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Eco²-Screening Method Supporting SME-Product and Process Innovations in Electronics Manufacturing Services Sector

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Abstract
Consumption exceeds ecological limitations and still the market develops an insufficient incentive for the consideration of environmental aspects in the supply chain. In order to mitigate negative environmental effects, influence is needed in the earliest possible phase of innovation processes. Numerous studies, however, detect systematic use of ecological and economical innovation instruments mainly in large enterprises. In inverse consequence small and medium enterprises (SMEs) implement fewer environmental innovations, even though 99 % of the enterprises in Germany count less than 500 employees and adhere significant innovation potential. In order to provide a scope for action for SMEs an instrument for consideration of environmental product and process implications is needed that claims little economical resources of users and is easily applicable. Based on the Design Science Research Process a Screening method is developed for SMEs in the Electronics Manufacturing Services sector to enable a monitoring of ecological and economical optimization of innovation processes, while not demanding costly Life Cycle Assessment or additional questioning of suppliers. The eco²-screening method uses existing data and follows a modular design.

Keywords: product-innovation, process innovation, economic-ecological assessment; environmental analysis, SME research

1. Introduction

In 1972, scientists already warned on behalf of the Club of Rome about the approaching overshoot to the carrying capacities of the ecosystem, caused by uncontrolled growth, corresponding industrialization, ever increasing environmental pollution and undamped consumption of values of natural resources (Meadows et al., 2020). This irrevocably leads to the necessity of allocation under resource scarcity as well as limited regeneration abilities of ecological mediums which are subject to environmental protection. Spillovers of this exploitation are climate change, and loss of biodiversity (Arneth et al., 2019; Brondizio et al., 2019; Paltsev et al., 2021). As a result, the need for action on sustainable development is of increasing importance: Additionally to climate protection, the Agenda 2030 addresses the clean utilization of energy, and sustainable production. For that matter circular economy and expansion of utilization of renewable resources are supposed to lead to sustainable growth (Martens & Obenland, 2017). The so-called Green Deal describes the more detailed time horizon for this objective at the level of the European Union. It serves as a guidance for societal and economical reorientation to cope with the challenges of climate and environmental protection.

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It is a commonly accepted fact that both at product and process level win-win situations can arise from the utilization of economic and ecological efficiency potentials, especially if wastage is strictly diminished (Schmidheiny, 1992). Nevertheless, there is a discrepancy of the overshoots to environmental carrying capacities that already occurred in the past and yet continued exploitation of the ecosphere. This is caused because "the environment" is a public asset. This results, among others, in the dilemma that markets accept ecologically sound characteristics only in exceptional cases. Environmental aspects are only insufficiently considered during the entrepreneurial design activities on products and processes (Schusser, 2018).

Carrillo-Hermosilla et al. show and categorize the great number of barriers to ecologically inclusive design processes (Carrillo-Hermosilla et al., 2009, pp. 28-50). Especially small and medium-sized enterprises (SMEs) are affected by these restrictions, since they do not own adequate capacities to systematically increase resource efficiency in product and process design beyond customer demand. Numerous studies conclude that systematic utilization of ecological and economical potentials is mostly conducted in in big enterprises (e.g., Del Río et al., 2017; Marin et a., 2015; Parrilli et al., 2022; Rammer et al., 2017). In Germany, 99 % of the enterprises count less than 500 employees. Combining these results, the studies show that most German enterprises use innovation potential is insufficiently.

There is a consensus among scientists that consistent implementation of ecological influence to the characteristics of products and processes needs to be conducted in the earliest phase of innovation. On the sample of the German Electronic Manufactuing Services (EMS) Industry an eco²-screening method is developed that takes the restrictions of SMEs into consideration. It shall be flexibly usable and demand little entrepreneurial resources. Starting point for the method design is the consideration of data on material flows already existing in the company, a modular structure, and the minimization of required expert knowledge. In the following section, key terms are introduced, and existing methods are discussed as a basis for the development of an own approach. Then, eco²-screening procedures are proposed, explaining necessary data, meaning of parameters and indicators, and ideal values. Benefits and limits of the approach will be discussed at the end of the contribution.

