Integrating sustainability into day-to-day business: a tactical management dashboard for O-LCA

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ABSTRACT

In order to respond to the challenge of sustainable development, organizations need to manage the social, environmental and economic impacts of their activities. Existing approaches to manage organizational sustainability either are limited by a narrow perspective or lack concepts and tools to integrate sustainability considerations into day-to-day business. We address this issue by proposing a tactical management dashboard based on Organizational Life Cycle Assessment (O-LCA), an authoritative and comprehensive methodology for organizational sustainability analysis. We have developed a concept for a tactical sustainability management dashboard based on O-LCA guidelines and best-practices for dashboard design that allows managers (who may not be LCA experts) to explore, analyze and interpret O-LCA study results. The concept was implemented in an early software prototype and evaluated regarding its usability. Our concept and prototype show the viability and utility of a management tool based on O-LCA.

CCS CONCEPTS

• **Information systems** → **Decision support systems**; • **Applied computing** → **Business process management**.

KEYWORDS

Organizational Life Cycle Assessment, Sustainability Dashboard, Sustainable Business Process Management

ACM Reference Format:

Vera Büdel, Andreas Fritsch, and Andreas Oberweis. 2020. Integrating sustainability into day-to-day business: a tactical management dashboard for O-LCA. In *7th International Conference on ICT for Sustainability (ICT4S2020), June 21–26, 2020, Bristol, United Kingdom.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3401335.3401665

1 INTRODUCTION

Organizations have, for example through their consumption of resources and production of emissions, a major impact on environment, society and economy [41]. As the consequences of a lack of sustainability, such as the loss of species and global warming, are becoming more and more noticeable, it is increasingly important for companies to take steps to mitigate especially their environmental and social impacts [33]. Therefore, there is a rising demand for approaches to analyze and improve organizational sustainability [41]. To avoid mere burden shifting and to achieve actual improvements, a holistic and integrated analysis of the whole organizational life cycle and all relevant impacts is crucial. An authoritative approach for this, and hence a foundation for this paper, is Organizational Life Cycle Assessment (O-LCA) [48, 54].

However, the complexity of O-LCA due to the large amount of data, is a challenge. When interpreting O-LCA studies, two of the main difficulties for the users are, how to cope with the quantity of results, and how to make them understandable for a general audience [1, 51]. Especially non-experts struggle with handling and interpreting O-LCA studies in practice [51, 54]. But measures for an improved organizational sustainability can only be taken if decision-makers are able to understand interlinkages and derive effective courses of action. It is therefore essential to find ways to communicate O-LCA results to an untrained audience and to make them interpretable for non-experts [6, 11]. Dashboards are especially useful to communicate and visualize complex data and to support decision-making in organizations [60]. The goal of this paper is the development of an O-LCA dashboard for the holistic consideration of corporate sustainability, which communicates sustainability information for decision makers in an easily understandable way. In this paper, we describe a concept and software prototype for a sustainability dashboard based on O-LCA and dashboard design best practises. For this purpose, we first examine the fundamentals of O-LCA and dashboard design and compare our vision to related work in Section 2. Then, in Section 3, the requirements for the dashboard are derived from the gained insights. In Section 4 we describe concrete realizations for the defined requirements, as they were implemented in a software prototype. The results of a usability evaluation are laid out in Section 5 and contributions and limitations of our work discussed in Section 6. Finally, Section 7 gives a conclusion and outlook for the future.

2 BACKGROUND AND RELATED WORK

2.1 Organizational Life Cycle Assessment

Life Cycle Assessment is an established methodology for analyzing a product's sustainability from a life cycle perspective. While originally mostly concerned with environmental impacts of products, there are recent efforts to adapt the approach for social aspects [52] and organizational analysis [34, 54]. Organizational Life Cycle assessment (O-LCA) aims to compile and evaluate the "inputs, outputs, and potential environmental impacts of the activities associated with the organization as a whole or portion thereof adopting

ICT4S2020, June 21–26, 2020, Bristol, United Kingdom

Table 1: Comparison of the different dashboard types (based on [6, 8]).

	Strategic	Tactical	Operational
Functionality	Management of people and processes	Causal analysis and multidimensional exploration of information	Monitoring of critical processes and activities
Users	Executives, managers, employees	Managers, analysts	Supervisors, specialists
Information	Summarized / weakly detailed	Summarized / detailed	Detailed
Updates	Monthly / quarterly	Daily / weekly	Hourly / daily
Important Design Elements	Simple presentation Widespread publication Comparison to plan Commentable and collaborative Inclusion of recommendations	Interactive Structured and guided Detailed Contextualized Support of advanced analytics	Clear and simple presentation Selective and efficient Highlighting of exceptions Customizable Timely information

a life cycle perspective" [22]. In the case of a single product, taking a life cycle perspective means to consider all phases of a product's life cycle from the extraction of raw materials needed for its production to its final disposal [20]. One can think of an O-LCA as the sum of an organization's products' LCAs [54]. While the existing standard [22] and guidelines [54] focus on environmental impacts, the integration of the social dimension of sustainability is possible [34]. From a management perspective, an O-LCA analysis may lay the foundation for strategic decision making, improvement of business processes, sustainability reporting and marketing [54].

