1 Introduction

The striving for sustainable development is undoubtedly one of the great challenges of the 21st century. In the past, mankind has wastefully used depletable natural resources and polluted the environment while frequently disregarding social aspects. Besides numerous environmental strains and social imbalances, this behavior also undermines the basis for future economic development. Against the background of this three-faceted problem, the popular concept of the 'triple bottom line' introduced by Elkington (1998) proposes sustainability as balancing economic, environmental, and social aspects. At a general level, the overall aim of sustainable development can be best expressed by "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987).

In a business context, companies are increasingly forced to broaden their scope by incorporating environmental and social aspects into their decision-making processes to remain competitive and prospering. In fact, research indicates that addressing aspects of sustainability is not only beneficial for a company's long-term performance (Eccles *et al.*, 2014), but even for its long-term existence (Porter and Kramer, 2006). In light of this, it is essential to bring the "notion[s] of sustainability [...] into the boardrooms of companies" (Schaltegger and Burritt, 2005, p. 187). These considerations lead to the guiding business principle of corporate sustainability, defined "as the successful market-oriented realization and integration of ecological, social and economic challenges to a company" (Schaltegger *et al.*, 2013, p. 220). However, the task to incorporate sustainability aspects into corporate decision-making is challenging and complex (Azapagic, 2003). To surmount these challenges, academia is expected to take a leading role in developing approaches that put practitioners in a position to fulfill the requirements of corporate sustainability.

The objective of the present doctoral dissertation is to reveal ways to implement and enhance corporate sustainability. This is done by means of integrating selected methods and concepts, namely the concepts of transdisciplinarity, reverse logistics, and green information systems as well as methods and tools from the discipline of operations research. All of them have already proven their value individually in contributing to the overarching goal of enhancing corporate sustainability. On the downside, they also show specific shortcomings if applied in isolation. An integration of concepts and methods is supposed to overcome some of these shortcomings and, thus, is even more promising in facilitating corporate sustainability. In light of that, a total of seven contributions are presented within this doctoral dissertation, all of which investigate particular parts of the outlined research domain. All articles are published in internationally renowned scientific journals or conference proceedings. The selected methods and concepts are embedded in an overall research framework, and so are the contributions, in order to illustrate how they are interwoven to create mutual benefits and ultimately enhance corporate sustainability.

The general structure of the present doctoral dissertation is as follows: The design of the proposed research framework, an introduction to the selected methods and concepts, and the classification of the scientific contributions are subject of the remainder of this section 1. Sections 2 to 8 present the actual scientific contributions. Finally, section 9 draws a conclusion and points out promising fields for further research.

1.1 Overall Research Framework

The starting point of research on corporate sustainability is generally the real-world challenge of sustainable development and the related urgency for managers to properly consider sustainability aspects in their decision-making processes. The resulting target of corporate sustainability is essential for companies for a variety of reasons. They range from legal compliance, maintaining competitiveness, increasing shareholder value to corporate reputation and related brand value (Schaltegger and Burritt, 2005).

In management science and business practice a well-acknowledged approach to induce organizational change in order to achieve a specific target focuses on the interplay of the **dimensions** 'people', 'process', and 'technology'. The proper alignment and management of these dimensions help corporate decision-makers to "increase the efficiency and effectiveness in meeting [...] goals" (Williams and Leask, 2011, p. 2). In the present doctoral dissertation this approach is adopted and applied to the domain of corporate sustainability. A simultaneous consideration of all three dimensions is necessary to achieve this overarching goal. Thus, an interconnection of dimensions via common methods is proposed.

The ultimate goal of the triad of 'people', 'process', and 'technology', which are complemented by cross-dimensional methods, is advancing corporate sustainability. Figure 1 illustrates the overall research framework with its three-pillar structure and the interconnecting methods.

