AN INFORMATION SYSTEM DESIGN THEORY FOR GREEN INFORMATION SYSTEMS FOR SUSTAINABILITY REPORTING - INTEGRATING THEORY WITH EVIDENCE FROM MULTIPLE CASE STUDIES

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Abstract

Due to increasingly noticeable environmental impacts of business activities and consequently rising demands for environmental information by organizational stakeholders, reliable sustainability reporting (SR) is ever more important for firms. As the task of detailed sustainability reporting is complex and involves gathering and processing of a considerable amount of data, green information systems (Green IS) are seen as suitable to support this task. While some Green IS for SR are commercially available, their adoption is low. One reason is that there is a lack of knowledge of how to design these IS. This paper seeks to provide guidance for the design of Green IS for SR by suggesting an information system design theory (ISDT), which is a set of primarily prescriptive statements describing how to construct the class of Green IS for SR. Therefore, we synthesize knowledge gained from organizational and management theories with insights from 29 case studies conducted in a variety of industries. In result we derived a specific ISDT for Green IS for SR, that contributes to solve the trade-offs between environmental data transparency, complexity and data collection effort. Thus, the proposed ISDT paves the way for future improved Green IS for SR and sustainable development.

Keywords: Green Information Systems, Sustainability reporting, Environmental management informations systems, Design Science, Information System Design Theory.

1 Introduction

There is a wide consensus to limit the increase of the global mean temperature beneath the threshold of 2ºC above pre-industrial levels to avoid "*dangerous anthropogenic interference with the climate system*" (UNFCCC 1992). In order to stabilize CO_2 concentration at this level, until 2050 emissions have to be reduced to around 80 - 95 % below the level of 1990 (IPCC 2007; Stern 2007). The information system (IS) discipline has been slow to acknowledge the problem of global warming and to move into this direction (Watson et al. 2010). However, since Watson et al.'s (2010) and Melville's (2010) important contributions Green IS is gaining increasing attention and traction within IS research. Green IS is defined as the use of IS or IT to achieve environmental sustainability (Chen et al. 2008) and has emerged as a key strategic field in IS research as it is considered as a "*change actant in sustainability innovation*" (Bengtsson and Ågerfalk 2011, p. 96).

A major task of Green IS is supporting the process of organizational sustainability reporting (see Teuteberg and Straßenburg 2009 for a literature review). Sustainability reporting (SR) comprises the integrated disclosure of economic, ecologic and social performance of a firm to its stakeholders (Global Reporting Initiative (GRI) 2014). While economic and social data is present in business IS (e.g. revenues, workforce), data regarding environmental impacts are often "*not digitized*" (Melville and Whisnant 2012) and are only available on high aggregation levels. For instance, paper-based annual electricity invoices regularly serve as foundation for sustainability reporting omitting valuable information necessary to establish an in-depth understanding of the data. Moreover, environmental indicator data is mostly treated like overhead costs, resulting in average values that make sustainability reports vague and advanced environmental sense-making impossible. Therefore, environmental data needs to be identified, collected and/or calculated by either direct measurement (e.g. digital electricity meters) or calculation to provide related key performance indicators (KPI) separately (GRI 2014). Such calculations are carried out by multiplying business activity data (e.g., fuel consumption) with environmental impact factors (e.g. carbon dioxide emission per one litre of fuel), which both needs to be determined prior to indicator distribution. Green IS support these tasks as their purpose is to "*systematically obtaining, processing and making environmentally relevant information available"* (Page und Rautenstrauch 2001, p. 5). However, the diffusion in practice is low (Junker 2010), since existing Green IS for sustainability reporting used in organizations are not particularly innovative, have limited integration capabilities, and often do not provide environmental data in the required level of detail (Melville and Whisnant 2012; Hilpert et al. 2014). Melville (2010, p. 11) accordingly contends that "*there is a lack of knowledge regarding how to design such systems and design science research could shed light on these issues*". Recent design science research (DSR) emphasizes the role of information system design theories (ISDT) (Kuechler and Vaishnavi 2012; Gregor and Jones 2007), which provide a set of primarily prescriptive statements describing how a class of artifacts should be constructed and how these artifacts should behave (Gregor and Jones 2007). Therefore, particularly in an emergent field as Green IS an ISDT is important to offer theory-based guidance for the design of Green IS to researchers and practitioners alike.

In the following, we focus on developing an ISDT for Green IS for SR in organizational contexts for two reasons. First, the class of Green IS is particularly important when it comes to organizational sustainability transformations. Organizational decision-makers need information about environmental indicator data, before they can take action towards more sustainable business practices (Loos et al. 2011; Choo 2006; Butler 2011). Second, using an ISDT as described in our study helps researchers and practitioners to build Green IS more effectively and efficiently. The proposed ISDT is based on organizational theory, management science and findings of prior (Green) IS research. Unlike much DSR, the present study additionally integrates evidence from case studies of companies, who already report their sustainability performance to incorporate practitioners' point of views.

The remainder of the paper unfolds as follows: We first set out the background on Green IS for SR, Design Science Research (DSR) and the development and relevance of ISDTs. In the next section, we derive theory-based meta requirements and components. We then integrate the insights gained from 29 case studies, refining and developing meta requirements, a meta design, a design method and testable hypotheses. The paper concludes with a discussion of the key results, implications for further research, and recommendations for future research in DSR and Green IS.

