Corporate Strategy Based Quantitative Assessment of Sustainability Indicators at the Example of a Laser Powder Bed Fusion Process

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Abstract. The definition of the sustainability of a product or a process depends on certain consideration. Frameworks for a methodological evaluation of environmental sustainability are proposed in ISO 14040/44 though a standardized assessment based on fixed parameters and standards is not suitable for every application. Here, an approach to define sustainability based on individually formulated corporate strategies using the example of the "cradle-to-grave" assessment using Laser Powder Bed Fusion (LPBF) as an additive manufacturing process is presented. By means of this approach, components of corporate strategies are identified and analyzed regarding existing conflicting goals and correlated with previously defined sustainability potentials. The result of this correlation is strategy-specific influencing factors, indicators and quantifiable variables that relate to the process chain of the LPBF method under investigation. A method is presented which, based on the correlations determined, enables to quantitatively assess the sustainability of the product during its life cycle. The application of this method is shown and verified at the example of two literature-based corporate strategies. Finally, the challenges for future developments of sustainability-oriented quantification options are discussed on the basis of the results.

Keywords: Sustainability assessment · Corporate strategy · Laser Powder Bed Fusion

1 Introduction

In the process of the current omnipresent sustainability debate, politics as well as science and economy are taking a critical look at the development of the interplay between humanity, the environment and the available resources [1]. This leads to the question of how long-term entrepreneurial growth can be generated without damaging the pillars of sustainability. In the scope of this paper, a methodical procedure is to be developed in order to be able to identify influencing factors for a sustainability assessment of the LPBF-process on the basis of a superordinate, individually composed corporate strategy.

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Using a literature-based identification of company-specific strategy components and the determination of positive and negative strategy-dependent goal conflicts, sustainability potentials are combined with the process chain of the LPBF method on the basis of the frame work of Ehlers et al. (2020) [2]. As a consequence, process-specific influencing factors as well as indicators and quantifiable variables can be identified as a result of the approach result. The method is then verified on two differently oriented company strategies and the results are discussed in conclusion. The research results are available as raw data in Wurst (2021) and will be published following this paper [3].

2 Theoretical Approach

2.1 Corporate Strategies

Regardless of the nature of formulated goals and actions require a strategy as a planned behaviour in order to be able to achieve these goals in interaction with the environment [4]. Thus, in addition to goals and visions, a strategy includes both necessary actions and a defined time horizon [5]. A strategy function as a guidance in dealing with complex situations [6]. In this context, a corporate strategy is a possibility for goal-oriented and long-term planning without ignoring the changing environment [7].

In addition to planning as a "path-goal" description, a corporate strategy comprises four further fundamental aspects for building up and maintaining success potentials. In the form of the "5 P's", Mintzberg (1987) summarises the contents of a corporate strategy as "Plan", "Ploy", "Pattern", "Position" and "Perspective" [8–10]. In the course of the "Ploy", elaborated tactics are placed in a target context and combined with decision patterns and regularly used types of action in the "Pattern" phase. Beyond the boundaries of the company, the "Position" and "Perspective" phases serve both the external positioning in competition and the perception by the environment [8–10].

Based on these aspects of a strategy, Ant (2018) presented a "10-phase" model for developing a corporate strategy. Divided into phases - starting with the "mission statement" and ending with the "evaluation of the overall approach" - it is possible to develop a strategy from the initial situation to the archievement of strategic goals [8]. In this paper, the focus is on the fifth and sixth phase of the model the fundamental question of the orientation of a corporate strategy is answered in these phases. Based on a multidimensional consideration of the problem in the course of the elaboration of scenarios, versatile approaches to solutions can be developed as an innovative basis for new strategic approaches [8]. Building on these scenarios, the vision of the company can be formulated as an orientation for all future developments [7]. In this sixth phase, the directions of the company are sustainably defined with the aim of realising long-term economic growth. By combining different competitive strategies that are approximately congruent in their goal orientation, there is the possibility of forming a long-term competitive advantage [8]. This competitive advantage is based on the assumption that all strategic considerations in the company are unique and cannot be imitated by the competition [8].

Identification the Components of a Corporate Strategy. As this paper focuses on the sustainability of production and manufacturing processes, it is first necessary to identify

the components of corporate strategies that are directly related to value creation in the production context.