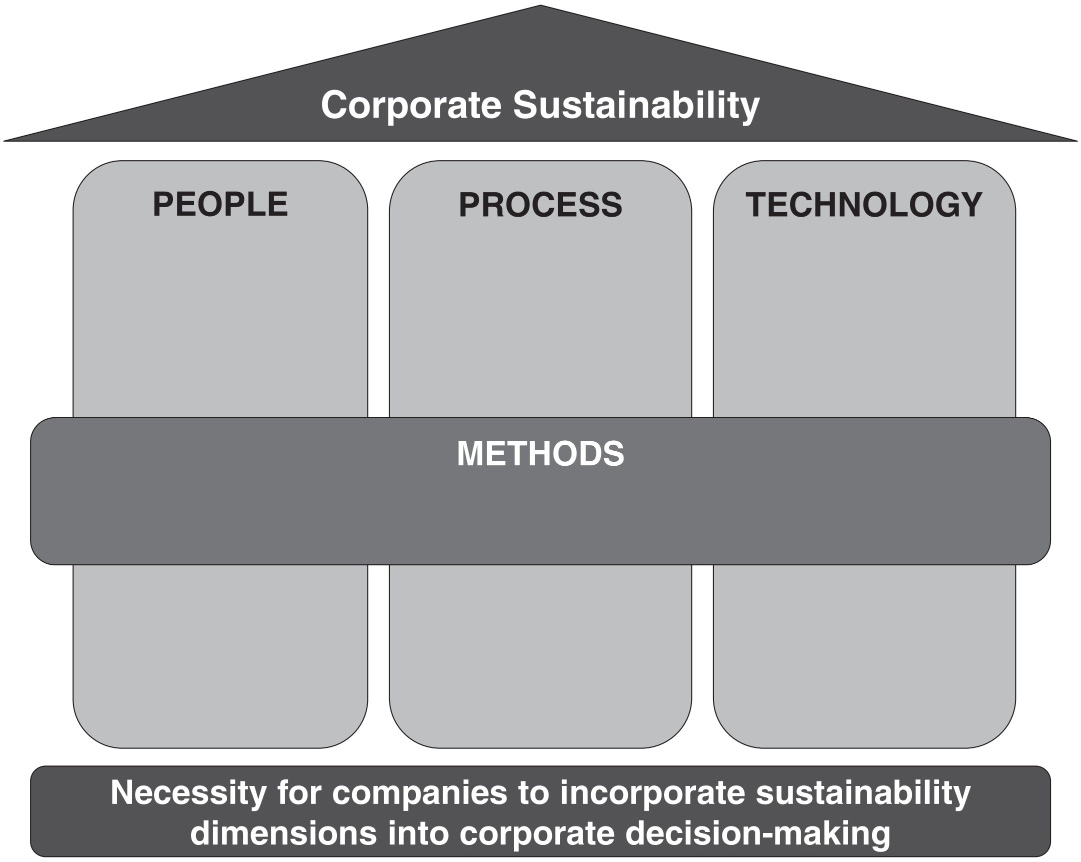

Figure 1: Overall research framework

The **'people'** dimension encompasses the effective sustainability-oriented alignment of human resources and their efficient interplay in general. The **'process'** dimension incorporates specific activities, programs, and measures whose implementation potentially moves organizations forward on their path to corporate sustainability. The **'technology'** dimension aims at the use of technology and the development of technical innovations to support the overall objective. Each of these rather abstract dimensions can be addressed using specific **concepts** to enhance corporate sustainability, of which previous research has identified a broad range. Some of them are introduced in the following to give a brief outline (for more comprehensive overviews refer to Azapagic, 2003 and Lacy *et al.*, 2009).

Within the 'people' dimension specific concepts like human resources management that explicitly addresses issues of sustainability (Dao *et al.*, 2011) as well as the design of discipline-crossing collaboration and coordination by means of interdisciplinarity and transdisciplinarity (Schaltegger *et al.*, 2013) are dominant. The 'process' dimension embodies specific concepts such as energy-efficient scheduling (Denz, 2015; Gahm *et al.*, 2015), waste management and reduction (Laner and Rechberger, 2008), and reverse logistics (Presley *et al.*, 2007), amongst others. Within the 'technology' dimension, specific concepts that play a key role in driving businesses towards sustainability comprise technical innovations towards more efficient manufacturing equipment (Jovane *et al.*, 2008) as well as information technology and tailored information systems (Elliot, 2011; Melville, 2010).

Within the present doctoral dissertation, a single concept for each dimension is selected and integrated with others to leverage corporate sustainability:

'People' dimension:	**Transdisciplinarity**
'Processes' dimension:	**Reverse logistics**
'Technology' dimension:	**Green information systems**

Each of these concepts is intended to improve corporate sustainability if adequately implemented (de Brito and Dekker, 2004; Melville, 2010; Schaltegger *et al.*, 2013). An integration of these concepts could be mutually beneficial and, thus, be an even more promising lever to achieve this goal. Yet, up to now, approaches that perform their systematic integration to generate synergies are scarce, to the best of the author's knowledge.