In the following, we describe the framework and concepts of O-LCA that are relevant for our work based on the formative ISO standards and guidelines [20–22]: An O-LCA study consists of four phases: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. In the first phase, goal and scope definition, the intended application, reason, and target audience are to be defined. For defining the scope, it is necessary to delineate the reporting organization and its context (as the reporting organization may be part of a bigger organization). Furthermore, one has to decide whether the full life cycle is covered in the analysis (cradle-to-grave) or only a part (cradle-to-gate or gate-to-gate). In the second phase, inventory analysis, input and output data for the activities within the scope of the study are collected, in order to model the system under analysis. There is an important distinction between direct and indirect activities. Direct activities are enacted within the reporting organization, while indirect activities happen outside (i.e. up- or downstream in the life cycle). It is important to note, that an O-LCA study typically includes supporting activities, that are not directly related with production, like management or marketing. This is a strength of the organizational scope, as these activities and associated impacts are often neglected in product LCAs [54]. The goal of phase three, impact assessment, is to understand and evaluate the (environmental) impacts associated with the life cycle of the reporting organization. To achieve this, the input- and output indicators are classified according to the impact categories they contribute to (e.g. CO2 emissions contribute to climate change). The characterization of these contributions allows to quantify these impacts in an impact indicator. Finally (phase 4), the findings of the inventory analysis and impact assessment are to be interpreted in order to find conclusions and recommendations for improvements.

2.2 Dashboard Design

The term dashboard refers to a performance-management tool, which summarizes and visualizes data and presents the most important information on a single screen. It thus supports its users in conducting tasks, like the monitoring of indicators or the exploration of information, and hence assists in reaching organizational goals [24, 60]. Due to the limited capacity of the human working memory, one of the most important properties of a dashboard is the aggregation of the most relevant data. The information in the dashboard is designed so that attention is directed to the most important contents [8, 60]. Hence, it must be clearly defined what purpose the dashboard serves in order to be able to extract the relevant data and to choose the best form of its presentation [8]. Accordingly, depending on the type of business activity they support, dashboards can be divided into three types: *strategic*, *tactical*, and *operational* [6, 8]. The type has various implications for the design and handling of the dashboard (see Table 1). Strategic dashboards are used to give managers a quick, high-level overview of key performance indicators, whereas operational dashboards are used for detailed and timely monitoring of critical processes and activities. Tactical dashboards have the purpose of analyzing and exploring complex data from different perspectives and levels of detail [6, 8].

2.3 Vision for a Sustainability Dashboard

The nature of O-LCA is well suited for causal analysis and multidimensional exploration of information. Therefore, we consider a tactical design of the dashboard with an emphasis on interactivity with the displayed data (cf. Section 2.2). Ideally, such a sustainability dashboard should have the following characteristics: First, all sustainability dimensions (social, environmental and economic) should be considered [1]. Only through an integrated contemplation of the three dimensions, critical trade-offs can be avoided [52, 53].

[1]Note that different concepts of sustainability and thus differing sustainability dimensions are defined in research. We chose the three dimensions mentioned above for the purpose of this paper since they are well accepted by industry [29] and the same concept is assumed in the O-LCA guidelines [54].

Table 2: Classification of related designs by dashboard characteristics.

Literature	Environmental	Economic	Social	Multiple	Organizational Perspective	Life Cycle Approach
Bash et al. (2011) [2]	X	X	X	X		(X)
Fegraus et al. (2012) [7]	X		X	X		
Hunt et al. (2014) [19]	X	X	X	X	(X)	
Lozano (2006) [31]	X	X	X	X	(X)	
Meul et al. (2008) [36]	X	X	X	X	(X)	
Pa et al. (2017) [42]	X			(X)		
Traverso et al. (2012) [50]	X	X	X	X		X
Yun et al. (2014) [61]	X					

At the same time, a multi-impact analysis in accordance with O-LCA should be carried out, i.e. several sustainability impacts should be considered for every dimension [54]. Additional to a comprehensive understanding of sustainability, an important criterion for the dashboard is the organizational perspective. Furthermore, our dashboard should follow the life cycle approach of O-LCA to enable a comprehensive analysis of sustainability (cf. section 2.1). Thus, the whole organization with its value chain is to be considered in the dashboard (cf. section 2.1). Since the dashboard should support the understanding and the interpretation of O-LCA results, the data displayed in the dashboard should be explorable across their multiple dimensions. Additionally, hotspots and their causes should be easily identifiable.

2.4 Related Sustainability Dashboard Designs

In the following, we examine papers that propose comparable dashboards design and evaluate them along the characteristics specified in our vision in the previous subsection (cf. section 2.3, Table 2).

Aside from two of the papers (cf. [42, 61]), which only consider environmental sustainability, several sustainability dimensions and indicators are used in all papers. The main gaps in existing sustainability dashboards can be identified in the organizational perspective and life cycle approach (cf. Table 2). Only three papers contain a sustainability assessment at an organizational level, although they are limited to a specific type of company (cf. [19, 31, 36]). A dashboard, which was generally built for a sustainability analysis with the scope of the company and its value chain, could not be found. A life cycle approach was only implemented in one paper (cf. [50]), while it is mentioned as a future extension in [2]. [50] probably comes closest to the objective with the "Dashboard of Sustainability" described in their paper, although this is not designed for the analysis of organizations. The dashboard concept developed in this paper closes the apparent gaps in Table 2 in the organizational perspective and life cycle approach by using O-LCA as methodological basis and thus supporting a comprehensive life cycle based business sustainability assessment.