Assuming that a corporate strategy significantly supports the pursuit of corporate goals, each corporate strategy must be seen as an individual combination of different components [5]. The identification of requirements involves according to Mintzberg (1987) three questions [10]:

- "On what principle are the results of the company's decisions based?"
- "What goals is the company pursuing?"
- "How does the company see itself in the market/competition?"

To identify a component of a corporate strategy, one or more of these questions must be answered. Based on a literature research, 23 different components could be identified, each of which is to be understood as a collective term that summarises the strategy scenarios described in the literature [3]. The focus of the literature examined lies in the areas of strategic management and strategy development. In addition, publications in the context of lean management and corporate social responsibility allow statements regarding the effects on related corporate strategies.

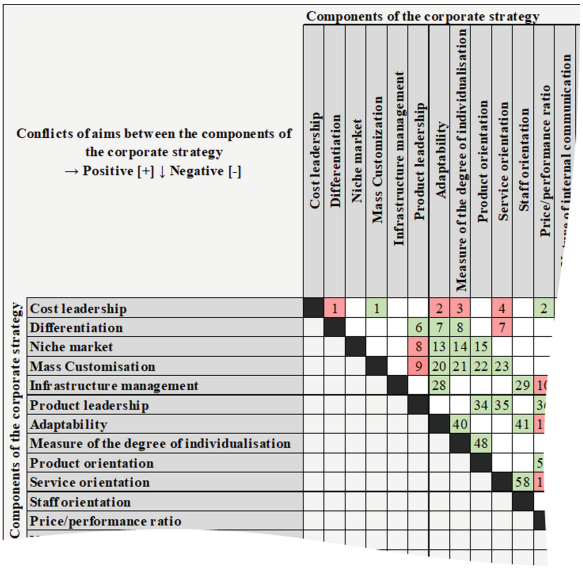

Fig. 1. Detail of the matrix of conflicting goals between the components of the corporate strategy [3].

For the example of the component of "product orientation", the corporate strategy is based on the assumption that all measures of the company are oriented on both the company and the life cycle of the products [8, 11]. Thus, increasing sustainability across the different phases of the product life cycle is a linked corporate objective [8, 11]. The

latter - the form of the competitive advantage - also provides an answer to the questions of what position the company occupies in the market and how the goal of building a sustainable competitive advantage through the product is to be realised.

Identifying the Conflicting Goals of the Components of a Corporate Strategy. Moreover, with the aim of capturing sustainability as holistically as possible, the question arises as to what extent the various components of the corporate strategy exhibit synergy effects among each other.

On the one hand, positive synergy effects should be utilised through mutually reinforcing interrelationships and, on the other hand, it should be possible to exclude contradictory strategy components.

The 93 identified positive and negative conflicting aims are partially depicted in Fig. 1 in form of a matrix and are based on the interrelationships described in the literature, starting with the analysis of exemplary companies or entire sectors. The various strategy components are plotted on both axes and then correlated with each other. The identified correlations were made up of both basic the results of case studies with a practical orientation and economic correlations, such as the possibility of customer-specific individualisation through the design of products (22) [12].

For the example of "differentiation", a positive conflict of objectives can be identified with the strategy component of "increasing innovative capacity". This positive link is based on the fact that innovative companies pursue the goal of developing a competitive advantage that cannot be imitated or substituted [13].

2.2 Potentials for Sustainability

Identification of Sustainability Potentials for the LPBF Process. The identification of sustainability potentials is one way to capture the sustainability definition within concrete production processes or product life cycles [2]. These potentials provide the connection between the individual corporate strategy and the resulting definition of multidimensional sustainability with the manufacturing process under investigation. Following the framework of Ehlers et al. (2020), there are also positive and negative relations between these potentials [2].

Each sustainability potential can be assigned to one or more sustainability dimensions depending on the impact of the potential. Since the focus of this paper is a generative manufacturing process, the relevant sustainability potentials are primarily located in the economic and the ecological dimension [2, 14, 15].

