An Environmental Management Information System for Closing Knowledge Gaps in Corporate Sustainable Decision-Making

Completed Research Paper

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Abstract

Decision-making on issues of corporate sustainability is an emerging topic in both academia and business practice. Nevertheless, contemporary environmental decision-support models show significant shortcomings that call into question the usefulness and applicability of the results of such decision-making. To improve the quality of corporate sustainable decision-making, we apply a design-science approach to develop an environmental management information system. This design-artifact is developed based on technical feasibility and business requirements that are elaborated in collaboration with practitioners. We identify domain-specific information demands and source systems. Appropriate systems and their interrelations are also described. Overall, both academia and business practice would benefit from the developed artifact, which is tailored for issues of corporate sustainability, as it enables holistic decision-making based on sound data sourcing, warehousing, and appropriate decision-support applications. Finally, we demonstrate the applicability of the artifact within a real-world case study concerning product take-back and reprocessing of used IT equipment.

Keywords: Green IS, Sustainable Supply Chain Management, Design Science, Transdisciplinarity, Operations Research

Introduction

Legal requirements, environmental burdens stemming from value generation, and increased customer awareness paired with societal pressures have motivated businesses to reconsider traditional corporate decision-making. To properly address these challenges and to support the overall goal of pushing economies toward patterns of sustainability, great attention is devoted to the concept of sustainable supply chain management (SSCM). SSCM promotes "creating goods by using processes and systems that are non-polluting, that conserve energy and natural resources in economically viable, safe and healthy ways" (Glavic and Lukman 2007, p. 1883). To enable corporate decision-making that incorporates sustainability, traditional economic metrics have to be supplemented with ecological and social criteria. Although there is a common understanding of the importance of such multidimensional decision-making, prevailing corporate decision-making processes, which mostly rely on quantitative modelling techniques, widely neglect non-economic perspectives. This shortcoming is attributable to the lack of data on the ecological and social effects of production. Prevailing business information systems (IS), e.g. SAP ERP, do not provide such information, which is usually heterogeneous and poly-structured, emanating from manifold different sources.

Hence, it is mandatory to underpin sustainability-oriented decision-making with appropriate IS, which are fundamental to transform industrial organizations into sustainable players (Stiel and Teuteberg 2013; Watson et al. 2012). Observations from the literature and practice highlight that the "synergy between environmental management and information systems has not yet been realized to the extent which is possible" (El-Gayar and Fritz 2006, p. 775). Hence, this research aims to enhance "IS-enabled organizational practices and processes that improve environmental and economic performance" (Melville 2010, p. 2). In doing so, we consider an environmental management information system (EMIS) to be most appropriate to address the challenges of corporate SSCM. Such a system acts as an enabler for structured and goal-oriented data gathering, administration, integration, and processing. In this way, the quality of managerial decision support systems (DSS) for corporate sustainability issues will improve. Overall, we aim to answer the following guiding research question:

How can an EMIS be conceptualized and designed to eventually improve SSCM decision-making?

We adopt a design-science approach, where the EMIS represents the research artifact (Hevner et al. 2004). More granularly, our research is directed by subordinate research questions (inspired by El-Gayar and Fritz 2006):

Q1: What information is required to advance both economic and environmental sustainability in corporate decision-making?

Q2: From which sources can this information be obtained?

Q3: Which technological choices are appropriate to process this information and how should it be presented to support corporate decision-makers?

Q4: What effect does such an IS have on the acceptance of sustainability-oriented corporate decisions?

These subordinate research questions relate to central components of design theory as proposed by Markus et al. (2002) and Walls et al. (1992): The *set of user requirements* is identified by answering Q1 in collaboration with corporate stakeholders. Q2 and Q3 aim to define the *set of system features* that appropriately satisfy the stated requirements. The *test of practice* is subject to Q4, where the effectiveness of the system regarding the overall research question within a real-world application is evaluated. The design-science research methodology presented by Peffers et al. (2007) is implemented as an *effective way of guiding the process of development* with consideration of the design-science principles adopted from Hevner et al. (2004).

The present research enables academia and corporate executives to improve decision-making in the context of complex sustainability challenges. It contributes to the IS community by identifying relevant components of SSCM research and by providing a promising approach to tackle central SSCM problems. From a corporate perspective, the EMIS supports corporate executives in proactively shaping a sustainability-oriented business strategy. To ensure the social acceptance of the proposed IS within companies, we strongly cooperate with corporate stakeholders who are responsible for supply-chain management, environmental management, and reverse logistics throughout the requirements analysis and conduct frequent feedback loops during the project.

The remainder of the article is structured as follows: First, we analyze the status quo of IS aimed at sustainability issues in both research and corporate decision-making. In this way, we reveal the knowledge gap that the artifact addresses. Second, we describe the actual implementation of the structured research methodology that ensures a rigorous research process. Third, we introduce the resulting EMIS by describing each layer of the architecture. Subsequently, we demonstrate the usefulness of the developed EMIS by applying it to an industry case that arises from the business field of closed-loop supply chain (CLSC) management. This application is followed by a discussion of the artifact that highlights its benefits for both academics and practitioners.

IS as an Enabler for SSCM

Sustainable Supply Chain Management

The integration of sustainability into a corporate context refers to managerial behavior that respects the 'triple bottom line' (Elkington 1999), namely, the integration of economic, environmental, and social aspects into a company's objective system. The present research concentrates on economic and environmental aspects of sustainability, as these dimensions regularly dominate the social dimension within the field of SSCM research. In this sense, SSCM incorporates wastes, emissions, and product lifecycles into corporate goal systems (Loeser 2013). SSCM commonly comprises decision problems, such as energy-oriented production scheduling (Yildirim and Mouzan 2012), emission and waste reduction (Tan 2007), utilization of raw materials (Majozi and Gouws 2009), and reverse logistics and CLSC management (Rubio et al. 2008). Mathematical modeling is predominantly used as a research methodology to address such problems (Palvia et al. 2006).

The availability of valid data is a prerequisite for sound mathematical decision support. Relevant data range from economic information to environmental factors. Data on the latter are difficult to compile, suffer from "a gap related to understanding the measurement of environmental impacts" (Hovorka and Corbett 2012, p.3), and thus "are often over-simplified or are even neglected" (Schultmann et al. 2004, p.737). Indeed, corporate IS widely ignore the environmental dimension. Existing DSS neither provide a sufficient breadth of data nor properly integrate them (Hu and Zeng 2010). This lack of such DSS discourages today's decision makers from properly adopting sustainability strategies (Ahmed and Sundaram 2007; Loos et al. 2011). These literature-based findings are verified by insights that we generated in collaboration with industry partners. Through this collaboration, we could observe that rudimentary knowledge on relevant information, processes, and interrelationships hinders amplified corporate involvement – meaning that corporate involvement exceeds legislative requirements – in sustainable operations.

In summary, SSCM-related decision support suffers from shortcomings related to groundwork in the field of holistic and valid data collection, data processing, and data provision, which may be tackled through appropriate IS.