To simultaneously consider all three dimensions, which is necessary in order to address corporate sustainability in a holistic manner (Dao *et al.*, 2011), the present doctoral dissertation focuses on methods of operations research:

Methods:	**Operations research**

This discipline provides a toolset that serves as a common instrument within each of the selected concepts. Other methods for enhancing corporate sustainability, such as life-cycle analysis and management (Azapagic, 2003), are not discussed within the present doctoral dissertation.

The selected concepts and methods are described in greater detail in the following.

1.2 People – The Concept of Transdisciplinarity

Establishing sustainability within a corporate context is a complex challenge that necessitates the systematic integration of manifold expertise from diverse disciplines such as management science, engineering and natural sciences (Sahamie *et al.*, 2013, C1). In addition, close collaboration and cooperation between academia and practice is mandatory to guarantee tailored approaches that address and solve real-world problems. This especially requires frameworks which structure this collaboration (Stindt *et al.*, 2016, C6).

Taking a look into different forms of collaboration among disciplines, literature basically distinguishes between multi-, pluri-, cross-, inter- and transdisciplinarity (Jantsch, 1972). A differentiation between these types generally occurs on the level of cooperation (Jahn *et al.*, 2012). In contrast to less integrative forms, interdisciplinarity takes a perspective that bridges isolated, traditional disciplinary boundaries and urges for cooperation that is coordinated from a higher level concept (Max-Neef, 2005). Interdisciplinarity in turn is a prerequisite for transdisciplinarity, which even extends purely interdisciplinary approaches by the inclusion of stakeholders from practice (Jahn *et al.*, 2012). In this way, transdisciplinarity "by definition takes real world phenomena as its starting point" (Schaltegger, 2013, p. 223) and "is the result of a coordination between all hierarchical levels" (Max-Neef, 2005, p. 7). Thus, the paradigm of transdisciplinarity fits best to surmount the particular challenge of sustainability (Schneidewind, 2010) and is predetermined to enhance corporate sustainability as well.

In the context of the developed research framework, transdisciplinary research itself can also serve as a foundation for identifying advanced concepts and levers within the three dimensions such as institutional transformations, innovational processes, and technology developments (Hirsch Hadorn *et al.*, 2006). In addition, transdisciplinary approaches are even able to create more holistic views on already existing concepts. For instance, this is true for the processes of product recovery and reverse logistics (Stindt *et al.*, 2016, C2) and green information systems (Hovorka and Corbett, 2012). In general, transdisciplinary approaches are able to contribute to all three aspects of corporate sustainability.

1.3 Process – The Concept of Reverse Logistics

It is widely acknowledged that "reverse logistics can be seen as part of sustainable development" (de Brito and Dekker, 2004, p. 6). In fact, this is also true for the resulting structures of closed-loop supply chains, since they are "are assumed to be sustainable supply chains almost by definition" (Quariguasi Frota Neto *et al.*, 2010, p. 4463). Sustainable supply chains are in turn a major lever for companies to especially incorporate aspects of environmental sustainability into their business (Wu and Pagell, 2011).

The term 'reverse logistics' basically describes all activities that are mandatory to return, recover, and remarket/reintegrate used products. A more detailed definition of reverse logistics is provided by Rogers and Tibben-Lembke (1998, p. 2), who state that reverse logistics encompasses "[t]he process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". This definition has been extended in recent years by the inclusion of activities that are necessary to remarket the recovered products (Rogers *et al.*, 2012).

The implementation of the process of reverse logistics in practice results in reverse supply chains, which complement the 'traditional', forward flow of goods with an opposite flow of used products from consumers via recovery facilities to either secondary markets, other points of reintegration, or a proper disposal. The combination of forward supply chains and reverse supply chains is commonly referred to as closed-loop supply chains (de Brito and Dekker, 2004). The management of such value chains, which relate to product recovery, shows specific planning problems, additional uncertainties, and a high complexity (Nuss *et al.*, 2015, C3).

Reverse logistics, reverse supply chains, and closed-loop supply chains are able to contribute to all three aspects of sustainability, as they produce a profit in many cases (Stindt and Nuss, 2014, C4), reduce environmental burdens (Quariguasi Frota Neto *et al.*, 2010), and may be able to generate social benefits (Sarkis *et al.*, 2010). If no sufficient incentives are provided, legislation is often enacted to force companies to implement reverse logistics. The European Directive on Waste Electrical and Electronic Equipment (WEEE-Directive) represents such a case (Nuss *et al.*, 2016, C5).