Identifying the Factors Influencing Sustainability Using the Example of the Process. In order to be able to identify influencing factors of sustainability using a concrete example, influencing factors are first defined according to Weltring (2015) as possibilities of "recording determinants that influence a target value as objectively as possible" [16]. Specifically related to sustainability, the following questions can be formulated:

- "What factors influence [the sustainability of the analysed manufacturing process] and in what way?"
- "What is the cause and reason for this influence?"

Based on these questions, the process chain of the LPBF process is examined as a collection of the processes directly affecting the target value to identify influencing factors. According to Lachmayer et al. (2016), this can be divided into four process sections and associated process steps (cf. Fig. 2 according to [17]).

Through a comprehensive literature research based on publications that deal with the definition and evaluation of sustainability and those whose contents focus on the concepts and implementation of additive manufacturing processes, a total of 18 different factors influencing sustainability for the LPBF process chain can be identified. Since the "preceding processes" of production are material-dependent and not individually adaptable, this process section as well as the associated process steps cannot be adapted to the orientation of the company [3, 17, 18].

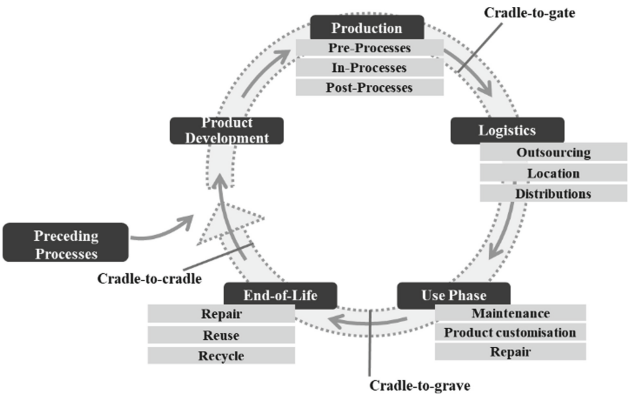

Fig. 2. Process chain of the LPBF method according to Lachmayer et al. (2016) [17]

In the product development phase the method for identifying the influencing factors can be explained. First of all, it is necessary to answer the initial question of what factors has a significant influence on which of the three sustainability dimensions in this process step. Since the focus is on exploiting the targeted potentials, both the design of the production processes and the material to be used must be adapted. As a result three influencing factors in the form of "process design", "material selection" and "exploitation of potentials" emerge as relevant. The second question to be answered relates to the causes and reasons for this influence on the sustainability of the LPBF process. In this context, indicators for each of the identified influencing factors were determined on the basis of a literature review. Each indicator serves to capture values that positively or negatively impact the influencing factor. For the example of "material selection", the proportion of toxic substances that are processed during the production of the component offers a possibility for a cross-process comparison. In addition, the relative proportion of primary resources used provides information on the acceptance of the process in relation to the use of recycled secondary resources.

Classification of the Influencing Factors in the Context of Sustainability Potentials Using the Example of the Process Chain of the LPBF process. In determining the

sustainability potential of an influencing factor or related indicator, a cause-and-effect relationship must exist between them. Regardless of the characteristic, in the form of a positive or negative cause-effect relationship, there is a direct dependency and thus also an influence on sustainability. Moreover, a potential can be assigned not to just one indicator, but to a large number of different indicators that can extend over the entire product life cycle. Based on this assumption, it is possible to capture as holistic a picture of sustainability as possible with a small number of different potentials. The linked data of the assessable factors serve - analogous to classic key performance indicators - to monitor the current company performance [5]. In context of this paper, "sustainable corporate performance" is the measure of congruence between the corporate strategy and the company-specific sustainability strategy.

As a result of this assignment, a varying number of sustainability potentials outcomes for the different influencing factors and indicators. For a better understanding of the assignments made, the four indicators "operating materials", "auxiliary materials", "process and cooling water" and "length of the value chain" can be identified for the example of the influencing factor "process design", which can be assigned to both cross-influencing factor and indicator-specific potentials.

Thus, the "reduction of waste" and the "increase of process efficiency" result as characteristic sustainability potentials for the considered influencing factor of "process design". Since in the process section of production the degree of waste correlates directly with the efficiency of the processes, these are linked, among other things, to the consumption of operating materials [19].

