x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Maxwell et al. (2006)</td>
<td>x x x</td>
<td>None</td>
</tr>
<tr>
<td>Sahamie et al. (2013)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Schrettle et al. (2014)</td>
<td>x x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Seuring (2004)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Tsoufas and Pappis (2006)</td>
<td>x</td>
<td>CLSC</td>
</tr>
<tr>
<td>Turker and Altuntas (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Varsei et al. (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Zhu and Cote (2004)</td>
<td>x x</td>
<td>GSCM</td>
</tr>
</tbody>
</table>
## Appendix C – Articles on theory development

<table>
<thead>
<tr>
<th>Articles on theory development</th>
<th>Sustainability Dimension</th>
<th>Focused paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beske (2012)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Boons et al. (2012)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Brindley and Oxborrow (2014)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Carter and Rogers (2008)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Ciliberti et al. (2008)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>de Brito et al. (2008)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Diabat et al. (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Foerstl et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Formentini and Taticchi (2016)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Gavronksi et al. (2011)</td>
<td>x x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Giunipero et al. (2012)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Grosvold et al. (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>de Sousa Jabbour et al. (2014)</td>
<td>x x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Khalid et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Leppelt et al. (2013)</td>
<td>x x x</td>
<td>None</td>
</tr>
<tr>
<td>Liu et al. (2012)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Meixell and Louma (2015)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Mitra and Datta (2014)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Moore and Manning (2009)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Morali and Searcy (2013)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Pagell and Wu (2009)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Pagell et al. (2010)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Sancha et al. (2016)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Seuring (2004)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Seuring (2011)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Seuring and Müller (2008)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Signori et al. (2015)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Soléér (2010)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Tachizawa and Wong (2014)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Tate et al. (2010)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Vachon and Klassen (2006)</td>
<td>x</td>
<td>GSCM</td>
</tr>
<tr>
<td>Vurro et al. (2009)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Walker and Jones (2012)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Walker et al. (2008)</td>
<td>x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Wolf (2011)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Wolf (2014)</td>
<td>x x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Wolf and Seuring (2010)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Wu and Pagell (2011)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
<tr>
<td>Zailani et al. (2012)</td>
<td>x x</td>
<td>SSCM</td>
</tr>
</tbody>
</table>
Appendix D – Articles on performance measurement

<table>
<thead>
<tr>
<th>Articles on performance measurement</th>
<th>Sustainability Dimension</th>
<th>Focused paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Economic</td>
<td>Ecologic</td>
</tr>
<tr>
<td>Ahi and Searcy (2015)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bai et al. (2012)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Chardine-Baumann and Botta-Genoulaz (2014)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Chopra and Wu (2016)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Erol et al. (2011)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Golicic and Smith (2013)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Gomes et al. (2014)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Gotschol et al. (2014)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Kushwaha and Sharma (2015)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Nikolaou et al. (2013)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Ortas et al. (2014)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Roth and Kaberger (2002)</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

References


Generic planning approach for SSCM


Review of research on closed loop supply chain management in the process industry

Contribution C2

Abstract: Closed loop supply chain (CLSC) management is a major enabler for sustainability in value creating networks. This contribution aims to describe and analyze the main characteristics of CLSC planning in the process industry and the related publications, in order to determine the evolution and gaps of this current research over time and improve our understanding of this issue. We built up a database with the articles on CLSC in different sectors of the process industry and identified the most relevant journals within this field. Furthermore, we derive and identify the requirements for CLSC considerations in the process industry for verifying whether these requirements are met in the literature so far. In addition, we have explored the topic, the methodology and the techniques of analysis, as well as other relevant aspects of the research in this field. We mainly focus on general and specific quantitative approaches, observing what has been done and how, where and by whom it has been carried out. The result is an extensive review of the research work itself and their limitations having an influence on CLSC concepts for the process industry. We conclude with some suggestions to those who begin to research on this apparently disregarded topic.

