SIMILARITIES AND DIFFERENCES BETWEEN ENVIRONMENTAL SOUNDNESS AND RESOURCE EFFICIENCY AND THEIR CONSEQUENCES FOR DESIGN SUPPORT

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Abstract

Environmental soundness and resource efficiency are important issues that should both be taken into account when engaging with sustainability. In recent years, several tools to assist designers to do this have been developed in design research. It is often incorrectly assumed that existing EcoDesign methods are absolute suitable to support designers in the development of resource efficient products. The comparison of the two topics, environmental soundness and resource efficiency, shows that although they have an overlap, significant differences can be identified. For design methodology, this means that some existing EcoDesign methods can be used to develop resource efficient products or can be adapted to resource efficiency. However, this is not sufficient. There is a lack of support for the anticipation of possible supply bottlenecks, which is a central characteristic of resource efficiency. How to integrate this topic into companies remains unclear.

Keywords: Resource efficiency, EcoDesign, Criticality, Supply bottlenecks, Risk management

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1 INTRODUCTION

Technical progress and economic growth play a central role in today's industrial societies. However, the downside to this was detected several decades ago. The dramatic consequences of prosperity and the limits to growth have been demonstrated, e. g. in the MIT study *The Limits to Growth* (Meadows et al., 1972), drawing attention to global environmental problems: the topic *sustainability* emerged. According to the widely recognized definition in the Brundtland Report, “sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). Sustainability has three dimensions of equal importance: ecology, economy and society (Petschow et al., 1998).

Today, the environmental issue is on the political agenda, and increasingly, in public debate. In conjunction with this, the role that companies play has been recognized. Companies can contribute to reducing their environmental impact by developing environmentally sound products. Partly driven by legal requirements and partly by customer requirements, businesses provide an increasing number of environmentally sound products, contributing to ecological sustainability.

Especially in recent years, the issue of *resource efficiency* became the focus of discussion too. Supply uncertainties, resource scarcity and global resource conflicts ignited by these issues, as well as high and volatile raw material prices, show the relevance of the topic. The issue of resource efficiency is promoted through numerous funding activities and initiatives on the political front and by business organizations (e. g. resource efficiency is one of seven flagships of the Europe 2020 strategy (European Commission, 2010b)). Because of the potentially fatal consequences of supply interruption, the consideration of resource efficiency is highly relevant to companies as well.

Although the issue of *resource efficiency* is now quite common, the discussion still lacks a single, generally accepted understanding of the term. Resource efficiency is frequently mixed with environmental soundness or sustainability. Although there is an overlap and they should ideally have the same level of importance from a sustainability perspective, environmental soundness and resource efficiency are not the same (Berger and Finkbeiner, 2008, Dreuw et al., 2011). When resource efficiency is considered from a business perspective in particular, there are some significant differences.

Within both topics, product designers play an important role, as their design decisions determine product properties and influence the processes in the product life cycle. Thus they have a certain influence on the environmental impact of products (Birkhofer et al., 2000) and on the efficient use of resources. Methodical support to design resource efficient products has not been sufficiently considered in design research so far. Whereas various methods and tools were, and still are, developed to assist the design of environmentally friendly products, every available approach cannot be directly used to support the development of resource efficient products.

This paper therefore introduces an understanding of *environmental soundness* and *resource efficiency* from a business perspective. Based on this, the two subjects are compared, similarities and differences are identified, and the consequences for the development of methodical support for designers are shown.

2 UNDERSTANDING OF THE RELEVANT TERMS

Although the issues of environmental compatibility and resource efficiency are the focus of public discussion, understanding of the terms can be quite diverse. Especially for resource efficiency, there is not yet a universally valid and accepted definition. This is why the following two sections will outline the terms used in this paper.

2.1 Environmental soundness

Products influence the environment throughout their entire life cycle. *Environment* is, in this context, mostly understood as the surroundings of a system (e.g. a product system), consisting of humans, animals, plants, water, air, natural resources and land, as well as their interrelations (EN ISO 14001, 2004).

Environmental impacts are not caused by the product itself, they result from every process in a product’s life cycle (Schott, 1998) (Figure 1), from raw material extraction and manufacturing, over usage and transport processes, to the disposal of the product. Each of these processes requires several inputs, such as energy or material, to generate the needed output, such as an intermediate product or the product itself. Besides these desired outputs, there are undesired outputs, such as emissions and waste. In particular, the extraction of substances from the environment and emissions are undesirable from an environmental perspective, since they can cause a variety of serious environmental changes through many environmental mechanisms (Schott, 1998). Through the observation of the associated negative consequences, such as climate change and soil acidification, the awareness of society is increased and ‘environmentally responsible’ products are increasingly demanded by customers or are forced by legislative authorities.