2 Green IS for sustainability reporting

Green IS addresses questions related to IS adoption and usage of individuals, groups, organizations, and society that help eco-sustainable practices to emerge and diffuse (Dedrick 2010; Loos et al. 2011; Chen et al. 2010; Ijab et al. 2012). While Green IS cannot contribute directly to eco-sustainability, information systems can promote process changes enabling the emergence of greener business practices (Loos et al. 2011). The impacts of Green IS on eco-sustainability can be categorized in first order effects associated with direct environmental effects of IS/IT due to their physical existence and usage (“Green IT”), second order effects comprising indirect effects of IS/IT on eco-sustainability due to more sustainable business processes (“Green by IS”), and third order effects encompassing IS/IT-induced changes of behaviour towards more eco-sustainability (vom Brocke and Seidel 2012, pp. 296-297; Hilty et al. 2006, p. 1619).

Prior research on Green IS focused on conceptional pieces (e.g., Watson et al. 2010; Butler 2011; Pernici et al. 2012), case studies (e.g., Molla 2009; Seidel et al. 2010; Bengtsson and Ågerfalk 2011; Butler 2011; Ijab et al. 2012), or empirical research (e.g., Molla 2009; Kranz and Picot 2011; Schmidt et al. 2011; Wunderlich et al. 2013). The design science oriented papers in Green IS were predominantly argumentative- or conceptual-deductive analyses (e.g., Melville 2010; vom Brocke and Seidel 2012) or provide reference models (e.g., Flath et al. 2012; see Stolze et al. 2012 and Elliot 2011 for overviews). The subclass Green IS for SR refers to second and third order effects enabling more sustainable business processes and behavioural changes due to improved environmental reporting and management accounting. Existing research on Green IS for SR encompasses systematic literature reviews (Teuteberg and Straßenburg 2009), as well as conceptual frameworks, classifications and argumentative deductive analysis (Page and Rautenstrauch 2001; Wohlgemuth et al. 2005; Watson et al. 2010; Butler 2011). However, detailed and tangible functional requirements of Green IS for SR have not been proposed yet (Junker 2010). First efforts to develop artifacts (Isenmann et al. 2008; Marx Gomez 2011; Hilpert et al. 2013) and to incorporate requirements from practice have been made (Gräuler et al. 2012). However those are rather superficial to the class of Green IS of SR. Concrete requirements, design principles and guidance for the design of Green IS for SR are still missing.

Melville (2010, p. 14) argues that “*information systems are an important but inadequately understood weapon in the arsenal of organizations in their quest for environmental sustainability by enabling new practices and processes in support of belief formation, action formation, and outcome assessment*”. However, to date we know very little about how to design information systems that contribute to reconsider organizational strategies and actions and to assess their outcome. Thus, at this early stage Green IS for SR are especially important as precise and timely information on environmental impacts is prerequisite to make more informed and better decisions. Watson et al. (2012) therefore state that future Green IS research should design IS that support sense- and decision-making by the design of improved data capture, processing, and delivery systems. An important question is hence “*which functional affordances should deliberately be considered in the design of green information systems*” (Seidel et al. 2013). This study contributes to answer this question and formulates an ISDT for Green IS for sustainability reporting.

3 The Role of Information System Design Theories

The design science research paradigm increasingly diffuses into the global IS community (Winter 2008; Goes 2014) and is recognized as an “equal companion to behavioural science in the information system field” (March and Storey 2008, p. 1; Hevner 2007). DSR incorporates building and evaluating information system artifacts, using them for theorizing and knowledge creation (March and Smith 1995). DSR is motivated by business needs (relevance) and guided by theory (rigor) (Hevner 2004). March and Storey (2008) state that a design science research contribution needs to identify a relevant organizational IT problem and demonstrate that there is no adequate solution. Venable (2006, p. 185) defines a problem as a “perceived difference between what is and what should be”. Recent research has proposed guidelines for conducting and reporting DSR (Hevner et al. 2004; Peffers et al. 2007; March and Storey 2008; Aier and Fischer 2011; Kuechler and Vaishnavi 2012; Gregor and Hevner 2013) and propagated information system design theories and theorizing in DSR (Walls et al. 1992;

March and Smith 1995; Markus et al. 2002; Gregor 2002; Gregor and Jones 2007; Baskerville and Pries-Heje 2010).

ISDTs are well-known constructs in the DSR paradigm, comprising a set of primarily prescriptive and functional statements that describe and capture “how a class of artifacts behave” (Walls et al. 1992, p. 42) resulting in meta-requirements, meta design, design method, and testable design product hypotheses (Gregor and Jones 2007). Meta requirements are specific categories of user requirements, providing a solution for the perceived problem that is transformed into distinctive features of a system solution. The outcome of a system designed according to an ISDT can be evaluated by testable design hypotheses (Markus et al. 2002). Hence, an ISDT can be characterized as a theory for design and action (Jones and Gregor 2004; Gregor 2006) providing a concept that addresses the gap between what is and what should be (Aier and Fischer 2011; Venable 2006).

Based on an ISDT, artifact instances pertaining to a particular class of information systems can be developed. Typically, an ISDT is derived from kernel theories from social, design, or natural sciences (Walls et al. 1992). Kernel theories inform the entire DSR process leading to meta requirements for the construction process that are related to functional affordances (Kuechler and Vaishnavi 2012). Criteria for the evaluation of DSR artifacts have been defined by March and Smith (1995) and Aier et al. (2011). Furthermore, single stakeholders of the artifact with goals should agree on the utility of resulting artifacts (Aier and Fischer 2011).

