Challenges of Integrating Social Lifecycle Sustainability Assessment into Product Lifecycle Management - State of the Art -

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Abstract. Despite the importance of Social Life Cycle Sustainability Assessment (S-LCSA), little research has addressed its integration into Product Lifecycle Management (PLM) systems. This paper presents a structured review of relevant research and practice. Also, to address practical aspects in more detail, it focuses on challenges and potential for adoption of such an integrated system at an electronics company.

We began by reviewing literature on implementations of Social-LCSA and identifying research needs. Then we investigated the status of Social-LCSA within the electronics industry, both by reviewing literature and interviewing decision makers, to identify challenges and the potential for adopting S-LCSA at an electronics company. We found low maturity of Social-LCSA, particularly difficulty in quantifying social sustainability. Adoption of Social-LCSA was less common among electronics industry suppliers, especially mining & smelting plants. Our results could provide a basis for conducting case studies that could further clarify issues involved in integrations of Social-LCSA into PLM systems.

Keywords: Social Lifecycle Sustainability Assessment (S-LCSA) · Product Lifecycle Management (PLM) · Structured literature review · Social-LCSA integration into PLM system · Social-LCSA framework

1 Introduction

Increasingly pressure to improve sustainability comes from stakeholders such as society, non-profit-organizations (NPO), journalists, non-government-organizations (NGO), consumers and governments. Industries must respond, because production and products influence sustainability in at least three dimensions: economic, environmental and social. Industry must account for competition, changing markets that make the value

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chain a complex system, evolving laws and regulations. Manufacturing companies must undertake preventative approaches to environmental pollution within their manufacturing processes.

Consumers (C) and Government & Leadership (G) are playing increasingly active roles in achieving a sustainable world. Sustainability-driven manufacturing can provide a competitive advantage because it appeals to customers who value brand, image and reputation. Collaborative work increases the complexity of addressing sustainability. As shown in Fig. 1, Engineers & Designers (D), Manufacturer/Vendor (M) and Material Analyst (Ma), and other actors are involved in Sustainable World, cross-business functions. Globalization makes the situation more acute.

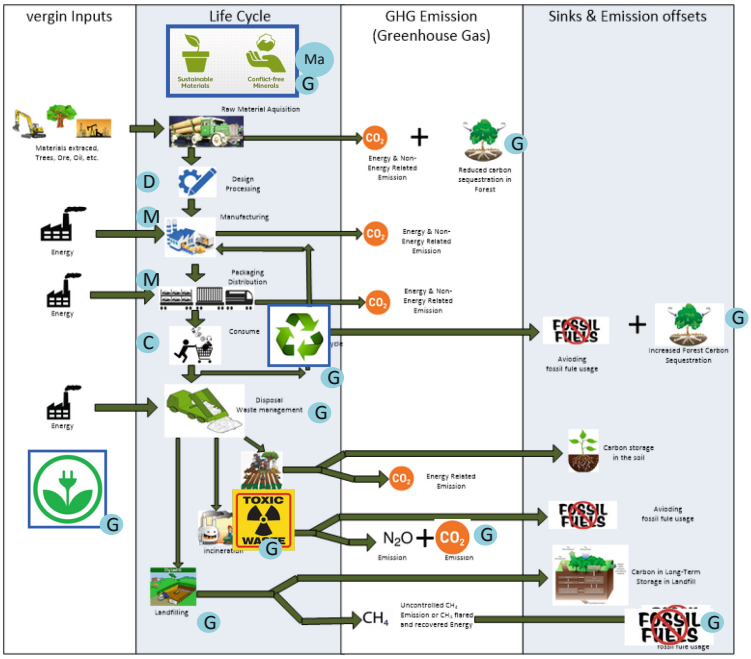

Fig. 1. Actors in sustainable world

A Life Cycle Assessment (LCA) tool can help determine impacts of products or systems over a range of environmental and resource issues. It measures all environmental impacts across the entire lifecycle. Currently, the most accepted framework and lifecycle-based approach for assessing a product's impacts on all three sustainability dimensions in an integrated way is Life Cycle Sustainability Assessment (LCSA). It is currently regarded as the only viable framework for comprehensive sustainability

assessment of products. It can be understood as the evaluation of the combined positive and negative effects of a product over its entire lifecycle on the three dimensions of sustainability[1].

