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On the Applicability of Sustainability Assessment Tools in Manufacturing

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Abstract

The literature on sustainability assessment abounds with different tools, methods, models and frameworks, and the amount of literature on sustainability assessment applied to the field of manufacturing is rapidly growing. This study aims to review the state of the art associated with the latter, synthesising and analysing the applicability of the different approaches with their practical applicability in real-world manufacturing at the heart of the discussion. Based on review of research trends within sustainability assessment, we identified a list of tools addressing three pillars of sustainability which all can be applied on company level. These tools were evaluated from a manufacturing company's point of view, including (1) reliability; (2) manufacturing company's context; (3) time and resources required for assessment; (4) point out problem areas; and (5) point out solutions. Finally, the sustainability assessment framework based on a value chain concept is proposed as a possible solution for handling challenges related to sustainability assessment in manufacturing.

Keywords: Sustainability assessment tools; Sustainable manufacturing; Applied sustainability assessment.

1. Introduction

Sustainability assessment is one of the essential parts of sustainable development; i.e., if we cannot measure the level of sustainability on company level, we do not know if we do the right things and are heading in the right direction with our improvement initiatives. Any manufacturing company that wants to improve sustainability faces the challenge of assessing its performance. How should then a company assess its current sustainability state? How does it know which solution is more sustainable? How can it define and solve problems on the way towards sustainability? How can potential solutions be identified? Answering these questions is not a new challenge; many researchers have been working for years on developing sustainability assessment methodologies, methods and tools [1]. However, relatively few of these methods and tools are applied by manufacturing companies. Some of the perceived reasons will be briefly introduced below, using the most relevant research as reference.

Firstly, many of the strategies are developed on national or more local level, and few are targeting the level needed for application within manufacturing [1-3]. Secondly, sustainability assessment tools may sometimes be considered too theoretical and general [3, 4], or too technical and complicated for manufacturing companies [5-7]. This creates a communication gap between the academic and manufacturing domains. While researchers work to develop the 'perfect' sustainability assessment tool, manufacturers do not know how or from where to start their journey towards more sustainable practices. Thirdly, the majority of existing assessment tools is aimed at external reporting and lacks useful information for internal decision makers [8]. For instance, the outcome of the assessment may be presented as "sustainability rate is 82%", or "54 points", or "0.4", or "environmental aspect is more developed than social and economic ones". This type of the results does not provide manufacturing companies with information that is practical for internal usage. This may create a barrier for manufacturing companies for completing assessments. In addition, it may require a lot of efforts from an already scare resource basis; and if the necessary resources where available, there is no guarantee that the assessment would show where problems are and what to do with them. Fourthly, the overall costs required to implement some of the

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tools such as widely known Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Life Cycle Costing, Process Energy Analysis, Social Life Cycle Assessment, Cost Benefit Analysis, etc. [2, 9] are high. These assessment tools require high-level expert competence and many of them address just one or two sustainability aspects.

The aim of this work is to analyse how existing sustainability assessment tools satisfy manufacturing needs. Efforts will also be made to analyse their applicability to identify real manufacturing needs and problems. Manufacturing needs are defined in the third section as a list of requirements to sustainability assessment from a manufacturing point of view. The focus of this study is on manufacturing companies that have not yet started sustainability practices or have just started.

The remaining part of this paper is structured in the following way: Section 2 presents an overview of existing trends in sustainability assessments. We have identified different company-level tools addressing three pillars of sustainability. Section 3 introduces a set of criteria for analysis based on manufacturing company perspective. In Section 4, practically useful tools addressing the three pillars of sustainability at company level are evaluated with regards to criteria defined in the previous section. In Section 5, the sustainability assessment framework based on the value chain concept is presented. Finally, Section 6 presents the discussion and outlines possible pathways towards more practical strategies for sustainability assessment in manufacturing companies.

2. Overview of existing sustainability assessment practices

Previous studies show that there is a variety of different approaches towards the development of sustainability assessment tools. In the following, a brief overview of existing trends in sustainability assessment will be presented.

