

7-1-2013

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Florian Stiel

University of Osnabrueck, Osnabrueck, Germany, florian.stiel@uos.de

Frank Teuteberg

University of Osnabrueck, Osnabrueck, Germany, frank.teuteberg@uni-osnabrueck.de

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TOWARDS A CONCEPTUAL FRAMEWORK FOR LIFE CYCLE ASSESSMENT IN SUSTAINABLE INFORMATION SYSTEMS MANAGEMENT

Stiel, Florian, Osnabrück University, Katharinenstraße 1, 49069 Osnabrück, Germany,
florian.stiel@uos.de

Teuteberg, Frank, Osnabrück University, Katharinenstraße 1, 49069 Osnabrück, Germany,
frank.teuteberg@uos.de

Abstract

Information Systems (IS) play an important role for the sustainable development of business organisations. New metrics and methodologies are required to explore the interactions between IS, organisations and the environment. The Life Cycle Assessment (LCA) methodology already proved its ability to measure environmental impacts of complex systems in other industries. However, when trying to adopt these methods to IS, researchers face problems as to comparability and transparency, two major aspects within the concept of LCA. Therefore, our work suggests a framework for LCA in Sustainable IS Management to avoid emerged methodical problems. Thereby, our research follows the design science approach, merging LCA methodologies with characteristics of Sustainable IS. The outcome of our approach is a conceptual framework of methodologies, supporting the assessment of IS solutions in early stages. The evaluation of the framework is applied by functional testing and the assessment of a business scenario.

Keywords: *environmental sustainability, life cycle assessment, conceptual framework, design science approach*

1 Introduction

The principles of a sustainable economy, that meet the needs of present and future generations (World Commission on Environment and Development, 1987), have been introduced to corporate management already in the 1990^s. Elkington (1998) developed the “triple bottom line” describing corporate sustainability as an approach to consider social, economic as well as ecologic aspects in strategic decision making. These days, especially the increase of environmental efficiency throughout value chains is one of the most striking challenges for companies, and expertise in the field of Life Cycle Assessment (LCA) is a key competence to meet it (Nidumolu et al., 2009). The attention for aspects of sustainable development within the Information Systems (IS) community awakened during the widely recognized conferences ECIS and ICIS in 2009. IS can both act as a driver and as an inhibitor of sustainable development due to its own energy demand and its potential to change business processes to reduce their environmental impacts (Vom Brocke et al., 2012). Schmidt et al. (2009) provide a framework for a Sustainable IS Management, transferring the ideas of Elkington (1998) into the scope of IS Management. Erekat et al. (2009) argue for life cycle considerations within decision making in IT sourcing processes. It was Melville (2010) who first raised awareness for environmental sustainability also in one of the leading IS journals, the MIS Quarterly. Melville animated the IS research society’s interest for the LCA methodology by asking two methodical research questions: How can new research methodologies, such as LCA, be applied to the interaction of information systems, organizations and natural environments, as addressed by Watson et al., (2010)? How can metrics measuring environmental impacts be applied to measure the outcomes of IS use? Melville (2010) detects a lack of knowledge concerning the environmental impact assessment of IS opposed to other technological systems within the oil-, gas- or biotechnology. This leads us to the underlying research questions of this paper:

- Why did first applications of LCA not lead to a broader diffusion of the methodology into IS management and research? (RQ 1)
- How can LCA methodologies be adjusted to better meet the characteristics of IS and prevent the inhibitors for a diffusion of LCA into IS management and research? (RQ 2)

First, in section 2 we review extant research on the LCA methodology and recent LCA work on IS business processes, artifacts and infrastructures. Then, we also figure out problems and weaknesses of existing LCA studies assessing IS artifacts and infrastructures to answer RQ 1. In section 3 we implement a framework by establishing an overlap between value creation within the methods of IS and LCA in order to respond to the challenge of a more sustainable development and answer RQ 2. Section 4 covers the evaluation of the framework and section 5 the implications, limitation of the approach as well as future work.