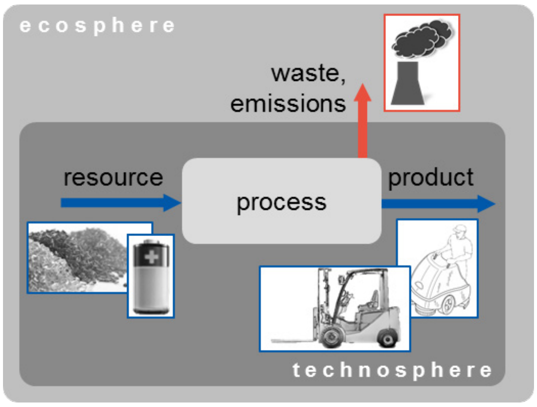

Figure 1. Processes and their environmental impacts

Every product entails technical processes in its life cycle; every technical process is, directly or indirectly, connected with inputs from or outputs to the environment and thus cause environmental impacts. From this, it follows that there are no totally environmentally friendly products. There are only products that are less damaging to the environment (Tischner et al., 2000). The environmental impacts have to be minimized. However, the solution to this problem is not necessarily abstinence from the use of technical products. Such a solution would probably not be accepted in the marketplace. Instead, environmentally sound products find a compromise between high benefits for the user and low environmental impacts during the product life cycle. Environmental impacts are assessed relative to other parameters, like this mentioned benefit to the user (Birkhofer et al., 1998). Because of this, some authors also use the term *eco-efficiency* (World Business Council for Sustainable Development, 2000, Schmidt-Bleek and Tischner, 1995).
The topic of environmental soundness therefore focuses on damage assessment, with the goal of preserving the natural environment and the capacity of ecological systems.

2.2 Resource efficiency

Resource scarcity and supply uncertainty lead to higher and volatile prices, which can have far-reaching consequences for companies. Resource efficiency, as a means of coping with these problems, is therefore an important topic, especially for companies.
The understanding of *resource efficiency* used in this paper was introduced in (Link et al., 2014) and is based on the general understanding of *efficiency*, i. e. the ratio of the benefit to the related effort (VDI 4800 Blatt 1, 2014, Kosmol et al., 2012). Thus, a resource efficient product provides a desired benefit using minimum resource effort over the product life cycle, as expressed in the following equation (Link et al., 2014):

$$Resource\ efficiency = \frac{desired\ benefit}{resource\ effort = f\ (amount,\ \ criticality)} \qquad (1)$$

The meaning of *resource efficiency* depends largely on stakeholder perspective from a global, national or corporate level. The resources that should be considered and the criteria for criticality can be quite different (Link et al., 2014). In this paper, the topic is discussed from the perspective of mechanical engineering companies.
A *resource* is generally an input that is required to operate a process (Albrecht et al., 2012, Kosmol et al., 2012). It can be a natural or technical resource (Link et al., 2014). *Natural resources*, e. g. metals, wood and water, are objects of nature. *Technical resources* have been extracted from nature and processed by humans, e. g. technical materials, electrical energy, semi-finished products and

components. Technical resources are highly relevant to manufacturing companies. In their production processes, they seldom use natural raw materials directly, usually using predominantly technical resources, such as semi-finished products. This is illustrated by the example of manufacturing a drive shaft (Figure 2). The drive shaft is typically made of a solid bar (a technical resource) instead of iron ore (a natural resource). To discuss the topic of resource efficiency, natural resources should be considered as well as technical resources.