Analysing the thirteen most popular sets of indicators for sustainability assessment [8], (e.g. Global Reporting Initiative, OECD Core indicators, Environmental indicators for European Union), the authors conclude that most of these indicators tend to focus on external reporting and lack internally useable information for decision makers. A group of researchers analysed eight sustainability assessments and identified that some of these tools focus on product assessment rather than manufacturing processes. Other tools address only environmental aspect, whereas the remainder may be considered too general for practical application [3]. Several sets of indices and indicators, which address sustainability assessment on the company level (e.g. ISO 14000, Dow Jones Sustainability Indexes, Global Reporting Initiative), are commonly criticised in the literature because of their too general nature [4]. Other sustainability indices presented in the literature are the set of indicators for sustainable production [10], Composite Sustainable Development Index [11], Sustainable Manufacturing Index [7], NIST (National Institute of Standards and Technology) indicators for product and process assessment [12], and NIST Sustainable Manufacturing Indicators Repository [13, 14].

A group of assessment tools based on the Gibson's integrated sustainability framework [15], considers sustainability as an interdependence of the three pillars rather than a combination of each one: assessment of the integrated power system plan [16], sustainability appraisal of sugarcane-ethanol production mill [17]. For assessing one biodiesel plant, an assessment method was proposed based on the combination of the Gibson's integrated sustainability framework and the Waltner-Toews' resilience approach [18]. These tools address tree pillars of sustainability for application on the plant level. However, sustainability assessment criteria may be considered too vague, which in turn may create a barrier for the use of this approach.

One direction in the development of sustainability assessment tools is based on the implication of fuzzy methods for handling human-subjective opinions. For instance, the so-called Fuzzy Interference System (FIS)-based model, which is intended for sustainability assessment of manufacturing SMEs [4]. Another tool based on a fuzzy expert system is used to assess sustainability of the product returns and recovery operations in the supply chain, through time, cost, waste and quality attributes [19]. The results are based on subjective experts' opinions about the company. Thus, the reliability of the result can be low, and the result is not able to point out problems and potential solutions.

Analysing 55 existing assessment tools, researchers concluded that most of these tools miss a holistic approach on sustainability [6]. Analysis of another seventeen assessment tools indicates that, although these tools are widely used and solve many of the assigned tasks, most of them address just one or two sustainability aspects [9]. The same conclusion was made by [2] based on an overview of 41 sustainability indices. However, only few of them are relevant for manufacturing companies and with limited efforts on providing a sustainability assessment taking into account multiple-faceted aspect of sustainability. In addition, most of the cases focus only on one of the dimensions.

Some tools aiming to conduct sustainable manufacturing analysis provide just an environmental assessment. Examples include, among others, an activity-based, object-oriented method for sustainability assessment of manufactured parts during manufacturing phase of life [20], sustainability assessment of manufacturing process of Radio-Frequency Identification (RFID)-based systems [21], sustainability assessment of manufacturing flow for a new component [22], manufacturing environmental performance evaluation [23], sustainability assessment based on a mixed integer linear programming model [24]. One of the research groups states that most available assessment tools focus on environmental aspects of manufacturing system sustainability [25].

Recently, significant efforts have been made to develop sustainability assessment tools addressing all three aspects of sustainability. However, most of the tools are developed for specific products, processes, or parts of manufacturing system. Examples of such tools include: sustainability assessment of manufacturing system reuse based on Analytic Hierarchy Process (AHP) [25]; evaluation of product based on fuzzy comprehensive assessment method [26]; sustainability performance measurement for product life cycle [8]; integrating sustainable manufacturing assessment for a production workcell based on AHP and multi-criteria-decision-making method [27]; a matrix evaluation model for sustainability assessment of manufacturing technologies [28]; sustainability assessment framework for remanufacturing industry [29]; and Product Sustainability Assessment (PROSA) [30]. Although, some sustainability assessment tools are developed for a specific industry, it is possible to use them in other industries. One example of such a tool is the AHP based-model for Sustainable Manufacturing Performance Evaluation in Automotive Industry [31].

One of the more recent research works in Life Cycle Assessment presents a framework for Life Cycle Sustainability Assessment based on eLCA, sLCA and eLCC [32]. This framework aims to modify life cycle assessment by addressing three pillars of sustainability. Although this framework can be used on a company level, the article fails to provide a clear assessment procedure.