IS and Environmental Decision-making

In general, IS are meant to support decision-making processes and to empower executives to gain timely access to relevant information. With the help of IS, informational knowledge is created, which represents a critical asset in traditional supply chain management (SCM) (Pui Yuk et al. 2007). Such knowledge is even more crucial when problems are more complex owing to the addition of sustainability aspects to the traditional perspective. Therefore, IS are considered crucial within the transformation to sustainability (Chen et al. 2008; Malhotra et al. 2013). Overall, this challenge requires for a new class of IS, which renders this area one of the growing and prioritized topics in IS research (Watson et al. 2012).

ERP systems represent the most common IS in business practice. Hence, we start by analyzing this class of IS with respect to their support in environmentally oriented decision-making. In general, ERP systems store master records and transactional data and provide data analytics. These systems predominantly focus on economic aspects of business operations. Crucial information regarding production and supply chain processes is summarized in the objects 'material' and 'work schedule'. Figure 1 depicts the standard views concerning these objects within a SAP ERP 6.0 system, supplemented by the views 'emission' and 'toxicity' (marked in grey). The latter two are prerequisite for sustainability assessment but are not yet part of ERP systems. Hence, we can subsume that traditional ERP systems certainly contribute to the economic dimension of sustainability but that they fall short addressing the environmental dimension.

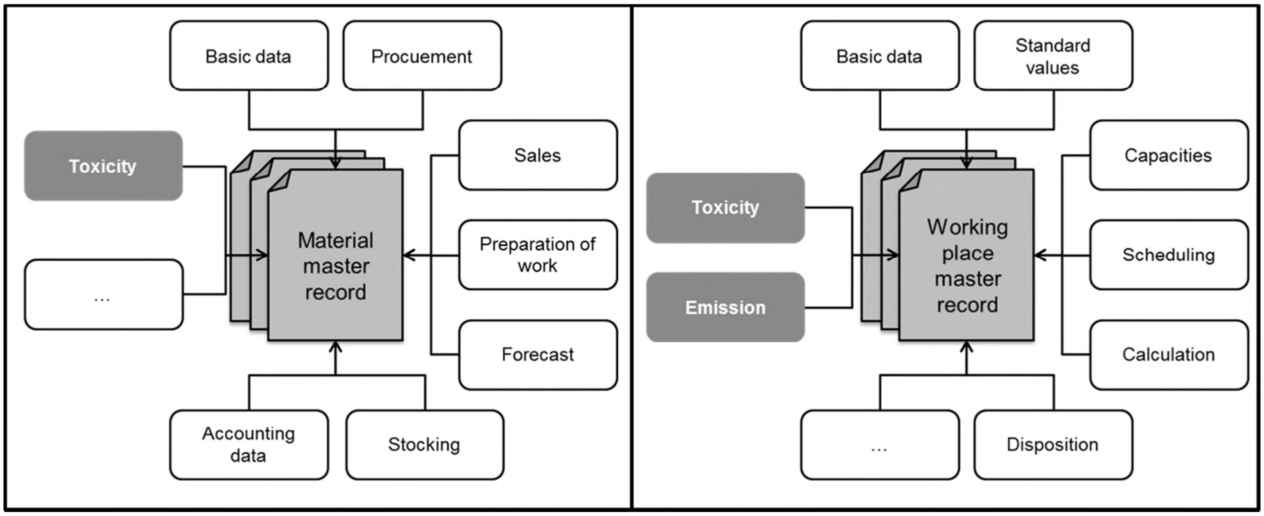

Figure 1. Extended master data records concerning SSCM analysis inspired by SAP (2014)

In summary, standard ERP systems do not sufficiently tackle the problem of SSCM. Consequently, we broaden the scope to IS that explicitly incorporate sustainability issues. Within the relatively young research field of sustainability-oriented IS, a number of various terms and concepts exist (Loeser 2013). Common terms are Green IT, Green IS, and EMIS (Watson et al. 2010). The overarching goal of *Green IT* is to create a more resource-efficient IT infrastructure by reducing both energy consumption and e-waste (Loos et al. 2011). In contrast, *Green IS* are not meant to contribute to sustainability directly. They rather provide transparency and are a foundation for decision-making that supports the transition to eco-friendly business practices (Loeser 2013). As our developed artifact acts as an enabler for altering business practice to sustainability, this research is positioned in the field of Green IS.

Although emphasis on corporate environmental performance is growing, "much of the IS and management literature ignores the natural environment" (Watson et al. 2012, p. 9). Indeed, the number of publications on Green IS is limited (Simmonds and Bhattacherjee 2012). Furthermore, this research field is fragmented, covering diverse topics, such as IS for compliance and reporting purposes (Loos et al. 2011; Simmonds and Bhattacherjee 2012), environmental balance scorecards (Wittstruck and Teuteberg 2011), and LCA-based systems for eco-design (Donnelly et al. 2006). Ahmed and Sundaram (2007) present a framework for integrated corporate sustainability modelling and reporting. They discuss the topic of data capturing but neglect to integrate it into their framework.

EMIS can be considered to be an application of Green IS. Such systems are defined as "organizational-technical systems for systematically obtaining, processing, and making relevant environmental information available in companies" (Page and Rautenstrauch 2002, p. 5). EMIS serve the purpose of integrating traditional economic metrics with more complex environmental information, and they are explicitly designed to integrate heterogeneous and decentralized systems. We understand EMIS in a broad sense to also include environmental DSS (Page and Rautenstrauch 2002). Hence, EMIS constitute a tool for data administration, data processing, modelling, simulation, and optimization with the ultimate goal of providing corporate decision support. Overall, EMIS as IS are a crucial enabler in the pursuit of sustainability (Loeser et al. 2013) and "a potential solution to environmental issues" (Loos et al. 2011). Unfortunately, contemporary systems "are currently not applying strategic information and decision support" (Graeuler et al. 2013, p. 98).

The proposed EMIS mainly contributes to the knowledge base by tackling the following challenges: First, we design an artifact, as design-oriented research approaches are widely neglected but are needed in the context of sustainability (Malhotra et al. 2013). Second, contemporary EMIS focus on operational issues concerning reactive compliance management tasks and do not sufficiently address requirements of strategic sustainability assessment (Graeuler et al. 2013). Indeed, EMIS enabling proactive, long-term planning are lacking, although a strong need for such systems is identified (Simmonds and Bhattacherjee 2012). The proposed EMIS explicitly enhances decision makers' capabilities in addressing strategic issues. Such "IS for environmental sustainability allow companies to proactively transform value chain activities to benefit both economically and environmentally" (Malhotra et al. 2013, p. 1265). Third, corporate decision-makers lack an in-depth understanding of relevant data. Accordingly, recent modelling approaches emanating from academia mostly concentrate on aspects of modelling instead of fundamental data knowledge, which diminishes the transferability of the results (Ahmed and Sundaram 2007). To tackle this issue, the presented approach allows for both reflective disclosure, which describes the monitoring and analysis of current practice, and information democratization, which is defined as the access and usage of sustainability-related information from different source systems (Seidel et al. 2013).

Research Methodology

As the 'design process kernel theory' (Walls et al. 1992; Gleasure et al. 2012), we adopt the model developed by Bensch (2012) (Figure 2). This model integrates the 'design-science research methodology process model' (Peffers et al. 2007) with guidelines for design-science (Hevner et al. 2004). These guidelines are set as design principles for the present research. In this way, the artifact is systematically developed based on an incremental approach that switches between construction phases and evaluation phases. As this research originates from problems that are observed in both academia and business practice, we select a problem-centered research initiation (Peffers et al. 2007). In the following, we describe the implementation of each subsequent step within the research project.