Life cycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social and economic impacts in decision-making processes towards more sustainable products throughout their life cycles. This comprehensive assessment can be expressed by the following conceptual formula:[2]

$$[\mathrm{E}-\mathrm{LCA}]+[\mathrm{S}-\mathrm{LCA}]+[\mathrm{LCC}]=[\mathrm{LCSA}]$$

where E-LCA denotes the conventional environmental lifecycle assessment, Social-LCA (Social Life Cycle Assessment) represents the assessment of positive and negative social impacts along the product lifecycle.

Experts disagree on whether LCC (Life Cycle Costing), the assessment of economic impacts along product lifecycle, is necessary for an analysis. However, if cash flow is important, include it in the analysis [1].

Early definitions of Life Cycle Management covered environmental, social and economic issues (Hunkeler et al. 2004; Remmen et al. 2007) along a product lifecycle. These ideas are in line with developments in life cycle assessment that further expand the context of LCA to include social and economic elements under the life cycle sustainability assessment (LCSA) framework (Finkbeiner et al. 2010; Klöpffer 2008; UNEP 2011). Some researchers identified new challenges related to the criticality of materials (Sonnemann et al. 2015). Incorporating LCSA in decision-making processes at the product, process and individual organizational levels could maximize profit. Finkbeiner (2011) was first to describe the term "lifecycle sustainability management (LCSM)" [2].

Figure 2 shows LCA defines a product system by the system boundary and the product lifecycle that is divided into stages for the inventory analysis (LCI). LCI considers the environmental inputs and outputs. At the broadest level four stages may be identified: material production, product manufacturing, product use, and product disposal.

In the lifecycle analysis of product systems, *materials information* is necessary wherever materials are used in manufacturing, in products, or needed as ancillary inputs. Hence, materials data are essential to an LCI and to a full LCA. Materials should be selected in each PLM stage to enable tracking and sustainability checks along PLM. Figure 3 shows how we propose to align PLM with the material life cycle, since the product and materials cycles are parallel and intersecting. Some researchers have recommended enabling PLM for Material Selection because the potential of using PLM for material selection is great; e.g. Gabi…

[1] Source: UNEP (2012) Social Life Cycle Assessment and Life Cycle Sustainability Assessment.

[2] https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/life-cycle-sustainability-assessment/.

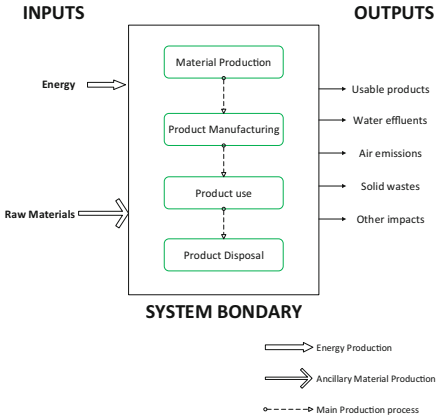

Fig. 2. Using LCA approach for material life cycle. Source: "Assessment of Environmental Lifecycle Approach for Industrial Materials and Products" by Steven B. Young

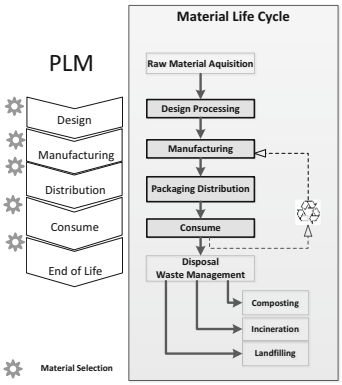

Fig. 3. PLM vs. material life cycle

Knowledge about the environmental performance is important in the LCA design process. Fortunately, a lot of information is available in this process, especially in modern, powerful PDM/PLM tools. Linking LCA and PLM therefore can be a good start[3], e.g. selecting recyclable materials, avoiding usage of fossil fuel, and tracking material flow from material extraction to final disposition.