2. Assessment Bases for Eco-Innovation

The term innovation means the "technological and/or social systemic change process which consists of the invention of an idea for change and its application in practice" (Carrillo-Hermosilla et al., 2009, p. 8). It can be divided between incremental and radical innovations; whereby incremental innovations serve the enhancement of efficiency of existing systems and radical innovations shall substitute existing solutions with completely new designs. A technological and/or systematic change process is conceivable at system level, but also at subsystem level (Tushmann & Anderson, 2004, p. 5). Even the change of (sub)systems by means of adding components (End of Pipe) can be considered as innovative if the technology is considered new (Carrillo-Hermosilla et al., 2009, p. 94). Both products and processes can be subject to innovations and there can be overlapping and interacting aspects between the two categories. E.g., the development of new products must often comply to existing production technology for realization. On the other hand,

the further development of processes can only be implemented, if the solution still complies to production requirements of products.
The basic objective of development processes is optimization. Classically, optimization is carried out based on market demands, so that the potential market cycle of products, which determines potential turnover and market durability (Opitz, 2009, p. 44), is of central interest. Optimization approaches of economic processes and products that consider environmental impacts, must look beyond this purely economic point of view and include an assessment of the physical life cycle of products from raw material acquisition to the end-of-life-management and the disposal of residues. In this kind of analysis both the desired commodities (products) but also the undesired commodities (by-products) are of interest (Vahrenkamp & Siepermann, 2008, p. 61). Especially the undesired commodities that arise along the value chain constitute use of resources without immediate benefit (wastage).
During ecological analysis of products and process systems (and their material flows) environmental aspects of transfer processes are focused, like the consumption of energy, water, use of materials in kind and amount as well as the causing of emissions, waste, and wastewater. In the 1990s, several methods were introduced to assess these environmental aspects. The most complex and extensive method is the life cycle assessment, which is conducted in the four phases "goal and scope", "inventory analysis", "impact assessment" und "interpretation". The procedure is consolidated in the ISO-standard 14044. The systematic registration and quantification of physical material flows within the scope of assessment is called inventory analysis or material flow analysis (Brunner & Rechberger, 2017). Based on this assessment phase an impact assessment is established for identification of potential environmental impacts emitted from the scope of assessment. The results can be used as input for development and design processes. The methodological challenge of a life cycle assessment is the ambition to holistically evaluate the environmental impacts of product systems along all phases of the life cycle, from the generation of raw material, the production, distribution, and use phase, all the way to recycling processes, and disposal (cradle to grave). A fully conducted life cycle assessment may not exclude any energy or material flows and must include all potential quantifications of flows that are relevant to the inventory analysis or the impact assessment. This results in the need for extensive data collection both internal and external to the conducting enterprise. The conversion of physical consumption data into environmental impact assessment requires at best a database for the collection of upstream and downstream data, and extensive know-how for accurate compilation of the full analysis and display of potential environmental impacts.
To increase manageability, various shortened assessment methods were introduced based on the life cycle assessment approach. Here, climate assessment on the basis of CO_2-equivalents receives recognition and increasing attention. It supports both a product-related cradle-to-grave assessments (or parts thereof) as well as an organization-related screening of entrepreneurial processes. Corresponding procedures are consolidated in ISO-standards as well as Greenhouse Gas (GHG) protocols. The more the needed data need to be generated outside the company-gates, the more effort is required for conducting the CO_2-balance. This is true for the data to be generated, and for the needed CO_2-equivalents that are needed as factors for the calculation of the final statement on CO_2-

(equivalent)-emissions within the chosen scope of assessment. The GHG-protocol lists the following motivations for conducting a CO_2-balance: managing GHG risks and identifying reduction opportunities, public reporting and participation in voluntary GHG programs, participating in mandatory reporting programs, participating in GHG markets, recognition for early voluntary action (GHG Protocol, p. 11). From this it becomes evident that climate assessment approaches can benefit the identification of reduction potentials, but mostly objectives of entrepreneurial communication account for their initiation.