2 Status Quo of Sustainable IS Management and Life Cycle Assessment

Value creation in the field of IS takes place by delivering artifacts or infrastructures to a market. Zarnekow et al., (2006) introduce a model for the scope of IS value creation based on the SCOR model for supply chains (Supply Chain Council, 2008). According to this model, IS management covers one segment of the supply chain encompassing the processes source, make, deliver, return and govern between a resource market and an internal or external sales market as presented in Figure 1. The output of a segment, delivered to the sales market, is a varying bundle of products and services such as artifacts and infrastructures (Zarnekow et al., 2006). As seen in recent studies, the bundles are inhomogeneous in functionality and appearance, e.g. computational logic (Boyd et al., 2009), online newspaper distribution (Moberg et al., 2010) or computer workplace (Maga et al., 2012).

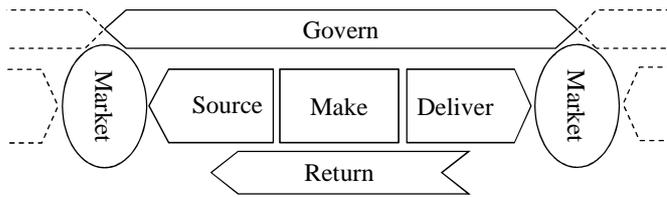


Figure 1. IS value chain segment (Zarnekow et al., 2006)

Despite the great variety in their outer appearance, all information technology (IT) functions are based on a set of basic functionalities, i.e. transmission, processing and storage of syntactical information (Pal, 2008), e.g. online newspaper distribution based on the basic function of information transmission or computer workplace as a mixture offering all three basic functions to the user. The governance processes associated with every value chain segment cover measurements and strategic procedures to align the other processes to the business objective. The business objectives for a Sustainable IS Management (Schmidt et al., 2009) determined by Erek et al. (2009) and Wittstruck & Teuteberg (2011) are presented in Table 1 but do not claim to be complete.

Reference	Objective
(Erek et al., 2009)	Achieve transparency of the suppliers' products and services Minimize the consumption of resources while maximizing the output Meet internal and external (stakeholder) demands Recycle and reuse materials
(Wittstruck and Teuteberg, 2011)	Reduce material and energy consumption Use renewable energy sources Create save and healthy working environments

Table 1 Objectives of a Sustainable IS Management

Melville (2010) suggests a link between the objectives of Sustainable IS Management, as the driver of sustainable action, and LCA as a method to measure the resulting outcome in terms of environmental impact. LCA is a method of “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO, 2006a). Thereby, LCA addresses a huge number of concepts, which the objectives of Sustainable IS Management are built upon, e.g. resource and energy consumption, health, supply chains and product life cycle or recycling and reuse.

Principles of the LCA methodology are the environmental life cycle perspective (from cradle to grave), the relative approach (referring to a functional unit), an iterative scientific approach as well as a transparent and comprehensive proceeding. According to the ISO standard 14040 the consistency of a LCA with these principles needs to be reviewed to enhance its credibility (ISO, 2006a). Besides the requirements determined by the ISO standard, the aspect of comparability (e.g. for benchmarking) was discussed by Emblemståg and Bras (1999). Even thou comparability of the LCA's results is not crucial for its methodical correctness, it is essential to ensure its recognition within a business and management context, e.g. for life cycle considerations within IT sourcing as mentioned by Erek et al. (2009).

The framework introduced in the ISO standard 14040, structures LCA into four phases: (1) definition of goal and scope, (2) inventory analysis, (3) impact assessment and (4) interpretation (ISO, 2006a). Finnveden et al. (2009) and the ISO (2006a) underline the importance of the first of four phases, definition of goal and scope, as a presetting of methodologies and choice of data during the other phases. Especially the choice of a functional unit and system boundaries to define the scope of the LCA has a significant influence on the consistency with the mentioned principles (Guinée et al., 2002). The definition the functional unit also influences comparability of alternative solutions to fulfil the same functional demand, e.g. paper versus email information distribution (Bousquin et al., 2012;

Emblemsvåg and Bras, 1999). Moreover, different approaches for the definition of system boundaries (Finnveden et al., 2009), such as cradle-to-gate or gate-to-gate analysis (Jiménez-González et al., 2000) and cradle-to-grave (Full-LCA) (ISO, 2006a), lead to incomparable results between the derived environmental impact data (Emblemsvåg and Bras, 1999).