To develop an ISDT for the class of Green IS for SR we apply an iterative development cycle building upon and further developing Markus et al.’s recommendations (2002). As depicted in figure 2 the cycle is comprised of four steps: (1) Identify kernel theories and build theory-based ISDT, (2) refine ISDT based on insights from business practice, (3) construct the artifact, and (4) evaluate the artifact. In contrast to Markus et al. (2002) we include an interim step (step 2) to enrich theory-based insights by practitioner’s knowledge. The rationales are that, similar to action design research (Sein et al. 2011) practitioners have considerable knowledge in relation to the problem space, leading to a more practice-oriented and relevant ISDT (Sarker and Lee 2002). According to Walls et al. (1992) an ISDT comprises several components that can only be obtained by practitioner experience such as design methods. Owing to the page restrictions, we focus on the first and second step in this paper. The third and fourth step of our iterative development cycle, building an evaluating an artifact based on this ISDT is currently in progress and will be explained briefly in the discussion.

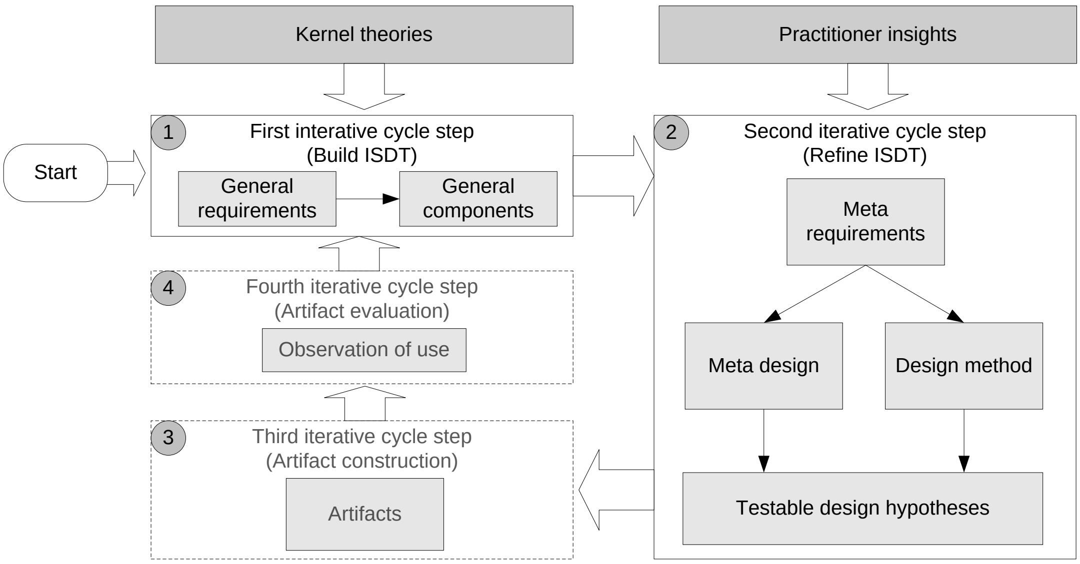

Figure 1. Iterative ISDT development cycle

4 Theory-informed ISDT (Step 1)

Drawing on organizational theory and management science, Choo (2006) describes how organizations interpret information on the corporate environment to understand what is happening and how the organization may respond to changes in the environment. Using well-documented case studies, he argues that organizations process and analyse information to decide for suitable courses of action with regard to an organization's strategy, processes, and products. Based on the experiences and results emerging from a decision, organizations learn and acquire new knowledge and capabilities. However, Choo (2006) provides evidence that many organizations rely on established decision making routines rather than seeking to gather and incorporate new information from multiple sources. This is dangerous since the implication of missing important signals could be harmful for an organization's survival. Consequently, acquiring information and interpreting this information is vital as "we need to know 'what is going on and why' before we are able to decide 'what is to be done'" (Choo 2006, p. 310).

As environmental sustainability information is often complex and equivocal (Butler 2011), information systems are needed that "*create an actionable context in which organizations can engage in a sense-making process related to understanding emerging environmental requirements*" (Seidel et al. 2013). Thus, a core affordance of Green IS is to enable and foster organizations' sense-making capabilities regarding environmental sustainability as the outcome quality of the downstream processes, i.e. decision-making and knowledge-creation, and organizational sustainability outcomes depend on understanding the problem's issue comprehensively (see figure 2). Therefore, Green IS for SR needs to provide organizational stakeholders with "base data for measuring an environmental state" (Watson et al. 2012, p. 11) and tools for gathering, analysing, and interpreting this information.

Prior IS literature has identified two imperatives for IS supporting organizational sense-making: *reflective disclosure* and *information democratization* (Seidel et al. 2013). Reflective disclosure refers to the Green IS capabilities of monitoring, analysing, and presenting information in relation to environmental impact data. Hence, reflective disclosure plays an essential role for the formation of beliefs and actions and the assessment of outcomes of new practices and processes (see Melville 2010; Seidel et al. 2013). Green IS, which support employees to access information and to interact with others regarding issues concerning environmental sustainability, allow for information democratization (Seidel et al. 2013). This affordance enables employees to engage and participate in decisions and actions pertaining to organizational sustainability transformations.