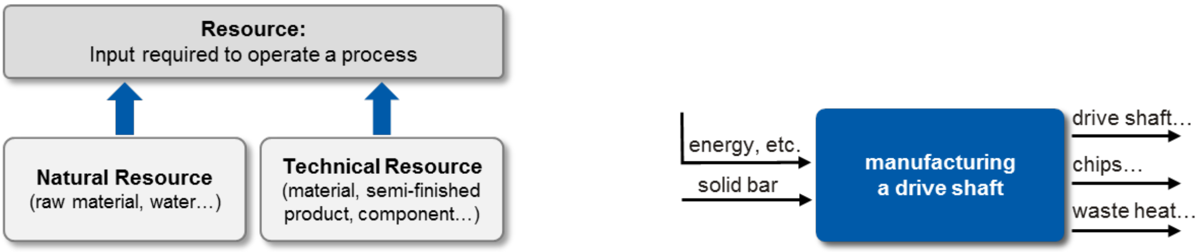

Figure 2. Classification of resources as an input for a process (Link et al., 2014)

For a holistic view of resource efficiency, examining the amount of resources used is not sufficient (Bach et al., 2014). Scarce and essential resources particularly require efficient use. Thus, criticality has to be considered to assess the resource effort (Equation 1). This reflects the aspect of availability of a resource. Based on the general risk definition (e.g. in (DIN ISO 31000, 2009)), criticality is mostly defined by two aspects: the likelihood of a supply restriction and the consequence of the supply restriction.

Supply bottlenecks are commonly attributed to the finiteness of the geological deposits of raw materials. In fact, a more important question is whether the raw material is profitably extractable using the available technology (Frondel et al., 2007). Consequently, it is a question of availability. The availability of raw materials can be restricted by many other aspects, such as a ban on exports, coupled production, high demand and natural disasters. These effects have to be considered when assessing the likelihood of a supply restriction.

As explained in (Link et al., 2014), because supply bottlenecks can occur not only at the raw material level, but also at further value-added steps, companies using technical resources must consider all value-added steps. For example, semi-finished products with specific dimensions (e. g. a sheet in a specific thickness) or a special coating can be problematically related to their availability. It is important to identify potential supply bottlenecks to react early enough to a shortage and avoid economic losses for the company.

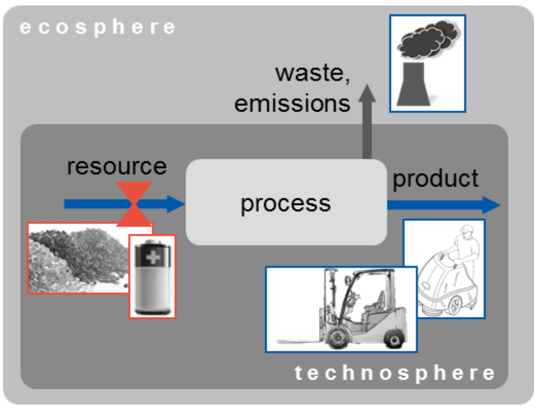

Figure 3. Supply bottleneck of resources

Because of short-term events, the availability of resources can change quickly. It is not always possible to forecast supply interruptions, consequently, it is difficult to measure them. There are many situations where the likelihood of a supply bottleneck is high. If a resource can only be produced by one company, the likelihood of a supply bottleneck is much higher than if there are many manufacturers. For this reason, the likelihood and the consequence of the supply restriction are assessed. The topic of resource efficiency is therefore focused on risk assessment, with the goal being to preserve the availability of resources (Figure 3).

3 COMPARISON OF ENVIRONMENTAL SOUNDNESS AND RESOURCE EFFICIENCY

The topics environmental soundness and resource efficiency both emanate from sustainability. As well as a few similarities, there are fundamental differences, e. g. aims and the assessment basis. Both issues differ, especially the environmental aspect and the aspect of criticality.
Based on the presented understanding of *environmental soundness* and *resource efficiency,* the two topics are compared and the similarities and differences are shown. Therefore, the various attributes are analyzed and summarized in Table 1.

Table 1. Comparison of environmental soundness and resource efficiency

Attribute	Environmental soundness	Resource efficiency
Aim	Prevent damage to the environment, conserve environmental performance	Secure availability of resources, prevent supply bottlenecks, conserve resources
Basic requirement	Market appropriateness, provision of desired benefit	
Assessed phenomena	Damage assessment	Risk assessment
Assessment basis	Focus on process outputs	Focus on process inputs
Scope	Global	(Individual) company
Formation of total value	Summative	Not summative
Variability	Temporal variability is usually neglected	Temporal variability is relevant
Possible approaches	Choose processes with low environmental impact	Choose resources with low criticality
	Reduce the amount of needed resources	

3.1 Aim

As discussed, transformation of the environment is the price paid for technical progress. These transformations are more and more damaging to the environment and have global dimensions, such as eutrophication, soil acidification, climate change and toxicity. The environment is the source of raw materials and the sink for emissions and waste. But the capacity of the environment is limited. As a means to minimize all of these impacts, environmentally sound products are strived for. The goal is to prevent damage to the environment and to conserve its performance.
In contrast to this, the aim of resource efficiency is to conserve resources and secure their availability. The availability of natural resources is relevant and supply bottlenecks of technical resources have to be considered as well.