To explore the use of functional units and system boundaries within recent LCA publications on IS we applied a structured literature review (Webster and Watson, 2002). Within the ten top ranked journals by the Association for Information Systems (AIS) MIS Journal Ranking, we identified relevant publications containing environmental impact analysis. In order to also include recent research, we reviewed the proceedings of ICIS as well as ECIS, two of the most important and best ranked conferences in the field of IS. Moreover, we applied internet based research by means of Google Scholar, Scencedirect and ISI Web of Knowledge using the following keywords: “life cycle assessment”, “environmental impact” combined with “IT infrastructures”, “IT component”, “IT concept”, “ICT solution”, “IS solution”, “IT solution” encompassing IS related publications and reports from other disciplines. The timeframe for our structured literature review ranges from 1997, the year of the ISO standard 14040 publication, to September 2012. In Table 2, we sorted the identified papers by date of publication in ascending order and compared them according to the following criteria: (1) Does the study calculate environmental impacts referring to a benchmark process (comparative approach)? (2) Which functional unit is chosen? (3) Which system boundaries are defined? (4) How many impact categories are addressed or does the study provide a Full-LCA? (5) Does the study provide an evaluation approach to support its outcomes?

Object description & Reference	Comparative approach	Functional Unit	System boundaries	Impact Categories	Evaluation approach
Internet advertising (Taylor and Koomey, 2008)	No	Million impression distributions	Gate-to-gate use phase	2	Sensitivity analysis
Computational logic (Boyd et al., 2009)	No	MIPS	Cradle-to-gate without end of life	2	Uncertainty assessment
Six music delivery methods (Weber et al., 2009)	Yes	One music album delivery	Gate-to-gate	2	Monte Carlo simulation
Computational logic during the last 15 years (Boyd et al., 2010)	No	Average device, transistors, chip area	Gate-to-gate	Full-LCA	None
Printed and tablet e-paper (Moberg et al., 2010)	Yes	Newspaper distribution for one year	Cradle-to-grave	Full-LCA	Sensitivity analysis classification to recent work
E-book vs. print media (Moberg et al., 2011)	Yes	One book brought and read	Cradle-to-grave	Full-LCA	Sensitivity analysis
Server (Weber, 2012)	No	One server	Cradle-to-grave	1	Monte Carlo simulation
Sensor network designs (Bonvoisin et al., 2012)	Yes	Hourly data provision for ten years	Cradle-to-grave	Full-LCA	Scenario analysis
PC vs. thin client computing (Maga et al., 2012)	Yes	One computer workplace	Cradle-to-grave	2	None

Table 2 Recent work in environmental impact assessment related to IS management

All identified publications using LCA methodology (Taylor and Koomey (2008) did not contribute to LCA, however they addressed environmental impacts) were published within the last three years and outside the IS community journals and proceeding that were considered (Top 10 journals AIS ranking, ICIS and ECIS conference proceedings). The publication dates indicate that there has been a growing

interest in environmental impacts of IT infrastructures within the last years. However, the results worked out in other disciplines did not lead to a diffusion of the LCA results or methodology to IS research which supports the arguments of Melville (2010). Reasons for the weak diffusion can be found in the methodological divergence of the studies leading to weaknesses in comparability and transparency, thus to a limited use of the research results for further research (e.g. further LCA studies). The publications show significant varieties in the definition of the functional units. Often none IS products (e.g. book, music album) or services (e.g. provision of a workplace) are chosen to quantify the performance of the IS, which results in a weak transparency. Also, the defined system boundaries vary between cradle-to-grave, cradle-to-gate and gate-to-gate approaches. Sometimes single processes or life cycle stages are excluded, which reduces the comparability of the results and impedes transparent verification. The differences regarding impact categories varying between single carbon footprints and full-LCA, also contributes to a limited comparability and transparency. The fact that one publication classifies the results to other LCA studies for evaluation supports the finding of a limited comparability between the studies. More often we find Monte Carlo simulation and sensitivity analysis as the underlying evaluation methods. To improve the approach of LCA in the field of IS, we introduce a framework to strengthen LCA studies within the initial stage of goal and scope definition. It should guide authors to improve transparency and comparability of the results to advance environmental sustainability in IS research.