1.4 Technology – The Concept of Green Information Systems

Information technology and information systems are seen as crucial enabler to support companies in the challenge of realizing corporate sustainability (Elliot, 2011; Teuteberg and Marx Gómez, 2010; Watson *et al.*, 2010), which are both labelled 'green' in this case. Green information technology mainly focuses on reducing energy consumption of equipment. Contrastingly, the understanding of green information systems "refers to the design and implementation of information systems that contribute to sustainable business processes" (Watson *et al.*, 2008, p. 16). They are especially seen as an enabler to improve environmental sustainability performance (Melville, 2010), which is an important part of corporate sustainability.

One way for companies to address environmental sustainability by means of green information systems is the design, implementation, and operation of environmental management information systems. These are defined as "organizational-technical systems for systematically obtaining, processing, and making available relevant environmental information available in companies" (El-Gayar and Fritz, 2006, p. 756). Complementing the information provided by these systems with a decision-support layer results in decision support systems, which are specifically designed for sustainable decision-making (Hersh, 1999). Such holistic system architectures have already proven their value in practice, for example when applied to the process of reverse logistics (Stindt *et al.*, 2014). Another example focuses on the energy sector, where such systems are able to systematically share both economic and environmental information with all entities involved. This approach leads to the incorporation of "sustainability aspects into both corporate and consumer decision-making" (Nuss, 2015, p.1, C7) which ultimately enhances (corporate) sustainability.

The role of information technology and information systems in contributing to economic and environmental aspects of sustainability is gaining increasing attention in academia and consitutes a nascent research field (Melville, 2010; Watson *et al.*, 2010). However, social aspects seem to be somewhat disintegrated from this development.

1.5 Methods – The Toolset of Operations Research

The discipline of operations research comprises scientific approaches that basically aim to develop and apply quantitative models and methods to problem-solving. In this way, operations research ultimately provides decision support for executive managers (Wagner, 1969). The starting point to apply methods of operations research is usually an unstructured real-world problem, which is subsequently translated into a mathematical model. Specific techniques determine a solution for this model, which is again retranslated to practice addressing the real-world problem (Werners, 2013). Within this generic problem-solving process, used methods comprise optimization and mathematical programming, simulation, and statistical techniques (Altay and Green, 2006).

Methods of operations research represent an appropriate cross-dimensional toolset for the dimensions 'people', 'process', and 'technology' in general. It also turns out to be a good fit as cross-conceptual toolset for the concepts of transdisciplinarity, reverse logistics, and green information systems, for the following reasons:

Transdisciplinarity is able to play a key role in sustainability-related operations research. Quantitative approaches that address issues of sustainability naturally require a holistic model formulation, which necessitates the convergence of both knowledge and data from various disciplines (Sahamie *et al.*, 2013, C1). Transdisciplinary approaches are highly beneficial to ensure an adequate translation of the real-world problem into a representative mathematical model. Information obtained from all relevant disciplines forms a solid data base for the model. This is especially true for the process of reverse logistics and the field of sustainable energy systems (Stindt *et al.*, 2016, C6).

In general, operations research is proposed as a contributing discipline in making logistics more sustainable (Dekker *et al.*, 2012). Also in the subfield of reverse logistics, planning problems are commonly modeled and solved using methods of operations research to ultimately provide decision support to practitioners (Fleischmann *et al.*, 1997; Nuss *et al.*, 2016, C5; Stindt and Nuss, 2014, C4). Related models have to incorporate specific characteristics of reverse logistics and related closed-loop supply chains. In addition, such operations are subject to additional uncertainties, which increase overall complexity (Nuss *et al.*, 2015, C3). All of this must be adequately considered to ensure appropriate solutions at the interface of reverse logistics and operations research.

Methods of operations research are a key element in decision support systems (Hersh, 1999), also in the context of green information systems (Nuss, 2015, C7). For this purpose, "quantitative models may be embedded in [...] systems to automate and optimize decisions" (Dekker *et al.*, 2004). Dedicated decision support layers within specific system architectures are proposed to perform that task. In total, such green information systems gather, consolidate, process, and distribute data from various sources to assist corporate decision-makers. To particularly respond to challenges of sustainability, processed data usually comprise economic, environmental, and social information to balance these dimensions in objective functions and to compute sustainability indicators (Stindt *et al.*, 2014).

