Toward the Next Generation of Corporate Environmental Management Information Systems: What is Still Missing?

Jorge Marx Gómez and Frank Teuteberg

Abstract This paper outlines the development as well as the technical features of a corporate environmental management information system (CEMIS) and explains how integrated system-oriented information systems can facilitate environmental sustainability in business organizations. Furthermore, the paper discusses implications (lessons learned) of the IT-for-Green project. The paper also discusses further requirements of traditional CEMIS toward a next generation of CEMIS focusing on a more strategic level instead of a compliance approach and on an interactive exchange of information between stakeholders, as well as the realization of synergy effects using green services.

Keywords Corporate environmental management information systems · Sustainability reporting and dialogue · Green IT · Green production and logistics

1 Introduction

Despite the heightened concern of business organizations for environmental sustainability, strategic decision support systems have failed to prevail in practice. Environmental Management Information Systems (EMIS) have been designed for operational data storage and documentation purposes to support compliance with environmental directives. However, the increasing demand for comprehensive environmental reporting as well as proactive environmental management imply new challenges for the integration of EMIS into the established corporate Information

J. Marx Gómez (✉)
Chair of Business Informatics, Department of Computing Science, Oldenburg University, Oldenburg, Germany
e-mail: jorge.marx.gomez@uni-oldenburg.de

F. Teuteberg
Accounting and Information Systems, Osnabrück University, Osnabrück, Germany
e-mail: frank.teuteberg@uni-osnabrueck.de

L.M. Hilty and B. Aebischer (eds.), *ICT Innovations for Sustainability*,
Advances in Intelligent Systems and Computing 310,
DOI 10.1007/978-3-319-09228-7_19

Technology (IT) landscape. The joint IT-for-Green project [1] aims to develop a new, integrated, and service-oriented type of EMIS called Corporate Environmental Management Information System (CEMIS). The resulting information system supports practitioners with the implementation of environment-related workflows, such as life cycle assessment, environmental monitoring, and Sustainability Reporting (SR), by obtaining, processing, and disseminating information.

The ideas of environmental and sustainable development started to influence development of and research on Information Systems (IS) at the beginning of the 21st century on a wider international base. The first conferences on the topic, such as the International Conference on Information Technologies in Environmental Engineering (ITEE), the International Symposium Informatics for Environmental Protection (EnviroInfo), and the International Symposium on Environmental Software Systems (ISESS), took place in the years 2001–2003. Melville [2] and Watson et al. [3] published the first contributions to the concept of environmental sustainability in one of the leading IS journals, the MIS Quarterly. But even though a huge number of information systems have been successfully implemented for the operational level, strategic decision support systems have failed to be disseminated into business practices. This contradiction motivated us to investigate the following research question:

How can information systems successfully enable sustainable strategic decision-making within business organizations by collecting, storing, and processing information with appropriate means?

We answer this question by designing, implementing, and evaluating our CEMIS and by giving an example. Furthermore, we derive a reference architecture from the example. Our system is built in a modular manner, with service orientation as a major conceptual design element. In this context, service orientation means that the smallest units of the modules are realized as services (called Green Web Services); these services are published in the Green Service Mall (service registry). Following the service-orientation approach, functionality will be established and expanded via the integration of new or modified services to add any kind of functionality. The design science approach [4] is applied for realizing the software.

This chapter is structured as follows: In Sect. 2 a brief description of the IT-for-Green project is given. The status quo of environmental management information systems (EMIS) is described, based on a systematic literature review (Sect. 3). The results (IS artifacts) of our research are outlined in Sect. 4, followed by a discussion of design considerations of CEMIS in Sect. 5. A CEMIS reference architecture is presented in Sect. 6. Lessons learned are discussed in Sect. 7, and conclusions are drawn in Sect. 8.

2 IT-for-Green Project

The ubiquity of IT in modern society and the progressive merging of digital and physical systems have created the basis for companies contributing more systematically to sustainable development. Common objectives of sustainabilityoriented management include a fundamental redesign of business processes, a general increase in transparency, and more efficient handling of energy and material resources.

The IT-for-Green project supports companies in increasing their resource and energy efficiency with the help of information technology—that is, by means of Corporate Environmental Management Information Systems (CEMIS). However, formerly conventional CEMIS merely serve to ensure compliance with environmental laws and regulations and hence fall short of the full potential that IT holds for environmental management. The new generation of CEMIS (CEMIS 2.0) needs a stronger strategic focus and is intended to provide more direct support to decision-makers within companies.

The project IT for Green aims at modeling the entire product life cycle supported by a CEMIS, including the input side (measuring the energy efficiency of a company's ICT), the transformation phase (production/logistics and sustainable product development), and the output side (corporate communications and Sustainability Reporting, SR). To this end, three interlocked modules are developed as reference implementations for an innovative CEMIS 2.0. Participating companies may also procure the modules in the form of services via a Cloud Computing Mall.

Researchers of the IT-for-Green project are members of the innovation network ertemis [5], which consists of researchers from the Universities of Oldenburg (Prof. Jorge Marx Gómez and Prof. Wolfgang Nebel), Osnabrück (Prof. Frank Teuteberg), and Göttingen (Prof. Jutta Geldermann). The University of Lüneburg (Prof. Andreas Möller, Prof. Burkhardt Funk, Prof. Peter Niemeyer) is also involved as an associate partner. Industry partners include CeWe Color, Hellmann World Wide Logistics, Nowis, and erecon. Furthermore, over 30 companies contribute their practical expertise to IT-for-Green.

Ertemis aims to facilitate knowledge transfer between research and practice and to advance interdisciplinary research on CEMIS 2.0.

3 CEMIS Status Quo: A Literature Review

A common definition explains CEMIS as an organizational and technical system with the ability to collect, process, and supply environmentally relevant information in a company [6]. This definition omits the bigger picture since it does not incorporate any information from supply-chain partners or publicly available information which is needed to make well-founded decisions regarding environmental sustainability. By following the proposed holistic approach using the three modules described in a later section, Green IT measures can be enabled and leveraged.

Present CEMIS follow a rather operative approach with tasks such as legally required reporting [7], therefore there is little assistance when it comes to strategic decision support [8, 9]. Integration with other systems (e.g., ERP, CRM, and publicly available data) and automated sustainability reporting have been broadly discussed in the literature, but are yet to be implemented [10]. These are key components of the future CEMIS, since a contribution to sustainable development can be realized only if the causes and effects of ecological, social, and economic key performance indicators (KPI) are recognized and an efficient way of handling relevant data is developed.