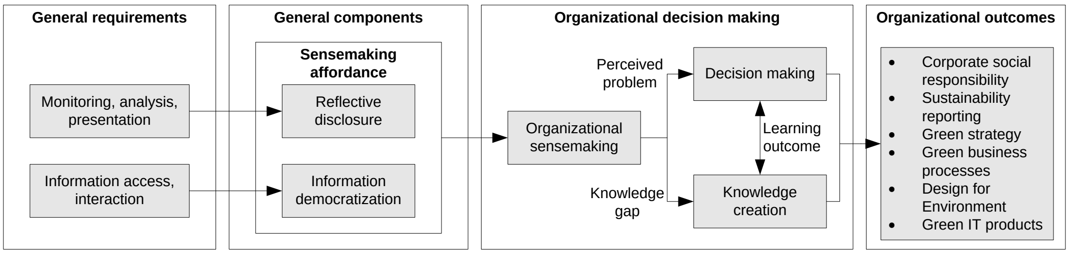

Figure 2. Green IS and the process of sustainable sense-making and sustainable practicing (adapted from Butler 2011 and Seidel et al. 2013)

For acquiring and monitoring environmental indicator data in a reliable and economic way sensor networks (set of spatially distributed devices reporting the status of a physical item or environmental condition, e.g. monitoring air composition) and sensitized objects (physical good sensing and reporting data about its use, e.g. appliance reporting power consumption) are vital (Watson et al. 2010). Information systems need to collect and store the information gathered by sensor networks and sensitized objects and supply this information to organizational stakeholders so they can make use of this information (Watson et al. 2010). A Green IS thus needs to have a component that helps users exploring the data and understanding the reasons and causal relationships between the data and the factors that actually influence the extent of environmental impacts. To avoid ambiguity and uncertainties of environmental indicator data and to satisfy employees' information needs the information provided to organizational stakeholders should fulfil the requirements concerning (1) ubiquity (access to information unconstrained by time and location), (2) uniqueness (exactly knowing the location and characteristics of an entity), (3) unison (information consistency), and (4) universality (avoiding incompatibilities) (Junglas and Watson 2006; Watson et al. 2011). The resulting theory-based meta requirements and components are summarized in figure 3.

Theory-based general requirements

GR 1: Green IS for SR need to collect and store information about environmental impacts.
GR 2: Green IS for SR need to support reconsidering the formation of beliefs and actions as well as the assessment of outcome related to business practices.
GR 3: Green IS For SR need to support organizational sense-making by dissemination of information and interaction.

Theory-based general components

GC 1: Sensor networks and sensitized objects that monitor and manage physical assets.
GC 2: A component that collects environmental indicator data from sensor networks and sensitized objects.
GC 3: A component that allows analyzing and interpreting environmental indicator data on different aggregation levels.
GC 4: A component that allows employees to communicate and interact with environmental information.
GC 5: Features that support exporting and exchanging environmental indicator data in human- and machine readable formats.

Figure 3. Theory-based general requirements and components of Green IS

5 Practice-informed ISDT (Step 2)

To enrich the requirements resulting from theory, we employed a multi-case-study approach to explore the understudied phenomena of Green IS for SR in depth (Yin 2009). Out of all companies that disclosed sustainability reports according to the GRI standard located in Germany in the year 2013 (n = 109), 29 companies agreed to participate in the study (response rate: 26 %). The rationale of choosing this sample was that firms voluntarily reporting their performance in terms of eco-sustainability have greater knowledge and experience concerning the affordances on Green IS for SR. The final sample includes firms varying in size and sectors as summarized in table 1.

	No. of employees			
Sector	**< 1,000**	**1,000 - 10,000**	**> 10,000**	**Sum**
Financial Services	3	3	1	**7**
Consumer Goods	1	1	3	**5**
Energy Utility	1	1	2	**4**
Healthcare	-	-	1	**1**
Manufacturing	-	4	3	**7**
Other	3	-	2	**5**
Sum	**8**	**9**	**12**	**29**

Table 1. Sample characteristics

We conducted semi-structured, exploratory interviews with chief sustainability officers (n = 10), heads of division for corporate sustainability and IT (n = 8), managing directors for corporate sustainability (n = 7), and heads of corporate sustainability communication (n = 4) having several years of experience in the field. The interviews were conducted via telephone and lasted 32 to 67 minutes (median: 41 minutes). Preliminary to the interviews, a short overview of the research goals and main questions was sent to the participants to give them the opportunity to prepare themselves. The interviews sought to explore the current usage of Green IS to collect, process, and report environmental indicator data, if and how this data is exchanged between corporate IS as well as requirements on Green IS for SR. Further, we triangulated the data by scrutinizing firms' sustainability reports to identify KPIs, sustainability management approaches and IS used in the reporting process.