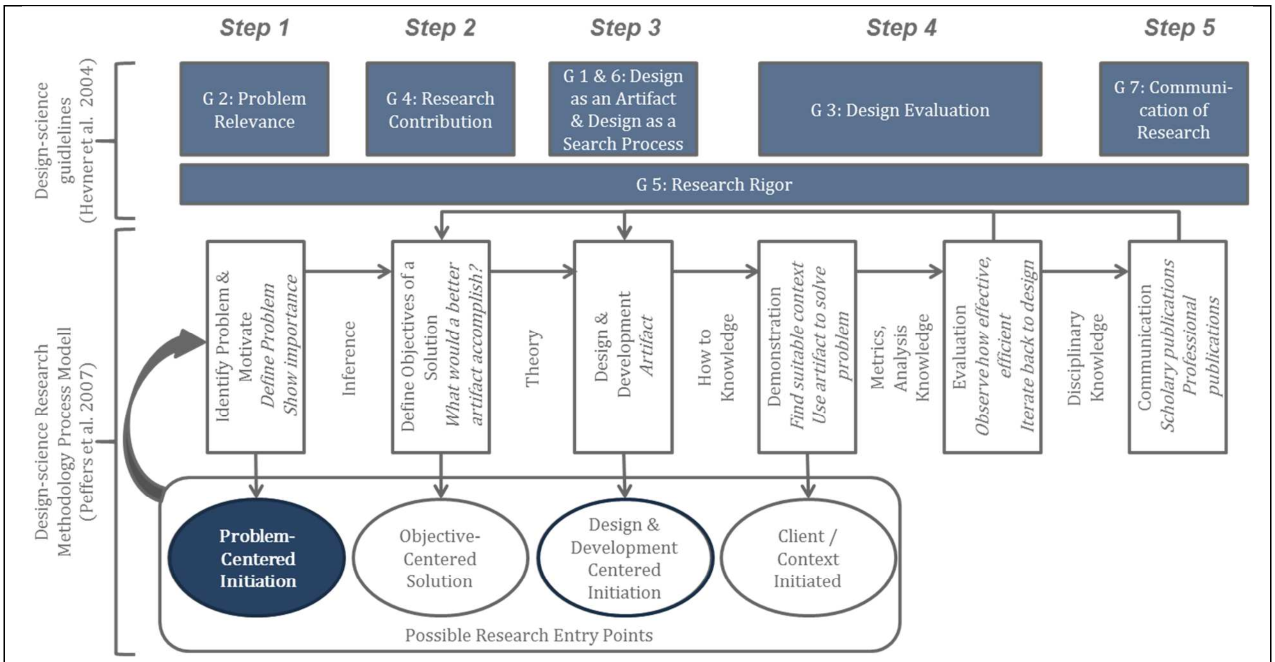

Figure 2. Applied design-science research model, based on Bensch (2012), Hevner et al. (2004), Peffers et al. (2007)

Step 1 – Identify Problem & Motivate: The guideline of 'problem relevance' recommends developing "technology-based solutions to important and relevant business problems" (Hevner et al. 2004). As described above, our research emanates from problems that we observe in both the literature and business practice (G2). Regarding business practice, we rely on expertise from projects with partners from the industries of plastics & polymer, paper & pulp, chemicals, and IT equipment. The research gaps are identified by conducting a structured literature review in line with vom Brocke et al. (2009). Subsequently, we match the academic issues with real-world problems.

Step 2 – Define objectives of a solution: In line with the research question delineated in the introduction, the artifact aims to tackle the described shortcomings of current decision support approaches in SSCM. We conduct the analysis of user requirements in close collaboration with relevant corporate decision-makers, who are responsible for supply-chain management, environmental management, and reverse logistics. This set of executives and departments stems from an analysis of corporate stakeholders that are involved into decision processes concerning the described decision problems in the context of SSCM. Overall, the EMIS improves the validity and transferability of SSCM-oriented mathematical models by improving both the quality and the availability of the underlying data. It contributes by bridging the discourse on EMIS with operations research and thus helps to improve future quantitative research on SSCM and practical applications of sustainable strategies (G4).

Step 3 – Design and development: The central epistemic object is the system model for an SSCM-oriented EMIS, which represents the artifact (G1). An artifact's design and development may be based on a 'design product kernel theory'. For this purpose, we rely on both the IS and the environmental management knowledge bases supplemented by industrial theory-in-use (Fischer et al. 2010; Gleasure et al. 2012) (G6). The conceptual design of the artifact is based on acknowledged reference architectures and methodologies that are established within IS research. We devote particular attention to the applicability of the resulting system for the purpose of corporate decision-making. In this sense, we build on the design properties for user-friendly corporate EMIS proposed by Graeuler et al. (2013). Moreover, we maintained frequent exchange with industry partners in user meetings to iteratively design the system in order to guarantee both problem appropriateness and user acceptance.

Step 4 –Demonstration & Evaluation: This step tests the developed artifact concerning its practical feasibility and its contribution to close the identified research gap. First, the evaluation in practice, carried out by the construction of a prototype as a pre-release version of an application system, demonstrates the general applicability of the system. The prototype is evaluated in its target environment using a hybrid evaluation process involving both observational field studies in academic-industry projects and experimental assessments based on existing academic optimization models (G3). The EMIS is constantly assessed with respect to its ability to improve parameter determination and the quality of the results in the models. In addition to the technical value of the system, we evaluate its social implications with a particular focus on the impact of the generated insights on decision-making processes and results. Within this article, the evaluation is exemplified in a real-world case study that was conducted in collaboration with both the product take-back and SCM department of a major OEM of IT equipment.

Step 5 – Communication: With this article, we communicate the results of the research to both the academic community and practitioners from a technical and a management point of view (G7). This "enables practitioners to take advantage of the benefits offered by the artifact and it enables researchers to build a cumulative knowledge base for further extension and evaluation" (Hevner et al. 2004, p. 90). For academics, we address the knowledge gap related to data uncertainties within SSCM. For practitioners, we identify both managerial-relevant decision criteria and sources where related information can be obtained. We ultimately propose an effective IS architecture for corporate sustainable decision-making. Based on the conceptual model, IT designers and implementers can design and expand existing systems in a systematic manner. Eventually, the decision model is adapted and validated by a case study. The outcomes for practitioners are communicated to both management and technology-oriented audiences.

Requirements for research rigor are followed throughout the research project (G5), as the research is based on established academic methods emanating from both IS research and management sciences.

Concept of an EMIS for SSCM

The resulting EMIS may be classified as a strategic management support tool enabling quantitative modelling through mathematical modeling, statistical analysis, and simulation (Page and Rautenstrauch 2002). As it supports proactive management of the long-term business strategy in addition to operational examinations, the artifact is clearly distinguishable from existing systems. Based on industry observation and discussion with corporate decision makers, we choose a stand-alone approach, as such an approach facilitates system integration within heterogeneous corporate IT landscapes. In addition, real-time integration, which would be an advantage of an integrated system, is not as crucial for strategic decision-making as it is for operational tasks (Teuteberg and Straßenburg 2009).

