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A state-of-the-art review and evaluation of tools for factory sustainability assessment

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Abstract

The type of tools for sustainability assessment is manifold and is growing consistently to meet more and more of society's needs. This paper presents a review and evaluation study of existing assessment tools collected from a variety of sources. The aim is to clarify the difference between those sustainability assessments tools and increase factory planner's awareness towards the different tool properties. In this work representative assessment tools are evaluated and described with respect to their specific focus and benefits as well as drawbacks. Based on that a research gap is identified and further research directions can be derived.

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1. Introduction

Sustainability has become an essential topic in areas such as politics, society, research and industry [1]. Present and future generations are all facing challenges as climate change, decreasing bio-diversity, increasing air-pollution etc. A large effort has been spent on this topic, from the basic definitions of sustainability [2], business opportunities [3], [4] to different tools up to different indicators for sustainability assessment [5]–[7]. All definitions, tools and indicators have their own focuses, strengths and weaknesses, since each has been developed for its own reason. Existing tools often involve drawbacks such as a time-consuming assessment due to tool complexity or lacking applicability to companies from other industrial sectors – those issues need to be overcome in order to develop a sustainability assessment tool for practical use.

But due to the variety and amount of definitions, tools and indicators, it has become more and more challenging to have an overview of different existing work, especially when it comes to the sustainability assessment in specific areas, e.g. for the use in factory planning.

Factory planning has an essential role regarding the sustainability of a factory. Already during the factory planning stage all of the aspects of sustainability need to be considered in order to build a sustainable factory in the future. In the stage of factory planning, factory planners need to consider various aspects during different planning phases. In the initial planning phase, the factory's location is one thing that needs to be considered. Aspects related to the location can be personnel availability, general environmental impact, economic impacts and more. In the later planning phase, planners need to emphasize details in the factory floor such as personnel safety around each machine, each machine's energy consumption, vending machines availability for personnel and more [8, 9].

This means factory planners need a tool showing what sustainability indicators and aspects they need to consider during the factory development phase. A holistic tool will guide factory planner to plan in a more systematic way and minimize the planning complexity related to sustainability.

Actual tools are developed to assess existing factories for further improvements and not for building a new

factory. However these kind of sustainability assessment tools can also be used as a guideline for factory planners when they plan a factory from beginning or re-design a factory if the detail level and complexity level is right. The sustainability assessment tools shall support factory planners in order to think in the right direction.

This work aims to clarify the difference between various existing sustainability assessment tools to raise factory planner's awareness of the different properties of assessment tools, for a better planned or improved factory. Additionally, drawbacks and benefits of existing approaches are analyzed and directions for further research are derived.

2. General definitions

The terms sustainability, manufacturing and factory can have different meanings depended on the user's perception, background, knowledge and more. This study is in conformity to the three traditional pillars of sustainability: economic, environmental and social sustainability [8]. The frequently cited definition of sustainable development according to the Brundtland Report [2] describes the underlying thoughts of sustainability as it is used in this study: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" [2] A frequently used method for structuring a sustainability framework is to organize it into classes and subclasses, e.g. the three sustainability pillars – for the example of the environmental perspective – with themes like fresh water and subthemes like water quality, and assign indicators to themes or subthemes [6].

Manufacturing is defined as the "process of converting raw materials, components, or parts into finished goods that meet a customer's expectations or specifications" [11] and can be seen as "the core operation in a product's supply chain" [12]. A factory is defined as "building or group of buildings where goods are manufactured or assembled mainly by machine" [13].

3. Method

More than 100 papers and 50 tools collected from different sources e.g. conference proceedings, journals and the internet have been studied in order to get an overview of the existing tools for sustainability assessment. 12 tools have been selected as representatives for further analysis because they are most related to manufacturing companies among the collected tools. A three-step approach is carried out to identify and clarify the differences of the existing sustainability assessment tools. Firstly, evaluation

criteria are developed to tackle the issues and goals mentioned in the introduction. Secondly, each tool's strengths and weaknesses are evaluated based on the developed criteria. Lastly, the results of the analysis are summarized and structured as matrix in order to identify a current gap for focused future research.

Based on a first analysis of existing approaches four common criteria for a broad application in industry are formulated. To be able to find a useful sustainability assessment tool for factory planning these four criteria need to be fulfilled.

1) Generic applicability

An assessment tool should enable cross-industry comparison. Specialized tools, e.g. company specific tools, allow a detailed investigation directly tailored to the individual case, but are also limited to their field of application. Therefore, either the tools are not applicable to companies from other industrial branches or the assessment results are hardly comparable.

