LIFE CYCLE SUSTAINABILITY ASSESSMENT

Assessing the contribution of products to the United Nations’ Sustainable Development Goals: a methodological proposal

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Abstract

Purpose The 17 Sustainable Development Goals (SDGs) and their 169 targets pose the most important framework for sustainable development worldwide. However, the contributions of products and companies to the SDGs using social and environmental life cycle assessment (S-LCA; E-LCA) have not been thoroughly addressed in the scientific literature. The purpose of this research is therefore to identify product-related targets, derive suitable indicators and develop a social life cycle impact assessment (S-LCIA) method.

Methods To systematically select product-related targets, two questions are developed. The questions ask whether a product (a) has a direct impact on the achievement of the target or (b) if the companies along the life cycle that produce or offer the product have a direct influence on the achievement of the respective target. Suitable indicators are derived and adapted from generally accepted frameworks such as the Global Indicator Framework (GIF-SDG). To develop an S-LCIA method, the targets are translated into conditions beneficial or damaging to the achievement of the target to estimate the socio-economic impact of the product using a scale from +1 to −1. In cases where the targets remain vague, a systematic five-step approach to derive a quantifiable target involving five steps is applied.

Results and discussion The main contribution of this paper is to propose a coherent method to measure the contribution of products to the targets. All 17 SDGs and 61 of the 169 targets (36%) were evaluated as product-related. For 57% of the product-related targets, indicators from the GIF-SDGs could at least partly be used after slight adaptations, while for the remaining 43% of the product-related targets, indicators were taken from other frameworks or sources or had to be added. In total, 45 indicators have been identified to be suitable for assessing the potential contribution of products to the 61 targets. To illustrate the systematic five-step approach to quantitatively assess the contribution of products to the targets, five types of contribution functions are presented in detail.

Conclusions The presented method allows companies to analyse their impact and that of their products on the targets both within their own company and in the supply chain. As especially the latter is increasingly demanded by supply chain laws in different countries such as France, the Netherlands or the UK, the method fills an important research gap. However, future research to examine the proposed approach, the derived indicators and the impact assessment method is strongly encouraged.

Keywords 2030 agenda of the United Nations · Life cycle sustainability assessment · Social impact assessment · Social performance measurement · Sustainability accounting · Supply chain management · Corporate sustainability · Corporate social responsibility

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1 Introduction

The United Nations (UN) has adopted sustainable development as the global guiding principle for the world in 1992 in Rio de Janeiro (UNCED 1992). Sustainable development has been defined as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNWCED 1987). Since then, most nations have adopted sustainable development as
a guiding principle of their policies. However, implementation was and still is difficult (Drexhage and Murphy 2010). In September 2015, the United Nations (UN) adopted the Sustainable Development Goals (SDGs): 17 goals with 169 targets to be achieved by 2030 (United Nations 2015a), which followed the Millennium Development Goals (United Nations 2015b). With the Agenda 2030 and its 17 SDGs, a paradigm shift was realised: from goals for developing countries to sustainable development goals for all nations worldwide. This is considered a milestone as all 193 UN member states have agreed for the first time in history on a set of goals for sustainable development which serve as a basis for their policies.

Even though the SDGs have not been directly formulated for companies and their products, they can contribute to achieving these goals. Ban Ki-Moon, former General Secretary of the United Nations, explicitly invited companies to support the achievement of the SDGs: “Business is a vital partner in achieving the Sustainable Development Goals. Companies can contribute through their core activities, and we ask companies everywhere to assess their impact, set ambitious goals, and communicate transparently about the results” (GRI et al. 2015, p. 4). Indeed, reports from professional service organisations indicate that businesses are taking a vital interest in how they can contribute to the SDGs (e.g. Association of Chartered Certified Accountants 2017; KPMG 2018; PwC 2015).

For companies, however, it is difficult to assess which of the 169 targets they can and should contribute to and which they have hardly any influence on. Additionally, methods to systematically measure the contribution of companies and their products are still scarce. A report from PwC found that businesses tend to either greenwash (also called SDG-washed) or “cherry-pick the SDGs they want to focus on and ignore others that don’t meet their corporate priorities or comfort zones” (PwC 2015, p. 12). To prevent cherry-picking and facilitate the adoption of SDGs, academia must develop methods to help companies to identify relevant SDGs and to find ways to measure their contribution or the contribution of their products and services (henceforth referred to only as products for ease of reading).