The structure of the EMIS (see Figure 3) is based on previous works (Bensch et al. 2014). We build on well-recognized reference architectures for EMIS (Graeuler et al. 2013; Teuteberg and Straßenburg 2009) combined with business warehouse architectures (Mehrwald 2004). The resulting architecture reflects the participating systems and their interrelations as well as the corresponding data flows based on technical feasibility and business requirements. The EMIS consists of three distinct layers. The *source system layer* depicts the systems from which relevant data are extracted. These data are processed within the *data warehouse layer* and are ultimately submitted to the *decision support layer*, where the mathematical modelling takes place.

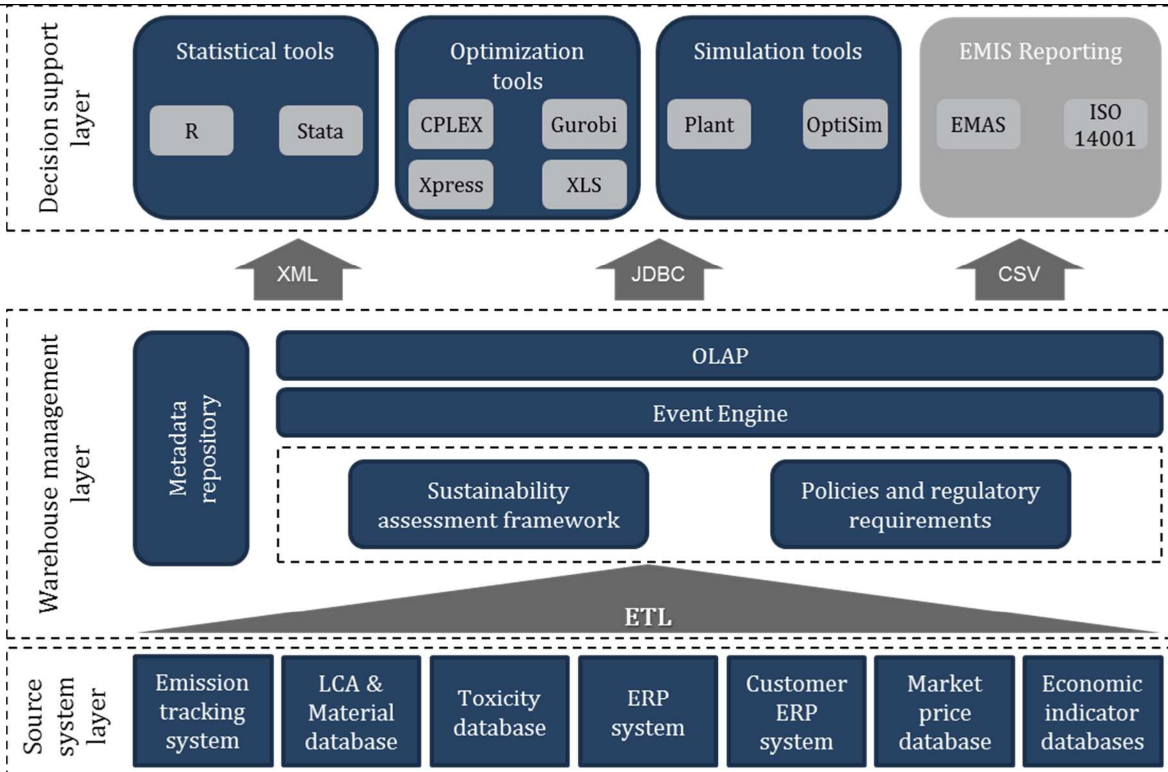

Figure 3. Architecture of a SSCM-oriented EMIS

Source System Layer

The relevant source systems are described against the background of a multidimensional assessment of SSCM-related planning problems. Commonly, these problems require similar data sets, which go beyond the scope of traditional economic-oriented IS. Emission and toxicity information as part of material master records and work schedules would be of specific interest for most SSCM applications. These heterogeneous and poly-structured information requirements are satisfied by integrating both internal and external source systems, which is in line with Graeuler et al. (2013). To demonstrate this, we illustrate the data needs and possible sources related to the SSCM challenge of CLSC decision-making. This example is chosen because such problems require a relatively large set of data. Other problems in SSCM, e.g. energy-oriented production scheduling or green product development, may be tackled with a subset of these data and minor adaptations.

Backflow forecasting is a fundamental challenge in CLSC decision-making. Based on viable information on first place sales, historical data on product utilization lifecycles, and economic parameters, statistical methods are applied to forecast product backflows. The residual value of recovered goods drives the profitability of a CLSC strategy. This value is influenced by the product's material composition and the obtainable market prices for reprocessed goods and components. From an environmental perspective, information on the emergence of undesired by-products, waste streams, and emissions is of specific interest. Amin and Zhang (2013), Dindarian et al. (2012), Pishvaee and Razmi (2012), Quariguasi Frota Neto and Bloemhof (2012), and Sahamie et al. (2013) document these information requirements. In the following we describe the specific data source systems.

Existing corporate *ERP systems* provide traditional economic data, such as cost data including process costs, material costs, and disassembly costs, as well as procurement and sales information. Additionally, quantities of sourced material components and related data sheets may be of specific interest. Further relevant information, such as material master data, bills of materials, machinery utilization, and processing times, is also available in standard ERP systems. In the case of large business customers, product backflows can be projected through interfaces to the customer's ERP system or own CRM systems. These systems monitor the installed base at customer sites and identify its age structure. Forecasting of return flows from smaller business customers and consumers necessitates adequate statistical methods. Such methods may use historical data or economic indicators for explanatory models. Public economic indicator databases, such as *Eurostat* or *Destatis*, may provide the needed information.

Environmental data can be obtained from toxicity databases, emission tracking systems, and LCA & Material databases. Regarding toxicity measurement, two databases are eligible. On the one hand, the *Toxic Release Inventory* provides information on the occurrence of toxic substances and by-products throughout certain steps of production. On the other hand, the European Chemicals Agency (ECHA) administers implementation of the European REACH regulation. The corresponding *ECHA database* comprises information on used chemicals and provides information on the hazardous properties of each element. Carbon emissions by certain process steps may be approximated by using the *IPCC Emission Factor database* or *International Emission Factor Database*. The *Carbon Tracker* relies on primary data collection for transportation. This primary data collection is meaningful, as actual emissions through transportation are up to 34% higher than emissions indicated by the information provided by truck manufacturers (Hilpert et al. 2013). The material composition of certain components and products as well as information on by-products and certain eco-impact dimensions (incl. CO_2 emissions) can be extracted from LCA & Material databases. Most comprehensive data are provided by *Eco-Invent* and the *US Lifecycle Inventory Database*. In addition, industry-specific systems may prove to be beneficial. For instance, the *International Material Data System* offers detailed data on materials and components that are used in automobiles.

The remarketing prices for the reprocessed goods are a crucial driving force for the economic profitability of the CLSC. In contrast to primary sales, expected revenues from product recovery cannot be easily extracted from the corporate ERP system. Therefore, we use an automated 'grabber' tool that collects price data for e-waste, remanufactured, and reused IT products that are traded on *Ebay*. The resulting data are stored in a XLS-based market price database.