2) Rapid assessment

To support factory planner an assessment tool needs to be easy to use and it's complexity need to be on a reasonable level. Detailed tools might picture sustainability aspects very accurately, but the assessment of a factory is very time-consuming due to the tool complexity. In order to spend reasonable effort for the assessment, the assessment depth has to be adjusted. An assessment time of approximately 120 minutes is considered as reasonable. This two hours approach is mainly chosen based on authors practical experiences collected from different factory tours. Authors have noticed that a normal factory tour usually takes around two hours, including some questions and discussions during the tour. For this reason a tool to assess overall factory sustainability should be around two hours, hence assessment can be combined with factory tours if needed.

3) Application on factory level

Tools need to be applicable for factory assessment. Tools developed, e.g. for country assessment or for considering only parts of a factory such as a business unit, are not applicable to a whole factory and therefore less useful for a complete assessment.

4) Holistic view of sustainability

Tools need to have a holistic view of sustainability so that all three pillars of sustainability are addressed. Tools developed to measure specific aspects of sustainability (e.g. environmental aspects with the Ecological Footprint) can provide a precise analysis, but it is not enough to reflect the holistic view of sustainability.

4. Result

The result chapter is divided into two parts. In the first part, each selected tool is briefly described by the main characteristics and reviewed according to its strengths and weaknesses. Afterwards, the results are summarized and presented in a matrix. In this way, a gap in current research is identified.

4.1. Tool review

1) Barometer of Sustainability (1997)

The Barometer of Sustainability, proposed in 1997, distinguishes between two subthemes of sustainability: Human Well-being and Ecosystem Well-being. It considers environmental aspects as well as social aspects of sustainability, but does not put emphasis on economic aspects. [14]

The model uses a five step rating scale from “unsustainable” to “sustainable”. This kind of qualitative assessment is suitable for a rapid assessment. The tool has not been created explicitly for factory assessment. Nevertheless, the approach is flexible adaptable for factory assessment. In dependence on the adaption procedure, cross-industry comparison can be enabled. [14]

2) Dow Jones Sustainability Index (1999)

The Dow Jones Sustainability Index (DJSI) was published first in 1999. It is a tool for company assessment with financial focus and available in various versions, e.g. DJSI World or DJSI Europe [15], [16]. The DJSI mainly focuses on economic issues, although social and environmental aspects are considered as well [5].

In dependence on the version, a report contains up to 340 components (e.g. company’s approaches to improve accessibility of drugs in both developing and developed countries) [5], [17]. The index complexity causes a great amount of necessary data. The intensive assessment effort is also claimed in literature [15]. Nevertheless, the DJSI benchmarks the Top 10% companies within a region, country or the world and is applied on factory level [5]. The components are evaluated by questions, general criteria as well as industry-specific ones. According to [5] “*At least 50% of the questionnaire covers industry-specific risks and opportunities*”, which limits the comparability of results of factories from different sectors.

3) GRI Reporting Framework (1999)

The Global Reporting Initiative (GRI) published the first version for a company sustainability assessment framework in 1999 [18]. The assessment goal is to support decision-making towards common sustainability goals. The framework consists of a set of indicators in

order to address all traditional pillars of sustainability by evaluating social, environmental and economic aspects [18].

The GRI Reporting Framework 2011 includes a set of 81 indicators [7]. The indicators are expressed in various measuring units, for example in

- Joule for the indicator “Energy saved due to conservation and efficiency improvements” [7] or
- Kilogram for the indicator “Total weight of waste by type and disposal method” [7].

Indicators such as “Total direct and indirect greenhouse gas emissions by weight” [7] are calling for a high amount of collected data. Their assessment is associated with an increased amount of time. The framework has been developed for company or factory assessment and can be used for any organization independent on its size and industry-sector. About one third of the indicators are optional, whereby the cross-industry and cross-company comparison is limited to the core set of indicators. [7]

4) IChemE Sustainability Metrics (2002)

The model introduced by the Institution of Chemical Engineers (IChemE) in 2002 covers social, environmental as well as economic sustainability aspects expressed in themes [19]. Each theme is subcategorized in three subthemes. The subthemes are described by 50 indicators (e.g. Net water consumed per unit mass of product), which are derived by more than 300 single values (e.g. Water used in cooling per year). The great data amount and high level of detail increase the assessment time and prevents a rapid sustainability assessment [19].

The detailed tool is applicable for factory assessment, whereas the respondent chooses which metrics are applied and later reported. To ensure that all pillars of sustainability are equally addressed, the respondent’s freedom of choice is limited [19]. Moreover, the tool is specified for the industrial branch of process industry [20] and does not allow cross-industry comparison [21].