On the Attractiveness of Product Recovery: The Forces that Shape Reverse Markets

Contribution C3

Abstract: Product recovery is a major contributor for implementing sustainable business practices. Within such operations, which are either driven by legislation or economic rationales, practitioners face strategic issues concerning reverse market entry and positioning. Although the complexity of acting on reverse markets is widely acknowledged, a comprehensive framework to facilitate decision-making in this area is lacking. In an attempt to fill that gap, we develop a model that supports original equipment manufacturers’ (OEMs) assessment of the attractiveness of reverse markets. We identify, from a comprehensive literature analysis, in-depth interviews, and engagement with a dozen companies from different countries, factors that influence key characteristics of reverse markets, and consolidate this lengthy list into a comprehensive model intuitively applicable to business practice. The model combines five forces that drive reverse markets: Access to recoverable products, Threat of IRCs’ market entry, Rivalry for recoverable products, Adverse effects on core business, and Remarketing opportunities. We propose for each, a set of attributes that influences its power and direction. To demonstrate the efficacy of the model, we apply it in two industry settings, recovery of white goods in the United Kingdom and paper recycling in Germany. The present research enables OEMs to understand the structure and forces that drive reverse markets, identify levers to influence those markets, anticipate market developments, and formulate resilient strategies for product recovery.

The Reverse Supply Chain Planning Matrix: A Classification Scheme for Planning Problems in Reverse Logistics

Contribution C4

Abstract: This paper presents a conceptual planning framework for reverse supply chain operations based on an extensive literature review and industry expertise. Such a holistic scheme for classification of planning tasks is necessary as the intensification of research on reverse logistics and closed-loop supply chains in recent years has raised a number of planning problems that differ from those of solely forward-oriented supply chains. Up to now, a common and comprehensive definition of relevant planning problems along the reverse chain has not existed. Thus, a thorough understanding of the interdependence between these elements is missing. This paper aims to systematically identify planning problems, which are assigned to different planning horizons and distinct process stages of product recovery. The result is a classification scheme, called a ‘Reverse Supply Chain Planning Matrix’ (RSCPM), which categorizes planning problems and shows their interrelation in recovery operations. It serves both academia and practitioners as a holistic overview for planning and decision tasks. Moreover, decision-makers are supported in identifying the relevant variables in reverse supply chains and in revealing the consequences of one decision regarding other parameters of the system. To the best of the authors’ knowledge, the RSCPM is the first attempt to comprehensively structure the field of reverse supply chain research by identifying, defining and interconnecting planning problems within an integrated framework, as is common in the forward case.

Transdisciplinary Research in Sustainable Operations – An Application to Closed-Loop Supply Chains

Contribution C5

Abstract: This contribution provides implications for academic research and practitioners, as it identifies the lack, necessity and major benefits of transdisciplinary research and the collaboration of academics and industry in order to fulfill the goals of a sustainable supply chain. Closed-loop supply chain management is a major contributor to implementing sustainable operations. An essential prerequisite for successful realization is the expertise and cooperation of representatives from engineering, management and natural sciences as well as practice. We identify a need for transdisciplinary collaboration within two steps. First, a literature review points out that various research disciplines as well as practice mostly operate in isolation. Second, we develop a framework that highlights the benefits of collaboration between these research areas. This paper provides an overview to better understand current trends in this complex field, which is a rich area for research that is still in its infancy.

How Transdisciplinarity Can Help to Improve Operations Research on Sustainable Supply Chains – A Transdisciplinary Modeling Framework  

Contribution C6

Abstract: We present a transdisciplinary modeling framework that enhances collaborative research on sustainable supply chain management (SSCM). Decision support concerning such systems is commonly provided using operations research (OR) methodologies. The quality of respective models depends on the appropriateness of both mathematical representation of the focal system and data input. Concerning this matter, OR faces severe criticism as groundwork is commonly neglected. This results in a lack of holistic understanding and in insufficient modeling of real-world problems. Crucial characteristics of the underlying system are often over-simplified due to single-discipline assessments. Particularly, in the context of complex sustainability challenges, multiple (non-)academic competencies and expertise are required. Although latest research indicates that collaborative research settings are highly beneficial regarding SSCM, a dearth of integration between disciplines exists. Therefore, we develop a conceptual framework that helps to overcome these shortcomings based on the paradigm of transdisciplinary research, which needs substantiation to enhance collaboration and to ensure applicability. Accordingly, we propose appropriate methodologies for each step within the framework. Overall, the framework enables holistic analysis of a focal system by providing a sound approach for SSCM-oriented transdisciplinary research projects. The value of the framework is eventually demonstrated by two cases that deal with SSCM issues.
Analysis of European Closed-loop Supply Chain Network for WEEE – An OEM Perspective

Contribution C7

Abstract: To profoundly analyze the viability of a European product recovery network from an OEM’s perspective, we develop a mixed-integer linear model. This quantitative decision-model aims to maximize profits generated from collection and reprocessing activities of a manufacturer for electrical and electronic equipment (EEE). Beside classic economic aspects we incorporate legal limitations (e.g. the WEEE-Directive and the Regulation on shipments of waste) into both the constraints and the objective function. Hence, legislative elements are considered as central influencing factors. Based on several scenarios, we examine the “critical mass” of potentially acquirable goods to profitably run a network for collection and recovery of WEEE. Our analyses base on real-world data that originate from cooperation with a globally acting manufacturer for IT. This enables the transfer of our results to business practice as well as to future legislative actions.