The ETL process from the source systems, including the web-based systems, can be realized by using data exchange formats (e.g. XML); data connectors, such as Java Database Connectivity (JDBC); or other extraction tools, such as JasperETL and SpagoBI.

Warehouse Management Layer

The data warehouse integrates and processes relevant data from upstream systems in a multidimensional manner to allow Online Analytical Processing (OLAP) operations. Hence, a central component of the warehouse management layer is the OLAP service. The OLAP structure defines the availability and granularity of data. Figure 4 depicts a corresponding multi-dimensional data model. The data provided by the OLAP represent the converged information that is derived from the source systems. After processing, the key figures are transferred to the decision support layer as parameters. In this sense, this layer can be considered as pre-processing for subsequent analysis with DSS, as the aggregated data are used as input parameters. Moreover, the sourced data are enriched with legislative requirements, which are incorporated within the warehouse management layer. A further functionality of this layer is the provision of frameworks for sustainability assessment via aggregation logics. These frameworks are necessary within the EMIS because of the semantic gap between the poly-structured data. Moreover, such frameworks provide threshold values for certain parameters. An overview of frameworks is given by Ahmed and Sundaram (2007).

Decision Support Layer

Decision support in the context of corporate sustainability may comprise problems regarding sustainable procurement, R&D for green products, product design for recovery, energy- and emission-efficient production planning, ecological vehicle routing, and network design. Depending on the underlying decision problem, adequate DSS tools are selected. For this purpose, optimization, simulation, and statistical tools are embedded within the EMIS. These decision support techniques rely on parameters that are generated within the warehouse management layer through performance indicators. The indicators are used as input parameters for the DSS. In addition to actual decision support, EMIS reports can be created as a 'by-product' of OLAP services. Again, we use data connection standards that are readable by prevalent DSS software to implement the interfaces.

Evaluation of EMIS

We evaluate the artifact by application to field studies in industry projects. While the EMIS is applicable to several problems of SSCM (e.g. energy-oriented production scheduling), the case that we delineate in the following is located in the area of CLSC management. Although CLSCs are regarded to be "sustainable supply chains almost by definition" (Quariguasi Frota Neto et al. 2010), it is necessary to consider both the economic and the ecologic dimension of the problem. Therefore, we apply a multi-criteria decision-making approach based on the EMIS.

Problem description

We conduct the evaluation throughout an industry-project in collaboration with a large IT equipment OEM. Driven by legislation, customer requirements, and efforts to create a green image, this OEM assesses the extensions of their recovery operations in Germany. Currently, structured take-back of waste of electrical and electronic equipment (WEEE) is implemented only on a very small scale. To establish a nationwide collection and reprocessing program, a reverse logistics network that comprises collection facilities, reprocessing plants, and logistic activities needs to be developed. A detailed discussion of the relevant planning tasks in this field is given in Nuss et al. (2014). For the purpose of this project, we build a transdisciplinary team comprising researchers and corporate experts from the business units of 'product recovery operations' and 'environmental management'. The issue is tackled as a bi-criteria problem consisting of an economic and emission-oriented perspective.

Solution approach using EMIS

To address the corporate challenge, we eventually implement a bi-criteria, mixed-integer linear programming (MILP) approach based on the proposed EMIS. The relevant information is sourced from the systems discussed above. These data are subsequently transferred to the data warehouse. Regarding the data structure, a multidimensional data model is developed based on the business requirements of the project partner (Figure 4).

While the data model is largely transferable to other problems related to SSCM, certain dimensions are specific in CLSC assessments: RecoveryOption, RecoveryOperation, and Quality. For instance, the dimension 'RecoveryOperation' refers to work schedules and work places. These objects describe the detailed procedure of distinct recovery operations. The relevant economic information is available in standard ERP systems. As already shown, the master record for a working place in classical ERP systems lacks data on emissions and toxicity (Figure 1). In this sense, the EMIS supplements the missing information and provides corresponding values by using the calculated key figures. Overall, the EMIS enables a user to match costs, emissions, and toxicity to each operation. Furthermore, a disaggregation of products is important as the economic and technical viability of retrieval or recycling is dependent on the components and raw materials that are used in a certain product. In addition, the measure toxicity is required even though it is not an explicit part of the objective function. Toxic components and raw materials limit the feasibility of recycling and disposal or negatively affect the cost structure.