5) Rapid Plant Assessment Tool (2002)

The tool for Rapid Plant Assessment (RPA) was published in 2002 and aims to evaluate a plant’s leanness in a short time. It enables a rapid assessment and is developed for the application on factory level. However, the tool lacks in this generic applicability since it is restricted to factories with flow production. [22]

The RPA tool is built up by two evaluation sheets: a questionnaire and a framework. The questionnaire consists out of 20 Yes-No-Questions addressing aspects of lean (e.g. one piece flow). The questions are related to the framework’s 11 assessment categories, which are qualitatively rated on a 6-step scale from “poor” to “best

in class”. Both the questionnaire and the framework concentrate on the assessment of economic aspects. [22]

6) Sustainability Assessment in Mining and Minerals Industry (2004)

The framework aims on assessing and improving the sustainability of the mining and minerals industry-sector [23]. The introduced set of indicators addresses social, environmental and economic sustainability and assesses therefore the aspects of sustainability in a holistic way. The aspects of sustainability are described by 132 indicators, which are assigned to 21 themes. The indicators are expressed in different units, e.g. dollar per year or percentage. The variety of scales and the number of indicators inhibits the rapid accessibility.

In addition to that, the indicators (e.g. Number of quarries/mines closed) are developed for the mining and minerals industry, which prevents the cross-industry comparability and limits the use for factory assessment. [23]

7) Composite Sustainable Development Index (2005)

Krajnc and Glavic (2005) introduced a methodology for developing a Composite Sustainable Development Index (CSDI) that aims to assess a company’s sustainability [24]. The company, which applies the methodology, selects or develops indicators to address and emphasis on all three traditional aspects of sustainability. If the cross-industry comparison is not considered during the indicator selection and development, the resulting tool’s use for general assessment is limited. The resulting set of indicators is developed in order to carry out an assessment on factory level. Dependent on the chosen number of indicators and the measuring scales, rapid assessment can be enabled [24].

8) ITT Flygt Sustainability Index (2006)

The ITT Flygt Sustainability Index has been developed by the Mälardalen University in Sweden for the manufacturer ITT Flygt and addresses all three pillars of sustainability [25]. The ITT Flygt Sustainability Index has been created for assessments on factory or company level. The number of indicators (e.g. “Energy for transportation”) is limited to 40 indicators, which are all assessed on a unified scale between +10 and -100 [25]. The small number of indicators and the simple scaling system ensure a rapid sustainability assessment.

The indicator set has been compiled by the company itself, in order to measure the company’s own achievements towards sustainability. In this way, the company’s specific sustainability goals are reflected by the indicator selection. This fact and the strong focus on

the manufactured product limit the tool’s application for cross-industry comparison.

9) Ford of Europe’s Product Sustainability Index (2007)

The Ford Product Sustainability Index (FPSI) provides a holistic sustainability assessment by considering all three traditional faces of sustainability. It is composed of 8 indicators, which are assigned to the classes of sustainability (social, environmental and economic) [26].

To gain the indicator values, the tool uses the methodology of life cycle assessment, which is considered as data intense and leads to an increased assessment time [27]. Moreover, the FPSI has been developed for the automobile manufacturing industry [27]. The indicators (e.g. Drive-by-exterior Noise) measure the sustainability of the specific product – the car [27]. The strong product focus limits the applicability to products that car industry produces.

10) GM Metrics for Sustainable Manufacturing (2009)

General Motors (GM) launched a project in 2009 to benchmark existing metrics on the market, dealing with the topic of sustainable manufacturing [28]. The best metrics, compromising expenditure and benefit, were implemented and considered as GM Metrics for Sustainable Manufacturing (GM MSM). The GM MSM considers social, environmental and economic aspects by 6 categories of sustainability: Environmental Impact, Energy Consumption, Personal Health, Occupational Safety, Manufacturing Costs and Waste Management.

33 indicators (e.g. number of accidents requiring first aid) are subordinated to these groups [28]. The tool has been developed for the assessment on company or rather factory level. It allows a rapid assessment due to the manageable number and type of indicators. Nevertheless, it is designed for the company own sustainability goals and aims to monitor improvement measures [28]. GM MSM is suited to the car industry and its products, which limits the use for cross-industry comparisons. One example for limitation is the indicator “Steel consumption per unit”, which can hardly be applied for the food industry [28].