3 Development of a Framework for Life Cycle Assessment in Sustainable IS Management

3.1 Methodology

Our work follows the design science approach (Hevner et al., 2004). The developed artefact is a conceptual framework (Eisenhart, 1991) containing methodologies for the conduct of an LCA in IS. The relevance of a deeper understanding of LCA methodology was expounded by Nidumolu (2009) and Melville (2010). While developing our framework, we bring together the contribution of the recent work and the characteristics of Sustainable IS with the formal theoretical knowledge of LCA as a research methodology (cf. section 2). To prove utility, quality and efficacy of the framework, we evaluate the framework by functional testing and a descriptive scenario (Hevner et al., 2004). The functional test encompasses an execution of the methodology to the functional unit of the recent work to demonstrate its rigor to recent methodology. Utility and efficacy are proved by using the framework to solve an artificial business scenario applying available LCA databases in order to quantify the environmental efficiency of two alternative information systems, i.e. a virtualized and a non-virtualized server room. The completion of the research process is achieved when a framework has been developed, that enables IS researchers to conduct a comparable and transparent LCA and, that reflects the characteristics of Sustainable IS Management by functional unit and system boundary definition. The research results will eventually be disseminated by the publication of this and forthcoming work.

3.2 Framework

As derived in section 2, the divergent methodologies used in recent work prevent the diffusion of the LCA results into further IS research. As the section already clarifies, the definition of goal and scope as a pre-set value for the applied methods plays a key role overcoming the barriers that impede further use (Finnveden et al., 2009; Guinée et al., 2002; ISO, 2006a). For that purpose, a framework limited to the first phase of a LCA will be introduced gathering the two identified characteristics of Sustainable IS Management: (1) the three basic functionalities of IT for definition of functional units, (2) the IS value chain for definition of system boundaries.

The huge variety of functional units in recent work points to the underlying difficulties in finding an appropriate, comprehensive unit for the abstract product and service bundles provided by IS value chains. The variety in the defined units inhibits a potential use of the results in LCA databases and software tools used in Sustainable IS Management, causing a demand for a set of coherent functionalities and units. For other disciplines we find asserted units even for strongly inhomogeneous sets of processes within LCA databases (e.g. ecoinvent¹), such as *tkm* for transport services, *t* for manufacturing processes or *kWh* for energy processing and storage. Because functional units are quantitative measures for the function of a product or service (Finnveden et al., 2009), the first step to find a set of equally comprehensive functional units for Sustainable IS Management is to find a common set of measurable process functionalities for IS product and service bundles and to measure them in the second step.

As shown by Pal (2008) IS products and services can be traced back to a system of functionalities providing information transfer, processing and storage. Whereas transfer processes are characterized by a dislocated output of the same information, processing processes are characterized by manipulated information and storage processes are characterized by a time delayed output of the same information. The delivered bundle of an IS value chain segment can thus be characterized as multifunctional process providing the three functionalities, as depicted in Figure 2. When applying the LCA, the multifunctional process can be subdivided into single functional processes (information transfer, processing, storage) using allocation (Finnveden et al., 2009; Guinée et al., 2002), e.g. in (Moberg et al., 2011; Weber et al., 2009). Hence, the assessment of the environmental impacts is referred to just one single function, enabling comparison to other information systems with an equal functionality. Characterization of a process bundle due to the delivered functionality we call functionalization.

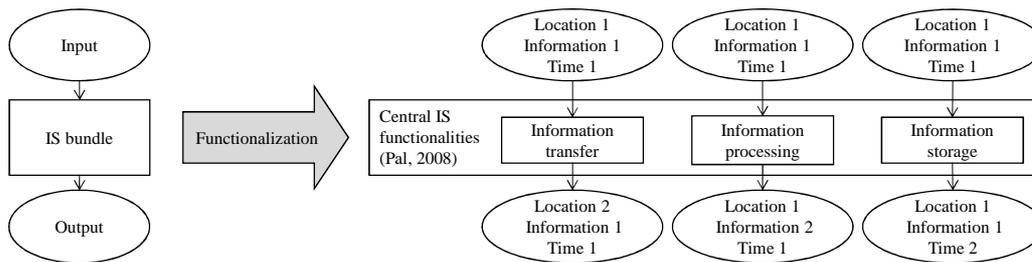


Figure 2. Functionalization of an IS product and service bundle

An example for functionalization could be the provision of a computer workplace introduced by Maga et al., (2012). The bundle *computer workplace* delivered to the worker provides a specific set of functionalities limited by the hardware performance. The processor allows the worker to convert information during work time. The hard disk allocates a specific storage capacity and the network adapters provide the functionality to transfer information. Now, the environmental impacts of the bundle can be referred to the different functionalities using allocation. They can also be quantitatively compared to related bundles with a different performance or verified against other LCA studies.