The data analysis has been executed using the approach of structured content analysis by Mayring (2000). The approach is used to filter certain aspects of the collected data and to evaluate it in terms of these criteria in several steps: Our coding approach started with an initial set of constructs from prior theorizing, using knowledge from existent literature on Green IS for SR and its required capabilities. Then, the interviews were taped, transcribed and coded as well as paraphrased and shortened with regard to the requirements and possible design methods, using the software ATLAS.ti. In the further analysis, the results and findings were translated from German into English using constant contextual comparisons during the analysis (Suh et al. 2009). In a following step, we derived a category system with mutually exclusive categories from the kernel theories and identified a typical example for each category. We then agreed on rules for coding in order to ensure correct classification of interviewee statements. In the next steps, we went through the material and merged similar parts and the corresponding codes. Finally, we connected the codes with the general requirements and components identified in the literature. In a following step, all interviewee statements were sent to the participants for validation and confirmation. Since we selected the units of analysis purposively (literal replication strategy) the case studies are expected to provide similar findings. To ensure valid and reliable results, we followed the recommendations of Yin (2009): To establish construct validity we used data triangulation analysing multiple sources of evidence (sustainability reports). Internal validity was addressed through pattern-matching and by considering rival explanations while external validity was established using theories in the case studies. The reliability of findings was addressed by using case study protocols and by setting up a database of research artifacts.

In the following, we describe the resulting ISDT including its four components, which are meta requirements, meta design, design method, and testable hypotheses.

5.1 Meta requirements

Typically, requirements are divided into functional and non-functional requirements (Jones and Gregor 2004). However, we do not divide the requirements into functional or non-functional, because we argue that this distinction is often not very selective. We rather separate the requirements by the stages of data input, processing, and output (IPO) and structured the semi-structured interviews in the same way. Each requirement emerging from the multiple case studies is summarized briefly in table 2 and will be explained in more detail. Further, it is denoted if the requirements mentioned by the interviewees is in line with general requirements and components derived from kernel theories. To ensure generalizability of the meta requirements we omit requirements that were not at least mentioned by a third of interviewees as well as general requirements that are not specific to Green IS for SR (e.g. data storage, usability).

Meta requirement	Explanation	Derived by	
		Kernel theories	Expert insights
IPO Stage: Data Collection (I)			
Ubiquitous delegated data collection	A flexible environmental data collection, which enables task delegation to causing business units as well as re-delegations within business units and which is accessible by every used device ubiquitously to collect and monitor business activity, flow and environmental impact data.	X	23
Data transparency	Features that enable to enrich captured environmental relevant data with additional information about data type and origin as well as collection proofs.		18
Data validation	An automated environmental relevant data validation at data collection level.		17
Automated input interfaces	Interfaces that enable collecting environmental impact and business activity data from existent business information systems automatically.		10

IPO Stage: Data Processing (P)			
Data interpretation	A module that enables users to make sense of the stored environmental data and KPIs and offers additional transparency information according to time, technology and location on an arbitrary aggregation level.	X	15
Evaluation and plausibility	A module that enables users to evaluate collected environmental data, using transparency information according to time, technology and location on freely selectable aggregation level as well as plausibility assessments within and across business units on an arbitrary aggregation level.		20
Customizable and flexible information patterns	A module that enables the creation, maintenance and customization of different information processing and distribution patterns to cope with different business needs and changing information processing and distribution requirements.		17
IPO Stage: Information output (O)			
Environmental indicator distribution	A module to provide environmental indicator data to different internal and external stakeholders in different level of details dependent on the intended usage.	X	29

Table 2. Meta requirements

The first design principle that is derived from kernel theories is *'ubiquitous data collection'*. As the environmental impacts often occur in globally dispersed business sites or units, this data often needs to be collected directly where it emerges and needs to accessible in a ubiquitous manner.

> *"The responsible facility manager visits the plant on a regular basis and reads out the actual count of the meter. This data is recorded in some way and is sent to the central sustainability business unit via e-mail on demand." (Energy utility company B)*

As the experts stated that much of the environmental data is collected locally, a Green IS for SR needs to be able to delegate the collection task to specific business units as well as to enable re-delegating within and across business units. The rationale is that coordinators often do not know who is responsible at a specific location and can provide the necessary information. Therefore a tracked re-delegation enables to gather data, while the coordinator must not exactly know the right person. However, while not knowing the responsible persons in different business units a priori, experts state that knowing the type (primary / secondary data) and collection method (e.g. estimated, calculated by input/output tables or measured by sensors) of data is crucial but often unclear. Thus *'data transparency'* is prerequisite in order to verify and make sense of provided environmental data. Thus, increasing the reliability through additional information about data type and collection method as well as proofing documents (e.g. copy of energy invoices or calculations) is vital for detailed and reliable sustainability reporting. In the stage of data input, we identified an additional requirement based on the case studies that could not be derived by kernel theories, namely *'Data validation'*. This component helps reducing human mistakes in the data collection process:

> *"Such an IS needs to control user inputs comprehensively and has to define clearly the meaning of values. A responsible data collection person often does not see the difference between zero, which means we have no emissions and NULL, meaning that no data is available. The IS should check automatically if data input mistakes have been made." (Manufacturing company A)*

As often mentioned by prior literature (Gräuler et al. 2012), we also gained insights about '*automated input interfaces*' for data collection. Another requirement has been stated in the interviews:

> *"The amount of environmental data from different sources gets almost infinite, thus we desperately seek for options to integrate data automatically from our business IS, hoping that automated data collection processes reduce the enormous daily effort." (Consumer goods company C)*