While the UN has supplemented a Global Indicator Framework for the Sustainable Development Goals (GIF-SDGs) that measures the respective targets using 231 indicators, these are mostly at the policy or state (macro) level (United Nations 2021). Vermeulen (2018) found that only about a quarter (25%) of the 169 targets were formulated in terms of endpoint impacts, e.g. on the natural environment or human health as well as planetary or social well-being. By contrast, most targets (54%) are formulated plans, projects or regulations for policy outputs or policymaking. A method for measuring the progress of individual countries in achieving the SDGs has been proposed by the Sustainable Development Solutions Network and the Bertelsmann Stiftung and updated various times (Sachs et al. 2021). This method has also been adapted by the OECD (2019) and uses a four-step approach to measuring the SDGs and uses reference values from other international agreements (e.g. reduce PM2.5 pollution to less than 10 µg/m², according to the WHO) as a second step. Additionally, Lisowski et al. (2020) proposed a structured procedure for selecting relevant environmental GIF-SDGs but not focussed further on the SDGs itself or on impact assessment. Hence, the role of businesses and other actors with regard to their contribution to the SDGs has been largely neglected in the literature (Herrera Almanza and Corona 2020; Spangenberg 2016).

A common method to measure the environmental, social and economic performance of a product is the life cycle sustainability assessment (LCSA) (UNEP/SETAC 2011; Chhipi-Shrestha et al. 2014). LCSA is “the evaluation of all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle” (UNEP/SETAC 2011, p. 3). It consists of three components: environmental life cycle assessment (ELCA), life cycle costing (LCC) and social life cycle assessment (SLCA) (Klöpffer 2003; UNEP/SETAC 2011). While E-LCA and LCC are quite established in the scientific literature as well as in corporate practice (Finkbeiner et al. 2006; Finnveden et al. 2009), S-LCA is at an earlier stage of development (Benölt et al. 2010; Jorgensen et al. 2008; Kühnen and Hahn 2017). That S-LCA is still less developed, both in general and specifically regarding the SDGs, can be attributed to the relative novelty of both S-LCA and the SDGs, but also to the complexity of social systems and the difficulty of translating qualitative data into quantitative assessment (Corona et al. 2017; Herrera Almanza and Corona 2020; Kühnen and Hahn 2017). This is also reflected in the fact that the S-LCA method has not yet been standardised by the International Organization for Standardization (ISO) as is the case with E-LCA (ISO 14044/44). S-LCA has only been described in guidelines by the United Nations Environmental Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) which leaves plenty of space for interpretation and further research (Benölt et al. 2010; UNEP 2020, UNEP/SETAC 2009). However, recently the further developed S-LCA guidelines have been published (UNEP 2020), and research on S-LCA is ongoing.

The following research will focus on developing a social life cycle impact assessment method (S-LCIA) method to assess the contribution of products to the targets. Indicators for E-LCA are, however, also proposed for comprehensiveness. LCC is beyond the scope of this paper but should be considered in future research.

An issue of S-LCA is the current lack of standardised indicators that relate to social performance (Kühnen and Hahn 2017; Traverso et al. 2012). Kühnen and Hahn (2017)
argue that the selection of indicators is currently mostly done based on common sense or based on previous studies as there are few existing frameworks or standardised sets of indicators that researchers and practitioners could rely on. A plausible method to select indicators can be to follow political decision processes. Wulf et al. (2018) therefore propose to use the targets to derive indicators for S-LCA. The UNEP Guidelines for S-LCA (2020) state that the SDGs underscore the importance of assessing social impacts of products and also give a list of the most prominent impact categories to assess the 17 SDGs. However, a detailed description of these and a method to assess the impact of products on the SDGs is still missing. Therefore, the paper will derive suitable indicators that allow measuring the respective target and is applicable to products.

Furthermore, there seems to be a high interest of companies to link LCSA to the SDGs, but robust and scientifically grounded approaches to assess a product’s impact on the SDGs are scarce (Weidema et al. 2018). Herrera Almanza and Corona (2020) conducted a study in the textile sector and related various S-LCA indicators to several SDGs. Thereby, the authors give an indication of which goals and targets are mostly affected by the product’s social supply chain but this method does not allow to measure the impacts of a certain product on the SDGs. The authors call for more S-LCA research that uses SDG-adjusted indicators that measure the scope of business activities to the current degree of global SDG accomplishment (Herrera Almanza and Corona 2020). Wulf et al. (2018) related various indicators provided by the Product Social Impact Life Cycle Assessment (PSILCA) database combined with indicators from E-LCA and LCC to the SDGs and found that several of the SDGs cannot be matched with existing indicators and that it remains difficult to relate the macro-level of the SDGs to the micro-level of product assessments. The latter finding is also supported by Vermeulen (2018), who proposed an integrated LCSA framework aligned to the SDGs. Hence, a comprehensive S-LCA method to consistently and effectively assess a product’s social contribution to the SDGs is missing and further research is much needed.