11) Sustainable Development Framework (SDF) (2009)

European Commission suggested a framework for assessing sustainable development in 2009 [29]. The framework consists of 10 themes (e.g. “Climate change and energy”) in order to cover the three traditional pillars of sustainability. The themes are described by 28 subthemes (e.g. “Greenhouse gas emissions by sector”) and more than 100 subordinated indicators (e.g. “Greenhouse gas intensity of energy consumption”). The

indicators are measured in a variety of units (e.g. in Tons CO2 equivalent or °C). The high amount and variety of needed data increase the assessment time and limits the use for a rapid assessment.

The framework intends to assess and monitor the EU’s development towards common sustainability issues by indicators like “Dispersion of regional employment rates, EU-27” [29]. Therefore, the framework cannot directly be applied to assess factories and needs to be adapted to factory or company level before use. In dependency of the adaptation procedure, the cross-industry comparison can be enabled.

12) Rapid Basin-wide Hydropower Sustainability Assessment Tool (2010)

The Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT) has been presented by the United States Agency for International Development in 2010 [30]. It aims at a worldwide sustainability assessment of hydropower plants and considers social as well as economic and environmental aspects to embody a holistic view of sustainability. The tool is built up of 11 topics with subordinated 53 assessment criteria. All criteria are scored on the same simple five-step scale from “poor” to “excellent”. Consequently, the RSAT enables a rapid assessment. The tool has been developed for hydropower plant assessment and is therefore not applicable to access a manufacturing company or performing cross-industry comparisons. For instance, the indicator “Multiple water use optimization” is used in this tool, but in the manufacturing domain the tool needs assessment criteria such as “Share of treated waste water” [30].

4.2. Evaluation Matrix

The just highlighted properties of the selected assessment tools are presented in a structured way in Figure 1. Each tool is evaluated due to its fulfillment of the derived criteria: rapid assessment, application on factory level, generic applicability to enable cross-industry comparison and holistic view of sustainability. In this way, a research gap can be identified easily.

+ = Criteria fulfilled
 O = Fulfilled with restrictions
 - = Criteria not fulfilled
¹dependent on the adaption process

Year	Assessment tools	Evaluation criteria			
		Rapid assessment	Application on factory level	Generic applicability	Holistic view of sustainability
1997	Barometer of Sustainability	+	-	O ¹	-
1999	Dow Jones Sustainability Index	-	+	O	O
1999	GRI Reporting Framework	-	+	O	+
2002	IChemE Sustainability Metrics	-	+	-	+
2002	Rapid Plant Assessment Tool	+	+	O	-
2004	Sustainability Assessment in Mining and Minerals Industry	-	O	-	+

2005	Composite Sustainable Development Index	+	+	O ¹	+
2006	ITT Flygt Sustainability Index	+	+	-	+
2007	Ford of Europe’s Product Sustainability Index	-	-	-	+
2009	GM Metrics for Sustainable Manufacturing	+	+	-	+
2009	Sustainable Development Framework	-	-	O ¹	+
2010	Rapid Basin-wide Hydropower Sustainability Assessment Tool	+	-	-	+

Fig. 1: Evaluation of tools evaluation criteria fulfillment.

5. Conclusion and discussion

In this study, a selected number of sustainability assessment tools between 1997 and 2010 have been evaluated by using four evaluation criteria. A proper assessment tool fulfilling all criteria in order to support factory planning in general could not be identified.

Nevertheless, some of the reviewed assessment tools, such as the Composite Sustainable Development Index [24], the ITT Flygt Sustainability Index [25] and the GM MSM [28] can be used or partially used for specific factory planning cases, but not for general use.

Vice versa some of the assessment tools such as the Barometer of Sustainability [14] can be used for general case of factory planning, but the details (indicators and aspects) in assessment tools are too general for the implementation in the factory planning process. When an indicator is too general factory planners face the issues of lacking data accuracy and assessment validity.

Some of the assessment tools do not fulfill the criterion of rapid assessment mainly due to the variety of different indicator units and scales. This issue can be prevented by the right choice of both the indicators and the scales. If the variety of measuring units is kept small, both the data collection and the aggregation are simplified and the assessment speed increases. The situation is similar for indicators, which are assessed on scales. A small number of different scales and the use of simple scales (e.g. a five step rating scale from 1 to 5) cause a reduction in the assessment time. The drawback of unifying and simplifying the measuring system is that the assessment accuracy decreases likewise. An appropriate tool for factory planners must find a compromise between these conflicting objectives.

A starting point for future research is to analyze and modify the development methodology of the best evaluated tools. Based on this work, a rapid assessment tool to support factory planners’ needs can be developed. Factory planners need to have an assessment tool which enables the cross company comparison, gives a holistic view of sustainability’s three pillars, has a manageable complexity level and is adaptable at factory level.

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