An analysis of third-party funded projects in the field of corporate environmental management from the last decade has shown a need for action and research in the interest of society, politics, business, and science. None of the projects scrutinized aimed at supporting all parts of the environmental management cycle, including input (energy and material efficiency), transformation processes (production integrated environmental protection), and the output side (sustainability reporting and strategic decision support) in a holistic and integrated way. However, a cross-corporate inspection of the sustainability of entire supply chains (sustainable supply chains) has been a relevant topic in scientific literature, but has—as yet—not found its way into business practice. For one of the most advanced approaches to sustainable supply chains, see the chapter by Rizzoli et al. [42] in this volume.

The research network ertemis and the project IT-for-Green will, in contrast to other projects, focus on exactly these aspects (integration of the strategic level and sustainability needs) of the next generation of CEMIS. The new CEMIS systems will provide advantages for business users by enabling them to:

- develop environmental production and reverse logistics processes,
- develop hybrid products (integrated and associated services) focusing on sustainability ideas in order to open up new markets for sustainable products,
- realize an interactive exchange of information between different stakeholders in the field of sustainability reporting based on new Internet technologies (blogs, wiki, semantic web, podcasts, etc.),
- realize synergy effects, cost-cutting effects, strategic advantages etc. by offering or using green services from the cloud (green clouds/Green Service Mall) or based on service-oriented architectures, and
- pinpoint complementary cause-effect relationships and their effects on different targets from a strategic perspective. Complementary in this case means that, for example, pursuing economic targets concurrently supports ecological ones.

Whereas traditional CEMIS might be regarded as rather isolated, function-oriented information systems [8], new CEMIS will take a holistic approach that guides organizations to a strategic orientation. In this way, next-generation CEMIS are—from our perspective—information systems that deal with material and energy efficiency, emission and waste minimization, reverse logistics, stakeholder support, legal compliance, and especially with strategic environmental management. As yet, such systems only exist as concepts within academic discussions and have not found their way into business practice. Therefore, research and knowledge transfer especially into small and medium enterprises (SME) is an important prerequisite for putting such systems into action. Ubiquitous ICT and continuous integration of digital and physical systems allow for a fundamental renewal of business processes regarding sustainable business development, for increased transparency as well as for better control of material and energy usage.

In order to map the entire life cycle of a product, we see a need [11] for three modules that in sum interact as a reference implementation and proof of concept for a next-generation CEMIS. These three modules are Green IT (focusing on energy efficiency in a data center), Green Production and Logistics (focusing on the transformation phase of the product life cycle), and Sustainability Reporting and Dialogue (focusing on sustainability communication). In order to build our research on a strong base of existing literature in the field, we conducted a systematic literature review [12, 13]. The literature review represents the "essential first step and foundation when undertaking a research project" [14], ensuring relevance by avoiding reinvestigation as well as rigor by effective use of existing knowledge [12]. In order to efficiently integrate the knowledge base, we followed the approach of a systematic and concept-centric review [13]. The literature search yielded 18 publications discussing the topic of EMIS/CEMIS in international peer-reviewed journals. The concept matrix depicted in Fig. 1 was developed on the basis of these contributions.

We can see from the matrix that sustainable reporting systems (discussed in 9 publications) as well as key performance indicator based systems (7) and output-oriented systems (7) are the types of EMIS/CEMIS receiving the most attention within the scientific community. This result leads to the assumption that EMIS/CEMIS are increasingly applied within the stakeholder dialogue, i.e., to generate sustainability reports and information on the environmental output of business organizations.

The large number of key performance indicator based systems is evidence for the increased application of EMIS/CEMIS within decision-making, which is also documented by the fact that process data (11) are the main data sources of current EMIS/CEMIS. This evidence correlates well with processes being the most common boundary of the systems (9). Roughly the same number of publications studied refer to each of the environmental media (9–12), reflecting the need for comprehensive EMIS/CEMIS that do not focus on single-scope solutions. Emissions (14), energy (13), waste (10), and material flows (7) are the most frequently mentioned objects of EMIS/CEMIS. This can perhaps be explained by increased application of the systems within the context of energy and material efficiency, which also indicates that EMIS evolve into strategic control instruments rather than operational systems. Model development and simulation (10) as well as active data warehouses (8) are the most common software tools among EMIS/CEMIS. Whereas model development and simulation tools are evidence of a more predictive or proactive use of EMIS/CEMIS, active data warehouses display a continuous demand for documentation systems. The most intensively discussed application areas for EMIS/CEMIS are reporting (10) and logistics (9), followed by procurement (8), production (7), waste management (7), and life cycle assessment (6), indicating the diffusion of EMIS/CEMIS to business domains beyond the classical scope of environmental management. Even though EMIS/CEMIS are predominantly stand-alone solutions (9), integrated systems are increasingly discussed and implemented (6). This brief outline of the observations gained from the literature forms the basis for formulating the following objectives for the implementation of EMIS/CEMIS:

	type						database					environmental medium				object					
	key performance indicator based	environmental accounting systems	sustainability reporting systems	input-oriented systems	process-oriented systems	output-oriented systems	material master data	structural data	process data	data on energy flows	organizational data	soil	air	water	waste	material flows	waste	emission	energy	hazardous material	facilities
Angeles 2013	x			x			x	x				x	x	x	x	x	x	x	x	x	
Beermann 2011		x		x		x			x	x		x	x	x	x			x	x	x	x
Carvalho et al. 2012			x		x						x	x	x	x	x	x	x	x	x	x	x
Erlandsson & Tillman 2009	x			x			x					x	x	x	x		x	x	x		
Fracchia et al. 2012				x			x	x				x			x	x	x	x	x		x
Govindan et al. 2013	x		x				x					x	x	x	x					x	
Green & Zelbst 2011			x					x	x		x	x	x	x	x		x	x		x	
Hilpert et al. 2013		x				x			x				x					x			
Green et al. 2011	x		x				x		x	x						x			x		
Liu et al. 2011			x					x	x					x			x	x		x	
Loos et al. 2011	x		x		x										x		x	x			
Meacham 2013			x		x				x		x					x	x		x		
Méline et al. 2013			x			x			x				x					x			
Myhre et al. 2011	x					x			x				x		x		x	x			
Page & Wohlgemuth 2010	x	x			x		x		x	x		x	x	x	x	x	x	x	x		x
Protogeros et al. 2011		x		x		x						x	x	x	x		x	x	x		
Sarkis et al. 2013		x	x			x	x		x	x					x	x	x		x	x	
Tian et al. 2011						x			x					x			x	x			
SUM	7	5	**9**	5	4	7	7	4	**11**	4	3	9	11	10	**12**	7	13	**14**	10	7	4