Shortened assessments can also focus selected environmental aspects, such as energy use or use of materials. E.g., Schmidt-Bleek introduced a procedure to identify the "material input per service unit" (MIPS) in 1994 (Schmidt-Bleek, 1994). The MIPS refrains from the holistic approach of product system assessment and reduces complexity to the single aspect of resource use. It maintains the cradle-to-grave view, so that production, use phase, maintenance and disposal are included in the statement. All used material amounts are quantified and balanced to the designed use (Zhao, 2013, p. 24). As a result, the effort needed to assemble the data for the MIPS is still high. The indicator "cumulative energy demand" (CED) shortens the inventory analysis even more and exclusively considers the total primary energy consumption in all phases of a product life cycle. This includes both energy uses in all energetically relevant value-adding steps and the calorific value of all energy sources contained in the product system. The determination of the CED requires significantly smaller effort than the MIPS. Like the MIPS, it produces measurable results. On the other hand, by exclusively focusing on energy flows, it only provides limited insight into efficiency.

Other well-known possibilities to limit effort and complexity of ecological assessments concern the definition of the scope of assessment along the life cycle of product systems: it can be reduced to include life cycle phase cradle-to-gate or even gate-to-gate, instead of the extensive scope cradle to grave. Such strategic limitations increase the probability of sufficient date availability and reduce complexity of the assessment with an acceptable loss of informative value of the results for the initiation of eco-innovation processes.

The introduced examples of assessment methods for the implementation of ecologically sound innovations are still complex and demand both specialized knowledge and enough capacities for application. Studies concerning energy efficiency indicate that scarce capacities, e.g., of financial, time frame, or human resources pose problems concerning feasibility especially for SMEs (Prashar, 2017, cited in Jalo et al., 2021, p. 3, 10). Based on the argumentation that SMEs have little capacities to systematically increase resource efficiency in product and process design beyond customer demand, it is not surprising that acceptance and utilization is therefore missing at industry level and SMEs do not see the additional benefit of assessment methods at material flow level (for an overview see Schusser, 2018). The conscious limitation of the scope of assessment to singular environmental aspects and life cycle phases results in shortened balances at diminished effort. On the other hand, the informative value is reduced, to the chosen scope of assessment, as well. It is not sufficient to break down the market failure concerning design requirements in entrepreneurial R&D-departments. We conclude that a method is needed that provides for the consideration of environmental aspects in product and process innovations while demanding little entrepreneurial capacities.

3. Method Choice and Design

The eco²-screening method introduced here, was developed with special regards to the Electronic Manufacturing Services (EMS) sector as a use case of industrial manufacturing with significant environmental impacts. The EMS-industry has developed from traditional manufacturing, structural re-organization in the sense of lean management, and is now starting to recognize its environmental footprint (Di Domizio et al., 2019). It is characterized by automation and digitization of the value chain, like few other industrial sectors. Ecological significance is caused by the use of scarce and critical natural resources, as well as high energy use at production and product level (Esfandyari et al. 2015). This is intensified by increasing demand of electronic equipment and resulting consumption of values. A transparent and holistic assessment of environmental aspects for this kind of production could not be found in the literature (Kolb, Schusser, 2019).
Peffers et al. (2007) criticize that "while design, the act of creating an explicitly applicable solution to a problem, is an accepted research paradigm in other disciplines, such as engineering, it has been employed in just a small minority of research papers published in our best journals to produce artifacts that are applicable to research or practice." (p. 48) The design science approach supports the development of methods that support the achievement of a specified objective (Simon, 1969, p.55). In this contribution, the objective is to design an approach that is applicable for SMEs and supports the introduction to the topic of eco-innovating. The resulting method is based on the use of existing material flow data (which are known because of economic controlling processes o rare created as their by-product) and enables an internal benchmarking of product or process design in the course of time.
Based on the science research process the approach "screening" is selected for the problem-solving process. In this context, screening is understood as an analysis of current-state characteristics that is regularly repeated (Schusser, 2018, p. 189). Key requirement is the manageability for users within SMEs. Existing knowledge concerning the consumption of values in processes are just as suitable for the start of the screening like existing information on similar products or processes (compared to the planned ones). Those can be generated from historic data of previous orders and design processes. Merely the access to existing data must be ensured. This will reduce the time investment at the beginning of the method-application and reduces the needed know-how of the user.
Which data sources are needed in this context, and where can they be found? It is assumed that manufacturing companies operate a *production planning and control system*. Here, order data are collected over time and with different levels of detail, e.g., machine utilization, processing of different lot sizes, processing times etc. In the context of this screening approach these data are considered as experience values (Rager, 2008, S. 5). Additionally to production planning and control systems, *data of customer orders* provide information, e.g. on requirements and demanded characteristics in case of contract manufacturing, or bills of materials for production that often state further information like the volume of gaseous and liquid materials or the weight of solid materials. The *article master or stock list* provides material information across all customer orders or the product portfolio. It is assembled in the production planning and control system. Further important information can be generated from *bills*. E.g., waste disposers record the weight of waste categories on their