Although the potential is great, little research has addressed how LCA can support PLM for Material Management. It is therefore worthwhile to discuss how LCA could be practiced to PLM in business contexts. For example, material selection is the prime concern of all engineering applications and design. This selection process can be defined by application requirements, possible materials, physical principles, and selection[4]. Selection of a material for engineering a new product involves several steps:

- Decide the requirements of the application, in terms of mechanical, thermal, environmental, electrical and chemical properties.
- Select materials for the application.
- Figure out what changes in the material properties are needed.
- Pick materials, which best fulfil the requirements of the application given possible changes in the material properties.

[3] Based on a survey of LCA practitioners carried out in 2006 LCA is mostly used to support business strategy (18%) and R&D (18%), as input to product or process design (15%), in education (13%) and for labeling or product declarations (11%).

[4] Retrieved from http://depts.washington.edu/matseed/mse_resources/Webpage/Bicycle/Material%20Selection%20Process.htm

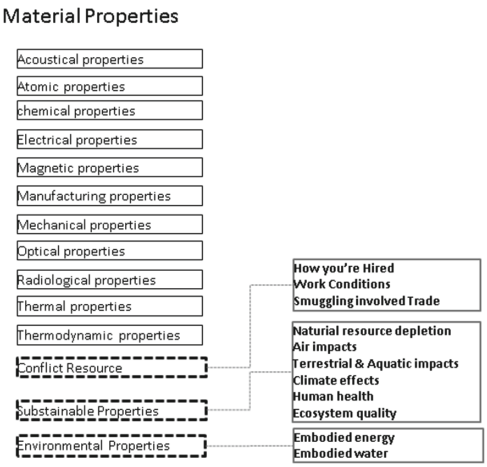

Fig. 4. Extension of the material property definition

This paper proposes to extend the definition of material properties to allow handling the conflict resource index (one of important social aspect) and sustainable properties that are remarked with a dotted line in Fig. 4. Furthermore, this paper aims also to organize the main references on Social-LCA to build a complete picture of the theoretical and practical implementation of this methodology in the electronics & electric sectors, especially with globalized supply chains. Also, it identifies needs for further research. The challenges and potential for Social-LCA at an electronic company will be identified to provide guidance for research into integrating Social-LCA with PLM and for managers attempting such integration. LCC is not covered in this paper because it is not essential to sustainability analysis in all situations.

The research has the following structure:

a. Literature review on Social-LCA with Integration into PLM to identify the main research needs.
b. Identification of recent lifecycle-based product sustainability assessments of electronic companies having globalized supply chains.
c. Findings about the challenges and potential of Social-LCA when integrated into PLM at an electronic company. These results could benefit decision-makers, stakeholders, enterprises and consumers.

2 Methods and Materials

2.1 Structured Literature Review of Social-LCA and PLM Integration

We structured our literature review to yield reproducible results - a reliable knowledge base without research bias – using the following steps [3]:

(I) Definition of review/check list; (II) Listing of research questions; (III) Identification of keywords; (IV) Selection of sources for literature search; (V) Define inclusion and exclusion criteria; (VI) Refining & finalizing keyword setting; (VII) Search of literature; (VIII) Evaluation and documentation of literature. Table 1 shows the review protocol.