The second step of functional unit development focuses on the definition of a scale to quantify the three basic functionalities. Quantities previously used for the characterisation of the functionalities are: information, dislocation, manipulation and delay. Existing standards and norms already contribute these quantities measuring (1) syntactical information by entropy (IEC, 2002), (2) dislocation by distance (ISO, 2006b), (3) data manipulation and processing by (calculating) performance (IEC, 2005) and (4) delay by time (ISO, 2006b). Different units are used to measure the introduced quantities depending on the context, such as kilometres or miles for distance or MIPS and FLOPS for performance. The correct use of the units strongly depends on the examined IS bundle but also on the addressor of the LCA. Thus, the units cannot be determined for all LCA applications equally.

¹ ecoinvent: One of the leading commercial databases for life cycle inventory data, available online: <http://www.ecoinvent.ch/>

However, the functional relations between the involved quantities characterizing the bundles functionality are the same. Table 3 shows the quantification of IS functionalities as a framework for functional unit definition, derived from analogue units used in the LCA databaseecoinvent by deductive reasoning. Processes (units) used for deduction are: (1) electricity transmission described by *energy multiplied by distance (kWh*km)*, (2) energy processing described by *electrical power multiplied by time (kW*h)* and material storage described by *mass multiplied by time (t*h)*.

IS functionality	Quantification
Information transfer	Entropy*distance
Information processing	Performance*time
Information storage	Entropy*time

Table 3 Framework for functional unit definition

For the definition of system boundaries, most studies apply a cradle-to-grave approach (Jiménez-González et al., 2000). However sometimes single processes or life cycle stages are excluded from the LCA due to missing data or insignificance for the overall impact of the system. Thus, even between studies using the same functional unit, comparability is limited. Moreover, the validity of studies may vary because of the naturally higher uncertainties of studies applying broader system boundaries. The framework should define comprehensive boundaries for LCA used in IS management regarding the IS managements reach and the range for the collection of specific data to improve comparability and validity. In order to avoid the qualitative weaknesses identified in recent work, we have divided the system boundaries into inner and outer system boundaries.

The inner system boundaries divide the technical system of one IS value chain segment from other technical systems (e.g. other segments) and from processes that are outside the reach of IS management. They contain all source, make, deliver and return processes of the IS value chain segment (cf. Figure 1) to provide the IS product and service bundle. These processes are directly governed by the Sustainable IS Management and include all energy and material flows between the resource market and the sales market, such as operation of a server room or transport of IT components within the company. The intercept points between the first sourcing process and the last delivering process mark the gates for a gate-to-gate inventory analysis of the IS bundle under investigation using specific data. The use of generic data should be avoided in order to ensure that waste of energy and material within the specific processes can be assessed. Granularity should be high enough to locate and depict inefficiencies within the value chain segment and to ensure the LCA's utility.

Flows crossing the inner system boundaries enter the processes within the outer system boundaries. Outer system boundaries separate the technical system from its environment and from insignificant processes containing all processes from cradle-to-grave. Processes between the inner and outer boundaries are still influenced by the IS value creation, even if they are located outside of its direct governance; such as the emission of CO₂ from a coal power station which can only be determined indirectly by a lower energy demand. Specific data for these processes are typically not applicable or applicable on high expenditure. To ensure the profitability of the LCA generic data should be used to quantify these processes during the phase of inventory assessment. Applying generic data from widely recognized databases also supports transparency and comparability of the derived results. Figure 3 illustrates the system boundaries, processes and life cycle stages adapting the models of IS value creation and ICT solutions by Zarnekow et al. (2006) and Maga et al. (2012).

The outer system boundaries mirror the chronological sequence of the life cycle from cradle-to-grave. The pitch point of the material extraction with the environment marks the cradle of the IS product and service bundle. The material extraction, manufacturing and dislocation stages contain all processes to produce the goods necessary to provide the bundle (e.g. IT infrastructures, energy and operating supplies). The use stage contains all processes between the two gates, resource market and sales market, to use the good and provide the IS product bundle (e.g. operation of servers and networks).