1.6 Putting the Contributions into the Context of the Research Framework

This subsection puts the scientific contributions into the context of the research framework. Depending on its research focus, each article is located at specific interfaces of the concepts of transdisciplinarity, reverse logistics, green information systems, and methods of operations research. Following this, the articles are classified into the overall research framework (see Figure 2). In this way, it is illustrated how they combine certain concepts and methods to enhance corporate sustainability. An outline of each article is given in the following.

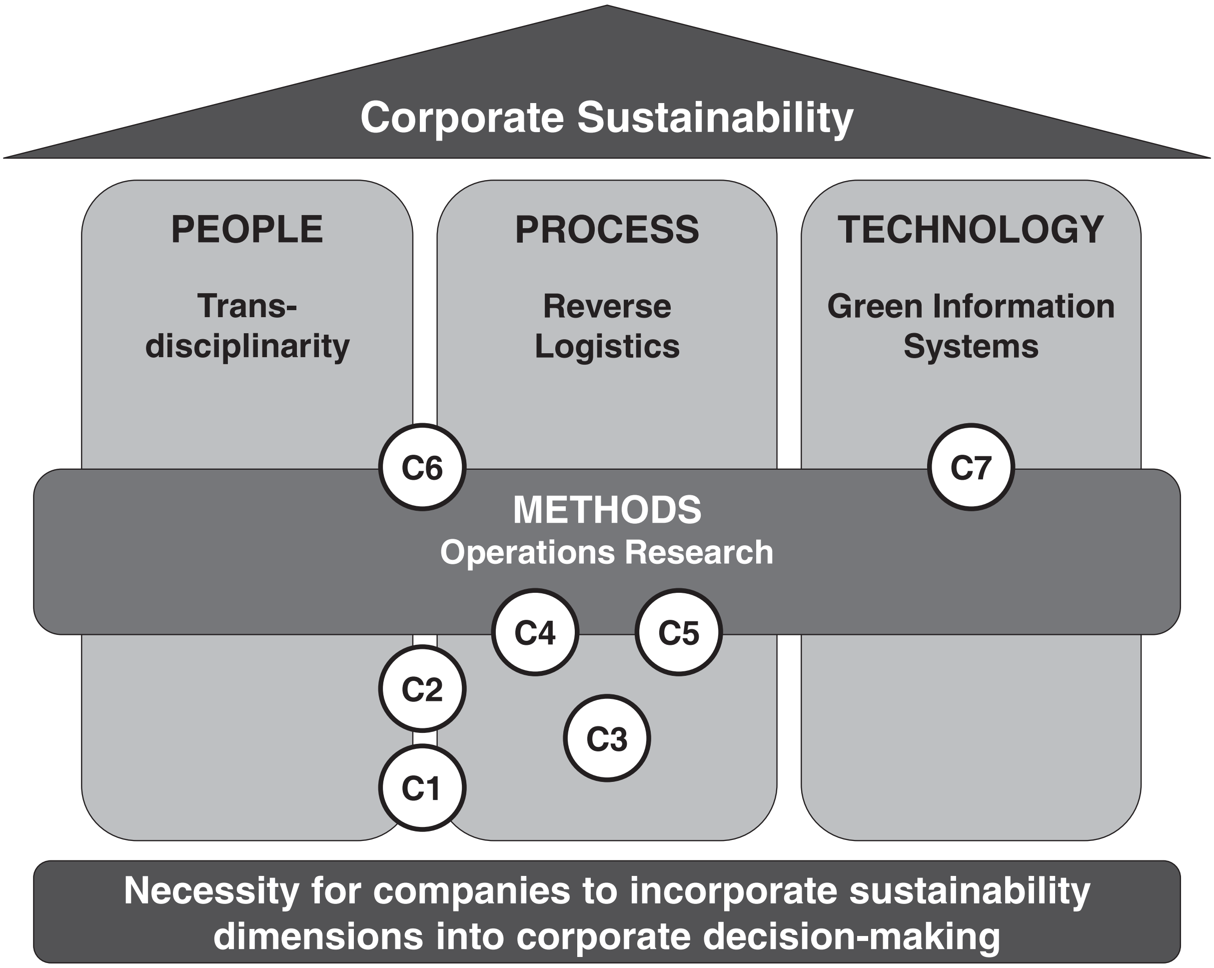

Figure 2: Contributions in the context of the overall research framework

The necessity and major benefits of transdisciplinary collaboration in implementing reverse logistics and related closed-loop supply chains are identified in **Sahamie *et al.* (2013, C1)**. It is argued that a major prerequisite for the successful realization lies in the integration of expertise from the disciplines of natural sciences, engineering, and management science as well as from practical stakeholders. Three layers of collaboration among these disciplines are identified. This helps to structure the field of collaboration, to identify interfaces between contributing disciplines, and to ultimately implement holistic reverse logistics and closed-loop supply chains.