Table 1. Review protocol

Review questions	"What are the thematic fields of research concerning social LCA with integration to PLM?" "What gaps exist in research?"
Keywords	Social Life Cycle Assessment LCSA sustainability Life cycle sustainability assessment (LCSA) "Social Life Cycle Assessment" + "PLM" "LCSA" + "Product lifecycle management"
Sources for literature search	Google Scholar | Semantic Scholar | Procedia CIRP[a]
Inclusion criteria	Title: same or similar as keywords mentioned above Abstract & Full Text: Social-LCA, or S-LCA framework, methods of PLM integration with any product lifecycle system
Exclusion criteria	Books; Non-English/non-German/non-Chinese publications; Application/analyses branch is other than electronic branch; Publication year earlier than 1990
Refining & finalizing keyword setting	Social Life Cycle Assessment + PLM
Evaluation/documentation	We will document the following important information in EXCEL Format: Publication Topic |Author | Publisher & Publication Year | Scope of Publication | Reference | Abstract

[a]Procedia CIRP is an open access product focusing entirely on publishing high quality proceedings from CIRP conferences, enabling fast dissemination so that conference delegates can publish their papers in a dedicated online issue on ScienceDirect.

Research Approach

- Type of study (empirical, theoretical, or both).
- Research application areas (industry sector).
- Sustainability dimension (which of the three dimensions of LCA the publication addresses).
- Type of case study (full case study or numerical example).
- Data for case study (extent to which real data was collected).
- Integration. Studies may be classified according to whether they address an integrated system, and if so, the kind of application of Social-LCA (Life Cycle Management (LCM); product lifecycle management (PLM), application life cycle management (ALM) for software, and data lifecycle management (DLM); information life cycle management (ILCM) [2].

2.2 Evaluation of Current Status in the Electronics and Electric Industries

This part of the research was conducted independently of the structured literature review on Social-LCA. Our approach resembled that of John W. Sutherland et al. [14], who explored social impacts identified by national-level social indicators, frameworks and principles. We also examined methodology development and various challenges for social life cycle assessment.

Martin Gerner found that "Quite a number of companies within the business segment are confronted with the dual challenge of both transforming their business models into future-proof concepts and paying tribute to an increase of sustainability awareness among customers simultaneously".

The gradual shift of business segments from hardware-related stationery and professional office supplies towards digitized media and IT business solutions addresses sustainability and corporate (social) responsibility as one core competence of related companies in a changing market environment (Altenburger 2013; Stanger 2017, p. 61; Zarnekow and Kolbe 2013). It is reasonable to focus upon corporate sustainability or sustainable entrepreneurship (Schaltegger and Wagner 2011, 225 et seqq.; Weidinger et al. 2014), interchangeably, examining subject plus contextual conditions. E.g. to analyze characters of industrial companies: are they "Innovation and business-model development" driven company, have a pivotal stake within the company's strategic development, e.g. heading for new product lines (eco-innovation), providing resourceful services, stretching brands etc.; or are they globally oriented companies, where cultural context plays important role.

2.3 Implications for Application at Electronic & Electric Company

In order to identify the most pressing challenges out of the ones identified by the two previous research steps to adopt Social-LCA, decision makers at electronic & electric company should be consulted. Interviews of experts and stakeholders should also reveal three types of knowledge for analysis: technical, procedural and interpretative. In reverse, an implementing concept will focus on the managerial aspects of corporate sustainability by returning analytically processed records to the case-presenting company [4].

3 Result and Decision

3.1 State of the Art of Social-LCA

The low amount of papers identified with our final keywords suggests that social Life Cycle Sustainability Assessment is still in an early stage of development. Our final set of 47 analyzed publications is consistent with the number of publications considered by other structured literature reviews [1, 4, 5].

3.1.1 Bibliometric Results

Figure 5 shows the chronic development of research in field of Social-LCA (with integration into PLM). It can be clearly seen that the majority of publications appeared after 2011, and the research is getting more and more attention. Publications peak in 2014, 2018 and 2019.