A rapidly growing literature on sustainability assessment in manufacturing indicates that the 'silver bullet assessment tool', which addresses the vast majority of requirements from manufacturing companies, has not yet been introduced. A group of researchers evaluated tools for factory sustainability assessment developed between 1997 and 2010, concluding that the tool, which is generic yet with holistic view on sustainability—one that is applicable on the factory level and requires limited time for assessment—remains to be developed [33]. The same authors developed a new tool denoted Rapid Sustainability Assessment Tool for Manufacturing SMEs [34]. This tool has reasonable timeframe, holistic focus on sustainability, applicability on the factory level, and ability to cross industry comparison. However, the tool utilise just qualitative indicators and the result is based on just subjective answers; i.e., the assessment does not consider any measured data.

A few tools have been developed based on a value stream mapping (VSM): Sustainable Manufacturing Mapping [5]; Sustainability Value Stream Mapping [35-37]; Sustainable Domain Value Stream Mapping [38]; Sustainable Value Chain Analysis in wine industry [39-41]. In one case study [42], the authors proposed to incorporate sustainability indicators into a value stream map for conducting holistic sustainability assessment. Although all tools based on value stream mapping refer to sustainability assessment, unfortunately, a significant portion of them focuses on the environmental aspect of sustainability only.

It can be seen from the above synthesis and analysis that the main commonalities in sustainability assessment tools for manufacturing companies are:

- tools that address only one or two aspects of sustainability on different levels (e.g. process, product, plant), including comprehensive tools for product or process assessment (e.g. LCA, EIA);
- tools that address three sustainability aspects and are developed for specific products, processes, work cells, cities and local communities, industries (e.g. automotive industry, wine industry);
- tools that address three pillars of sustainability on company level.

The last category of tools is of great interest as each of them addresses three sustainability aspects and can be applied on company level. Tools within the third category are: (1) Fuzzy-based sustainable manufacturing assessment model [4]; (2) Sustainable manufacturing mapping [5]; (3) Sustainable manufacturing indicators [7]; (4) Indicators for sustainable production [10]; (5) Integrated assessment of sustainable development [11]; (6) Integrated sustainability based on Gibson's approach [16-18]; (7) An AHP based-model for sustainable manufacturing performance evaluation [31]; (9) A holistic and rapid sustainability assessment tool [34]; (10) Sustainable value stream mapping [35, 36]; (11) Combining sustainable value stream mapping and simulation [37]; (12) Sustainable domain value stream (SdVSM) framework [38].

3. Criteria for analysis

Analysis of manufacturing needs and manufacturing expectations from sustainability assessment may help determine the applicability of existing tools. In addition, it may enable identification of challenges related to applicability. Some important questions in this connection are: What are the real needs of manufacturing companies? What are the manufacturing expectations from the sustainability assessment? How much resources is a company ready to use for sustainability assessment?

Managers should have a good reason to invest in sustainability tools and practices (e.g. water management system, life cycle assessment of one product) to improve some specific area in the company. That is why a detailed overview of the whole company can give an understanding of the current sustainability of the company as well as identify what kind of problems that it is presently facing. In this case, a sustainability assessment tool will be helpful. Since time and resources are usually the most critical issues for a company, the sustainability assessment should be conducted in a reasonably short time—without reducing the reliability of result and with limited resource demands.

Due to the above issues, various sustainability assessment tools were chosen for analysing the practical applicability of the output of sustainability assessment. The proposed categorization of sustainability assessment of manufacturing companies is manufacturing company's point of view. From this point of view, sustainability assessment should fulfil the following requirements: (1) to provide reliable information; (2) to address a manufacturing company's context; (3) to point out problem areas; (4) to point out solutions; (5) conducted within limited time and resources.

4. Analysis of sustainability assessments

In this section, the list of assessment tools defined above will be evaluated from a manufacturing point of view with the aim to identify their applicability and to identify the main challenges related to conducting the sustainability assessment. Evaluation of the tools is done based on the information provided by the developers of each tool, and is based on the results of the case studies presented in the reviewed articles.

Reliability of the assessment procedure as well as the data collected through the list of indicators are analysed. Due to utilisation of the AHP method for weighting indicators [7, 11, 31] or pairwise comparison technic [34], a result of the assessment can include relatively high level of uncertainties. The result of other tools includes uncertainties due to subjective experts' opinions used for assessment [4]. Some tools provide meaningful result only when making comparison to a base year [10, 11]. Thus, data for decision makers can come too late. Some other tools present the result on the indicator level and do not utilise the aggregation, normalisation and weighting of the indicators [5, 16-18, 35-37]. In case the tool has too many indicators, the result can be difficult to analyse. However, they may avoid uncertainties due to normalisation and weighting.