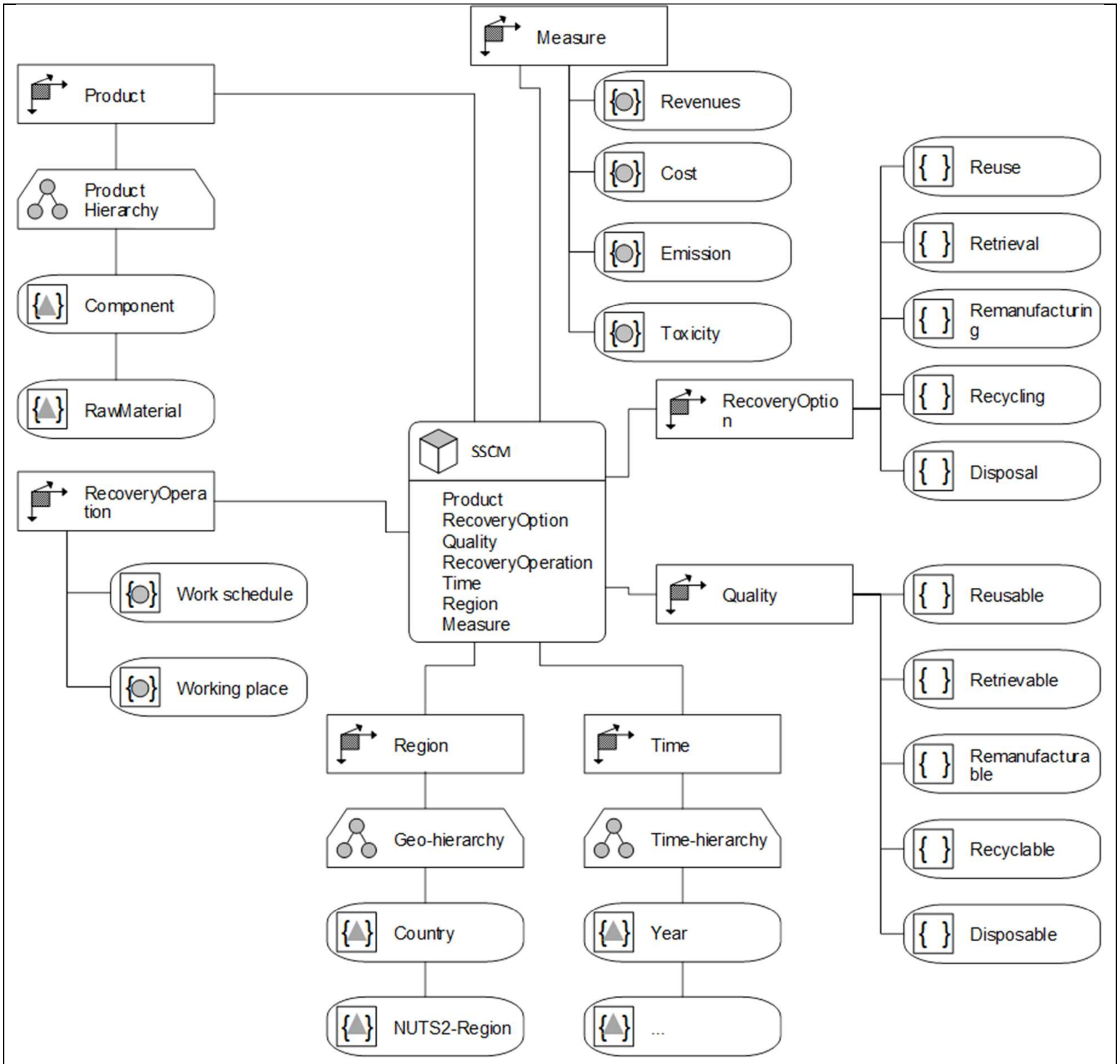

Figure 4. Multidimensional data model of an EMIS for SSCM

The viable and resilient data that are generated are subsequently used for actual decision support. The reverse logistics network design problem is strategic because of the high and irreversible investments that go along with such a decision. Hence, it is important to project future developments. A sensible and time-variant parameter is the amount and quality of backflows, which we refer to as arisings. To forecast future arisings of IT equipment, we use a statistical component of the EMIS, namely, R, which is a command line-based software environment for statistical computing and graphics. An econometric model was specified, and for illustration purposes, we use a linear regression model that explains the arisings (sourced from the ERP system). In an automated procedure, R is used to test several model transformations regarding their explanatory power and to perform regression testing for each instance. This procedure involves performing F-tests and t-tests, testing for heteroskedasticity or a violation of the assumption of normally distributed error terms, and analyzing the data for multi-collinearity. We use a regression model based on gross fixed capital formation — an economic indicator that can be sourced from Eurostat — to forecast future arisings of backflows. Throughout the whole process, R can also be used to provide plots to depict the information graphically.

At this point, the data are input into the MILP model as parameters. The model encompasses decisions regarding location selection for collection points (CPs) and recovery centers (RCs) as well as decisions regarding the flows between the selected facilities. In addition to the economic goal, represented by profit, ecological aims are pursued by incorporating CO_2 emissions for both the transport of backflows and operations. To properly represent both economic and ecological goals in the model, we decide to set up a bi-criteria objective function, which represents the trade-off between the two goals by introducing the weighting factors α and β. This is a common approach for models with multi-criteria objectives (Amin and Zhang 2013). The parameters split up into general parameters, cost parameters, and ecological parameters (see Table 1). The model is subject to various restrictions (see Table 2), which are generally divided into restrictions of flow equilibria (restrictions I.-VI.) and flow permissions (restrictions VII.-X.). An excerpt of the MILP model is formally described below:

Index Sets

$R = \{1, \dots, N\}$ Potential locations for CPs and RCs

$Q = \{1, 2, 3\}$ Different quality grades for recovery (recycling, retrieval, reuse)

$D = \{0, \dots, 9\}$ Distance classes

Decision Variables

$O_r^{CP} \in \{0,1\}$ Indicator opening collection point r ($r \in R$)

$O_r^{RC} \in \{0,1\}$ Indicator opening recovery center r ($r \in R$)

$W_{rs} \in \{0,1\}$ Indicates whether arisings are collected from region r to region s ($r, s \in R$)

X_r Sum of arisings that are collected to collection point r ($r \in R$)

Y_{rs} Flow from collection point in region r to recovery center in region s ($r, s \in R$)

Z_{rq} Quantity of backflows recovered to quality grade q in recovery center r ($r \in R$, $q \in Q$)

C_{rs} Number of necessary trips for collecting products from region r to collection point s ($r, s \in R$)

T_{rs} Number of necessary trips for transporting WEEE from collection point r to recovery center s ($r, s \in R$)

General Parameters		
Parameter	*Description*	*Source*
α	Weighting factor for economic goal ($\alpha \in [0; 1]$)	—
β	Weighting factor for ecological goal ($\beta = 1 - \alpha$)	—
d_{rs}	Distance between region r and region s	GoogleMaps
a_r	Future arisings of products in region r in kilo (projection)	ERP + customer ERP + Economic indicator
b	Average order size	ERP
c	Maximum truck load (FTL)	ERP
f^{disp}	Fraction of input flow to CPs that has to be disposed off	ERP
f_q	Fraction of input flow to RCs that is recovered to quality grade q ($q \in Q$)	ERP + LCA & Material database
$BigM$	Sufficiently large number	—

Cost Parameters		
rev_q	Obtainable revenues for one kilo of recovered products of quality grade q ($q \in Q$)	Market price database + LCA database + ERP
v_q^{RC}	Variable costs for recovery of one kilo of products of quality grade q ($q \in Q$)	ERP
v^{CP}	Variable costs for one kilo of products handled in CPs	ERP
$disp^{CP}$	Disposal costs for one kilo of products in CPs	ERP + LCA database + Toxicity database
fc^{CP}	Fixed costs for one collection point	ERP
fc^{RC}	Fixed costs for one recovery center	ERP
cc_{rsi}	Collection costs for one kilo of products transported over one km in distance class i ($i \in D$), i depends on d_{rs}	ERP
tc	Transportation costs (FTL) for one kilo over one km from CPs to RCs	ERP
Ecological Parameters		
fe^{CP}	Fixed CO_2 emissions for one collection point	Emission Factor Database
fe^{RC}	Fixed CO_2 emissions for one recovery center	Emission Factor Database
ce	Collection emissions for one kilo of products transported over one km	Emission tracking system
te	Transportation emissions (full truck load) for one kilo over one km from CPs to RCs	Emission tracking system

Table 1: Parameters and corresponding source system

Objective Function and Restrictions

$$\text{maximize} \left(\begin{array}{c} \alpha \cdot \overbrace{\left(\begin{array}{c} \sum_r \sum_q Z_{rq} \cdot rev_q - \sum_r \sum_q Z_{rq} \cdot v_q^{RC} - \sum_r O_r^{CP} \cdot fc^{CP} - \\ \sum_r O_r^{RC} \cdot fc^{RC} - \sum_r X_r \cdot v^{CP} - \sum_r \sum_s \sum_i W_{rs} \cdot a_r \cdot d_{rs} \cdot cc_{rsi} - \\ \sum_r \sum_s Y_{rs} \cdot a_r \cdot d_{rs} \cdot tc - \sum_r X_r \cdot f^{disp} \cdot disp^{CP} \end{array} \right)}^{Profit} - \\ \beta \cdot \underbrace{\left(\begin{array}{c} \sum_r O_r^{CP} \cdot fe^{CP} + \sum_r O_r^{RC} \cdot fe^{RC} + \\ \sum_r \sum_s 2 \cdot C_{rs} \cdot d_{rs} \cdot ce + \sum_r \sum_s 2 \cdot T_{rs} \cdot d_{rs} \cdot te \end{array} \right)}_{CO2-emissions} \end{array} \right) ; \quad s \in R, q \in Q, i \in D$$

subject to

	Mathematical formulation	*Verbal explanation*
I.	$\sum_{s \in R} W_{rs} = 1; \forall r \in R$	All arisings must be collected
II.	$W_{rr} = O_r^{CP}; \forall r \in R$	Opened CPs must collect in own regions
III.	$X_s = \sum_{r \in R} W_{rs} \cdot a_r - \sum_{t \epsilon R} W_{st} \cdot a_s ; \forall s \in R$	Flow equilibrium regarding CPs
IV.	$\sum_{s \in R} Y_{rs} = (1 - f^{disp}) \cdot X_r; \forall r \in R$	Collection point output flows must equal input flow minus disposal
V.	$\sum_{q \in Q} Z_{sq} = \sum_{r \in R} Y_{rs} ; \forall s \in R$	Flow equilibrium regarding RCs
VI.	$Z_{sq} = f_q \cdot \sum_{r \in R} Y_{rs} ; \forall s \in R, \forall q \in Q$	Flow split into distinct quality fractions in RCs
VII.	$W_{rs} \leq O_s^{CP}; \ \forall r, s \in R$	Collection only to regions with CPs