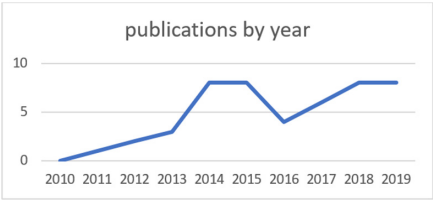

Fig. 5. Distribution of publications by year

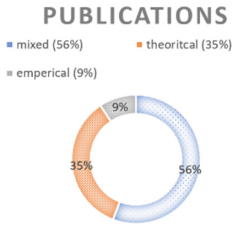

Fig. 6. Publications by type of study

Table 2 shows the distribution of publications by source. All sources that contributed only one publication were subsumed under "Rest". It is easily to see that Springer is the main medium in field of social LCA with integration into Life Cycle management. Other important journals for LCA include The International Journal of life Cycle Assessment or Journal of cleaner Production, Journal of remanufacturing, etc.

Table 2. Distribution of publications by source.

Publication by source	publications
Springer	13
Procedia CIRP	3
Journal of Industrial Ecology	5
semantic Scholar	6
Emerald Journals	3
Rest	11
total	41

Table 3. Publications by countries

Country	Publications	%
Switzerland	1	2
Czech	1	2
Germany	16	36
Finland	5	11
France	2	5
Italy	12	27
Korea	1	2
Nietherland	2	5
USA	4	9

The type of study or focus of research is also important for the evaluation of publications. Figure 6 shows that combined empirical and theoretical studies are mainly comprised of method developments that are subsequently tested by case study, which means the field of analyzed literature leans more strongly towards method development. Together with theoretical type of study, more than 90% of publications are about theorical and method development. This indicates also that the Social-LCA with integration into PLM is a new research area.

Table 3 show the distribution of publications by countries. Germany led (36%), followed by Italy (27%), Finland (11%), and USA (9%).

3.1.2 Classification of Literature by Thematic Fields

The maturity model was designed in such a way that a comprehensive capability analysis is possible in its application. It addresses the essential phases of the product lifecycle: planning, development, production planning, production, and operational and service tasks. The BABOK [6] explains the key terms used here as follows.

Framework: A generic lifecycle analysis or lifecycle assessment (LCA) explains the system structure. Most research into LCA has focused on the principle logic and improvements of the analysis framework or on empirical tests of conceptual frameworks. Klöpffer [7] and Finkbeiner et al. [8–10] defined the Life Cycle Sustainability Assessment framework. Martin Gerner (2019) [4] focused his research on LCA framework implementation strategy and applied the framework-implementation approach to corporate sustainability (Baumgartner and Rauter 2017, pp. 82–83). He also reported examples of applications of LCA framework implementation and provided recommendations. See Fig. 7 and Fig. 8.

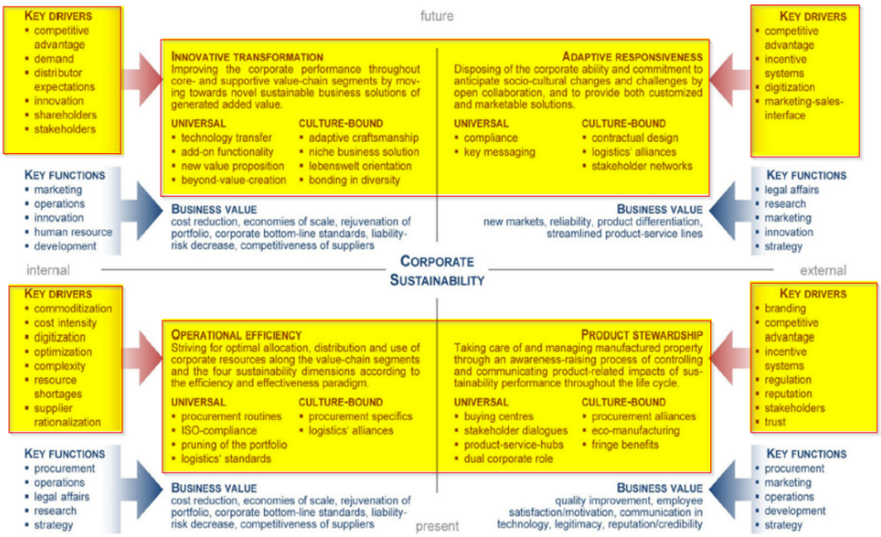

Fig. 7. Sample framework implementation strategy for corporate sustainability. Source: [4]