	methods/ tools							application area							integration level			system boundary				
	active data warehouses	model development and simulation	environmental databases	knowledge-based systems	document management	artificial intelligence (e.g. neuro-	meta-information	procurement	environmentally friendly production	Distribution/ eco-logistics	recycling planning	waste management	life cycle assessment	reporting	stand-alone	add-on	integrated	product	process	department	company	inter-corporate level
Angeles 2013		x							x				x	x			x	x				
Beermann 2011		x	x						x				x		x				x			
Carvalho et al. 2012	x			x	x									x	x			x			x	
Erlandsson & Tillman 2009				x	x			x	x								x	x		x		
Fracchia et al. 2012				x				x		x					x				x			x
Govindan et al. 2013	x						x	x		x	x			x								x
Green & Zelbst 2011	x			x				x		x				x								x
Hilpert et al. 2013		x								x			x		x				x			
Green et al. 2011	x							x	x	x		x		x			x		x			x
Liu et al. 2011	x	x										x		x	x				x			
Loos et al. 2011	x	x						x	x	x	x	x		x								
Meacham 2013	x							x		x		x		x			x					x
Méline et al. 2013		x								x				x	x				x			
Myhre et al. 2011		x									x	x	x		x				x	x		
Page & Wohlgemuth 2010		x							x				x						x			
Protogeros et al. 2011	x																x				x	
Sarkis et al. 2013		x	x		x			x	x	x		x	x	x	x		x				x	x
Tian et al. 2011		x										x			x				x			
SUM	8	**10**	2	4	3	0	1	8	7	9	3	7	6	**10**	**9**	0	6	3	**9**	2	3	6

Fig. 1 Concept matrix of EMIS literature

- supporting the realization of eco-friendly production, logistics, and disposal processes,
- enabling analysis of cause-effect relationships between economic and environmental objectives via energy and material flow management to enable sustainable strategic management,
- promoting interactive exchange of information with various stakeholders via reports and documentation of product- and process-related environmental impacts,
- integrating process databases and applications of different departments and locations, e.g., using web portals or cloud computing, and
- enabling model development and simulation as well as storage of data by means of an active data warehouse.

The software prototypes developed and presented in the papers analyzed were not evaluated formally and quantitatively. Besides, it can be seen that the systems developed in the realm of corporate environmental management are for the most part operative rather than strategic. There is still a lack of integration measures, for instance, for integrating CEMIS with accounting and production. In addition, there is a shortage of reference and maturity levels for CEMIS that can be parameterized and configured. So far, the results of the analyzed contributions are basically concepts and prototypic implementations whose comprehensive introduction in companies is still lacking. The market situation of software designed to support corporate environmental protection is relatively fragmented and confusing. Despite the growing importance of the topics environment and sustainability in political, social, and commercial environments, isolated applications are still more common in practice than integrated CEMIS [8].

Within the context of a market study in advance of this contribution, the authors were able to identify 110 software products in the range of corporate environmental information systems. Thus, the structure of the covered application areas is very heterogeneous. The systems can mainly be assigned to the categories

- environmental and environmental law databases,
- environmental management,
- environmental accounting, and
- material flow analysis and compliance management.

According to a research report by the Fraunhofer Institute of Labor Economics and Organization (IAO), approximately 60 % of the respondents use software to support their corporate environmental management [40, p. 90].

According to another study, software support is so far mainly limited to the application of Microsoft Office Excel™. The majority of the companies have not yet installed specific CEMIS [15]. All surveyed companies have environmental management systems in place, in accordance with EMAS or ISO 14001, thus they systematically conduct environmental protection.

Although CEMIS could be an adequate approach to support environmental activities in companies, it must be emphasized that the present concepts have not been able to establish themselves in corporate practice. Rather, they are predominantly used as poorly integrated solutions [16].

Various research projects aim to integrate CEMIS and ERP systems and develop reference models. Such reference models are, for instance: ECO-Integral [17], production and recycling planning as well as monitoring [18], organizational models and information systems for production-integrated environmental protection (OPUS) [19], and the reference model for CEMIS in the realm of in-plant logistics [41]. Despite these efforts, the present reference models have not yet been implemented by the providers of commercial CEMIS software, or at best only to some degree [41, p. 24].

CEMIS have been broadly discussed in the literature for the last two decades from varying perspectives; therefore the above literature review was conducted to identify preliminary work that aids the development of the authors' research. The results can be reviewed in Table 1 below.

4 IT Artifacts Developed in the IT-for-Green Project

The IT-for-Green project, funded by the European Regional Development Fund (EFRE), concentrates on the design of ICT artifacts for corporate environmental and sustainability management. In this development project, the three universities Göttingen, Oldenburg, and Osnabrück collaborate closely with cooperation partners from the region Lower Saxony. The envisaged research results are constructs, methods, models, and instantiations in terms of design research [4]. In order to ensure the relevance of the research, the approach of consortium research was selected. The ICT artifacts resulting from current developments are displayed in Table 3. Since the beginning of the project in 2010, 30 artifacts have already been

Table 1 Overview of related works

References	Contribution(s)
El-Gayar and Fritz [8]	Conceptual overview of CEMIS
	Analysis of supply of and demand for environmental information
	Detailed examples of the stakeholders' influence on environmental reporting
Teuteberg and Marx Gómez [9]	Analysis of the various challenges faced by next-generation CEMIS
	Proposal of a reference architecture
Teuteberg and Straßenburg [10]	Literature review of the scientific progress in the field
	Highlighting of unsolved problems
Melville [2]	Highlighting of the role IS can play in sustainability and environmental performance of organizations
	Research agenda spanning ten research questions, application of the belief-action-outcome framework
	Literature review

developed, and 21 papers on design research have been published. It can be seen that instantiations, the operationalized form of an artifact, as well as models make up the largest share of the development output. The disproportionally high number of instantiations (12) and the small number of methods (2) correlates with the observations in view of related works. The small number of constructs (2), as a highly formalized form of artifacts [4], indicates that research is distinctly applied and industry-oriented. Thus, the strong application and industry orientation of the external investors (EFRE/EU) is mirrored in the scientific project output. What is striking is the high number of models (14). A specific feature of models is the inherent description of the relationship between problem and problem solution [4]. Despite their relatively high degree of formalization, they can be of significant practical relevance [27]. The high number of models in connection with the high number of instantiations thus points to a practice-related approach as the primary focus of the research project. The artifacts construct (2) and method (2) account for only a minor share of development output. Numerically, publications at scientific conferences (12) constitute the largest proportion of all publications. Publications in magazines (1) and books (1) are less frequent (cf. Table 2).