Impact and dependency matrix between the components of the individual corporate strategy and the identified potentials of sustainability	Collection of potentials related to a targeted increase in sustainability									
	Reduction of CO2 emissions	Reduction in the use of resources	Development of alternatives to conventional manufacturing	Increasing functional integration	Reducing energy consumption	Reducing waste	Reducing wastage	Expanding hybrid production	Increasing recyclability	Improving the use of digitalisation
Components of the corporate strategy: Cost leadership			O		O		X			
Differentiation	O		X	X				X	X	X
Niche market	O		X	X				X	X	X
Mass Customisation					X	X	X	X		X
Infrastructure management	X	X	O		X	X	X	O	X	X
Product leadership				X					X	
Adaptability		O	X	X	O		O	X	X	X
Measure of the degree of individualisation			O	X				X	O	X
Product orientation				X					X	
Service orientation				X		O	O	O	X	O
Staff orientation			X			X	X	O		X
Price/performance ratio				X	X	O	O		X	O
Nature of internal communication										
Customer-oriented										

Fig. 3. Detail of the created impact and dependency matrix between 23 components of corporate strategies and 53 potentials of sustainability

The higher the relative ratio of input to output resources, the higher the process efficiency. There is thus a positive correlation between the indicator and the potential.

The potential "reduction of process steps" for the indicator "length of the value chain" is used as an example of an indicator-specific potential allocation. The length of the value chain decreases as well as the number of individual process steps as example for a positive correlation [3, 20].

Linking the Identified Influencing Factors with Components of the Corporate Strategy. To establish a link between the components of the corporate strategy, the production process under consideration and sustainability, the following combinatorics can be applied. The desired result of this linkage is an individually structured collection of relevant assessable variables for the LPBF process under investigation with indicators to be checked.

The direct (X) and indirect (O) links are combined in an effect and dependency matrix, which is shown as an example in Fig. 3. For the example of the strategy component of the "price/performance ratio", there is both a direct link with "energy consumption" during production and an indirect link with the "reduction of waste" due to inefficient processes and resulting increased production-specific costs in contrast to lean and thus sustainable production.

3 Literature-Based Case Study

In order to verify the method presented in this paper for linking corporate strategy with sustainability potentials, the assumptions made in this section are applied to two different literature-based corporate strategies as impulse generator, which is responsible for the composition of relevant assessable variables. In this context a corporate strategy from the field of the LPBF process and a sustainability-oriented corporate strategy are considered. Based on the method's results using two different corporate strategies, a conclusion is to be made regarding the reliability of the method's use.

The corporate strategy presented by Dispan et al. (2014) is based on current developments in the context of megatrends such as globalisation, demographic change and the advancing energy transition, the five strategy components listed in Table 1 serve as the reference for the sustainability strategy [21]. Assuming that digitalisation is a significant innovation driver for the formation of new business models and corporate strategies, the derived strategy focuses on internal corporate aspects [22].

In contrast to this sustainability orientation, the corporate strategy according to Echterhoff et al. (2016), with the elaboration of a B2B platform for additive manufacturing, is based on a future-oriented corporate strategy that focuses not only on traditional resource but also on human resource use [23]. Compared to the sustainable strategy components according to Dispan et al. (2014), Echterhoff et al. (2016) pursues the goal of building both the highest possible customer loyalty and market position [23].

3.1 Application of the Previously Described Method

Identify Sustainability Potentials of the Corporate Strategies Under Consideration. In identifying sustainability potentials for the two exemplary corporate strategies on the

Table 1. Identified components of corporate strategies according to Echterhoff et al. (2016) and Dispan et al. (2014)

Echterhoff et al. (2016)	p.	Dispan et al. (2014)	p.
Mass customization	13	Adaptability	64f
Product leadership	13	Staff orientation	63/65
Measure of the degree of individualisation	13	Nature of internal communication	63
Service orientation	13	Focus on rapid product development	63
Customer-oriented	13	Green corporate orientation	66

basis of the various identified strategy components, a preliminary analysis is required. Figure 4 shows the process of the method including the outcomes determined. In relation to the conflicting goals identified in advance, this results in positive and negative correlations between the strategy components for both corporate strategies, on the basis of which a statement can be made regarding the compatibility of these components. As an example for the corporate strategy according to Echterhoff et al. (2016), there is a positive conflict of objectives between "personnel orientation" and a "'green' corporate orientation", since according to Stibbe (2017) a commitment of the employees concerned is necessary in order to be able to successfully implement new aspects within a company [24].