While some companies see enormous benefits in terms of reducing manual data collection inaccuracies (Energy utility company B), others state that automatic data collection decreases the transparency as it increases the effort of plausibility checks (Other Sector company E). Further, environmental data and the IS that keep this data are highly heterogeneous. For this reason, the effort for implementing an interface can be very high. Therefore, interviewees contend that the usefulness of automated data collection interfaces depend on the cost-benefit ratio. If an interface is used only once in a year to report a specific single KPI the necessary effort is too high. Thus, only ten participants state that *'automated input interfaces'* in the data collection stage are a major requirement. Eight participants mentioned it as a requirement if the cost-benefit ratio is less or equal one. Additional to the requirements in the data collection stage, we refined the data processing requirements and expand them with additional insights. *'Data interpretation'* has already been derived by kernel theories as Choo (2006) proposes to support sense-making. One interviewee stated that:

> *"A lower aggregation level of data collection, e.g. on floor level of a building, and a higher frequency than once in a year would enable to really understand how and why the energy consumption increased and which environmental pollution is caused. This knowledge could be used to reduce the environmental impact of single objects and to increase the sustainability performance." (Financial Services company A)*

Whilst already known requirements of decision-support, this comment shows another crucial aspect of Green IS for SR, also corroborating requirements from 'input stage': If Green IS for SR really tries to achieve change towards more sustainability, then it must enable stakeholders to make sense of environmental impacts on all levels of aggregation (e.g. on the level of specific machines, sites, or products) which is only possible if more detailed environmental data with additional information is gathered. Otherwise, a Green IS for SR does not provide an improvement compared to the actual state. (Also) related to sense-making, the requirement of *'Evaluation and plausibility'* has been mentioned as very relevant by 20 experts. Especially plausibility checks are seen as a major task for Green IS for SR. While also important for entering data, experts mentioned that they need plausibility and evaluation checking capabilities, especially for two signature evaluation rules and cross business unit evaluation cycles (Manufacturing company A), in which different business units need to evaluate the data. *'Customizable and open information processing patterns'* is an additional requirement that has been mentioned in 17 interviews as indicated by the following comment:

> *„As we have to provide our sustainability performance indicators to different stakeholders, who have different requirements in terms of data accuracy, scope and format, we needed an IS that supports different reporting standards. For instance, the yearly enterprise carbon emissions for our sustainability report are different to the more timely reports according to environmental legislations or internal KPIs. We need a software which allows us to use and change different standards freely." (Energy utility company C)*

Actual software tools do not support different information distribution patterns (e.g. GRI G4 or European Federation of Financial Analysts Societies) but rather focus on a specific pattern, e.g. the GRI reporting framework. If a company also wants to use the data for internal management accounting purposes, experts stated that their current Green IS would have to be modified considerably. Alternatively, if the current Green IS supports different standards, the integration effort is enormous.

5.2 Meta design

The meta design includes features and design principles that can help achieving the meta requirements. Green IS for SR need to enable task delegations as well as accessing and entering the indicator data ubiquitously. For that reason the *ubiquitous delegated data collection* needs to be developed as a distributed IS. To enable all employees to enter environmental data the module should provide a graphical user interface (GUI) that needs to follow the design principle of platform independency, thus also supporting mobile devices (e.g. tablets, smartphones), depending on the data collection staff workflows. Therefore the GUI should use cross-platform compatible user interface libraries, e.g. Sencha Touch or Ext JS. Establishing *data transparency* is important for Green IS for SR as it enables to verify data and increases information quality. The data's origin and plausibility cannot be assessed by sustainability managers and hence they often need to request additional information by e-mail which is inefficient. A possible solution in terms of the meta design is to include data collection templates (Hobbs and Israel 1994) that consist of information enrichment features such as commentary fields or file uploads. Using these templates, employees responsible for collecting data can provide additional information on technology, time or location (WBCSD 2010) that is related to the environmental impact. Thus, these mechanisms increase information density and subsequently information transparency. Another design principle in the context of data collection is data *validation*. As a Green IS for SR should be a distributed IS, client- and server-side validation frameworks may be used to check automatically for implausible data inputs. As mentioned above, a common error is that the respective unit is mistaken, e.g. energy consumption in gigajoule differs from gigawatts. Interoperability can be achieved by several interfaces with existent IS in the company. For instance, activity data of a production process is available in production planning systems, while operating data logging systems record machine cycles to calculate the energy consumption, using the operating time and energy consumption. Further EDI-compatible (electronic data interchange) interfaces (would) enable n-tier suppliers to provide their environmental impact data for delivered intermediate or finished goods.

The data processing of a Green IS is composed of two major modules for data *interpretation* and *evaluation*. In terms of data interpretation, the environmental impact as well as the related additional temporal, geographical and technological information needs to be accessible via the GUI. To make sense of the data, to support decision-making and evaluation, established design principles and features of decision support systems should be included in the design. These range from visualization (e.g. charts, geographic visualization), comparison and aggregation features to rule-systems, automated solving strategies for GHG emission minimization (Holsapple and Whinston 1996) and simulation algorithms (Wohlgemuth et al. 2005). For instance, the exact location and time of GHG emissions in road transportation, visualized with Google Maps®, may increase sense-making capabilities (Hilpert et al. 2013). In terms of plausibility checking, features and principles from workflow management systems should be encompassed. For instance, the plausibility check of environmental data involves staff in different business units, thus event-driven automated distribution processes and computer-aided assistance, e.g. by artificial intelligence algorithms, may enable and improve the plausibility workflows process. As several (in some cases frequently changing) information provision patterns have to be supported (e.g. GRI), the IS should be capable to import markup language-encoded patterns (XML, XBRL) to allow an easy use and customization (Isenmann et al. 2008). Finally, environmental information and indicators need to be distributed and shared to enable knowledge creation. For this reason, the Green IS should include common exchange and export formats and provide interactive collaboration features for discussion and knowledge sharing. The proposed meta design is summarized in table 3 and linked to the underlying meta requirements.