This stage contains the IS driven value creation and is thus subdivided according to the IS value chain. The illustration of the return process was adjusted due to the chronological sequence of the surrounding life cycle and its close relation to the end of life stage. The end of life stage covers all processes to recycle, incinerate or dispose the entire waste material generated to provide the IS product bundle, the end of this stage marks its grave. The illustration also shows where specific and generic data have to be applied to depict inefficiencies of the internal processes and avoid expenditure to collecting external processes data.

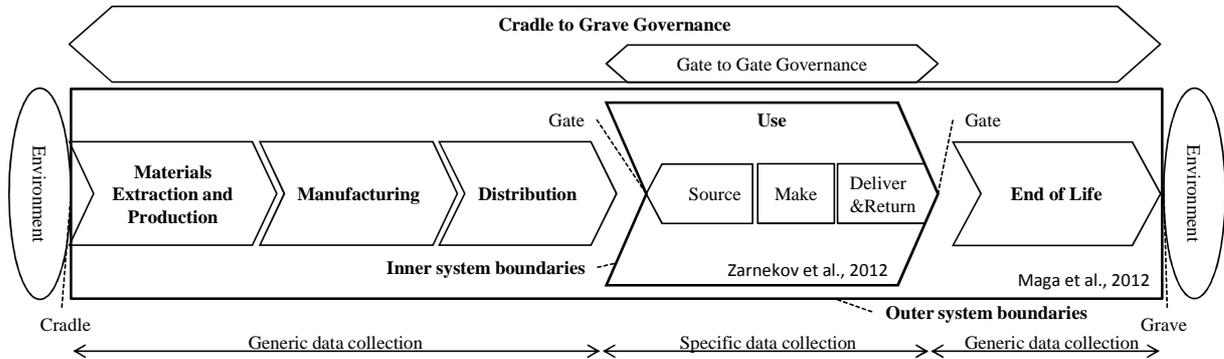


Figure 3. System boundary definition and specific and generic data collection adapting

The deduced framework for functional unit and system boundary definition is embedded into the ISO 14040 LCA framework as shown in Figure 4. The adjustments refer to the phases of goal definition, scope definition and inventory analysis. Goal and scope definition is affected in functional unit and system boundary definition. For the inventory analysis, the framework attributes the collection of specific and generic data to the inner and outer system boundaries. The other LCA phases are not affected by the developed phases.

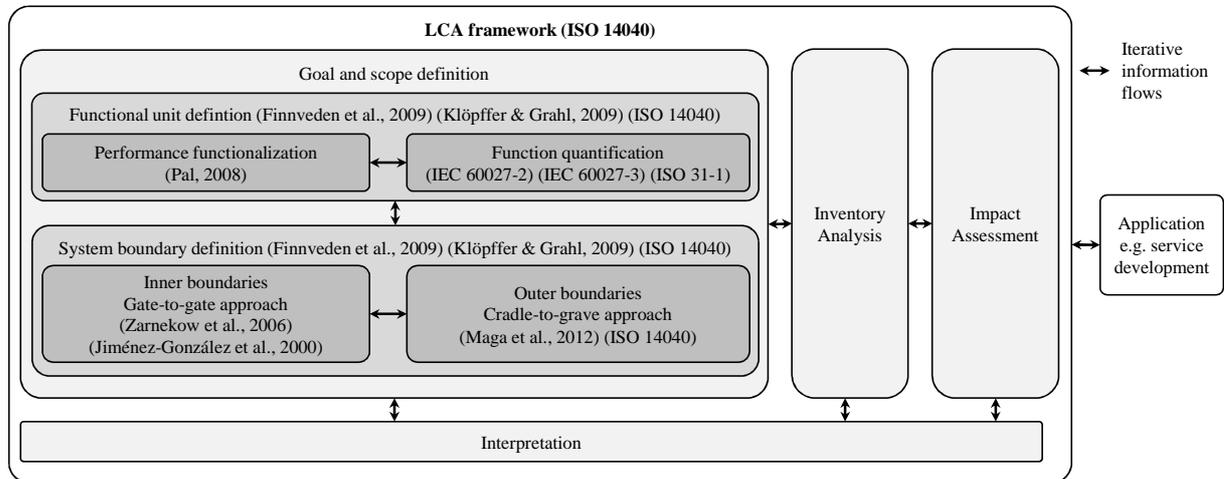


Figure 4. LCA framework for Sustainable IS Management based on ISO 14040 (2006)

4 Evaluation

4.1 Conceptual quality

In the first step, we evaluate the rigor of the framework, with the recent work and the methodology of the ISO 14040 standard. Therefore we apply a functional test executing functionalization and quantification to convert the functional units in Table 2 to the transparent quantifiable functionalities

presented in Table 3. The results of the test are depicted in Table 4. The table contains the original functional units (first column), the converted functions and quantities (second column) as well as the information whether a subdivision of the product system has to be applied for conversion (third column).