3 REQUIREMENTS FOR THE DASHBOARD

In this section, we describe requirements for an O-LCA dashboard. As explained previously, an important differentiating feature of the dashboard developed in this paper is the underlying O-LCA methodology. This is to support the implementation of a comprehensive life cycle analysis of organizational sustainability. The second general feature of the dashboard is the chosen tactical design (cf. Section 2.3). Accordingly, the general requirements for the dashboard were derived from the O-LCA process (marked with an "O") and the design elements of a tactical dashboard (marked with a "D"). The detailed requirements for the dashboard in this paper are listed below and explained in more detail in the following.

O1 Display of the organization's current sustainability indicators as well as its objectives.

To enable organizations to track their own sustainability performance the current values and the sustainability goals of the considered indicators should be displayed in the dashboard. The simultaneous presentation of the objective of every indicator helps to put its current value in relation, thus making it easier to assess and interpret performance [37]. Additionally, the definition of a clear goal for every sustainability indicator helps managers to translate their general visions into concrete sustainability goals and thus make the topic of sustainability more concrete in practice [36].

O2 Aggregation and display of the sustainability indicator hierarchy.

After the inventory data has been collected, it is then assigned to the impact categories selected by the company (classification) and, using characterization factors, the impact indicator of the category is calculated, which summarizes the inventory data. Once all impact categories have been defined and indicators calculated, the results can optionally be further normalized, weighted and aggregated [54]. Without these steps, the results are often very difficult to understand and interpret for decision makers, most of whom are typically not experts in sustainability analysis [50]. The handling of the many indicators is very complex and, in addition, they are difficult to display without a summary in the dashboard [44]. Therefore, another important requirement for the dashboard concept is the development of an aggregation scheme for the indicators, so that the results of the corporate sustainability analysis are more comprehensible and thus easier to interpret. [54]. The aggregation results in a hierarchical arrangement of the indicators, which should also be reflected in the dashboard. This allows to show the indicators at different levels of detail according to the tactical dashboard characteristics (cf. Table 1) and helps to counteract the problems of composite indicators by reflecting their structure, as well as the aggregation scheme, transparently in the hierarchy [55].

O3 Display of the scope of the analysis, i.e. the covered processes and activities of the organization.

After identifying the activities that are significantly involved in the sustainability impacts, the system, i.e. these activities with their relations, inputs, and outputs, is modelled in the following inventory phase [54]. Therefore, the dashboard should provide the possibility to present the organizations processes and activities considered in O-LCA in a model. Accordingly, a suitable notation must be integrated into the dashboard, which enables the modeling of processes and activities and their sustainability in a way that is easily understandable by non-LCA-experts.

The following requirements result from the tactical design of the dashboard in this paper:

D1 Inclusion of interactive features.
D2 Implementation of a structured and guided display.
D3 Inclusion of detailed information.
D4 Implementation of contextualization in the display.

Once all sustainability impacts have been identified and calculated, the interpretation of the O-LCA results is conducted. This involves identifying hotspots at various levels of aggregation, monitoring corporate sustainability and target fulfillment, and deriving action recommendations for the organization [54]. Accordingly, another important requirement is to design the dashboard tactically (cf. section 2.3). Therefore the core tactical features should be implemented in the dashboard (cf. Table 1). One of the most important design elements is interactivity [6], which enables the users to explore the data and thus to gain new insights. Additionally, interactivity helps with the presentation of complex and diverse data by using different formats and levels of aggregation [28, 60]. Interactivity with a visualization in a dashboard can be implemented in various ways, e.g. data filters, drill-downs (variation of the detail of the displayed data) or brushing [3, 49]. In addition to interactivity, the other tactical design elements, i.e. a structured and guided display, detailed information, and contextualization should also be included in the O-LCA dashboard. In the first development loop, we are focusing on implementing the basic functions of a tactical dashboard. They form the foundation for additional enhanced features, such as advanced analysis functions (cf. Table 1), which can be added in future developments.

4 IMPLEMENTATION

4.1 Indicator and Target Display

In this section concepts are developed to fullfil the requirements formulated in the previous chapter. The requirements will be addressed according to their order in Section 3.

The definition of the objective of the study is crucial for the implementation of O-LCA [54]. Accordingly, in addition to the actual values, the dashboard should also show the corresponding targets (cf. section 3, requirement **O1**). Since the goals are intended to give meaning to the actual indicators, they are displayed on the same scale for a better overview and interpretation [37]. Thus, when viewing the scale, a user can see directly how far the actual value differs from the target value. An appropriate solution for displaying actual and target values on a scale are so-called "bullet graphs" [8] (cf. Fig. 1), which will be used in our dashboard.