bills, suppliers sometimes give weight data on packaging volumes, and energy suppliers are required to inform about the energy uses of their customers.
Other sources for data stem from feedbacks of the manufacturing site at different points of the value adding process. Among these are down times, the volume of auxiliary materials or information on waste. Additionally, measurement, calculation, and research of comparative values from supplies supports data acquisition. E.g., the supply of material safety data sheets for chemicals is mandatory for suppliers and gives information on hazardous substances. The same is true for producers of electronic components based on the European directive 2002/95/EG Restriction of (the use of certain) Hazardous Substances in electrical and electronic Equipment" according to which the existence and limitation of specified hazardous substances must be declared.
The key objective of the eco²-screening method shall be the limitation of effort for the data acquisition and assembly, to ensure the manageability for SMEs with regards to human resources and time capacities. Commissioning of experts (e.g., for CE marking), the conduction of additional tests, and further measurements are not supposed to be needed. The required data were consciously selected to affect both economic and ecological objectives. This shall enable the identification of win-win-potentials both to economic and ecological efficiency, e.g., the reduction of wastage by corresponding optimization of resource use. The scope of assessment using the eco²-screening shall be defined as gate-to-gate, thus providing the easiest entry to ecological assessment, and supporting the sensitization for the topic of eco-innovation. The screening strategy shall follow the main principle that subsequent systems (products, processes) shall be optimized in all characteristics as compared to the previously analyzed systems. The eco²-screening method is used as an introduction to environmental assessment and does not claim an extensive assessment of all potentially relevant environmental aspects. It is to be understood as an additional assessment and does not include analysis of compliance to threshold values or critical values required by national or European legislation. E.g., electromagnetic fields related to hazard/pollution is not considered, as the EMC testing is one of the regulatory requirements and mandatory for the E label.

3.1 Product-Screening

Electronic assemblies can be energy-intensive, waste-intensive, difficult to de-assemble, contain hazardous and/or critical substances, cause intensive transportation, among others (Schusser, 2018, S. 146). As shown in the following figure, screening data are collected during entrepreneurial design processes and then assembled for comparison to historic data of previous products. This will demonstrate wastage and quantification of optimization potentials. If there are no similar products in the company history and the product is completely new, then the screening will provide the first data for subsequent modifications.

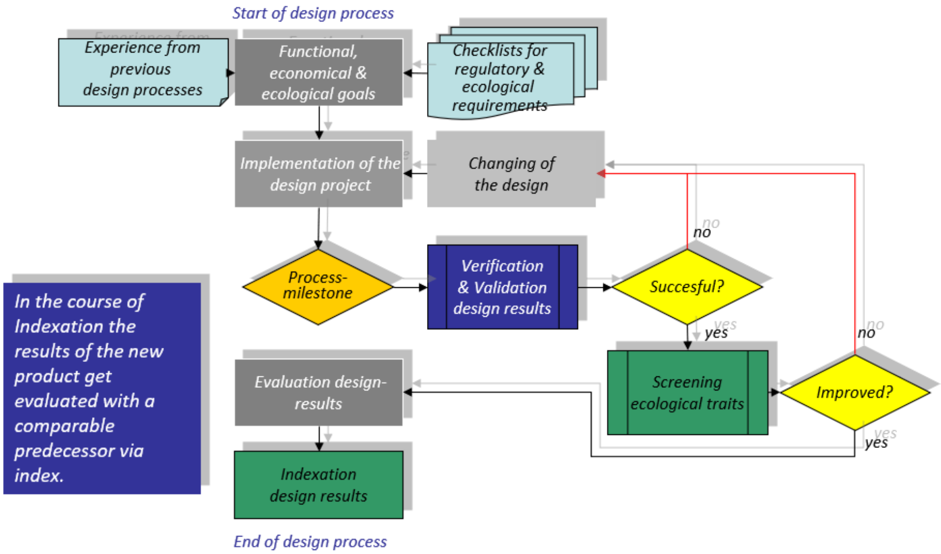

Fig. 1: screening procedure for product design

The following screening indicators are proposed for the product Screening:

Table 1: screening indicators product design

indicator meaning	**calculation**	**Ideal value**
Hazardous substance use volume of hazardous substances per product unit/process	$I_{HS} = \frac{weight\ of\ hazardous\ substances\ [g]}{total\ weight\ [g]}$	(→0)
Energy use in processes: energy use during the value adding process or energy use of the product unit	$I_{EU} = \frac{\sum_n energy\ uses\ [Wh]}{total\ weight\ [g]}$	(→0)
Material use Material use during the value adding process per product unit	$I_{MU} = \frac{\sum_n single\ components\ [pcs]}{total\ weight\ [g]}$	(→0)
Repeat parts number of components that are repeatedly used in the product or other existing products	$I_{RP} = \frac{\sum_n repeat\ components\ [pcs]}{\sum_n single\ components\ [pcs]}$	(→1)
Recycle ability Share of materials that can be recycled after use phase of the product	$I_R = \frac{\sum_n recyclable\ components\ [pcs]}{\sum_n single\ components\ [pcs]}$	(→1)
Durability lifetime of the product	$I_D = \frac{life\ time\ [a]}{planned\ life\ time, e.g., 12\ [a]}$	(→1)
Waste related to useful material share of waste per product unit	$I_W = \frac{\sum_n weight\ of\ waste\ [g]}{total\ weight\ [g]}$	(→0)
Packaging related to product share of packaging weight per product unit	$I_P = \frac{\sum_n weight\ of\ packaging\ material\ [g]}{total\ weight\ [g]}$	(→0)

The designed indicators are characterized by simplicity and immediate availability during the design process. Their calculated value is the basis for improvement. They were specifically designed to consider the specific characteristics of electronic assemblies. The needed data for the characterization of the product under consideration are already collected for the determination of the product price and the configuration of the bill of materials for production processes. Furthermore, they are included in default designs and are sometimes used for the generation of compliance declarations to customer-, functions-, and security requirements. The table shows an ideal value for each indicator to demonstrate optimization potential.

The indicator "hazardous substances" focusses on materials with potential hazardous effects in the production and use phase and may cause severe problems for the disposal at the end of a product life cycle. For hazardous substances that account for more than 0.1 weight percent of the total weight of the product declaration is mandatory for enterprises from 05.01.2021 on, according to the SCIP-directive. The indicator "durability" is exclusively designed to focus the use phase and supports the prevention of early disposal and thus additional purchases and increased need for natural resources. The indicator "material use" may influence the resource use, but also demonstrates implications for repair and recycling strategies. The indicators "energy use" and "repeat parts" are relevant to climate protection policies. Energy use will determine scope 2 emissions according to climate assessment (see section 2); repeat parts influence distribution processes, that is transportation and storage.

By adding the single indicators (or their reciprocals, depending on the determined ideal value) the total assessment indicator. In practice, the user may decide to determine specific statutory thresholds or objectives for singular indicators or the total index (e.g., based on experiences from past designs). Users can also decide to rate different indicators higher than others (e.g., due to customer demands or legal requirements). In the illustrated formula such a rating was not conducted. I_T is calculated:

$$I_T = I_{HS} + I_{EU} + I_{MU} + \frac{1}{I_{RP}} + \frac{1}{I_R} + I_W + I_P + \frac{1}{I_D}$$

3.2 Process-Screening

Similar to the product screening, the process screening supports the identification of optimization potentials in entrepreneurial processes and technologies. Processes are potentially energy intensive, maintenance intensive, waste intensive, require hazardous substances or big amounts of auxiliary materials, and may require reworking procedures (Schusser, 2018, p. 151-152). Just like the product screening the process screening supports the collection of consumption data in all value adding processes. This is considered the basic precondition for incremental and radical eco-innovations. The following indicators are proposed for process screening:

Table 2: screening indicators process design

indicator meaning	**calculation**	**Ideal value**
production time the production time of the product related to the production time of the previous product	$IP_{PT} = \frac{t_{new}[min]}{t_{previous}[min]}$	$(\rightarrow 0)$

indicator meaning	**calculation**	**Ideal value**
Auxiliary process time Share of auxiliary process time related to production time of the product or process	$IP_{AT} = \frac{\sum_n all\ t_{auxiliary\ process\ time}[min]}{t_{production\ time}[min]}$	(→ 0)
Down time Share of down time related to production time of the product or process	$IP_{DT} = \frac{\sum_n t_{down\ time}[min]}{t_{production\ time}[min]}$	(→ 0)
Rework time Share of rework time related to production time of the product or process	$IP_{RT} = \frac{\sum_n t_{rework\ time}[min]}{t_{production\ time}[min]}$	(→ 0)
Hazardous substances use Volume of hazardous substances in auxiliary materials per product unit or process	$IP_{HS} = \frac{\sum_n weight_{hazarous\ substance}^{auxiliary\ material}[g]}{weight_{total}[g]}$	(→ 0)
Auxiliary material use Volume of auxiliary materials in the value adding process per product unit	$IP_{AM} = \frac{\sum_n weight_{auxiliary\ materials}[g]}{weight_{total}[g]}$	(→ 0)

These indicators also refer directly to parameters known in the enterprise and used in other contexts. The data stem from production process control systems (production time, auxiliary time, down time indicators), distribution control systems that generate the information as part of direct costs and overhead costs to the product (auxiliary material use indicator), and post calculations for unplanned additional services (rework time indicator). For optimal efficiency, the ideal value of each indicator is determined as {0}; the calculated values constitute the basis for improvement.

Short throughput time, capacity utilization, and lot size optimization are also measurands of strategies like lean production or just-in-time concepts. Here, the time-related indicators support the prevention of several resource wastages: especially "down time" and "rework time" are undesired uses of resources without added value creation. The indicator "auxiliary material use" refers to process-related needs for natural resources and may indicate optimization potentials, analogous to the material use indicator in the product screening procedure. According to Vahrenkamp and Siepermann ecological production management must be positioned in terms of emissions protection (Vahrenkamp & Siepermann, 2008, p. 61). Therefore, the indicator "hazard substance use" was added to enable monitoring of auxiliary materials in processes, like lubricants, cleaning agents etc.

IP_T equals the overall assessment indicator for processes and ideally approaches the value {0}. The rating of single indicators is possible here, too. In the following formula, rating is illustrated for the "rework" indicator and the "down time" indicator to emphasize their particular importance for optimization.

$$IP_T = IP_{PT} + IP_{AT} + (2 * IP_{RT}) + (1{,}5 * IP_{DT}) + IP_{HS} + IP_{AM}$$

Differences to the product design process are content-related procedures and influence factors, leading to a higher rate of re-designs (incremental innovations. Constitutive for this is the fact that the processing of lots should be accompanied by a flexible post calculation. Such a procedure demands constant evaluation of failures and definition of plans of action. Cost pressure will lead to higher process efficiency incentives in this context. Furthermore, modification of process parameters is often possible without customer approval. Compared to product innovations (incremental or radical), process changes are less costly and easier to be implemented.