VIII.	$Y_{rs} \leq O_s^{RC} \cdot BigM; \forall r, s \in R$	Transport from CPs only to regions with recovery center
IX.	$\frac{(W_{rs} \cdot a_r)}{b} \leq C_{rs}; \forall r, s \in R$	Setting number of trips for collecting WEEE to CPs
X.	$\frac{Y_{rs}}{c} \leq T_{rs};\ \forall r, s \in R$	Setting number of trips for transporting WEEE to RCs

Table 2. Restrictions of MILP

The presented MILP model is implemented and solved with CPLEX.

Results

We perform eleven runs, in which we vary the parameters α and β in steps of 0.1. In doing so, we clarify the changes regarding profit, CO_2 emissions, and reverse logistics network structure that result from different weightings of the economic and ecological goals. Figure 5 depicts these changes. As shown, a robust solution is mainly provided within the interval $\alpha \in [0.4; 0.7]$, which represents valuable information for practitioners. On the one hand, the marginal cost to avoid one unit of CO_2 strongly increases for $\alpha \leq 0.2$. On the other hand, the marginal profit that emanates from emitting one more unit of CO_2 strongly decreases for $\alpha \geq 0.7$. Consequently, to properly balance both goals, an α-value in the robust interval should be selected.

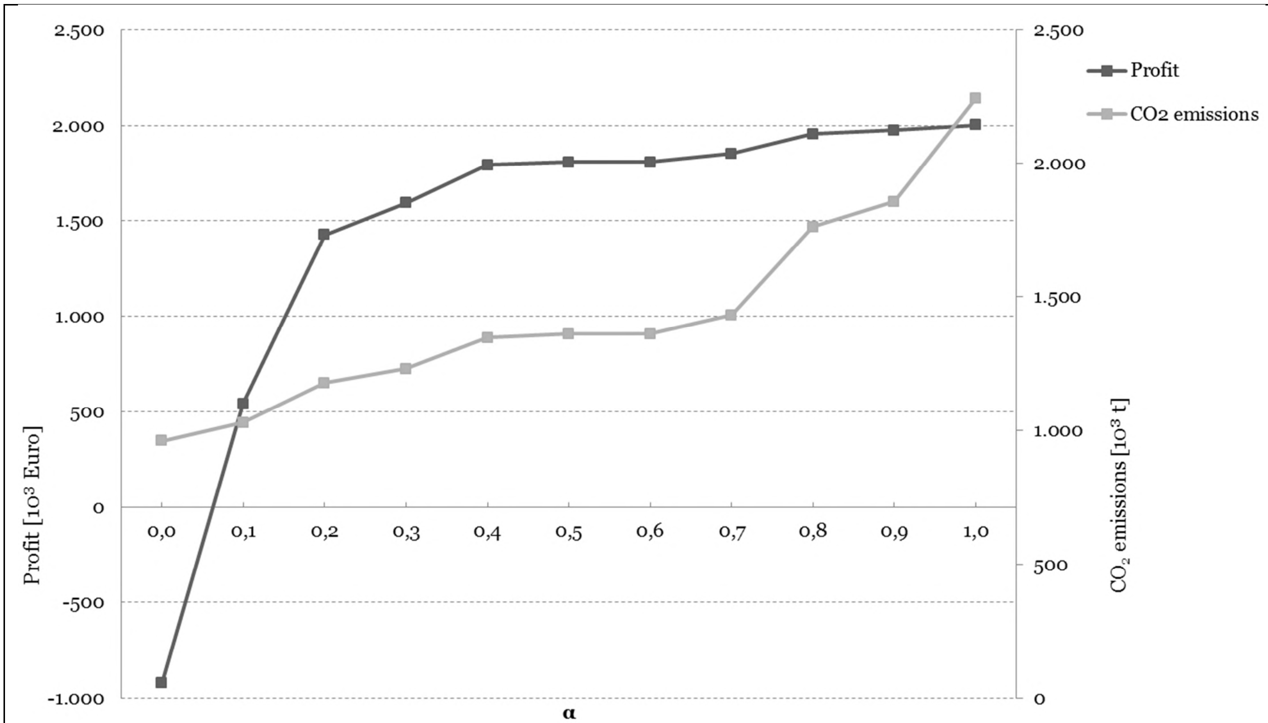

Figure 5. Profits and CO_2 emissions for different α values

The optimization procedure as well as the resulting variation of profit and CO_2 emissions can easily be adapted to changed parameters originating from OLAP services. Therefore, a prompt reaction to parameter changes is possible. On a short-term level, such changes may arise from altered revenue and cost structures on the economic side or higher fuel consumption that leads to higher CO_2 emissions on the ecological side. From a strategic point of view, the resulting reverse network structure should be of strong interest to corporate decision-makers. Figure 6 depicts the resulting network structures consisting of CPs, RCs, and linking flows for $\alpha = 0.1$, $\alpha = 0.5$, and $\alpha = 0.9$.

A comparison of the three reverse logistics networks reveals a strong influence of the weighting factors α and β on the network structure. This result is surprising, as the revenues are relatively stable, especially between the α values of 0.4 and 1.0. The number of CPs, depicted in Figure 6 by #CPs, in particular strongly varies. As setting up facilities is hardly reversible, this finding underlines the importance of a proper initial balancing of economic and ecological goals.

In summary, the present application identifies the benefits for corporate decision makers that arise from using the presented EMIS. Its comprehensive provision of both economic and ecological data leads to a holistic modeling of the underlying problem. The modeling and optimization based on these data enable practitioners to thoroughly balance both economic and ecological goals, which ultimately helps them to conduct thorough decision-making that also incorporates sustainability.