5 Design Considerations of CEMIS 2.0

Both scientists and practitioners were invited to participate in a survey in order to determine properties of next-generation CEMIS (CEMIS 2.0). A total of 33 responses were completed within a timeframe of 3 weeks in August 2011 and subsequently analyzed by the authors using PASW Statistics 18 and Microsoft Excel 2010.

Table 2 Artifacts produced in the IT-for-Green project

Medium	Designation of ICT artifact and source	Artifact according to [4]	Context
Conference	Framework for agent-based, adaptive business applications [20]	Model	Logistics
Conference	Service-oriented architecture [21, 22]	Model, instantiation	CEMIS
Conference	Event engine for automated processing of pre-defined control tasks [23]	Model, instantiation	CEMIS
Magazine	Framework for quality assessment of sustainability reports [24]	Model	SR
Conference	Instrument for process benchmarking [25]	Model, instantiation	Green BPM
Conference, magazine	Ontology, profiling tools, graphical editor, simulation framework [26, 27]	Construct, model, method, instantiation	Green IT
Conference	Conceptual framework [28]	Construct	Eco-balance
Conference	Practice-oriented development of application software [29]	Method, instantiation	Eco-balance
Book	Architecture and functionalities of a tool for web-based sustainability reporting [30]	Model, instantiation	SR
Magazine	BAO Model [31]	Model	SR
Conference	Web portal and maturity model [24]	Model, instantiation	Corporate environmental management
Magazine	Web platform for registration, automated classification, and assessment [32, 33]	Model, instantiation	Cloud services
Conference	Structured catalogue of criteria [34]	Model	BPM applications
Magazine	Design and implementation of an augmented sustainability report [35]	Instantiation	SR
Conference, magazine	Multi-criteria decision model [36, 37]	Model, instantiation	Decision support
Conference	Evaluation framework [38]	Model	SR
Conference	Design and simulation of a balanced scorecard [39]	Model	Sustainable supply chain management
n/a	Online visualization of a CEMIS market study [not published]	Instantiation	CEMIS
n/a	Online visualization of a sustainability report [not published]	Instantiation	SR

57.6 % of the respondents replied that they were scientists, the remaining 42.4 % indicated that they were practitioners. Additionally, practitioners were asked about their company's business sector. The most frequent sectors are chemical, plastics, mining, or energy (41.7 %), printing (16.7 %), and services (16.7 %).

63.6 % of all participants are directly affiliated with the project; 3.0 % are affiliated with the research network carrying out this research, but not with the project itself; and 33.3 % are affiliated with neither the project nor the research network.

Respondents were asked to rate the importance of each design property on a scale from 1 (high) to 5 (low). In the analysis, the design properties were ranked in ascending order by their arithmetic mean, i.e., the sum of all prioritizations of each property, divided by the number of votes. Table 3 shows the ranks of the prioritized properties broken down by votes by researchers, by practitioners, and totals (R); arithmetic mean (AM); standard deviation (SD); differences in mean values (Dif); and the statistical significance of differences among the perceived importance of the properties between practitioners and researchers according to a t-test using independent samples and unequal variance (Sign). As mentioned above, each property was rated on a scale from 1 to 5, resulting in an expected mean of 3. However, the results show that the overall mean score is 2.17 (2.27 for researchers, 2.03 for practitioners); in fact, only 2 of the 47 properties received a total mean higher than 3. The lower the arithmetic mean, the higher the priority. For better legibility, means under 2 are highlighted in bold and means equaling or above 3 in italics; statistically significant differences are highlighted in bold as well. In addition, the means of the top five criteria of each group (researchers, practitioners, and total) are underlined.

Table 3 shows differences in perceived importance for researchers and practitioners. For example, the difference in the arithmetic means for researchers and practitioners for the property "Consistency and traceability/transparency of calculations, information, and reports" (#29) is 0.63 points. It ranks 7th for researchers and 1st for practitioners. According to a t-test, this discrepancy is statistically significant, whereas discrepancies for most other properties are not. The discrepancies can be partially explained by the observation that researchers generally rated properties as being more important than practitioners did. These circumstances illustrate how important feedback from practitioners is to scientists.

Figure 2 visualizes the top design properties (i.e., those with an arithmetic mean lower than 2) and groups them by the goal that is pursued by their fulfillment.

These design properties form the functional and non-functional top-level requirements on which basis we designed the reference architecture of a CEMIS 2.0 (cf. Sect. 6).

Table 3 List of all design properties ordered by arithmetic mean

Design property		Researchers			Practitioners			Total				
No.	Category/Description	R	AM	SD	R	AM	SD	R	AM	SD	Dif	Sign
29	[T] Consistency and traceability/transparency of calculations, information, and reports	7	**1.78**	0.808	1	**1.15**	0.376	1	**1.52**	0.724	**0.63**	**0.008**
22	[T] Export to common file formats	3	**1.67**	0.767	2	**1.36**	0.497	2	**1.53**	0.671	0.31	0.178
25	[T] Flexible and transparent interfaces for integrating existing data and isolated applications	1	**1.53**	0.612	10	**1.64**	0.745	3	**1.58**	0.663	0.11	0.637
11	[O] Assistance with operative and strategic decisions	2	**1.63**	0.831	8	**1.64**	0.929	4	**1.64**	0.859	0.01	0.972
33	[T] Diverse user roles with corresponding rights	4	**1.68**	0.820	7	**1.57**	0.646	5	**1.64**	0.742	0.11	0.662
44	[T] Easy to use and comprehend; promotes enjoyment of work	14	**1.89**	1.049	3	**1.36**	0.633	6	**1.67**	0.924	0.53	0.078
40	[T] Good documentation/manuals/context and online help	6	**1.74**	0.562	12	**1.64**	1.082	7	**1.7**	0.81	0.10	0.77
20	[T] Automated calculation of KPI	5	**1.68**	0.749	20	**1.79**	1.122	8	**1.73**	0.911	0.11	0.772
46	[T] Adaptability to existing software and enterprise infrastructure	8	**1.79**	0.631	14	**1.64**	1.151	9	**1.73**	0.876	0.15	0.671
39	[T] Selection of level of abstraction ("drill-down")	12	**1.84**	0.765	11	**1.64**	0.745	10	**1.76**	0.751	0.20	0.459
6	[O] Integration of environmental management in business processes	17	2.00	0.667	5	**1.5**	0.65	11	**1.79**	0.696	**0.50**	**0.039**
7	[O] Data, process, and workflow integration	13	**1.89**	0.832	15	**1.69**	0.855	12	**1.81**	0.833	0.20	0.529
28	[T] Timeliness of data/warning if data are outdated	15	**1.94**	0.802	16	**1.71**	0.726	13	**1.84**	0.767	0.23	0.403
4	[E] Measurable economic, social, and ecologic advantages through software use	16	**1.95**	1.079	17	**1.79**	0.975	14	**1.88**	1.023	0.16	0.656
5	[E] Assistance with monetary valuation of KPI and data	25	2.21	1.084	4	**1.5**	0.519	15	**1.91**	0.947	**0.71**	**0.019**
13	[T] Comprehensive and configurable KPI-dashboards	21	2.11	1.150	9	**1.64**	0.745	16	**1.91**	1.011	0.47	0.172