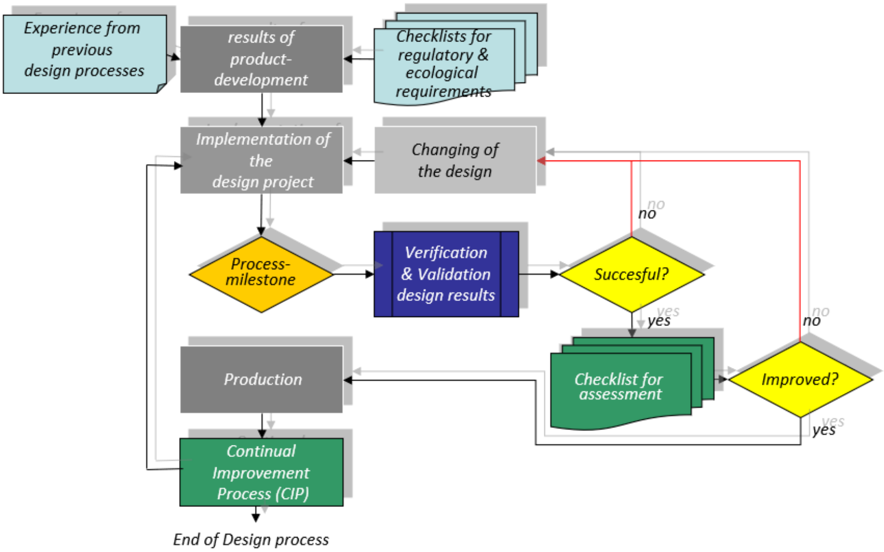

Fig. 2: screening procedure for process design

4. Discussion Based on a Case Study

The eco²-screening method follows the design research process and provides an applicable approach for ecological gate-to-gate assessment in the EMS-sector. Its objective is the introduction to analyses of physical energy and material flows for the identification of optimization potentials, thus potentially initializing innovation processes at product and process level. The proposed single indicators refer to several environmental aspects and environmental impact categories and can be characterized as immediate and commonly known, which supports data availability. The method will be applied in a case study of an audio interface card that is mainly used in hardware utilized in recording studios. This equipped circuit board has connectors on the front side and a protective metal housing. The following data basis was identified:

Table 3: data basis of the case study

Product		**Process**	
Total weight	871,23 g	Total weight	871,23 g
Total energy consumption	489,04 Wh	Total Production time	37,3 min
Sum of all parts	72 pcs	Down Time	0,6 min
Sum of repeat parts	37 pcs	Rework time	3,3 min
Sum of recyclable parts	15 pcs	Auxiliary process time	0,2 min
Weight of packaging	221 g	Production time Predecessor	38,8 min
Weight of waste	14,47 g	Weight auxiliary material	487,5 g
Mass of hazardous substances	536,26 g	Weight hazardous substances in auxiliary material	5,0 g
Durability	5 years		

The data basis consists of information, which are generally assembled in enterprises: Time related data was taken out of production planning and control system. Data on energy use was calculated proportionately based on the energy information from the energy supplier and the time related data (measurement is possible for more detailed data). Packaging weight was collected from the supplier information, while the total weight of the product stemmed from the article master. The weight of hazardous in auxiliary material was collected from material safety data sheets and declarations of suppliers concerning hazardous substances in the product components. Data on waste was calculated as the difference of the weight of delivered goods and weight of the components data (measurement is possible for more detailed data). As a result, the initiative effort for the application of the method was reduced to a minimum.

Table 4: product screening of the case study product

Indicators product design	**case study calculation**
Hazardous substance use (→0)	$I_{HS} = \frac{536{,}26\ g}{871{,}23g} = 0{,}62$
Energy use in processes: (→ 0)	$I_{EU} = \frac{489{,}04\ Wh}{871{,}23\ g} = 0{,}56$
Material use (→ 0)	$I_{MU} = \frac{72\ pcs}{871{,}23\ g} = 0{,}08$
Repeat parts (→ 1)	$I_{RP} = \frac{37\ pcs}{72\ pcs} = 0{,}51$
Recycle ability (→ 1)	$I_{R} = \frac{15\ pcs}{72\ pcs} = 0{,}21$
Durability (→ 1)	$I_{D} = \frac{5}{12} = 0{,}42$
Waste related to useful material (→ 0)	$I_{W} = \frac{14{,}47\ g}{871{,}23\ g} = 0{,}02$
Packaging related to product (→ 0)	$I_{P} = \frac{221\ g}{871{,}23\ g} = 0{,}25$

$$I_T = 0{,}62 + 0{,}56 + 0{,}08 + \frac{1}{0{,}51} + \frac{1}{0{,}21} + 0{,}02 + 0{,}25 + \frac{1}{0{,}42} = 10{,}63$$

Calculating the in chapter 3.1 proposed indicators it points especially to three indicators that disclose optimization potential: Hazardous substance use, energy use and recycle ability. While the repeat parts indicator is too high theoretically, it can´t be achieved better in practice. Altogether, improvement of the total index is possible and may call for design changes.