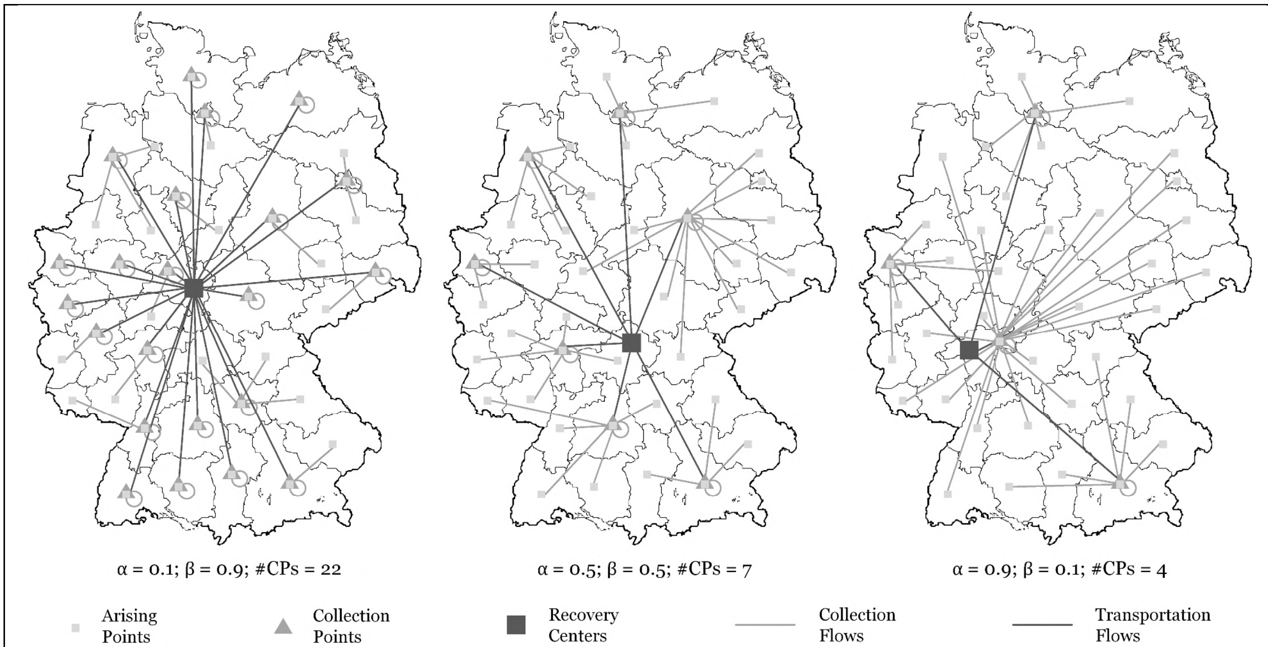

Figure 6. Resulting Reverse Logistics Networks for selected α values

Discussion

Based on our real-world case study, we demonstrate how the developed EMIS broadens the basis of decision-making and, thus, improves the quality of decision support models. In this way, the EMIS ultimately improves the transferability and resilience of results.

Practitioners directly benefit from such an EMIS. First, the system provides more holistic and accurate decision support. Second, we observed that such a tool encourages corporate decision-makers to consider non-economic dimensions in solving a problem. This ultimately facilitates a transition to sustainable business practices. Accordingly, the practitioners in the case study appreciated the detailed ecological and economic key performance indicators provided by the information cubes within the warehouse layer as a 'by-product'. Third, the results of the case study impressively show the value of incorporating sustainability aspects into corporate decision-making. By accounting for the environment, we reveal that minor sacrifices with respect to profit (a decrease of 10% for an α shift from 1.0 to 0.6) can be exchanged for significant improvements in eco-performance (a reduction of 40% in CO_2 emissions for the same shift). Such improvements in eco-performance may contribute to providing a green image for a company, which is likely to compensate for the initial financial sacrifice in the long run. Although this specific insight is only valid for the application in the case study, we are confident that similar results can be derived from many other instances. Finally, because of the generic structure of the EMIS, it can be easily adapted to many other areas related to corporate sustainability, apart from CLSC management.

From an academic point of view, the structured identification of fundamental data, corresponding sources, and their interrelations helps advance discussions and models for SSCM. A more resilient foundation for basic data will improve the acceptance of academic research in the business world. Eventually, this improved trust and confidence may facilitate the transferability of research results to practice and may pave the way for future academic-industry collaboration.

Conclusion

We present an EMIS for strategic decision-making in SSCM. This design-artifact is directly derived from the overarching research question. We develop the system by relying on industry expertise, acknowledged methodologies and principles in design-science, and relevant academic knowledge bases. Subsequently, we evaluate the artifact within a real-world case study assessing the product recovery activities of a major IT equipment manufacturer. Overall, we are able to answer the proposed subordinate research questions:

Q1: Business users' information requirements are identified based on the scientific literature, cooperation with industry partners, and the domain-specific knowledge of the authors.

Q2: We propose specific source systems to obtain the needed information.

Q3: The artifact combines technological feasibility and business considerations to tackle the challenge of sustainability in corporate decision-making. The technological development of the EMIS is consequently flanked by feedback loops with relevant corporate stakeholders, including decision-makers in charge of SCM or environmental management. In this way, we assure appropriate data granularity, data transformation, and quantitative decision support embedded into a user-accepted IS environment.

Q4: We experienced a higher acceptance of environmentally sound decision-making within the organizations resulting from the insights provided by our artifact. Managers are more willing to incorporate sustainability concerns into their rationale if they are provided with appropriate metrics.

Building on this research, academics and practitioners may pave the way toward a sustainable future by further improving "decision-making through the design of better data capture, processing, and delivery systems" (Watson et al. 2012, p. 11). In fact, we show that the EMIS provides valuable information for both interest groups in the field of SSCM. From a practitioner's perspective and the resource-based view on an organization, the presented EMIS enables market players to enhance their organizational capability and ultimately supports them in generating a competitive advantage by increasing sustainability-related knowledge. We observed that executives who were involved in the evaluation in the case study clearly appreciated the new insights generated by this set of information. In this way, the EMIS supports efforts to bring the "notion[s] of sustainability [...] into the boardrooms of companies" (Schaltegger and Burritt 2005, p. 187). For SSCM researchers, the EMIS provides a sound foundation for the development of future mathematical models that are both scientifically advancing and practically useful. Further, we describe a number of valuable data sources and their interrelations that may be levered to improve the validity of future decision models.

The presented research opens some interesting avenues for future research. The EMIS focuses on environmental and economic aspects of the sustainability concept. Hence, a logical next step is to extend the EMIS by adding social aspects. Promising starting points for tackling this issue are the inclusion of material criticality assessments that emphasize social impact (Achzet and Helbig 2013) or the Dodd-Frank Act, which aims to limit the negative societal effects of resource consumption. Another promising field of research may address the integration of further information that is not available in a structured manner. In this area, the development of domain-specific ontologies may broaden the potential number of information sources. Another scientific challenge is the advancement of proper assessment frameworks for eco-impact analysis. Further efforts are also necessary to advance the artifact to develop a marketable version. For such efforts, integration with well-acknowledged ERP and business intelligence systems, such as SAP or Oracle, may be one promising direction. Another research stream may aim to bundle the diverse environmentally oriented data source systems to provide them within an integrated service platform for corporate applications. Such research may facilitate integration with respect to interface definition and cross-organizational collaboration.

In summary, the presented EMIS contributes to the fields of IS and SSCM by providing a structured collection and provision of both viable and problem-specific information. This research thus closes existing knowledge gaps that limit the quality of environmentally oriented decision support. The EMIS aims to exploit the value of IS as a lever for SSCM and, therefore, facilitates the transition to sustainable business practices.

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