(continued)

Table 3 (continued)

Design property		Researchers			Practitioners			Total				
No.	Category/Description	R	AM	SD	R	AM	SD	R	AM	SD	Dif	Sign
16	[T] On-demand (ad hoc) sustainability reporting (automated generation of sustainability reports)	20	2.00	0.745	18	**1.79**	0.975	17	**1.91**	0.843	0.21	0.498
37	[T] Avoidance of informational overload; only display the needed information	19	2.00	0.943	21	**1.79**	0.893	18	**1.91**	0.914	0.21	0.511
10	[O] Avoidance of organizational efforts for management reporting	18	2.00	0.943	23	**1.86**	1.167	19	**1.94**	1.029	0.14	0.71
30	[T] Automated check for erroneous data entry using historical data	28	2.22	0.808	6	**1.57**	0.646	20	**1.94**	0.801	**0.65**	**0.017**
27	[T] Minimal manual data entry	9	**1.79**	0.787	31	2.21	1.424	21	**1.97**	1.104	0.42	0.326
31	[T] Access via browser	10	**1.83**	1.043	30	2.15	1.405	22	**1.97**	1.197	0.32	0.494
43	[T] Handling follows established standard software	26	2.21	1.084	13	**1.64**	0.929	23	**1.97**	1.045	0.57	0.117
45	[T] Adaptation to corporate growth (scalability and modular design)	27	2.21	0.918	22	**1.79**	0.802	24	2.03	0.883	0.42	0.168
19	[T] Display of cause-effect relationships, sensitivity analysis	11	**1.84**	0.501	35	2.36	1.008	25	2.06	0.788	0.52	0.096
9	[O] Analysis of processes and functions	24	2.21	1.032	24	**1.93**	0.997	26	2.09	1.011	0.28	0.435
14	[T] Greenhouse gas emission calculation and management	22	2.16	0.834	28	2.14	1.292	27	2.15	1.034	0.02	0.97
2	[PL] Usage of legally non-mandatory standards and corresponding KPI(-systems) (e.g., GreenScor, CoBIT, ISO 14000)	23	2.16	0.958	32	2.23	0.725	28	2.19	0.859	0.07	0.808
1	[PL] Attention to the dynamics of regulatory requirements	32	2.37	0.831	25	2	1.038	29	2.21	0.927	0.37	0.284
21	[T] Good predefined reports	29	2.32	0.946	27	2.07	0.917	30	2.21	0.927	0.25	0.461
15	[T] Preparation of documentation for audits	33	2.42	0.692	26	2	1.109	31	2.24	0.902	0.42	0.225
17	[T] Generation of an input-/output-balance	38	2.68	0.885	19	**1.79**	0.699	32	2.3	0.918	**0.89**	**0.003**

(continued)

Table 3 (continued)

Design property		Researchers			Practitioners			Total				
No.	Category/Description	R	AM	SD	R	AM	SD	R	AM	SD	Dif	Sign
26	[T] (Automated) logging of fine-granular consumption data from sensory networks	37	2.50	0.707	29	2.15	0.899	33	2.35	0.798	0.35	0.261
8	[O] Adequate mapping of organizational and process structures of the enterprise	35	2.47	1.073	33	2.29	0.825	34	2.39	0.966	0.18	0.574
18	[T] Forecasts, assistance for simulations	34	2.42	1.071	36	2.38	0.87	35	2.41	0.979	0.04	0.916
12	[O] Inter-company networking along the supply chain	31	2.37	0.895	43	2.64	1.082	36	2.48	0.972	0.27	0.446
38	[T] Rich offering of information and KPI for each enquiry	36	2.47	0.772	40	2.57	0.938	37	2.52	0.834	0.10	0.753
34	[T] Anonymous benchmarking with other organizations/organizational units	30	2.32	1.057	47	3.15	1.144	38	2.66	1.153	**0.83**	**0.046**
24	[T] Coverage of the requirements of material flow management	40	2.88	1.111	37	2.43	0.938	39	2.68	1.045	0.45	0.228
42	[T] Process-oriented models of CEMIS, e.g., predefined processes and/or workflows	39	2.74	1.147	42	2.62	1.193	40	2.69	1.148	0.12	0.776
3	[PL] Attention to privacy issues beyond legal requirements	41	*3.00*	1.291	34	2.36	1.151	41	2.73	1.257	0.64	0.143
23	[T] User-specific consumption information for personal benchmarking	44	*3.17*	1.249	39	2.5	1.286	42	2.87	1.289	0.67	0.152
41	[T] Training functionality (e.g., embedded tutorial videos)	43	*3.11*	0.937	41	2.57	1.342	43	2.88	1.139	0.54	0.215
47	[T] Usage of energy efficient infrastructures (e.g., virtualization, cloud computing)	42	*3.05*	1.471	44	2.77	1.235	44	2.94	1.366	0.28	0.56
36	[T] Storage of process instructions, work instructions, safety sheets, environmental statements, and (supplier) certificates	45	*3.33*	1.085	38	2.46	1.45	45	2.97	1.303	0.87	0.081
32	[T] Access via specialized applications for mobile devices (smartphone, tablet)	46	*3.50*	0.786	45	*3*	1.414	46	*3.28*	1.114	0.50	0.249
35	[T] Mapping of inventory lists and inventory cycles	47	*3.53*	1.179	46	*3*	0.853	47	*3.31*	1.072	0.53	0.172