Table 5: process screening of the case study

Indicator process design	**calculation**
production time (→ 0)	$IP_{PT} = \frac{37{,}3\ min}{38{,}8\ min} = 0{,}961$
Auxiliary process time (→ 0)	$IP_{AT} = \frac{0{,}2\ min}{37{,}3\ min} = 0{,}005$
Down time (→ 0)	$IP_{DT} = \frac{0{,}6\ min}{37{,}3\ min} = 0{,}016$

Indicator process design	calculation
Rework time (→ 0)	$IP_{RT} = \frac{3{,}3\ min}{37{,}3\ min} = 0{,}088$
Hazardous substances use (→ 0)	$IP_{HS} = \frac{5{,}0\ g}{871{,}23\ g} = 0{,}005$
Auxiliary material use (→ 0)	$IP_{AM} = \frac{487{,}5\ g}{871{,}23\ g} = 0{,}560$

$$IP_T = 0{,}961 + 0{,}005 + 2 * 0{,}88 + 1{,}5 * 0{,}016 + 0{,}05 + 0{,}560 = 1{,}731$$

The single indicators show that compared to the previous product the production time, rework time and auxiliary material use are still high. The cause of the latter two needs to be investigated and the process design should be modified accordingly. The resulting production procedure should be screened again.

The screening determined the efficiency aspects within a specified scope of action. It reduced the complexity and interrelations of the used ecological parameters. Of course, a high level of detail cannot be achieved this way. On the other hand, great details are not needed for the identification of potentials. The proposed method will not reach beyond a gate-to-gate scope without increasing the effort of application significantly. A first step into material flow analysis and innovative design based on physical quantities is provided. The eco²-screening method is conceptualized for SMEs. Here, scarce capacities for the implementation of systematic resource efficiency approaches beyond customer demand must be assumed. The screening method answers this challenge with a modular structure: the proposed indicators can be adapted, differently compiled, and rated individually to fit the user's needs. This enables flexible response to missing data as well as integration of different indicators considered as relevant. The method is applicable in highly disrupted supply chains, where users may have little influence or access to certain life cycle phases or production procedures (e.g., because of product ownership). Generally, the composition of the screening can be adapted to fit the needed extent of the assessment and the circumstances of the application.

The developed approach is easily applicable and uses known data in the enterprise, demanding no specified knowledge on ecological assessments. With the small number of proposed parameters, a first efficiency-benchmarking of design processes can be conducted. The principles "repeatability" and "comparability over time" shows similarities to the Kaizen-philosophy of continued change for the better. Thus, optimization can be achieved without comprehensive knowledge and still, because of the repeated application, the method gives an insight into the background of ecological evaluations and may achieve sensitization of the user and inclusive use in entrepreneurial evaluation processes. The data analysis will induce learning effects and gradually demand less time. Tabulation programs, template formulas and checklists should be prepared for the application of the method and include important information, e.g., conversion factors. The indicators, and the underlying mathematical concepts should be revised on a regularly basis. An expansion of the indicators is possible and may address further input- and output flows, like electrical-, gas-, water uses, real time emissions, noise, wastewater, specific waste categories like residues or packaging paper etc.

5. Conclusion

In response to the challenges of continued overshoot of carrying capacities of the ecosphere, enterprises can aim at optimization and increased efficiency via innovations processes at product and process level. An approach was proposed for the introduction to an environmental assessment and initiation of innovation processes in SMEs, which lack adequate capacities to identify such potentials. As seen in the case study the method shows which indicators and thus corresponding environmental aspects need to be improved. Improvement is possible without intensive investment of financial, time and human resources nature, thus minding the statement of Jalo et al., who claim relating to scarce capacities in SMEs. Based on the design science research process an eco²-screening method was developed for the monitoring of products and processes in the EMS-sector. It allows for the monitoring of economic and ecological design processes without demanding an extensive life cycle assessment or additional information from suppliers even though referring to a similar range of environmental aspects as opposed in shortened methods like MIPS or CED. The method supports the influencing of products and processes already during the development phase, where materials, hazardous substances and energy aspects are determined. Contrary to other approaches, the eco²-screening method remains at the gate-to-gate perspective, thus increasing applicability and decreasing effort for application. Following the critique of Peffers et al. that majority of methods published in the best journals lacking applicability in practice, this method follows the design science approach with the set of indicators for immediate application in the EMS sector. The proposed indicators can be characterized as simple, immediate, and using existing entrepreneurial data. This provides for an introduction to material flow-based assessments of products and processes at industrial level. The overall assessment indicators indicate optimization potentials that may lead to innovation processes. The developed eco²-screening method is flexible and applicable with little effort. It is thus appropriate for users in SMEs in the EMS-sector. Transferability to other sectors needs to be assessed. Another benefit of the screening approach is the repeatability which supports sensitization on the topic of eco-innovations.

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