3.2 Basic requirement

Market appropriateness, which is mainly determined by the customer, is a prerequisite for both topics. A product that has been manufactured but not accepted by the market is neither environmentally sound nor resource efficient. It is necessary to provide exactly the desired benefit for the customer. Resources – as well as the related environmental impacts – that are needed to generate an additional benefit can be saved. This is why the desired benefit should be analysed and questioned. As a consequence, it is possible that it is more effective not to maximize a product’s life. If the user does not need the higher lifetime provided by high-class materials, these materials are spent unnecessarily. By saving them, the resource input and the related environmental impacts can be reduced.

3.3 Assessed phenomena and assessment basis

Another difference between environmental soundness and resource efficiency is the assessed phenomena and the assessment basis. In environment soundness, technical processes, their emissions

and the related environmental impacts are considered. Thus, assessment is mainly based on outputs and their diverse and serious damages to the environment.
In contrast to this, with resource efficiency the resource effort is assessed. In this context, the criticality of resources is relevant. Because the early identification of a possible supply bottleneck is important, a risk assessment is conducted. Thus, the likelihood of a supply restriction and the consequence of this supply restriction are assessed. The focus of resource efficiency assessment is on the inputs needed for a process. The outputs of the process are considered only indirectly: By reducing the inputs and realizing the same benefit, the outputs are reduced as well. The environmental impacts of waste and emissions are not regarded.

3.4 Scope

As already discussed, environmental soundness addresses the whole environment. It has a global scope and the determination of environmental impacts is independent from any special stakeholder. The supply risk, however, depends often on the perspective of the stakeholder.
The example of rare earth elements helps to illustrate this. With the extraction of rare earth elements, a huge amount of toxic waste is produced that is deposited in artificial lakes. The natural mineral deposits of rare earth elements frequently include radioactive material. Thus, there is the danger of transferring radioactivity into the environment (Schüler, 2011). The result of environmental assessment of a product that contains rare earth elements is always the same no matter whether it is done from the perspective of a company located in Europe or in China, assuming they have the same production processes.
In the likelihood of supply restriction, the preconditions of a Chinese company and a European company differ. Today, China extracts nearly 90 % of the worldwide extracted rare earth elements (U.S. Geological Survey, 2015). In the case of an export restriction, availability for the European company would probably be greatly limited. In contrast, the Chinese economy would not necessarily be affected.
The situation concerning availability can differ from one company to another. This can be illustrated using the example of a battery, which could be a resource for a company that uses batteries in its products. The availability of these batteries can change abruptly, for example, when a new industry booms, e. g. the electro mobility. It may be that the previous customer is no longer as important to the producer of the batteries, who aligns with the new customers.

3.5 Formation of total value

In formation of a total value, the two topics also have different characteristics. To calculate the environmental impact of a resource, it is possible to multiply emissions from processes along the supply chain with their specific environmental impact and to add everything up. That does not work for supply restriction as they do not necessarily add up along the supply chain. In fact, the structure of the supply chain is relevant too. It could be that a momentary supply disruption of a raw material is compensated for along the supply chain (e. g. because of stock keeping by the suppliers), so that the availability of a component that contains this raw material is only slightly affected or not at all (Figure 4, left). Likewise, contrary effects can occur, so that availability is worsened along the supply chain (Figure 4, right).