Given a dual character of defining strategy by referring to both identifying and assessing present and future comparative advantages and potential for success and deriving detailed implications for policies and plans of implementation, the framework strategy explicitly focuses on conceptual guidelines for realizing such business opportunity (Morioka and de Carvalho 2016; Rusnjak 2014, p. 48–50).

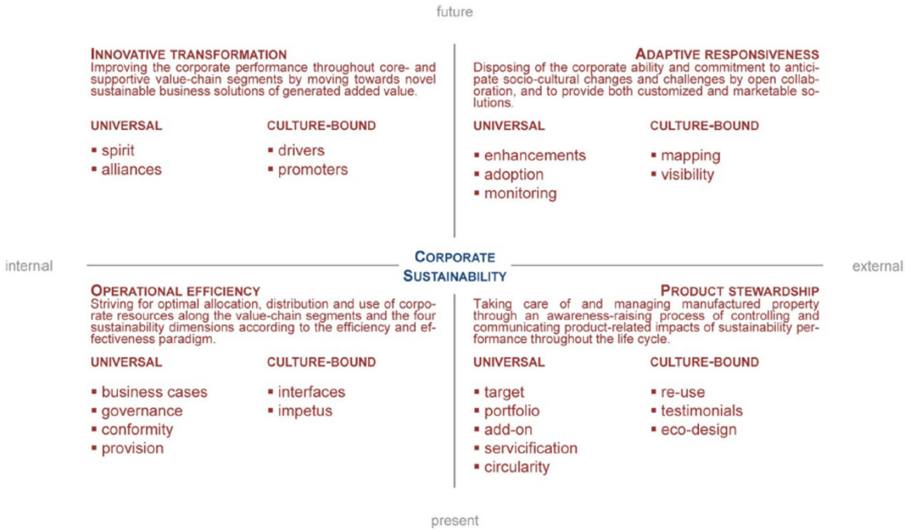

Fig. 8. Sample of implementing recommendations for corporate sustainability. Source: [4]

PLM is mainly a business management concept for sustainable products that can be applied in the industrial and service sectors with the aim of improving specific goods and services and enhancing the overall sustainability performance of the business and its value chains. PLM appeals to businesses that are ambitious and are committed to reduce their environmental and socio-economic burden, while maximizing economic and social values. PLM is intended to create sustainable value rather than improve short-term success. So, PLM requires a holistic view and a full understanding of interdependency of businesses, environmental and social issues [11].

Method and Method Integration: Publications about methods proposed extensions of or changes to higher-level frameworks. Research into method integration focused on case studies, applications of methods, or methodological triangulation.

Case-related research is mainly exploring, including interpreting-inductive elements grounded in contested assumptions and referring to underlying theoretic frameworks and methodological concepts of relevant importance (Gioia, Corley and Hamilton 2013, 17 et seqq.; Jastram 2012, p. 53; Kromrey 2002, 58 et seqq.) [4].