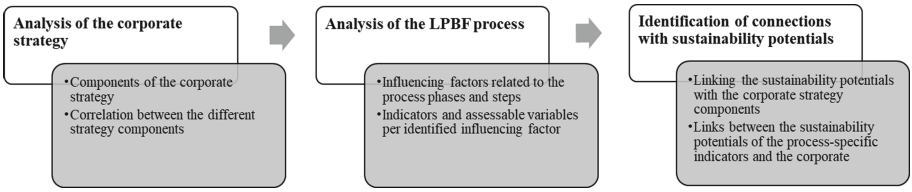

Fig. 4. Illustration of the applied method and identified factors

With the help of the developed impact and dependency matrix, a strategy-specific selection of relevant sustainability potentials can be created for the strategy components. For the concrete example of the strategies according to Echterhoff et al. (2016) and Dispan et al. (2014), a different collection of sustainability potentials results analogous to the varying strategy components. As a result of the classification of the strategy components in the effect and dependency matrix in which the sustainability potentials are classified with the components of the corporate strategy [3].

As the only sustainability potential of "improved handling of digitalisation" can be identified as an interface between the two corporate strategies. This can be explained by the increasing necessity of internal company networking and the megatrend of intelligent manufacturing [21]. According to Mohr (2020) advancing digitalisation allows for new innovation opportunities that go beyond the limits of pure production purposes and forms

the basis of all future potential and must be incorporated into a future-oriented corporate strategy [22].

Following the framework according to Ehlers et al. (2020), the sustainability potentials are related to each other and are upstream and downstream of each other [2]. Through these lever-potential relationships, a holistic picture can be created beyond the boundaries of the three dimensions, whereby a classification in the overarching sustainability context can take place.

This collection of related sustainability potentials forms the intersection between the corporate strategies under consideration and the process chains of the LPBF process under investigation.

Deriving the Influencing Variables Based on the Sustainability Potentials. For the example in the corporate strategy according to Echterhoff et al. (2016), two primary and 15 secondary indicators can be determined, and analogously for the sustainability strategy according to Dispan et al. (2014), 17 secondary indicators can be determined [3, 21, 23]. Due to the varying composition of these relevant indicators, statements can be derived regarding the focus within the process chain, as the indicators show strategy-specific deviations. The focus of the sustainability strategy is on the one hand on the process steps preceding the product development and on the other hand on the pre- and post-processes of production. In comparison to the strategy of additive manufacturing, the focus lies in the area of product development, the in- and post-processes of production and the phases of the end-of-life.

4 Conclusion and Outlook

The entire paper is based on the assumption that the individual design of the corporate strategy has a direct influence on the resulting sustainability of the process. To demonstrate this it can be observed that the various sustainability potentials and the influencing factors derived from them in the process chain of the two corporate strategies examined differ from each other. This divergence is thus the first consequence of a differentiation in corporate strategy. When the associated assessable factors are complemented with real values, further differences emerge within the resulting assessment process.

Another way of differentiating the results is to look at the primary and secondary influencing factors separately. This strategy-specific differentiation allows a statement regarding the compatibility of the primary identified potentials and dependent secondary levers. The iterative application of the method with constant assessable variables resulting from the underlying corporate strategy offers a possibility to identify internal changes in the area of sustainability. Depending on the characteristics of the period under consideration, a tendency can be determined as to whether and to what extent the available sustainability potentials can be exploited.

The developed method as well as the presented connections between sustainability potentials, components of the corporate strategy and the influence on the LPBF process generate strategy-specific results in the form of assessable variables. It is a way of linking purely economic strategic management with the actual product life cycle. The validity of this method must be verified with the help of a data collection of the identified evaluation

variables on the example of a demonstrator component. Important for the application of this method as well as a potential comparison of sustainability is the collection of data over the entire life cycle of the product in order to be able to determine a picture of the procedures, processes and products that is as holistic as possible.

In order to minimise the risk of inferior data quality due to a lack of data availability, Life Cycle Assessment databases, such as "ecoinvent", as well as holistic life cycle assessment software can be used to support the process.

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