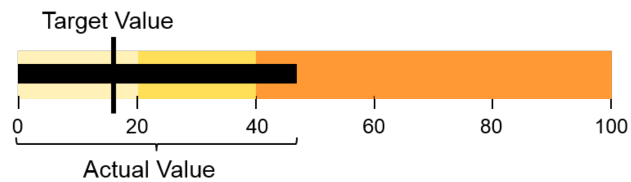

Figure 1: Representation of actual and target values in a bullet graph (based on [8]).

In a bullet graph the actual value is displayed as the length of a bar within a scale from zero to one hundred. The target value is represented by a vertical thick line (cf. Fig. 1). Whether the bar intersects the target line is already perceived preattentively due to the resulting cross shape, which allows the observer to notice quickly at which indicators the target was reached. In addition, a color coding serves to divide the scale qualitatively into "bad" (dark orange), "medium" (yellow) and "good" (light beige) values [8]. Each bullet graph in the dashboard is also provided with the name of the indicator and its numerical value.

4.2 Aggregation Scheme and Indicator Hierarchy

Although aggregation of sustainability indicators is controversial, the advantages, especially the improved interpretation and communication for the general public, outweigh the challenges for the purpose of the O-LCA dashboard in this paper [39]. For this reason, it was decided to further aggregate the impact indicators to reduce the complexity of the display and the amount of information to a cognitively processable quantity [44, 50] (cf. requirement **O2**). Before aggregation can be carried out, it must first be individually determined which indicators are to be considered in the organizational sustainability analysis. For this, the impact categories to be used and their associated inventory data are selected from existing proposal lists and databases [13]. As can be seen in Fig. 2, the division of sustainability, first into the three dimensions, then into the impact indicators and finally into the inventory data assigned to the impact categories, already results in a hierarchical structure of the sustainability indicators.

The aggregation scheme for the O-LCA dashboard follows this hierarchy and consists of three stages, each located between two levels of the hierarchy (cf. Fig. 2). At the lowest level are the inventory metrics that reflect the highest granularity of sustainability data provided in the dashboard. In the first stage, these are used to calculate the associated impact indicators based on their characterization factors for their impact categories previously selected for the study [13]. This is the classic characterization step of the impact assessment phase.

In the second aggregation step, the impact indicators are then normalized, weighted and aggregated to form composite indicators

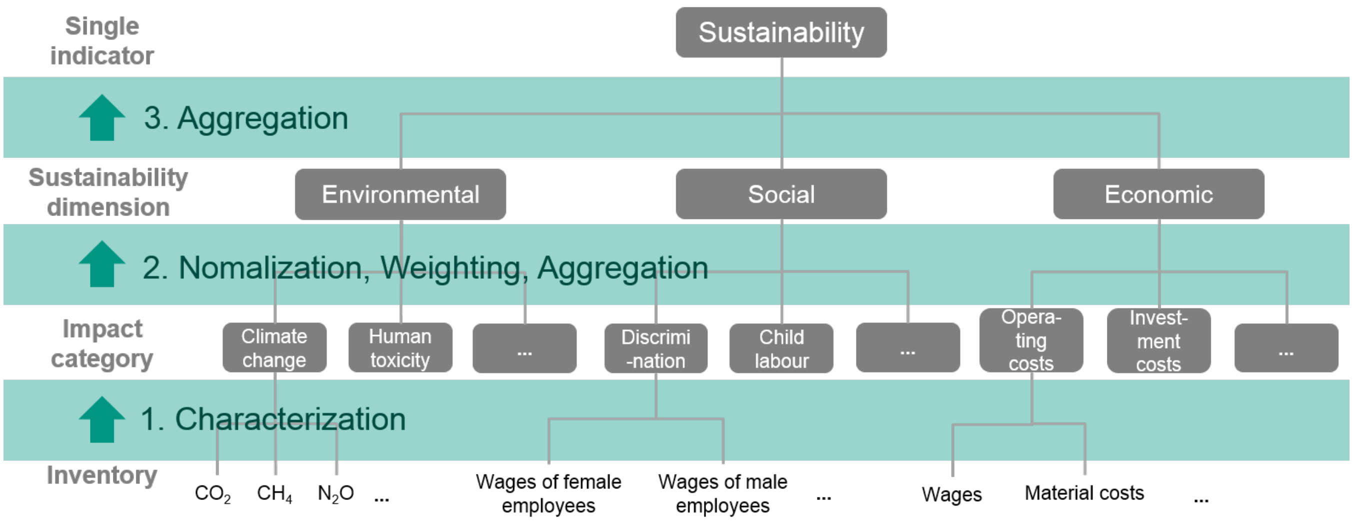

Figure 2: Schematic representation of the aggregation scheme used for the indicators in the dashboard.

for the ecological, social and economic sustainability dimension. To obtain a scaled value in the interval [0;1], a min-max normalization following [30] and [39] is selected for the dashboard. The normalization is formulated in such a way that a minimization problem arises after its implementation, i.e. the minimum value is optimal. To make the value more comprehensible to dashboard users and possible to display it on the scale of a bullet graph (cf. section 4.1), it is multiplied by 100. After the normalization, the indicators are weighted with a distance to target weighting. This means the actual value of an impact category is related to the target value of the organization. The more the target value is exceeded, the greater its weighting [23, 43]. Once the impact categories have been normalized and weighted, they can be summarized in composite indicators for the environmental, economic and social sustainability dimension. For this, an aggregation formula is used which is an adapted approach of [5] and allows an individual definition of the assumed degree of weak and strong sustainability (see [44, 46]). For further information about the proposed aggregation scheme see: https://git.scc.kit.edu/von-bis-public/o-lca-dashboard.