Functional units	Function (quantity)	Subdivision
Million impression distributions, one music album delivery, newspaper distribution for one year, one book bought and read	Transfer (entropy*distance)	No
MIPS, average device, transistors, chip area	Processing (performance*time)	No
One computer workplace, one server, hourly data provision for ten years	Transfer, processing, storage (entropy*distance, performance*time, entropy*time)	Yes

Table 4 Functional units and information related functionalities, quantities and units

Table 4 shows that functionalization and quantification introduced in this work is applicable to all recent work. For most LCA studies, the conversion of the functionalization and quantification does not induce a subdivision of the regarded system due to the single function of the system. In this case, functional units just have to be quantified due to their performance for information transfer, processing or storage (e.g. in bit). Some IS bundles (e.g. computer workplace) provide more than one functionality resulting in LCA studies addressing multifunctional processes. In these cases, the methodical framework of the ISO 14040 enables the subdivision of the system and allocation of its material and energy flows (cf. section 2) to assess the share of different IS functions to the total environmental impact of the system.

4.2 Utility and efficiency

Utility and efficiency of the introduced framework are evaluated by conducting a LCA for a business scenario based on artificial data (Stiel and Teuteberg, 2013). Data were obtained from studies and white papers concerning energy consumptions of datacentres (e.g. Koomey, 2008). In order to gather an efficient set of generic data, the widely established database ecoinvent is used during the execution of the LCA. The goal of the LCA is to quantify the different environmental effects caused by the energy consumption of a virtualized and a non-virtualized server room divided by the provided functionalities.

The business scenario contains the following information about a non-virtualized and an alternative virtualized server room: The servers of the rooms run mathematical simulation software and store the simulation results on file servers. At first, data are transferred to a fileserver located in the server room, then the servers run simulations, the results of the simulations are stored on the filesystems, and in the last step, the results are sent to another division of the company that is located 2 km away. After the results have successfully been received, the data are deleted from the filesystems to save storage capacity. A local area network is used for data exchange and all IT infrastructures of the room are cooled by air without utilization of the waste heat. The non-virtualized alternative requires ten servers (max. 200 Gigaflops calculating performance at 200 Watt electrical power) at an average server utilization of 20% resulting in a total power consumption of 20,333 kWh annually. The virtualized alternative requires four servers of the same kind running at a utilization of 50% and causes a total power consumption of 8,937 kWh annually. For both alternatives the consumption of data storage (5,000 Gigabyte at 50% average utility) and transfer infrastructures (5,000 Mbps at 1% average utility) are the same and already covered by the total power consumptions.

Applying functionalization shows that the functionality of the server room can be divided into (1) information processing by running the simulation tools, (2) information storage by storage of the results and (3) information transmission by the possibility to obtain data. From LCA perspective,

running the server room is a multifunctional process. According to Finnveden et al., (2009), we divided each server room into three subsystems, one for every function. Every product system contains IT components or modules (e.g. server, modem, LAN cable or hard disk drive) necessary to fulfil the function and the energy demand of the component. Some energy and material flows (e.g. energy for cooling in our scenario) are used by all three subsystems of one bundle. However, the energy for cooling can be allocated using electrical power consumption of the components and modules to draw a physical causation (Finnveden et al., 2009) to the subsystem. In this stage, the specific material and energy flows of the subsystems can be modelled using established LCA software to extend the system boundaries of the study to a cradle-to-grave approach using generic data from the database ecoinvent. In our scenario we used the database ecoinvent and the contained impact assessment method CML 2001 to calculate the total impact of the subsystems (e.g. kg CO_{2e} for the storage of data). To observe the relative approach, the impacts have to be referred to the performance of the subsystems (e.g. for the system information storing a 50% utilization of 5,000 Gigabyte for 1 years equals 2,500 *Gigabyte*years*). Table 5 contains the derived indicators after referring them to the subsystems performance applying artificial specific data for the IS, the developed framework, the ISO 14040 methodology and generic data from ecoinvent.