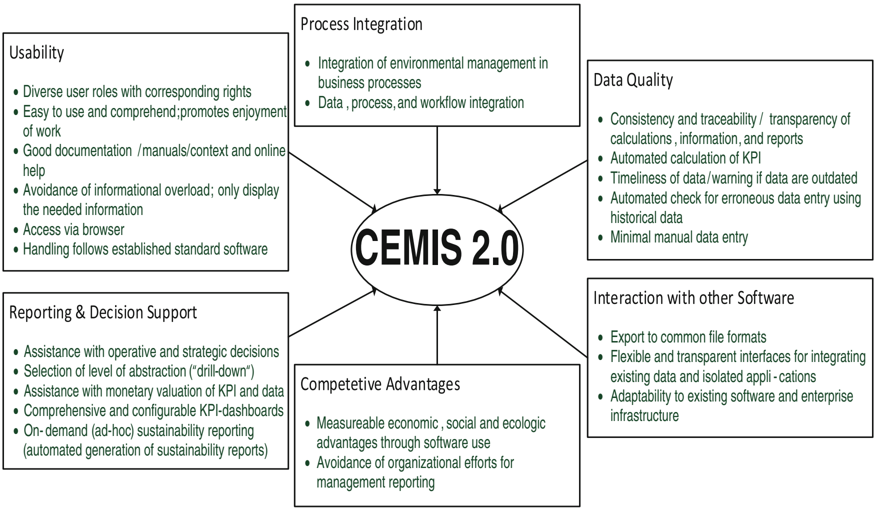

Fig. 2 CEMIS 2.0 top design properties in categories

6 Next-Generation CEMIS 2.0 Reference Architecture

Figure 3 is a schematic diagram of the CEMIS under development in the IT-for-Green project. The runtime environment forms the backbone of the system. It is organized in a modular and service-oriented manner and contains the following core building blocks: Green Service Mall, Workflow Engine, databases, Event Engine, and user interface.

The smallest functional units of the system are realized as Green Web Services and are available via the Green Service Mall. The Green Service Mall provides a service repository that supports all service phases from discovery to invocation and is accessible online.

The registration of external and internal services at runtime permits the development of services that are not available in the stock version of the CEMIS. It is also possible to change or update services at runtime without changing non-involved services and without the need to shut down the whole system. This concept features high flexibility paired with a highly integrative character. Moreover, embedding environmental considerations into any desired business processes allows for intermixed usage by self-hosted services, non-environmental services (such as transforming data into reports), and external service providers.

The Workflow Engine allows users to combine services and processes to create workflows using a graphical editor and manages the execution of workflows. "Execution" means starting, pausing, and stopping workflows, including the persistence of data and the actual workflow state. The engine enables internal business processes of an organization to discover and invoke Green Web Services, regardless of their origin (internal or external service provider). Due to various heterogeneous data, the architecture supports different kinds of database technologies,

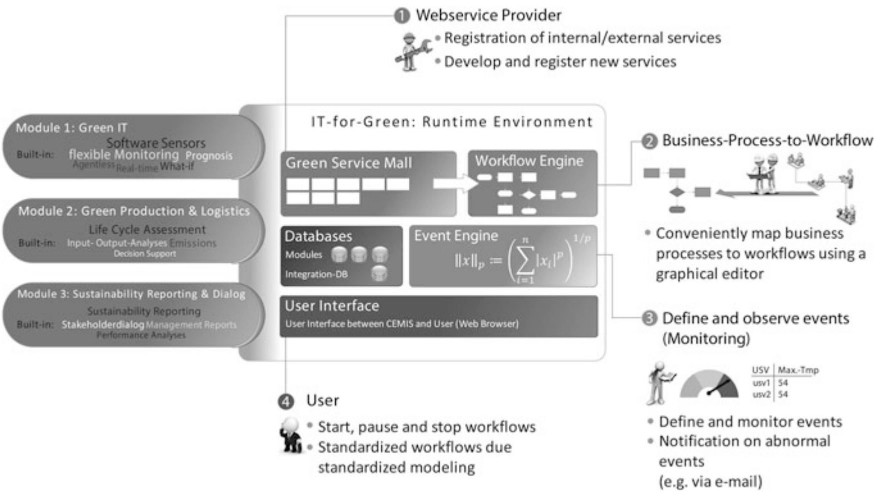

Fig. 3 CEMIS schematic diagram

such as relational databases or document-oriented databases (such as XML based databases). The Event Engine allows monitoring and ad hoc reporting of events by continuously comparing current states of user-selected indicators with “regular” behavior. Regular behavior in the current implementation is inferred from historical data, but can also be inferred from more complex methodologies (implemented as Web Services). If a collected data point varies significantly from historical means, predefined events may be triggered (e.g., sending a text message to a decision maker if the carbon footprint of a specific product is too high).

The user interface of the runtime environment visualizes the software and allows user interaction via a web browser. This means that the interaction is platform-independent and also that integration of an optimized mobile-device interface is possible. Interaction between a user and the runtime environment can be divided in two parts: the interaction between a user and the runtime environment itself and the interaction between a user and workflows. The interaction between a user and the runtime environment was implemented as a web application. The interaction between a user and a workflow needs more flexibility and is even more complex. We integrated a state-chart-based annotation language (SCXML) and extended the language with custom interaction elements (interaction states). Workflows are technically SCXML Documents which define service calls and the custom interaction elements. These custom interaction elements provide the possibility to render client-side HTML elements (or scripts such as JavaScript). This offers the opportunity to combine service calls with user-driven interaction in a flexible manner. Authorizations for specific functions (e.g., service calls, workflow execution) can be granted by using the rights and role system that is responsible for issuing permissions. The rights and role system does not restrict access to individual services, it hides the information from the unauthorized users (or groups) instead.

Table 4 Statements on the success factors and problem areas in consortium research

Success factors and problem areas	Central statements of the interviewees
Time arrangements	Major concern prior to the project, time problems especially with high-ranking dialogue partners
Cooperation based on mutual trust	Trust through: insight into one's own data, business processes, mutual benefits, secrecy, addressing of problems, anonymization
Goal setting/objective	A cooperative attitude on the part of project management is of central significance The importance of the various ways of transferring knowledge (publications, programming/development of artifacts, organization of conferences) within different groups (professors, employees, practitioners) must be respected The heterogeneity of the partners leads to different expectations, goals, and needs Practitioners prefer solutions to a specific problem, they are not interested in abstractions Scientific goal-setting should be viewed in an abstract way; the main focus is not on the identification of solutions for individual problems, but on finding universal solutions valid for a defined group of objects The central idea and the milestones for the achievement of the goals need to be recognizable Goals should be categorized in "must-be", "should-be", and "optional ("nice-to-have")"
Scope of action/access to resources	A realistic assessment of the partners' resources is difficult (software environment, external service provider, access to data) Projects that are classified as business-critical (e.g., hazardous materials) are more likely to be avoided. Especially in the realm of sustainability, practitioners are careful with respect to their company's image Restrictions of the practitioners' scope of action and creativity must be taken into account
Disclosure of results	Especially in the field of sustainability, companies highlight cooperation with universities in their external communications Publication of the scientific results must be enabled by means of agreements with regard to confidentiality
Participants'skills	The varying skills of the participants, especially of programmers, moderators, and employees working conceptually, need to be recognized and valued. The choice of partners should be addressed systematically Support provided by moderators, external partners, service providers such as management consultancies, networking, and a moderation partner who can, as a person from outside, offer constructive criticism and express recommendations are all valuable Particularly among heterogeneous partners, skills and knowledge gaps can easily be detected
Application of methods	The scientific partners should complement each other in terms of methods (e.g., prototyping, evaluation research, empirical