One tool presents the result as value added index and non-value added index [38]. This does not refer to sustainability rate; however, non-value added activities could show where improvements are required. What kind of data is collected defines what kind of picture is provided by the sustainability assessment. This is why the sets of indicators used by each tool need to be considered. Some tools utilise only qualitative indicators [4, 16-18, 31, 34], other tools utilise quantitative indicators instead [5, 7, 11, 35-37]. Just a few tools utilise the mix of qualitative and quantitative indicators [10, 38]. Utilisation of only one type of indicators (qualitative or quantitative) can reduce representativeness of the assessment. Moreover, none of the assessment tools explains whether they utilise absolute or relative metrics, lagging or leading indicators.

How good an assessment tool addresses the case company's context depends on the mix of indicators utilised by the tool. The standard list of indicators may not cover all aspects of specific manufacturing (e.g. hazardous substances, innovation). However, a standard indicator set allows reduction of assessment time since it eliminates the need for identification of indicators for each case company. Most of the analysed tools include the standard set of indicators such that the applicability to a specific company settings is limited [7, 10, 16-18, 31]. Some of the tools, however, include the standard list of indicators with the option to add specific indicators manually that take into account the context of the case company [4, 11]. Tools, based on the value stream mapping (VSM), include the standard set of indicators applied to each manufacturing process [35-38], as compared to most other tools which apply indicators to a specific case company (e.g. freshwater consumption, energy use). One tool, based on VSM, is designed in such a way that indicators must be chosen for each case company manually [5], which in turn increases time needed for conducting the assessment. One assessment tool utilises a standard set of indicators assigned to different factory elements [34]. Although, the tool does not allow expanding the indicators list, it provides the most comprehensive indicator set in comparison to other tools. According to the authors, these indicators cover the context of the case company.

Several of the tools point out problems just on the social, economic and environmental level [4, 5, 7, 10, 11, 31]. Also, these tools present the result as an overall score, which can be used to track sustainability rate over a period of time. Other tools are able to identify more specific problems, such as water availability, water quality, quality of livelihood opportunities [16-18]; water consumption, raw material usage, energy consumption, [35, 36]; sources of waste [37]; value added activities and non-value added activities [38]; land, freshwater, health, education [34]. Moreover, the design of a succeeding tool allows identification of the factory element in which the sustainability challenge occurs. This and tools based on VSM allow identification of specific problem areas in the company. While most of the tools can indicate the problems, associated with e.g. freshwater, VSM-based [35-38] and rapid sustainability assessment tool [34] can point towards the process or activity in the company where the problem with freshwater occurs.

Although none of the tools indicates possible solutions, results obtained by VSM tools can allow identification of possible solutions easier than other tools [35-38]. In addition, tools based on the combination of sustainability framework, factory model and indicator framework allow identification of potential solutions due to their design [34].

Most of the tools are time-consuming due to data collection [10, 16-18, 35-38] or due to an experts' interview required for weighting procedure [4, 11, 31]. In addition, some of the assessment tools require knowledge about AHP [7, 11, 31], VSM, [35-38], or combination of LCA, VSM and DES [5]. Only one tool from the list does not require specific knowledge or a lot of time for data collection [34]; the overall assessment time is around 2 hours.

For the aforementioned reasons, there is no doubt that the tool which identifies specific problems and solutions in the company based on the reliable information within limited time and with limited resources, and which addresses three pillars of sustainability with meaningful normalisation, weighting and aggregation procedure, has not been presented yet. However, the analysis made herein indicates that sustainability assessment based on the VSM approach may provide advantages over others assessment tools. While the assessment tools based on the VSM approach has a generic nature, they are able to address specific manufacturing company's context. Therefore, these tools may be capable to demonstrate more reliability of the result. In addition, tools based on VSM are able to point out specific problems for specific process or activity in the company—unlike most other tools. This may help the company to save time and money in further investigation of the root cause of the problem.

The second finding from the review is that while tools based on questionnaires (qualitative indicators) require less time and resources compared to other assessment tools, uncertainties of the result are high due to the subjective nature of the questionnaires. Tools based on VSM or tools based on Gibson's approach are relatively resource demanding. At the same time, the former addresses manufacturing context and points out specific problems. The latter addresses inter-linkages between three sustainability pillars, unlike other tools.