Eine quantitative Analyse europäischer Richtlinien und Verordnungen zur Abfall- und Kreislaufwirtschaft am Beispiel der Elektro- und Elektronikindustrie


Conclusion and Research Outlook

The research project summarized in this doctoral thesis is guided by the research questions that are formulated in the introduction. Within eight contributions advancements for both research and corporate decision-making on sustainability issues are delineated. This is done by structuring the highly complex and evolving research field and, thus, easing the identification and analysis of sustainability potentials along the supply chain (Research Question 1). This problem set is mainly addressed in Stindt (submitted, C1), Stindt and Sahamie (2014, C2) as well as Stindt et al. (accepted, C3) and Nuss et al. (2015, C4). Latter two present frameworks supporting managerial decision-making concerning product recovery. Sahamie et al. (2013, C5) and Stindt et al. (accepted, C6) as well as Stindt (submitted, C1) highlight major challenges of quantitative modeling when it comes to decision-making concerning a specific planning problem within SSCM contexts. Challenges include uncertainties regarding the characteristics and behaviour of the system under assessment and failures which may be induced by imprecise determination of input data. Therefore, this doctoral thesis presents specific methodologies and processes, latter mainly dealing with transdisciplinary approaches, to improve the reliability and validity of operations research models and the data used for instantiation (Research Questions 2 & 3). Applying these methodologies and processes results in more appropriate depictions of the real-world problem and increases the transferability of insights generated by quantitative decision-support models into the realm of business practice. Increased awareness for SSCM issues, more profound understanding of the patterns of corporate sustainability and a higher reliability of decision-support models contribute to a higher acceptance of sustainability-oriented decision-making and, henceforth, to diffusion of SSCM into corporate reality. Finally, the research project analyses the viability of a European recovery network for IT-equipment returned by B2B customers. The presented mixed-integer linear program is developed within a transdisciplinary research setting in cooperation with an
industrial partner enabling proper abstraction of the real-world problem and extensive acquisition of real-world data.

Although presenting a number of steps advancing the research on SSCM, this work shows some limitations. First of all, the research majorly focuses on a subset of corporate sustainability, namely on closed-loop supply chain management. It is believed that the insights generated for this topic are transferable to further SSCM topics. Nevertheless, this hypothesis should be tested in future research by application of the presented models and processes to adjacent challenges, like sustainable logistics or sustainable manufacturing. Moreover, the analyses mainly deal with strategic planning problems (Stindt et al, accepted, C3; Nuss et al. 2016, C8). The specific problems of tactical and operational planning are named, especially in Nuss et al. (2015, C4), but are not sufficiently tackled within this doctoral thesis. Hence, a specific examination of planning problems with short-term and mid-term planning horizons seems to be compulsory.

Apart from these points, this work leaves one further issue for future research. The mathematical models presented in Stindt and Nuss (2014, C7) and Nuss et al. (2016, C8) are developed within a transdisciplinary research setting generating insights that are transferable to business practice and are beneficial for legislators. Nevertheless, the models do not explicitly account for environmental and social aspects. In line with the planning approach proposed by Stindt (submitted, C1), a multi-criteria model comprising the economic, the ecological and the social dimension may be developed as an extension of the existing model. A promising pathway for determination of environmental parameters may be the implementation of life cycle assessment methodologies. More challenging is the acquisition of social data. For this purpose, evolving method like social life cycle assessments or social footprints may be evaluated concerning their applicability.

Concluding, this doctoral thesis refines the capabilities on sustainability-related decision-making in corporate and academic contexts. In eight scientific publications qualitative as well as quantitative decision-support tools applicable to strategic problems of sustainable supply chain management in general and closed-loop supply chain management in particular are proposed. These tools can be used by practitioners to amend existing decision-support models in order to suffice the requirements induced by the sustainability paradigm. From an academic perspective, this work structures the research field and proposes avenues for extending theoretical knowledge about sustainability within supply chains and for further advancements of operations research models incorporating economic, ecological and social
considerations. In this way, this work presents gradual steps within the pursuit of sustainable development, one of the major challenges mankind is contemorarily encountering.
General References