Applications of methods addressed principles of qualitative content analysis (Atkinson 2017, pp. 122–123; Mayring 2014; Silverman 2013, 340 et seqq.) to understand applications of theories on corporate sustainability. take into account the leading theoretical concepts applied by scholars on selected corporate contexts, and to identify how to adequately embed the intended case study; collecting case-related characteristics to elicit elucidating, confidential up-to-date information through a status-quo-analysis of sustainability-related strategic approaches, activities and initiatives, means and instruments, examine underlying corporate perceptions through SWOT-analysis, including business analysis (internal) and environment analysis (external), and to benchmark performance targets and monitoring processes through an analysis of

potential or opportunity assessment, respectively; and processing obtained findings in a strategic-directional way to adopt the value-chain-oriented reasoning based upon an extended lifecycle assessment (Frostell 2013, 842 et seqq.; Gauthier 2005) as structuring element, apply a multimethod approach of methodological triangulation, relying on stakeholder observation, expert interviews and company resources, and frame case-related characteristics as case study, including data collection, data analysis and data evaluation [4].

Methodological triangulation improves research validity through combining various techniques. The blend of multiple methods, not to be confused with mixed method, ensures best possible use of different sources of information, and thus generating sound and methodologically-grounded results, pertaining to qualitative research models, in particular (Bohnsack, Marotzki and Meuser 2006; Flick 2006, 2011; Kuckartz 2014, p. 19; Lamnek 2005; Mayring 2002, 73 et seqq., 2014, p. 8; Scholz and Tietje 2002; Silverman 2013, 199 et seqq., 2014, 22 et seqq.). (Prexl, 2010 301 et seqq.; Puls 2016) [6], Generally, this triangulation is evaluated by expert interviews, company resources and stakeholder observations.

Alternative Assessment Methods: Most researchers developed unique assessment methods but some incorporated parts of LSCA or LCSA frameworks. Luthe et al. [12] developed a tool that integrates LCA, Social-LCA, and economical aspects into product design, while Mjörnell et al. [13] integrated all three LCSA components into their sustainability assessment. Martin Gerner suggested integrating corporate sustainability into strategic management.

Case Studies: Most case studies tested applicability of the LCA framework and associated methods. Some case studies lacked effective ways of weighting sustainability dimensions and integrating all three dimensions., there are also some case studies and improving data availability addressed by examined publications, especially for Social-LCA [4, 8], were additionally identified as potential areas for improvement. E.g. A case study using LCSA framework with special focus on Social-LCA on mineral and compost fertilizers was conducted by Martínez-Blanco et al. [8] who used data from LCA databases (environmental impacts), LCC (purchase price), and Social-LCA to assess the sustainability impacts of fertilizers. Martin Gerner [4] focused upon corporate sustainability or sustainable entrepreneurship (Schaltegger and Wagner 2011, 225 et seqq.; Weidinger et al. 2014), interchangeably, these facets are to be elaborated by means of case study. in his case study Sustainability performance is related to [a] an extended lifecycle analysis (LCA), and [b] the triad of marketing in business-to-business relations, business segments in sustainability contexts, and culture bound/intercultural notions of sustainability.

His case study aimed at strengthening corporate sustainability with current and evolving culture-bound approaches. He provided guidelines for implementation at the operational level (Berns, Townend, Khayat, Balagopal and Reeves 2009, p. 7; Engert and Baumgartner 2016; Khalili 2011b, pp. 152–154) [4].

Data and Data Collection: Most researchers employed two approaches: (a) *Empirical Case Study*. Scholars used qualitative indicators of performance. Case-study research is most effectively carried out through combining multiple techniques simultaneously

(Gioia et al. 2013, p. 16; Jastram 2012, p. 58; Prexl 2010, p. 301; Scholz and Tietje 2002, 3–4, 9 et seqq., 14, 15 et seqq., 23–25) [4]; (b) *Theory-induced data collection*, stakeholder observation, expert interviews and company resources for research in industrial area.