Features and design principles	**Meta requirements**
Distributed IS, cross-platform compatible user interface libraries	Ubiquitous delegated data collection
Information enrichment templates, additional file uploading	Data transparency
Client and server-side validation frameworks	Data validation
Business information system interfaces, operating data logging and EDI interfaces	Automated input interfaces
GUI, visualization, simulation, modelling and KPI decision support	Data interpretation module
Event-driven document workflow management, workflow assistance	Data evaluation and plausibility
Markup language-based patterns and stylesheet-based formatting	Custom. and flexible info. patterns
Standard exchange formats, interaction and collaboration features	Environmental indicator distribution

Table 3. ISDT meta design

5.3 Design method

The design method includes more specific practices that help to develop artifacts according to the ISDT. For the present study the following practices explained in table 4 were derived from the expert interviews.

Requirement	Practice	No. of references
Ubiquitous delegated data collection	• Locate and install environmental sensors within business processes having a major environmental impact. • Identify staff for data collection, adapt GUI to their work processes and IS equipment and allow delegating the collection task to them automatically.	15
Data transparency	• Identify additional quality data that describe the environmental impacts and when (time), where (location), and how (technology) they occurred and were measured. • Integrate additional quality information and assessment documents (e.g. pictures of meter read-outs or energy consumption bills) as mandatory within data collection processes.	11
Automated input interfaces	• Integrate IS that store or carry activity flow or environmental impact data for major environmental impacting business processes by interfaces.	10
Data validation algorithms	• Identify the major human-made errors in data collection process and implement according validation rules in client-side algorithms. • Provide training units concerning data quality to employees that are responsible for data collection and reporting.	12
Data interpretation	• Identify departments that need sense-making support for their task and integrate them in the development process to fulfil their specific needs by providing visualization, simulation and (dis-)aggregation modelling tools based on transparency information.	8
Data evaluation and plausibility	• Establish event-based plausibility checking workflows for increased data quality and support it with computer-aided workflow assistance in the Green IS.	11
Customizable and flexible information patterns	• Identify environmental information processing and distribution goals and include related default patterns from governmental and nongovernmental organizations. • Allow users copying, creating and modifying information processing patterns according to their needs.	9
Environmental indicator distribution	• Provide the functionality to view and export environmental information on all detail and aggregation levels to fulfil different stakeholder information usage behaviour. • Include features to foster stakeholders' interaction and knowledge (e.g. forums, blogging, or tagging) on sustainability topics.	17

Table 4. ISDT design method practices

5.4 Testable design hypotheses

In the last step of the ISDT development process we derive testable design hypotheses (see table 5). Testable design hypotheses can be distinguished into design product and design process hypotheses (Walls et al. 1992). While design product hypotheses allow testing if the meta design satisfies the meta-requirements, design process hypotheses are used to verify if the design methods can result in an artifact that is consistent with the meta design (Walls et al. 1992; Gregor and Jones 2007). These hypotheses can take the general form of utility description, whereas goals are proposed as contingencies (Aier and Fischer 2011; Gregor and Jones 2007). In general, testable design hypotheses are based on kernel theories (Walls et al. 1992). However, as we did not use kernel theories for the development of our ISDT only, but rather enrich the theory-based general requirements and components with insights from sustainability reporting experts, we provide hypotheses according to all elements of our ISDT. The resulting hypotheses are geared to the class of Green IS for SR. While qualitative tests can be made on this abstraction level, they should be parameterized for quantitative tests with artifacts that are based on this ISDT.

Hypothesis type	Hypotheses
Design product hypotheses	*H1$_{Product}$: The use of a distributed and platform independent data collection GUI increases the capability of employees to collect environmental data on business process level.*
	H2$_{Product}$: A data collection GUI with additional explanatory information regarding the environmental impact of business processes increases the quality of environmental indicators.
	H3$_{Product}$: The use of existing business information system interfaces for environmental impact data collection increases the accuracy of environmental indicators.
	H4$_{Product}$: Client- and server-side validation mechanisms in the data collection process decrease the amount of corrupt environmental data.
	H5$_{Product}$: Temporal, technological and geographical sense-making tools for environmental data analyses increase organizational stakeholders' decision-making capabilities.
	H6$_{Product}$: Workflow mechanisms for environmental data plausibility checks increase the correctness of environmental data in the collection process.
	H7$_{Product}$: XML-based environmental information pattern processing increases the flexibility of environmental indicator and report distribution.
	H8$_{Product}$: The use of standard exchange and export formats increase the distribution and democratization of environmental indicators and reports.
Design process hypotheses	*H1$_{Process}$: Aligning the distributed GUI to work practice and IS equipment of data collecting staff reduces the necessary effort in environmental data collection tasks.*
	H2$_{Process}$: Mandatory additional temporal, technological and geographical data increases coordinators' ability to make sense of data collection process and data origin.
	H3$_{Process}$: The use of existing business information system interfaces reduces the effort to collect data on the environmental impact in business processes.
	H4$_{Process}$: Observing the major human-made data input errors and train staff regarding this mistakes reduces the necessary effort to audit the correctness of environmental data.
	H5$_{Process}$: Providing aligned sense-making tools for decision-making reduces the environmental impact of single business processes due to improved environmental management accounting.
	H6$_{Process}$: Optimized plausibility workflows reduce the time for environmental report preparation and distribution.
	H7$_{Process}$: Flexible and customizable reporting patterns reduce the effort for environmental report preparation and distribution.
	H8$_{Process}$: Standardized distribution and democratization increase the knowledge about environmental impacts of organizational stakeholders.