Based on these insights, **Stindt *et al.* (2016, C2)** make use of an international, interdisciplinary research team that closely collaborates with practitioners in various industry projects. Within this transdisciplinary setting a model that assesses the attractiveness of reverse markets from the perspective of an original equipment manufacturer is developed. For this purpose, factors that impact key characteristics of such markets are identified. They are subsequently consolidated to five forces that constitute reverse markets: Access to recoverable products, Threat of IRCs' market entry, Rivalry for recoverable products, Adverse effects on core business, and Remarketing opportunities. To demonstrate the value of the proposed model, it is applied to assess the attractiveness of two reverse markets, namely white goods in the United Kingdom and paper and pulp in Germany. Overall, the model represents a valuable and intuitive instrument for practitioners that plan to engage in reverse logistics.

Besides a market perspective, companies must also take their own capabilities into account to finally decide upon engaging in product recovery. In order to implement efficient reverse logistics a proper planning of corresponding tasks must be ensured. The planning tasks that have to be considered in resulting reverse supply chains and related closed-loop supply chains differ from those in solely forward-oriented supply chains. **Nuss *et al.* (2015, C3)** systematically identify all planning problems in this context by conducting an extensive literature review. Subsequently, the planning problems are categorized along the dimensions of process steps in reverse supply chains (product returns management, reprocessing operations, and remarketing/reintegration) and planning horizons (strategic, tactical, and operational). The result is called the Reverse Supply Chain Planning Matrix, which presents all planning problems in a structured and clear way. It serves as an intuitive and valuable tool for both academia and corporate decision-makers to consider all important planning aspects in reverse supply chains.

On a strategic level, a major identified planning task in reverse supply chains is reverse network design. **Stindt and Nuss (2014, C4)** investigate this challenge from the perspective of an original equipment manufacturer of electrical and electronic equipment. The implementation of a European-wide recovery network is modeled and solved using mathematical modeling and subsequent methods of optimization, namely mixed-integer linear programming. Within a scenario analysis, it is shown that such a network is able to make a profit if economies of scale are exploited. **Nuss *et al.* (2016, C5)** investigate a similar domain, although the focus of this article mainly is on the incorporation of legislative framework conditions. This encompasses the European Directive on Waste Electrical and Electronic Equipment (WEEE-Directive), but also other legal limitations such as the Regulation on Shipments of Waste. As a result the authors derive several recommendations for action that help corporate and political decision-makers to increase the environmental efficiency of such circular networks.

An integration of transdisciplinarity, reverse logistics, and operations research by means of a framework, which is called Transdisciplinary Modeling Framework, is the subject of **Stindt *et al.* (2016, C6)**. Transdisciplinarity is proposed to tackle major shortcomings of operations research in the context of sustainability such as an increasing disintegration from practice and inadequate model formulations. The developed Transdisciplinary Modeling Framework represents an instrument that structures transdisciplinary collaboration, fosters a common problem understanding, and improves verbal modeling, which is a crucial step prior to actual mathematical modeling. Finally, the application of the framework to two domains dealing with reverse logistics and sustainable energy systems gives first evidence about its value. The model formulations turn out to be more holistic and the data quality has significantly improved through the convergence of knowledge from both academia and practice.

Finally, **Nuss (2015, C7)** performs an integration of green information systems and operations research to foster sustainable decision-making in the energy sector by means of a specifically tailored environmental management information system. The application of the well-acknowledged methodology of design science leads to the creation of an artifact, which is embedded into the Energy Informatics Framework introduced by Watson *et al.* (2010). Consequently, the proposed system works at the interface of energy suppliers and consumers. It is based on previous works and reference architectures in similar domains (Stindt, 2014; Stindt *et al.*, 2014; Teuteberg and Marx Gómez, 2010). The developed system gathers data from both suppliers and consumers of electrical energy. These data are consolidated and processed using methods of operations research. The subsequent distribution of economic and environmental information to all actors in the energy sector fosters environmental-oriented decision-making. This results in an improved balancing of power supply and demand, which in turn contributes to overall sustainability. First evidence about the value of the developed system is given by means of a scenario-based demonstration case.

2

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

Contribution C1

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

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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.

Keywords: sustainability; closed-loop supply chains; interdisciplinarity; transdisciplinarity; recovery; reverse logistics