Against this background, the aims of this paper are threefold:

i. To develop an approach to identify targets which are related to products.
ii. To derive suitable indicators from existing frameworks.
iii. To develop an S-LCIA method based on the targets.

The paper is structured as follows: First, Sect. 2 contains the approach to derive the product-related targets, the corresponding indicators and the approach to developing an S-LCIA method. Second, the product-related targets and the corresponding indicators are given in Sect. 3. Additionally, the S-LCIA is described for the identified indicators. Third, the findings of the research in relation to the existing literature, its contribution and shortcomings are discussed. Last, the article is concluded by discussing its use in corporate practice and suggesting avenues for further research (Sect. 4).

2 Methods

The approach used consists of four steps and is described in the following Sects.: (2.1) the selection of product-related targets, (2.2) the identification of suitable indicators, (2.3) the development of an S-LCIA approach and (2.4) a first validation of the approach with stakeholders.

2.1 Selecting product-related targets

As stated in Sect. 1, the 17 SDGs were not primarily formulated for companies and for assessing the sustainability of products. Therefore, the product-related targets have to be identified first. This is done at the level of the 169 targets, which concretise the 17 SDGs (United Nations 2015a).

To systematically identify product-related targets in a replicable way, it was identified to which target or specific target components a product can make a potential contribution to achieve the respective target or target components. For that purpose, two questions were defined:

1. Case 1 (C1): Does the product have a direct impact on the achievement of the respective target along its life cycle and on which components of the target? This question aims to determine whether a contribution to the achievement of the target (positive or negative) or a part of it can be made directly through the potential impacts caused by the product itself. Impacts caused by the product itself can occur through emissions, e.g. emissions to air, water or soil, or the use of resources, e.g. primary energy resources, water, land, minerals or metals.

2. Case 2 (C2): Do the companies along the life cycle that produce or offer the product have a direct influence on the achievement of the respective target through their activities and on which components of the target? This question aims to identify whether a contribution to the achievement of the target (positive or negative) or a part of the target can be made by business activities of each single company involved along the value chain of the concerned product. This considers that the social performance of products is determined mainly by the organisational behaviour and the operations of the businesses involved. Business activities are all those in which the company itself acts directly. Examples include the level of wages paid, the
implementation of corruption avoidance practices or the coverage of social security support. On the other hand, potential indirect effects through business activities are not considered, for example when workers invest in their children’s education with their wages.

These cases are analysed for each of the 169 targets to find a possible product relation. To illustrate this process, some examples are described in Box 1.

**BOX 1: Selecting product-related targets**

Target 2b aims to “Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round” (UN 2015b). Neither the material flow (C1) nor the activities of companies involved in the production of products or provision of services (C2) can be directly linked to the aims of target 2b or parts of it. Therefore, it is not considered relevant to assess the contribution of products to this target.

By contrast, target 8.5 aims to “By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value” (UN 2015b). In the view of the involved experts and stakeholders (see chapter 2.4), the activities of the companies involved in the production of the product (C2) can be linked to the aim of providing “decent work for all” as well as achieving “equal pay for work of equal value”. However, the achievement of “full […] employment […] for all” is seen as a responsibility of governments but not as a responsibility of products, services or the providing company behind it. Obviously, companies are a key actor involved in providing jobs. However, one single company cannot achieve full employment on a society level, and the number of jobs that a company has to provide to contribute to full employment is hardly logically derivable. Instead, it is the responsibility of politics to ensure that the framework conditions are designed in such a way that companies can provide sufficient jobs for all. In contrast, a company is fully responsible for providing decent jobs. In the opinion of the involved experts and stakeholders, companies can therefore contribute to “decent work for all” as well as achieving “equal pay for work of equal value” but not “full […] employment […] for all”.

In the study, the targets are examined exhaustively for foods as food systems play a central role in the implementation of the SDGs. However, further branches, e.g. cosmetic and hygiene products, mobility and information technologies have also been discussed within a stakeholder workshop (see Sect. 2.4), but the elaborations here refer to food only. This focus resulted for example in some quite food-specific indicators like the coverage of sustainable agriculture, biodiversity, food losses and investments in conservation and sustainable use of biodiversity and ecosystems in the sustainability risk management.