Table 5. Design hypotheses for ISDT

6 Discussion and implications

We developed an ISDT for Green IS for SR according to Walls et al. (1992) using an iterative process proposed by Markus et al. (2002). Different to Markus et al. (2002) our ISDT uses both a theoretical lens for an initial design and a practical lens to refine the ISDT prior to artifact development. Our initial design was informed by key requirements and components from theories originating in organizational theory and management science (see Choo 2006; Butler 2011) as well as findings of prior IS research (Seidel et al. 2013; Watson et al. 2010; Junglas and Watson 2006). We enriched the theory-based requirements with evidence from 29 case studies which revealed further important instructions on meta requirements, design elements, and design methods.

Incorporating the expertise and experiences from experts in the domain of corporate sustainability and IS/IT was important to generate a comprehensive and relevant ISDT as we gained further valuable insights on common requirements or found additional ones. For instance, the usefulness of automated input interfaces depends on firm-specific data collection procedures. While such interfaces can reduce the efforts associated with data collection in one firm, they can increase the ambiguousness in other firms as no information on how the data is composed is available. The combined view on data transparency, validation, automation as well as interpretation points out the major trade-off within sustainability reporting, which is an unsolved problem and thus may be a reason for low adoption of Green IS for SR: Environmental performance information reflect new data types and sources that are complex to gather in business environments (Melville and Whisnant 2012). They mainly reflect environmental impact *'black boxes'* for the report coordinators and stakeholders (Callon 1986). Companies that are willing to report information in an appropriate level of detail are confronted with high efforts for data collection as they must open these *'black boxes'* (e.g. use primary measured data from sensors) to gain transparency instead of relying on average data from secondary life-cycle databases. As current Green IS for SR do not provide solutions for these contrasting interdependencies between transparency, effort and complexity, companies rely on secondary data and do not use specific Green IS for SR. Our ISDT explains how to solve the problem of environmental data transparency under given complexity, while reducing the necessary effort. The '*ubiquitous delegated data collection*' enables sustainability coordinators to assign the task to others without knowing *a priori* the relevant data collection rationales at a specific site, while being able to make sense of the data *ex post* in detail due to gathered transparency information. Vice versa, personnel responsible for data collection do not need to know the purpose of data or being experts in collection methods as they are guided by information enrichment and validation algorithms. Thus, our study contributes to defining the functional affordances in the design of Green IS (Seidel et al. 2013). The theory and practice informed ISDT extends our understanding how to open the environmental impact '*black boxes'* by achieving transparency while avoiding complexity and effort for data collection tasks. Thus, the unique contribution of this study is the task improvement by the specific combination of proposed requirements, principles and design methods.

However, the proposed ISDT has limitations that have to be considered carefully when building Green IS upon it. First, due to the interpretative nature of this research, it cannot be claimed that we captured all necessary requirements. Other researchers may have interpreted the qualitative data and the codes in a different way. However, we conducted the analysis and its description with great care employing data triangulation, involving two researchers that reviewed the data coding and analysis as well as engaging in consensus-building discussions. Further, we intentionally considered multiple perspectives and explanations. Second, an ISDT needs to be general enough to provide solutions for a class of information systems, while providing useful guidelines for designing a specific IS in this particular class. Thus, developing an ISDT always involves a trade-off between generalizability and specificity. As we focused on a generalized view (Weick 1989) future research can specify various components of the proposed ISDT with stand-alone ISDTs. For instance, the ubiquitous data collection module will comprise different components, e.g. a mobile application for reading out energy meter systems in production facilities (Wohlgemuth et al. 2010). Another example is the data interpretation module, which will comprise different decision support features each of which can have an own ISDT as well as separate artifacts. Therefore, further studies are needed that distinguish Green IS for SR into subclasses serving different groups of stakeholder and goals. Third, in the first step of our research we focused on the development of the ISDT. Thus, future research is needed that builds and evaluates artifacts developed according to the proposed ISDT (Steps three and four).

7 Conclusion

In this paper, we developed an information system design theory for the class of Green IS for sustainability reporting according to Walls et al. (1992) and Gregor and Jones (2007). The ISDT has been derived by a set of kernel theories and evidence from multiple case studies. Informing the ISDT by both theory and practice yielded several valuable insights. Thus, we encourage future research in design science to employ and further develop such a hybrid approach. We found that the main problem in current state of SR is that firms are faced with contrasting interdependencies between environmental data transparency, complexity and collection effort. The developed ISDT addresses this problem by a unique combination of ubiquitous delegation, transparency of gathered data, and task automation. Thus, the resulting ISDT may contribute to improved sustainability reporting software and also provides generalizable requirements for the class of Green IS. Therefore, we hope that it paves the way for future DSR in Green IS as it provides guidance to researchers and practitioners for the design and evaluation of information systems that contribute to organizational sustainability transformations.

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