Finally, the calculated composite indicators of the three sustainability dimensions are combined in a single sustainability indicator in the third step of the aggregation scheme. Since the dimension indicators are already on the scale from one hundred to zero, no further normalization of the values is required to calculate the individual indicator. By default, an equal weighting of the sustainability dimensions is used. The same aggregation formula as in step two is used to calculate the single sustainability indicator.

In order to reflect the underlying indicator hierarchy, the indicators should also be presented hierarchically in different levels of detail in the dashboard. The bullet graphs are arranged hierarchically to show this structure, so that the value and goal of each indicator is represented by a graph. The bullet graphs are connected with edges for hierarchical display, which reflect the hierarchical relationships of the indicators to each other and thus also the aggregation structure. In order to create transparency with regard to weighting and aggregation [39], the weightings of the indicators are noted on the edges (cf. Fig. 3, right side).

4.3 Display of the Scope

In addition to the sustainability indicators and goals, it must also be possible to represent direct and indirect activities of the organization and thus the scope of an O-LCA study in the dashboard (requirement **O3**). Our proposal here is to tap into existing research and knowledge in the field of Business Process Management (BPM), which is, among others, concerned with the analysis of activities in an organizational environment [59]. The concept of business processes is established in most companies today and therefore familiar to managers [17, 35]. Different modeling languages are available to visualize business processes. One example is Business Process Model and Notation (BPMN), which is considered as being cognitively effective [26, 40] and was developed with the goal to be understandable by all business users [59]. While BPMN provides a wide range of notational elements, the activity types "Task" (rounded squares in Fig. 3) and "Subprocesses" (rounded squares marked with a plus at the bottom) are sufficient for the purposes of the dashboard. They allow for the modeling of a hierarchical modularized activity structure in the dashboard [26, 35]. Additional BPMN elements, such as swimlanes, may be added to the process visualization if needed, e.g. to clarify the division of direct and indirect activities.[2] We propose the extension of the BPMN elements with indicator values in the header of the activities and a coloring analogous to the indicator hierarchy (based on [18] and [45]). In addition, activities with a normalized value greater than or equal to 80 are colored bright red. Activities with a very high sustainability impact in the process are to be highlighted so that users can immediately see where the sustainability hotspots are located.

[2]Note that strictly speaking the processes modeled in Fig. 3 are not syntactically correct, as BPMN requires the presence of a start and end event. We have left them out to reduce the cognitive load for the user. However, these could easily be added in order to further synchronize the O-LCA dashboard with BPM concepts.

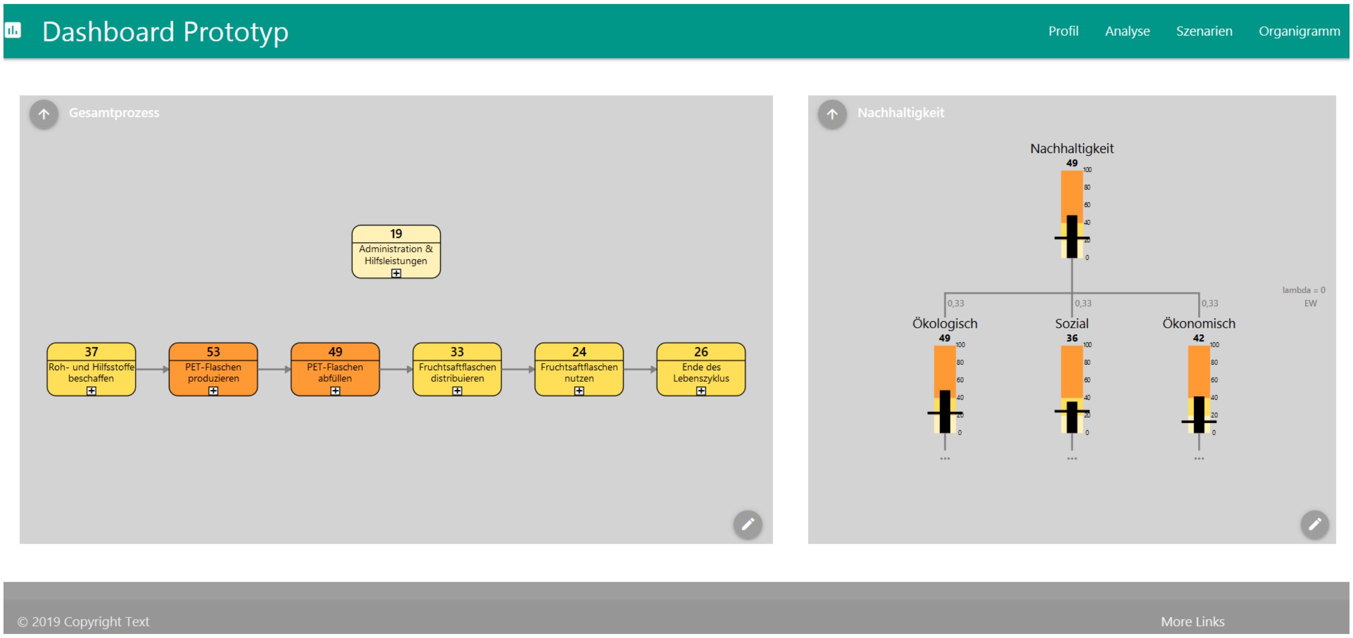

Figure 3: Screen view of the prototype.