(continued)

Table 4 (continued)

Success factors and problem areas	Central statements of the interviewees
	research) and share a common basis in terms of high-level scientific quality Practitioners should be integrated in the scientific work by means of practical methods (action and evaluation research)
Conceptualization and implementation	Purely scientific conceptualization is often not applicable in reality Practitioners should be integrated as early as the design phase by means of a proactive contribution of real data
Research capacity	Scientific research projects are sometimes given low priority by companies, which may lead to delays Practitioners reduce capacities in case success is not apparent (warning sign) Development of case studies by practitioners and application of the prototypes in reality. This is indeed a problem as action research consumes staff/resources and interferes with daily business
Communication/ organization	A central success factor is task-sharing among the partners There must be a two-way textual communication Clarity about communication even before the start of the project shapes expectations Contact persons need to be designated and reachable. A communication structure needs to be recognizable
Personal success and motivation	Intrinsic motivation for the project on the part of the practitioners is an important factor The benefits of the project results (e.g., business models, licensing models, spin-offs) should be discussed early on to enhance personal motivation Heterogeneity of the partners allows for creative problem-solving A project depends on the individual commitment of the participating parties Create personal successes for employees: newly acquired methodological and technical skills, experiences in cooperating with practitioners, an opportunity to get away from the everyday routine at the university and the company

7 Lessons Learned and Implications for Theory and Practice

Prior to this contribution, 11 researchers of the IT-for-Green consortium research project were surveyed as to their experiences, and as a result, 11 success factors and problem areas for consortium research were identified. Table 4 shows the interviewees' central statements. The success of the project is reflected in particular by positive statements made by the practitioners.

8 Conclusions

The results of the literature reviews, the expert interviews, and the industry workshops in the project IT-for-Green made clear that there is a shortage of scientifically sound and practically tested concepts as well as maturity and reference models (best practices) that support sustainable corporate development on the basis of CEMIS 2.0. The currently available CEMIS almost exclusively serve to establish conformity with the environmental legislation relevant in a particular case (end-of-pipe solutions). Economic, ecological, and social performance factors (key performance indicators), that is, the environmental performance of companies, are accordingly documented only ex-post.

In addition, there is a lack of adequate control mechanisms in practice that render transparent and monitor the cause-effect relationships between economic, ecological, and social key performance indicators and that control the measures for the realization of the objectives of sustainable corporate development on the basis of CEMIS 2.0.

A first step toward realization of CEMIS 2.0 has been taken by means of the reference architecture at hand.

The experiences, success factors, and problems (lessons learned) discussed in this paper show current challenges of consortium research for future projects in the realm of CEMIS 2.0.

Acknowledgments The authors thank Marita Imhorst, Florian Stiel, Matthias Gräuler, Sebastian van Vliet, and Andreas Solsbach for their effective support. This paper was created within the scope of the "IT-for-Green: energy and resource management with CEMIS 2.0" project. The project is funded by the European Fund for Regional Development (project no. W/A III 80119242).

References

1. IT-for-Green project. http://www.it-for-green.eu
2. Melville, N.P.: Information systems innovation for environmental sustainability. MIS. Q. **34**, 1–21 (2010)
3. Watson, R.T., Boudreau, M.-C., Chen, A.J.: Information systems and environmentally sustainable development: energy informatics and new directions for the IS community. Manag. Inf. Syst. Q. **34**, 23–38 (2010)
4. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. MIS. Q. **28**, 75–105 (2004)
5. European Research and Transfer Network for Environmental Management Information Systems (ertemis). http://www.ertemis.eu/ertemis/
6. Rautenstrauch, C.: Betriebliche Umweltinformationssysteme: Grundlagen, Konzepte und Systeme. Springer, Berlin (1999)
7. Loos, P., Nebel, W., Gómez, M.J., Hasan, H., Watson, R.T., vom Brocke, J., Seidel, S., Recker, J.: Green IT: a matter of business and information systems engineering? Bus. Inf. Syst. Eng **3**, 245–252 (2011)