3.2 Current Status in the Electronic and Electric Industry

Most European electronic & electric companies that have integrated LCA into the product development process have not effectively integrated social and economic impact assessment. First steps towards the operationalization of Social LCA have been taken by co-founding the Roundtable for Product Social Metrics, an industry-led initiative that produced a handbook on implementing product social impact assessment [4]. Environmental LCA is well-accepted and practiced throughout the world's top electric & electronics companies, like Siemens, Philips, GE, WAGO, BOSCH, etc., but few have employed comprehensive Life Cycle Sustainability Assessment of products. The immaturity of Social-LCA and the difficulty of gathering data on social impacts pose an additional barrier to implementing Social-LCA as part of an LCSA framework in industry. Most stake holders and experts consider an entire Social-LCA as too big a challenge, but many understand the importance of social risk assessment of supply chains in managing social risks.

There exists no universal strategy to integrate Social LCA into PLM (life Cycle Management). The strategy differs for each sub-cycle, including the following:

- Production management - Sustainability's focus is product stewardship, operational efficiency and/or innovative transformation
- Packaging/distribution management - Sustainability's focus is operational efficiency and/or adaptive responsiveness
- Service/use management - Sustainability's focus is product stewardship, innovative transformation and/or adaptive responsiveness
- End-of-life management - Sustainability's focus is product stewardship and/or innovative transformation

Industry is trending from corporate (social) responsibility towards an integrated concept of sustainability that is functionality-based and governance-oriented.

3.3 Implications for Applications at Electronic & Electric Industry

Our research determined the state of the art in the field of Social LCA and highlighted major areas for future research. We reported the status of product sustainability assessment in the electronic & electric industry and implications for the next steps towards the operationalization of Social-LCA. We identified several challenges for operationalization that hinder the adoption of LCSA at electronic & electric company.

We propose the following guidelines for further research.

Data Collection: Accessing internal, often confidential company information requires close interplay between academic and corporate entities [4]. Researchers should

prepare to handle different languages across a company. Questions should be formulated ad hoc referring to pre-structured questionnaires. Interviewers should follow common routine of salutation, reciprocal introduction, question and answer, brief discussion and feedback, follow-up, and leave-taking (Bogner et al. 2014, 27–48, 58 et seqq.; Gläser and Laudel 2012, 83 et seqq.; Silverman 2013, 199 et seqq.) [4].

Data Analysis: In qualitative analysis, procedural arguments are to be granted priority over procedural arguments. Validity is of more importance than reliability.

Data Evaluation: Interpreting findings retrieving from qualitative data consequentially should follow the algorithms of qualitative content analysis

Comparatively Low Maturity of Social-LCA

- Ensure consistency of social topics with company specific strategy.
- Evaluate currently available databases and decide on a mode of data acquisition.

4 Limitations

We searched the literature using only three sources and narrowed down search terms to reduce the number of hits. Our narrow search focus may have overlooked some relevant publications, especially those that addressed only one method that could be a part of Social-LCA.

The research design included the social dimension in the lifecycle structure of analysis. Results of expert interviews, company resources and stakeholder observation revealed that assuming a generic, five-part lifecycle assessment represents a stylized or archetypal model of approaching corporate reality. Researchers must transfer or relate findings to the value-chain segments in the corporate structure. Without further research, our findings do not provide a basis for conclusions of a general nature. Our qualitative approach means findings pertain with certainty only to the cases studied [4].

5 Conclusion

This paper identified challenges and potential for implementing an integration of Social Life Cycle Assessment (Social-LCA) into Product lifecycle Management (PLM) at an electronic & electric company. The three-part structure of sustainability performance, sustainability opportunity and sustainability commitment made it possible to first, assess the status quo of corporate sustainability-related strategic approaches, activities and initiatives, means and instruments; second, identify universal and culture-bound drivers corresponding to industry-sector-specific characteristics; and third, deduce operational guidelines in view of stakeholder awareness, strategic options, projects and best practices [4].

Every sustainability dimension, i.e. environmental, societal, economic and cultural, should be studied individually and then correlated with the generic lifecycle category,

i.e. supply chain, production, distribution/packaging, service/use, and end-of-life, and finally included into the afore mentioned three-step assessment.

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