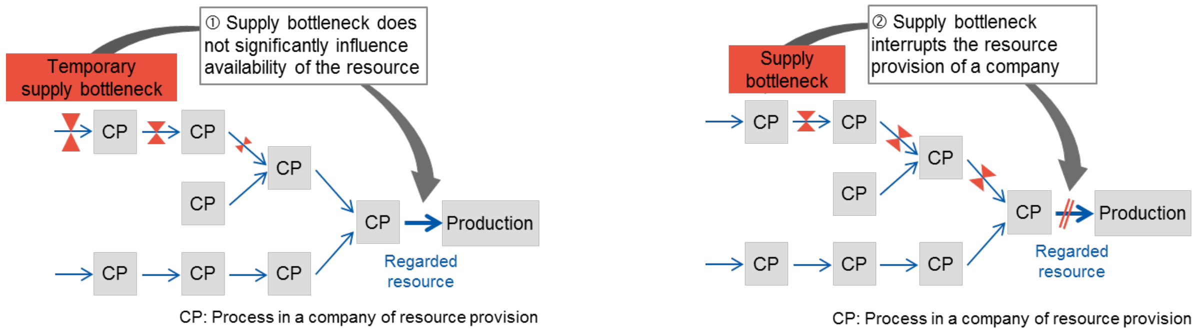

Figure 4. Examples of possible consequences of a bottleneck in a supply chain

3.6 Variability

When assessing the environmental impacts of a process, the impacts on the environment are assumed to be non-fluctuating as long as the manufacturing technology used remains unchanged. The environmental impacts of the process are determined, based on current scientific findings, and are used until new or more detailed findings are presented. Whereas a potential change over time is assumed to be marginal and is consequently neglected for environmental impacts, it plays a significant role in the availability of resources. For example, an abrupt change in availability due to the loss of a key supplier could largely affect company performance and business success. An awareness of the importance of resource availability as well as having a way to identify the most critical resources are consequently crucial in industrial practice.

3.7 Possible approaches to improvements

A range of approaches to improve environmental soundness or resource efficiency is available. Choosing processes with low environmental impacts can improve the environmental soundness of a product. Resource efficiency, however, might be improved by choosing resources with low criticality. A possible way to integrate environmental soundness and resource efficiency is the reduction of the overall amount of resources used over the product life cycle. Taking existing interdependencies into account, this approach leads to products that are characterised by less environmental impacts and less resource effort.

4 CONSEQUENCES FOR DESIGN SUPPORT FOR THE DEVELOPMENT OF RESOURCE EFFICIENT PRODUCTS

Designers determine product properties and behaviour through their design decisions. Thus, the environmental soundness and the resource efficiency of the product are significantly influenced by the designers. Today, designers have to consider many requirements and they perform many trade-offs. To assist them, various methods and tools have been, and still are, developed, in the field of environmental soundness. It could be assumed that EcoDesign methods can be utilized to develop resource efficient products. Comparison of the two topics based on the understanding of the terms in this paper has shown that, beside the obvious similarities, there are significant differences that should be considered during product development. Complete transferability seems to be implausible.

The prerequisite for the development of environmentally sound and resource efficient products is a holistic approach. Therefore, anticipation of processes across the product life cycle is a crucial step to influence the environmental soundness and resource efficiency within product design (Figure 5). In doing so, possible interactions between life cycle phases of the product should also be considered. In this way, it is possible to holistically optimize resource expenditure and environmental impact of products.

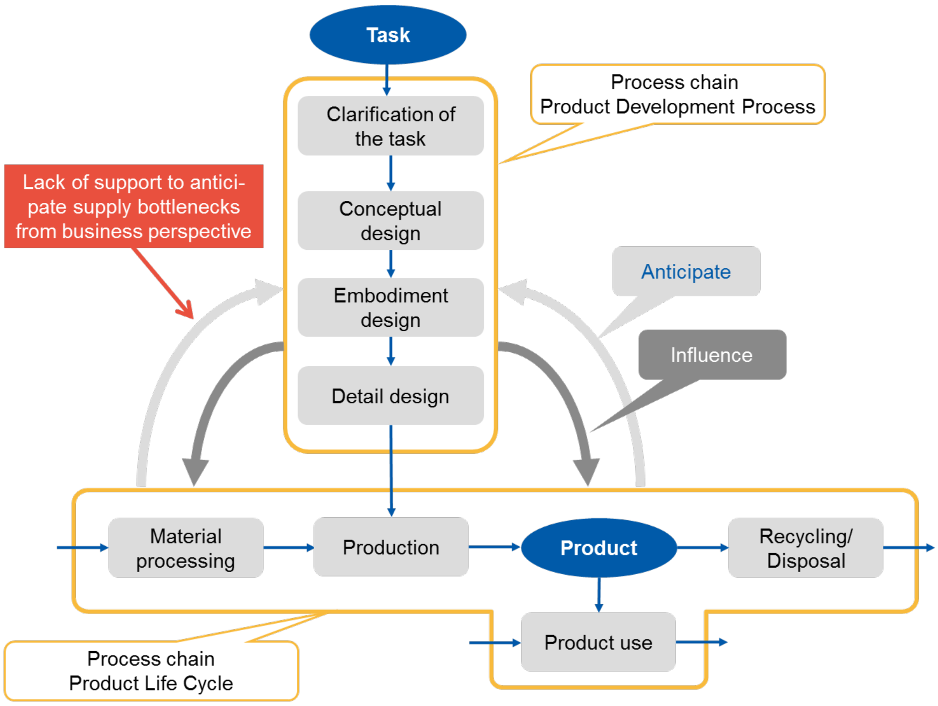

Figure 5. Model of holistic product and process development (Birkhofer et al., 2012, Abele et al., 2005)