4.4 Tactical Design Elements

After their development, the indicator hierarchy and the business process model are integrated into a dashboard so that the sustainability of a company is visualized in a way that is understandable for decision makers. In order to make the information in the presentation explorable and thus promote the acquisition of new knowledge, the dashboard is designed tactically [6] (requirements **D1** - **D4**). A first prototype of the dashboard was developed to illustrate the visualization and functional design of the dashboard concept in practice (see https://git.scc.kit.edu/von-bis-public/o-lca-dashboard). Based on this prototype, the implementation of the tactical design elements is now explained in more detail following their order from Section 3.

Interactive features, such as the ability to filter data, play a particularly important role in a tactical dashboard (requirement **D1**). One of the most important interactive implementation concepts is the realization of drill-downs, i.e. the possibility of varying the level of detail of the display. This is decisive for several analytical properties, since it allows not only interactive analysis but also a change in the level of detail of the displayed information and thus the hierarchical structure of both graphs. This makes it possible to show information relationships, structure the data and reduce the complexity of the representation, which supports comprehensibility and thus facilitates e.g. root cause analysis [3, 28, 60]. Both the level of detail of the indicator hierarchy and that of the business processes can be changed (cf. Fig. 4). The images adapt to the display level of the other graph and filter each other. This means that both the indicators and the process detailing can be varied at will in the two displays, allowing multidimensional analysis of corporate sustainability. As a further interactive function in addition to drill-down, brushing was implemented in the visualization concept (cf. [3]). If an element in one of the graphs is clicked once, both displays are filtered according to the selected element (i.e. a process step or a characteristic number), but the level of detail is not changed. This enables the user to understand the relationships between the displayed information [3].

A structuring and guidance of the display (requirement **D2**) is realized by "breadcrumbs", i.e. headings that adapt to the displayed detail level in the graph and thus indicate the position. Additionally, the navigation in the dashboard was designed intuitively in order not to disturb the flow of ideas of the user. The drill-down is triggered in the two graphs by double-clicking on the element that should be displayed in more detail. To switch to the superior detail level you can use the "back"-button in the upper left corner of each graph (cf. Fig. 3). Guidance to new users of the dashboard is given by a feature discovery, which explains the basic dashboard functions in a popup.

Detailed information (requirement **D3**) is included in the dashboard by providing inventory data on the lowest hierarchy level with high granularity. To help with orientation, the graph display is contextualized in each case (requirement **D4**). In the process, grayed out activities before and after the sub-process are used to display the process step before and after the zoomed-in sub-process (cf. Fig. 4). In the indicator hierarchy, the aggregation level subordinate to the selected indicator is used for contextualization, as well as three points that indicate a further, subordinate level (cf. Fig. 4).

5 EVALUATION

We conducted an evaluation of the dashboard prototype in order to uncover improvement potentials and to determine the degree of goal achievement [47]. The aim of the dashboard is to present corporate sustainability in a way that is understandable to its users.