The findings made herein also offer insights into the challenges of sustainability assessment: e.g., missing the holistic approach on sustainability; providing too general or too site-specific approach; subjectivity during a weighting procedure; too theoretical and complicated; requiring specific knowledge; primarily aimed at external reporting; resource consuming; lacking reliability of the result; lacking in addressing case company's context; pointing out problems at too general level; failing to point out possible solutions.

5. Sustainability assessment framework

Taking into account challenges identified in the analysis of existing sustainability assessment tools, the authors propose the sustainability assessment framework based on the value chain approach (Fig.1). The proposed framework can address manufacturing needs defined in Section 3, and may cope with general challenges related to sustainability assessment.

The framework allows assessment from the customer's perspective (CR on Fig.1) along with an assessment of product development where much of the sustainability outcomes are locked in. The framework addresses assessment of value chain activities (As), linkages (Ls), material flow (Mf) and information flow (IFef), and customer relationship (CR). Hence, assessment of three pillars of sustainability for each activity and linkage can provide a holistic view on the sustainability.

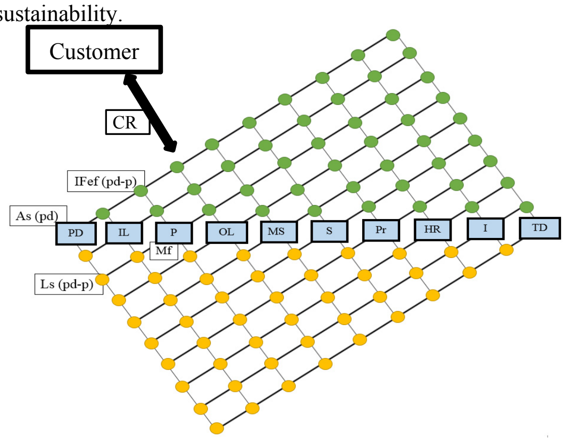

Fig. 1. Sustainability assessment framework. CR – customer relationship, As(pd) – activity's sustainability (product development), IFef(pd-d) – information flow efficiency between product development and production, Ls(pd-p) – linkage's sustainability between product development and production, Mf – material flow, PD – product development, IL – inbound logistics, P – production, OL – outbound logistics, MS – marketing, S – service, Pr – procurement, HR – HR management, I – infrastructure, TD – technological development.

Although there is strong general belief among researchers that the life cycle approach should be used for sustainability assessment of the product, some critical issues may be missed when assessing a manufacturing company as a system (i.e. different interconnections within a company and customer perspective). Thus, the value chain perspective could be an appropriate solution for sustainability assessment of manufacturing companies. Here product development can be seen as an activity which dictates sustainability of the production stage, use stage and the end-of-life. This approach can highlight how the product development stage influences other parts of the manufacturing process. In addition, the value chain concept is based on the customer needs and satisfaction. To incorporate this concept into the company, each downstream process/department can be considered as an intermediate customer and the needs of everyone will be considered. Also, assessment of linkages within a value chain will ensure that interconnection within the company as a system will be addressed. Moreover, analysis of existing assessment tools indicates that sustainability assessment based on value stream maps may have advantages over other assessment approaches; i.e., it addresses specific needs of the company, demonstrate more reliability of the result, able to point out specific problems for specific process or activity, and enable identification of possible solutions.

Future work will focus on the development of appropriate indicator sets which are capable to address manufacturing needs while considering the company as a system; indicator set which includes the mix of qualitative and quantitative, lagging and leading indicators, absolute and relative metrics. In addition, the verification and validation of the framework and indicator set are planned.

6. Discussion

In this section, a discussion on challenges related to applicability of sustainability assessment tools is presented. Moreover, the discussion concerns how to provide high level of applicability of sustainability assessment in manufacturing and how to fulfil manufacturing requirements.