Function	Emissions non-virtualized server room	Emissions virtualized server room
Information Transfer	0,34 kgCO _{2e} /kbit*km	0,29 kgCO _{2e} /kbit*km
Information Processing	3,44 kgCO _{2e} /TFLO	1,37 kgCO _{2e} /TFLO
Information Storage	0,87 kgCO _{2e} /Mbyte*a	0,74 kgCO _{2e} /Mbyte*a

Table 5 Functional units and information related functionalities, quantities and units

It could be illustrated that the application of the developed framework leads to quantitative environmental efficiency measures for IS, divided by the provided functionalities. In this example, the virtualized server room shows lower environmental impact of data processing, transfer and storage. The business scenario also shows that indirect energy and material flows (e.g. cooling energy) can be allocated to the functions within the framework. Moreover, existing LCA databases and software can be applied to conduct the LCA without any changes in data architecture. Thus, the framework can be efficiently used in IS business scenarios due to its compatibility with established LCA databases.

5 Conclusion

More than ever before, researchers and companies depend on methods to quantify the environmental improvement of their solutions. Complex value chains involving a huge number of organizations require methods, coherent for the whole system and valid for all participants. Thus, the exchange of product and service related environmental data has to be supported by an underlying framework, accepted by all participating organizations. The conceptual framework proposed in this paper contains a first step towards a common metric for the measurement of IS related environmental impacts. It is based on the scientific status quo in LCA methodology, considering the complexity of IS value chains. The results of the evaluation indicate that LCA, conducted due to the developed framework, can provide data to quantify the environmental impact of IS referred to its functionality.

However, there are limitations to the introduced approach. For instance, just the phase of goal and scope definition was addressed by the framework. There might be more phases where the characteristics of IS can lead to difficulties conducting LCA (e.g. electro smog as a missing but possible impact category during impact assessment, distances of web based data transfer during inventory analysis). The data derived by the impact assessment could be further processed (e.g. by decision analysis) in order to support decision making. Therefore, the interpretation phase might also be adjusted for a better communication of the LCA results to internal or external stakeholders. Moreover, the set of IS functionalities could be further extended to cover more common functionalities (e.g. information collecting). There are also limitations to the chosen evaluation

methodology. Our methodology is predominantly built upon literature and artificial data derived from literature. However, the evaluation approach could apply case studies or field studies, in order to show its utility in contemporary business cases based on contemporary data.

As a next step, we will try to address the limitations of the introduced approach to complete the framework, covering all four phases of the LCA methodology. Research questions are still open: *How do the characteristics of IS affect proceeding of a life cycle inventory analysis? Which impact assessment methods fit best the information demand of IS? Which impact categories have to be addressed by a sustainable IS? How can the impact assessment results be interpreted in order to support decision making?* These questions lead us to starting points of further research. To answer the questions LCA studies for different IS solutions, such as cloud computing, server virtualization, Green IT/IS solutions and energy management, will be conducted. These studies also contribute to a deeper evaluation of the developed framework based on real-world data. Business partners will be involved to evaluate believes in LCA and to guide diffusion of the methodology into IS business processes.

Acknowledgement: *This work is part of the project IT-for-Green (Next Generation CEMIS for Environmental, Energy and Resource Management). The IT-for-Green project is funded by the European regional development fund (grant number W/A III 80119242). The authors are pleased to acknowledge the support by all involved project partners. Furthermore, we would like to thank the anonymous reviewers for their insightful and constructive comments.*

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Life Cycle Assessment. Other topics in the series of overview information documents on the concepts of, and approaches to, integrated environmental management are listed below. Further titles in this series are being prepared and will be made available periodically. Sequence of release and titles are subject to change.Â Figure 1: Life Cycle Assessment framework based on the ISO 14040 model
Figure 2: Illustration of Life Cycle Assessment Procedure. TABLES.Â The results of a conceptual LCA can usually be presented using qualitative statements, graphics, flow diagrams or simple scoring systems which indicate which components or materials have the largest environmental impacts and why.