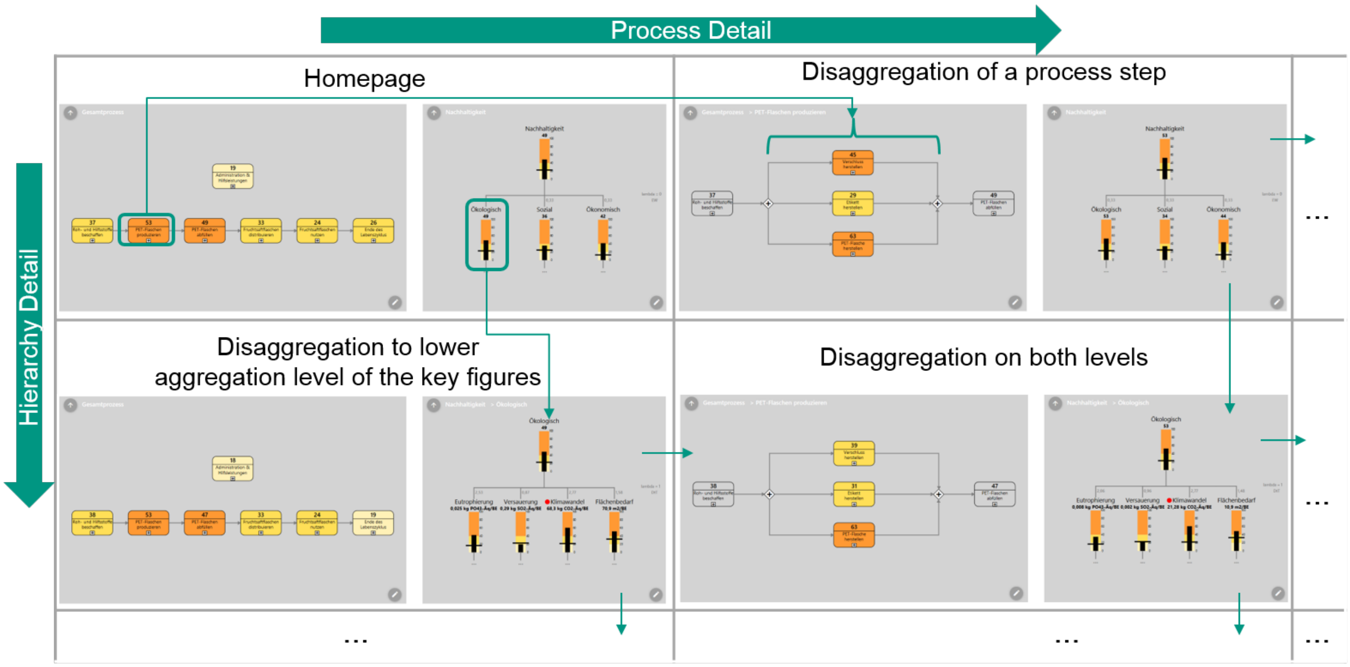

Figure 4: Different aggregation levels in the dashboard.

Therefore, the interaction of potential users with the system is particularly important for the evaluation of its usability [47]. The evaluation of the dashboard was conducted with five potential future users of the dashboard, as five test persons are usually sufficient to uncover 80% of all usability problems [58]. Since the dashboard is primarily aimed at making sustainability comprehensible to the general public, only non-sustainability experts were selected for the evaluation. Three of the test persons had a management background, while the other two worked in analysis and planning functions in their companies. Two participants also had knowledge of the design of IT services, which enabled them to incorporate their expertise into their feedback.

The usability was determined by means of a usability test. In this test, insights into the quality of dashboard development are gained by observing the behavior of the users when performing a practical task in the dashboard. In order to uncover the feelings and thought processes during the use of the dashboard, the method of thinking aloud was used. Finally, further user feedback on the dashboard was requested in an open conversation.

The presentation of corporate sustainability in the dashboard was generally perceived as well implemented by the users, and three of the respondents independently noted that they could well imagine using the dashboard to consider sustainability in their company. Furthermore, two respondents liked the clarification of the comprehensive sustainability approach by presenting the three dimensions in the indicator hierarchy. This would encourage potential users to focus not only on environmental sustainability.

The coloring of the process steps and the scale of the bullet graphs in the prototype was intuitively understood by each of the test persons. The weighting of the indicators and the composition of the aggregation indicators was perceived and correctly interpreted by the users, which became clear by asking questions about the background of the aggregation scheme. This indicates that the demand for a transparent presentation of the methods is fulfilled. The large amount of information presented in the dashboard, however, was criticized by two of the users. They found the visualization too overloaded for ordinary users. The most important suggestions for improvement about the presentation in the dashboard were to make the connection between the two graphs visually clear and to make the design more attractive.

The interactive functions of the dashboard, especially the possible variation of the level of detail in both graphs, were highlighted as very useful by three of the users in their feedback. However, the necessary drill-down in the indicator hierarchy to change the displayed indicators in the process steps was found to be complicated by some users. All respondents found it crucial that the dashboard displays and functions were explained to them before use. Consequently, the importance of providing training for the tool before use was emphasized. Furthermore, two test persons had problems at the beginning with the correct interpretation of the actual and target values of the bullet graphs.

6 DISCUSSION

Our concept and prototype for an O-LCA dashboard address the need to provide tools that integrate sustainability considerations into day-to-day business. We have defined requirements based on O-LCA and dashboard design best-practices and evaluated the utility of the prototype with management professionals. In the following we discuss contributions and limitations of our design regarding the evaluation results, O-LCA methodology, process visualization and its prototypical implementation.

6.1 Limitations of the Evaluation

After we conceptualized a first concept of the dashboard and implemented it in an early prototype, it was evaluated. This evaluation was aimed to give us first insights where the chances and improvement potentials of our design lay after the first development loop. In general, five subjects are sufficient to uncover the most severe usability problems [58]. Still, this small number of participants limits the validity of the evaluation findings. We see it as an early, formative evaluation that informs further improvement (as a basis to derive user requirements), rather than a final, summative evaluation (see also [57]).

6.2 Contribution to O-LCA Practice

The communication of life cycle information to non-LCA-experts is considered a remaining challenge in the field of LCA [15], in particular for O-LCA [32]. While the O-LCA methodology has been applied in practice [51], to our knowledge, up to now no concepts or concrete implementations of software tools that are geared towards the specific needs of O-LCA have been discussed in literature. By providing combined drill-down functionality for processes and indicators, our proposal supports the exploration of an organization's operations in order to identify hotspots and impact reduction opportunities. These are essential analytical goals for organizations when performing an O-LCA study [54]. This drill-down functionality for processes and indicators also sets our proposal apart from conventional LCA-software, which provide only limited support for zooming into report details. It should be noted, however, that only scientific papers on related sustainability dashboards were considered in section 2.4. Industrial software may already include some functionalities of the developed dashboard. Accordingly, future research should also include a comparison with existing tools for conventional (not necessarily sustainability-related) business analytics.