Within the range of EcoDesign tools and methods, there are many that should support a reduction in the amount of material and energy used throughout the product life cycle. As shown in Section 3.7, *reducing the amount of needed resources* leads to positive effects in environmental soundness and resource efficiency. These EcoDesign approaches can be transferred to resource efficiency.

The main difference in the design support of environmentally sound products and resource efficient products seems to be in the assessment of a product, which is usually done at the beginning of a product development process within the task clarification. To design an environmentally sound product or a resource efficient product, it is necessary to get to know the weak points. Therefore, analysing a reference product is common. In environmental soundness several tools exist to support this process: Life Cycle Assessment (EN ISO 14040, 2006, EN ISO 14044, 2006), pragmatic assessment tools (e.g. Eco-indicator 99 (Goedkoop and Spriensma, 2000)) and checklists (e.g. in (Brezet and Van Hemel, 1997)).

To develop resource efficient products, this analysis is important too. A general assessment basis and methods that support the designer do not yet exist (Figure 5). As already explained, detection of the amount of resources needed does not provide a holistic view of resource efficiency. The methodological peculiarity of resource efficiency lies in anticipating potential bottlenecks in the supply chain to classify resources for criticality and to be able to react to supply bottlenecks in time.

There are a number of studies that evaluate resources for criticality (e. g. (Duclos et al., 2010, Erdmann et al., 2011, European Commission, 2010a, Graedel et al., 2012)). However, as discussed in (Link et al., 2014), these approaches are not sufficient to assess criticality of resources from a business perspective as they are mainly limited to natural resources, especially raw materials. In addition, there are efforts to integrate availability aspects into existing life cycle assessment tools (e. g. (Bach et al., 2014, Schneider, 2014), further reading see e. g. (Klinglmair et al., 2014)).

As already mentioned, the peculiarity lies in anticipating potential supply bottlenecks. Regardless of issues such as resource efficiency, criticality and supply bottlenecks, related assessments are already conducted in companies. Various departments deal with topics such as quality management, risk management, procurement and supply chain management. Building on established methods is feasible, combining and expanding them.

Because assessment of the criticality of a technical resource is individual and company-specific, it is important that the methodical approach allows a degree of flexibility to account for company-specific aspects. A high level of practicality should also be ensured when engaging with this complex issue to support small to medium enterprises (SMEs). This is a prerequisite to encourage smaller companies to focus on resource efficiency.

5 CONCLUSION

Environmental soundness and resource efficiency are important issues that should both be taken into account when engaging with sustainability. Comparison of the two topics has shown that although they overlap, significant differences can be identified. While the topic of environmental soundness focuses on damage assessment, resource efficiency focuses on risk assessment. Environmental soundness can lead to ecological sustainability. Because of the drastic consequences of supply bottlenecks of a company resource and related economic losses, the topic resource efficiency is important for companies. Resource efficiency helps companies to be economically sustainable and support ecological sustainability when reducing the amount of resources needed. Even a relation of resource efficiency with the social dimension of sustainability could be observed, but is not the topic of this paper. Treating environmental soundness and resource efficiency separately is proposed, even though, ideally, they are both taken into account when engaging with sustainability.

Product developer design decisions significantly influence product properties and their environmental performance, as well as resource efficiency. Designers play a central role. In recent years, several tools to assist designers with this have been developed in design research. It could be assumed that existing EcoDesign methods can support designers in the development of resource efficient products. As shown in this paper, this is not possible in every case. Some of the existing EcoDesign methods can be used to develop resource efficient products or can be adapted to aid resource efficiency.

However, existing methods are insufficient. They do not anticipate possible supply bottlenecks, which are a central characteristic in resource efficiency. How to integrate this topic into companies remains unclear. Design research needs to sufficiently consider the topic of resource efficiency.

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