8. El-Gayar, O., Fritz, B.D.: Environmental management information systems (EMIS) for sustainable development: a conceptual overview. Commun. Assoc. Inf. Syst. **17**, 756–784 (2006)
9. Teuteberg, F., Gómez, J.C.M. (eds.): Corporate environmental management information systems: advancements and trends. Business Science Reference, Hershey, PA, USA (2010)
10. Teuteberg, F., Straßenburg, J.: State of the art and future research in environmental management information systems—a systematic literature review. Information Technologies in Environmental Engineering I, pp. 64–77. Springer, Berlin (2009)
11. Isenmann, R., Arndt, H.-K., Bey, C., Gómez, J.M., Solsbach, A.: XBRL-Taxonomie für Nachhaltigkeitsberichte—Vorschlag einer harmonisierten Dokumentstruktur zur Online-Kommunikation von Organisationen. In: Bichler, M., Hess, T., Krcmar, H., Lechner, U., Matthes, F., Picot, A., Speitkamp, B., Wolf, P. (eds.) Multikonferenz Wirtschaftsinformatik 2008, pp. 601–613. GITO, Berlin (2008)
12. vom Brocke, J., Simons, A., Niehaves, B., Reimer, K., Plattfaut, R., Cleven, A.: Reconstructing the giant: on the importance of rigour in documenting the literature search process. Proceedings of the European Conference on Information Systems, pp. 2206–2217, Verona (2009)
13. Webster, J., Watson, R.T.: Analyzing the past to prepare for the future: writing a literature review. Manag. Inf. Syst. Q. **26**, 13–23 (2002)
14. Baker, M.J.: Writing a Literature Review. Mark. Rev. **1**, 219–247 (2000)
15. Lang-Koetz, C., Heubach, D.: Stand des Umweltcontrolling und dessen Softwareunterstützung in der Industrie Ergebnisse einer Umfrage unter produzierenden Unternehmen in Baden-Württemberg. Fraunhofer-Gesellschaft, Stuttgart (2004)
16. Isenmann, R., Rautenstrauch, C.: Horizontale und vertikale Integration Betrieblicher Umweltinformationssysteme (BUIS) in Betriebswirtschaftliche Anwendungsszenarien. uwf—Umweltwirtschaftsforum. **15**, 75–81 (2007)
17. Krcmar, H., Dold, G., Fischer, H., Strobel, M., Seifert, E.K.: Informationssysteme für das Umweltmanagement: das Referenzmodell ECO-Integral. Oldenbourg, München (2000)
18. Rautenstrauch, C.: Fachkonzept für ein integriertes Produktions-, Recyclingplanungs- und Steuerungssystem (PRPS-system. de Gruyter, W. Berlin, New York (1997)
19. Bullinger, H.-J.: Auftragsabwicklung optimieren nach Umwelt- und Kostenzielen: OPUS—Organisationsmodelle und Informationssysteme für einen produktionsintegrierten Umweltschutz. Springer, Berlin u.a (2000)
20. Memari, A., Wagner vom Berg, B., Marx Gómez, J.: An agent-based framework for adaptive sustainable transportation. Paper presented at the WETICE 2011: 20th IEEE International Conference on Collaboration Technologies and Infrastructures (2011)
21. Mahmoud, T.: CEMIS next generation supported by semantic enterprise service-oriented architecture. International Conference on Web Information Systems and Technologies 1–10 (2013)
22. Mahmoud, T., Marx Gómez, J., Rezgui, A., Peters, D., Solsbach, A.: Enhanced (BI) systems with on-demand data based on semantic-enabled enterprise (SOA). In: Proceedings of the 20th European Conference on Information Systems, Paper 184, Barcelona, Spain (2012)
23. Rapp, B., Bremer, J.: Design of an event engine for next generation CEMIS: a use case. In: Arndt, H.-K., Knetsch, G., Pillmann, W. (eds.) Man, Environment, Bauhaus: Light up the Ideas of Environmental Informatics. 26th International Conference on Informatics for Environmental Protection. pp. 759–766. Shaker, Aachen (2012)
24. Frehe, V., Stiel, F., Teuteberg, F.: Web-portal und Reifegradmodell für ein Benchmarking des betrieblichen Umweltmanagements. Informatik (2013)
25. Gräuler, M., Teuteberg, F.: Experimental evaluation of a process benchmarking tool in a green business process management context. In: Proceedings der Wirtschaftsinformatik, Leipzig (2013)
26. Vornberger, J., Nebel, W.: Systematic Server-Level Profiling of a Data Center: Methodology and Empirical Data. Tagung der Fachgr. Betriebliche Umweltinformationssysteme der Gesellschaft für Inform. e.V. (2013)

27. Memari, A., Vornberger, J., Marx Gómez, J., Nebel, W.: A data center simulation framework based on an ontological foundation. Research Report, Oldenburg University (2014)
28. Stiel, F., Teuteberg, F.: Towards a conceptual framwork for life cycle assessment in sustainable information systems management. In: Proceedings of the 21st European Conference on Information Systems (ECIS 2013), Utrecht (2013)
29. Gössling, H., Hausmann, M., Renatus, F., Uphoff, K., Geldermann, J.: Praxisorientierte Entwicklung einer Ökobilanzierungssoftware für KMU. Tagung der Fachgr. Betriebliche Umweltinformationssysteme der Gesellschaft für Inform. e.V. (2013)
30. Solsbach, A., Lipnitskaya, S., van Vliet, S.: Internetbasierte Nachhaltigkeitsbericht-erstattung im Kontext des Umwelt-, Energie- und Ressourcenmanagements mit BUIS der nächsten Generation. In: Marx Gómez, J.M., Lang, C., Wohlgemuth, V. (eds.) IT-gestütztes Ressourcen- und Energiemanagement. Konferenzband zu den 5. BUIS-Tagen, pp. 421–431 (2013)
31. Gräuler, M., Freundlieb, M., Ortwerth, K., Teuteberg, F.: Understanding the beliefs, actions and outcomes of sustainability reporting: an experimental approach. Inf. Syst. Front. **15**, 779–797 (2013)
32. Teuteberg, F., Martens, B.: CloudServiceMarket: Klassifizieren und Bewerten von Cloud Computing Service auf der Basis von Künstlichen Neuronalen Netzen. GI-Jahrestagung. (2012)
33. Martens, B., Teuteberg, F., Gräuler, M.: Datenbank und Reifegradmodell für die Auswahl und Bewertung von Cloud-Computing-Services. HMD-Praxis der Wirtschaftsinformatik. Cloud Comput **47**, 52–61 (2010)
34. Walterbusch, M., Grove, S., Breitschwerdt, R.: Case-based selection of business process modeling tools: an evaluation criteria framework. In: Proceedings of the 19th Americas Conference on Information Systems, pp. 1–10 (2013)
35. Freundlieb, M., Teuteberg, F.: Augmented sustainability reports: a design science approach. AIS Trans. Human-Comput. Interact. **4**, 230–247 (2012)
36. Wittstruck, D., Teuteberg, F.: Towards a holistic approach for sustainable partner selection in the electrics and electronics industry. In: Proceedings of the IFIP 8.6 Working Conference (2011)
37. Wittstruck, D., Teuteberg, F.: Integrating the concept of sustainability into the partner selection process: a fuzzy-AHP-TOPSIS approach. Int. J. Logist. Syst. Manag. **12**, 195–226 (2012)
38. Freundlieb, M., Teuteberg, F.: Evaluating the quality of web based sustainability reports: a multi-method framework. In: Proceedings of the 45th Hawaii International Conference on System Sciences, pp. 1177–1186, Maui, Hawaii, USA (2012)
39. Wittstruck, D., Teuteberg, F.: Development and simulation of a balanced scorecard for sustainable supply chain management—a system dynamics approach. In: Proceedings of the 10th International Conference on Wirtschaftsinformatik, Zürich, pp. 332–341 (2011)
40. Lang, C., Steinfeldt, M., Loew, T., Beucker, S., Heubach, D., Keil, M.: Konzepte zur Einführung und Anwendung von Umweltcontrollinginstrumenten in Unternehmen: Endbericht des Forschungsprojekts INTUS. http://www.innovation.iao.fraunhofer.de/fhg/Images/EndberichtForschungsprojektINTUS_tcm124-69767.pdf; Zugriff am 27 April 2010
41. Lang, C.V.: Konzeption eines Referenzmodells für betriebliche Umweltinformationssysteme im Bereich der innerbetrieblichen Logistik. Shaker, Aachen (2007)
42. Rizzoli, A.E., Montemanni, R., Bettoni, A., Canetta, L.: Software support for sustainable supply chain configuration and management. In: Hilty, L.M., Aebischer, B. (eds.) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing, vol. 310, pp. 271–283. Springer, Switzerland (2015)