A rapidly growing amount of literature on sustainability assessment in manufacturing indicates that there is a gap between the needs of manufacturing companies to improve their sustainability practices and the capabilities of the most commonly available tools. Previous studies show that there is a variety of different approaches employed in sustainability assessment tools. A literature review shows that several efforts have been made to develop a sustainable development index also for the application in manufacturing. However, there are still many challenges regarding indices: subjectivity and uncertainty due to aggregation, normalisation and weighting; lack of internal information for decision makers. In addition, existing indices are criticised for being too general [4]. More specifically, it has been stated that "most of the indices fail to meet scientific requirements to normalisation, weighting, and aggregation" [43]. Some efforts have been made to develop sustainability assessment tools based on AHP, fuzzy logic or pairwise comparison technic. As a result, these tools require specific knowledge and any opening for subjectivity of weighting procedure will affect the reliability of the result. Thus, the applicability of these tools in real-world manufacturing may be reduced.

The applicability of the existing assessment tools from a proposed manufacturing point of view is affected by reliability of the result, time and resources required, ability to address manufacturing context, point out problem areas and solutions. Time and resources required for sustainability assessment are critical factors, which affect a company's willingness (or ability) to conduct assessment. The resource demand is mainly caused by data collection. Some researchers solve this problem by only utilizing qualitative indicators. According to the above analysis, tools based on questionnaires allow to conduct assessment within as little as 2 hours [34]. However, this may come at the price of reliability of the result. Other developers of assessment tools solve this problem by reducing the amount of indicators to the minimum. However, this can affect the ability of the tool to assess a manufacturing company as a system. In turn, this can lead to sub-optimisation. Optimisation of one component of the whole system—which is widely practiced nowadays—may lead to sub-optimisation of the system [44]. As a consequence, there is a chance that individual employee/department/product/etc. may do well on their own measures, whereas the whole system may be destabilised.

The accuracy of the result depends on the reliability of data used for assessment in addition to the reliability of the assessment tool itself. The reliability of data used for the assessment depends on what kind of data a company provides (i.e. true, updated data) and what type of data is chosen for assessment. It is clear that the way sustainability is measured, directs the sustainability to be achieved. This leads to the conclusion that utilising a suitable set of sustainability indicators is equally important as having a reliable tool.

Different requirements to the indicator sets should be taken into account during the selection of indicators. The main requirement to any sustainability assessment tool is to address three sustainability pillars equally. The set of indicators should preferably be a mix of leading and lagging indicators, with qualitative and quantitative metrics associated to each indicator [45], as well as absolute and relative metrics [46]. Moreover, trade-offs between external and internal performance measures are required [47]. In addition, "gaming" is one more challenge related to indicators driven by human nature. People tend to percept indicators as a game, as in the case with "first bag on the belt" indicator [48].

Reliability of a sustainability assessment tool essentially depends on the meaningful aggregation, normalisation and weighting procedures. Aggregation, normalisation and weighing procedures should provide as little uncertainties as possible. It can be noticed, however, that tools which utilise aggregation, normalisation and weighting procedures are more appropriate for external reporting, while subjectivity of these procedures affects the reliability of the result. In turn, the result obtained by tools which do not utilise any aggregation of the indicators (e.g. tools based on the VSM), are more appropriate for internal usage. One solution can be to employ two different procedures to collected data; one procedure will aggregate data for external reporting, other procedure will present data for internal decision-makers.

Review and analysis of existing assessment tools show that several researchers have been working to develop indicator sets for sustainability assessment of a product, a process or a company. Other researchers have been developing assessment tools (e.g. aggregation, normalisation and weighting procedures), and using existing indicators frameworks. Unfortunately, research with balanced development of indicator set and assessment tool is still lacking.

The need for sustainability assessment to provide meaningful information for decision makers has been discussed elsewhere. One research finding [49] demonstrates that although various scientific and case-based methods are applied to measure manufacturing sustainability, incorporating sustainability in decision-making has not been fully realised by neither academics nor practitioners. One of the reasons is that most of the tools are aimed at external reporting. Hence, a few tools are capable to identify specific problems, whereas none of the existing tools point out possible solutions. Thus, the applicability of the existing tools is limited. Previous research results stated that "although appropriate tools may exist, SMEs rarely have the competence and time available to identify which tools are most applicable to their business context and capabilities, nor to undertake necessary customisation of identified tools to fit their actual needs" [50]. This statement supports the fact that there is no strong link between sustainability assessment tools and sustainability practices. Ideally, a sustainability assessment should serve to indicate specific problem areas in the company, while enabling identification of appropriate sustainability practices by manufacturing companies, especially by SMEs.

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