6.3 Limitations Related to LCA Methodology

An important limitation of this work comes with the proposed aggregation of sustainability indicators. The aggregation of the impact categories, i.e. steps two and three of the aggregation scheme, is controversial in LCA literature. Both the normalization and the weighting methods are connected to value decisions and therefore cause uncertainties in the derived composite indicators [14]. Furthermore, the links and dependencies between the sustainability dimensions are neglected in the aggregation scheme. An important challenge is therefore the development of cross-sectional indicators, such as the so-called decoupling indicators, which reflect the dynamics between the indicators [37]. Finally, the development of a suitable aggregation for the comprehensive assessment of corporate sustainability is a methodological challenge, but is not addressed in the ISO guidelines [46]. There are simply no official, uniform instructions on the subject of aggregation yet. As a result, further research is needed to develop the most suitable methods for life cycle analysis and to provide appropriate guidance. Given these open discussions, weighting can be considered an optional element of LCA [10], and is in our case justified by the purpose of the dashboard. The risk of hiding underlying value decisions is somewhat mitigated by making the indicator hierarchy explorable.

A comprehensive consideration of corporate sustainability should cover the entire life cycle of the organization and all potential impacts regarding the three dimensions of sustainability [11]. In principle, our proposed aggregation scheme allows to integrate an arbitrary number of indicators for each sustainability dimension. However, this is only possible to a limited extent in practice. The effort required to assess sustainability is very high, which is why the scope and number of indicators is often limited [54]. In addition, the methods for analysing social and economic sustainability at organizational level are not yet well developed and therefore difficult to apply in practice [4, 33]. One of the most important tasks to enable a comprehensive consideration of corporate sustainability in the future is therefore a further development of appropriate methods for social and econcomic assessment [11]. Furthermore, weekly or even daily data updates, a requirement for tactical dashboards (cf. Table 1), are not feasible due to the great effort required to collect sustainability data. For the three sustainability dimensions considered, different update intervals would be reasonable, as the time periods between the effects and their impacts vary considerably depending on the sustainability dimension. For example, daily or weekly updates are useful for economic indicators, while they are superfluous for ecological indicators, which take a very long time to change. Here annual updates are more appropriate [27, 37].

6.4 Contributions and Limitations of Process Visualizations

We have proposed the application and adaptation of BPMN notation elements to visualize the sustainability of activities. To our knowledge, this is the first proposal to apply business process management concepts to O-LCA. Other authors have proposed the integration of sustainability aspects into business process modeling languages (e.g. [12, 16, 17]), but without considering a life cycle perspective. The advantage of such a visualization is that it "speaks the language" of managers and process owners in organizations. Still, process models may get large and complex very quickly. This challenge is shared with traditional LCA software. Open questions on how to deal with inherent model complexity and how to communicate effectively with visual notations remain [38]. Also for the modeling language BPMN, there is room for improvement in terms of graphical simplicity and its comprehensibility to non-experts [26]. But BPM researchers are increasingly aware of this issue and a body of knowledge is developing (e.g. [9, 25]).

6.5 Limitations of Prototypical Implementation

Ultimately, the development of the dashboard or a tool for the consideration of corporate sustainability is a continuous process [24], which is why the concept resulting from this work should not be regarded as a final solution, but still needs to be developed and improved in many areas. Accordingly, the potential for improvement identified in the evaluation must be iteratively implemented and tested in further development loops in order to finally realize a production ready dashboard. In its current state, the dashboard does only visualize pre-calculated data and process models. In order to expand to a full LCA tool, it needs to be extended with (or provide interfaces to) process modeling functionality, LCA databases and calculation methods (cf. [56]). Further visualizations like a map view for regionalized (social) impacts may provide additional utility.

7 CONCLUSION

The objective of our future work is to develop a comprehensive management tool that supports all phases of O-LCA. The dashboard presented here already fulfils part of this vision with its objective of supporting the understanding and interpretation of an organization's sustainability data. The type of visualization and the approach are first steps in the desired direction. However, for full support of a comprehensive corporate sustainability analysis, the dashboard must be developed into a comprehensive and integrated O-LCA tool in the future and support further phases of the sustainability analysis, such as data collection and calculation. In addition, there is still room for improvement for the dashboard, which should be implemented in future development iterations. Nevertheless, it is an important building block for the development of an O-LCA tool by showing an approach how to communicate corporate sustainability to decision makers in a comprehensible way. The drill-down functions and process representations of the dashboard are distinctive features compared to other tools and thus provide added value for further developments. This work should therefore be seen as an impulse to develop a comprehensive tool for the sustainability analysis of companies. Due to the increasing relevance of the topic of sustainability and the complexity of the necessary comprehensive survey, such a tool is urgently needed by organizations.

ACKNOWLEDGMENTS

We thank Silvia Forin (TU Berlin) for sharing her expertise in Organizational Life Cycle Assessment and providing useful suggestions for this paper.

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