## 2.2 Identifying suitable indicators

After identifying the product-related targets and the parts of targets to which products can contribute, suitable indicators are derived. An indicator is defined as suitable if it allows measuring the respective target and is applicable to products. To be compatible, the indicators are primarily drawn from generally accepted frameworks. As the SDGs are the reference point of this approach, the indicators of the GIF-SDG were analysed first (United Nations 2021). The GIF-SDG proposes indicators for measuring the targets, but these mostly aim to measure the contributions at the policy or state level. As this method aims to measure the contributions at the product level and not the policy or state level, the indicators identified as suitable had to be adapted in many cases. Indicators were adapted if the scope was outside the level of companies and products with the aim to narrow their scope. For instance, indicator 1.1.1 of the GIF-SDG measures the “proportion of the population living below the international poverty line”. As it is deemed suitable to measure the target 1.1 “By 2030, eradicate extreme poverty for all people everywhere […],” it is selected as an indicator within this method. However, since a company can only contribute to improving the situation of workers involved in the production of the product as well as of other employees such as procurement, research and development (R&D) or sales but not all people everywhere, the indicator has been adapted to measure this contribution. It now measures “workers/employees earning below UN poverty line of $1.90 per day”.

The GIF-SDG indicators were supplemented by the indicators proposed within the framework of the European Commission’s Environmental Footprint (EF) process (EC-JRC 2017; EC 2018). This was necessary as especially the indicators addressing ecological and health-related issues focus on the policy or state level and many could not be used to measure the contribution of products. The indicators of the EF process on the other hand focus on products and services and address ecological and health-related issues. Therefore, the indicators of the EF process are more suitable for this analysis. This framework was chosen because it is – as the GIF-SDG – a supranational indicator framework agreed upon in a stakeholder dialogue of several years and validated in pilot studies. Furthermore, the indicators are particularly designed for the impact assessment of products and thus, do not need adaptation. As EF indicators have been used, when it was not possible to adapt the GIF-SDG to products, the content of the target has been used for the matching of EF indicators to targets. For instance, for SDG 3.9 “[…] substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination”, it was looked for EF indicators measuring health impacts with respect to hazardous chemicals used along a product’s life cycle. This was identified to be the case for the two EF indicators “Comparative Toxic Unit for Human Health (Human toxicity): cancer and non-cancer”. Furthermore, it was looked for EF indicators measuring potential negative impacts on health due to air, water and soil pollution and contamination. These effects can be modelled by the EF indicators “Photochemical ozone creation
potential”, “Disease incidences (Particulate matter)” and “Comparative Toxic Unit for ecosystems (Ecotoxicity)”. The same procedure was followed for the other targets. If no suitable indicator could be found in generally accepted frameworks, indicators were taken from other sources or were developed specially to measure the contribution the respective target.

Thereafter, indicators have been differentiated in inventory indicators, defined as “indicators assessed at the inventory level by aggregating inventory flows” (Arvidsson 2021, p. 1), and impact indicators, defined as “quantifiable representation of an impact category” (ISO 14040:2006, p. 13). Next, indicators have been assigned to E-LCA and S-LCA impact categories. E-LCA impact categories such as land use, biodiversity, eutrophication, human toxicity, photochemical ozone formation, particulate matter, ecotoxicity, water scarcity, resource depletion, climate change, ionising radiation and acidification have been taken from the framework of the European Commission’s EF process (EC-JRC 2017; EC 2018). In S-LCA, there is an agreement on six impact categories, human rights, working conditions, health and safety, cultural heritage, governance and socio-economic repercussions, and 31 sub-categories (UNEP 2020).

2.3 Social life cycle impact assessment

The social life cycle impact assessment (S-LCIA) aims at calculating and evaluating social impacts throughout the life cycle of the product (UNEP 2020). This includes all steps of the value chain and can be related to all countries and regions, depending on the scope of the analysis. As this method presented here aims to assess the impact of products on the targets, it aims to assess performance and not risks. As defined by the S-LCA guidelines, risks address a potentially adverse impact on stakeholders based on probabilities. Performance, on the other hand, refers to concrete outcomes of businesses on relevant stakeholders (UNEP 2020). As the S-LCA guidelines note that S-LCIA “mainly focuses on evaluating potential social impacts – not social impacts per se” (UNEP 2020, p. 80), the method proposed here aims to enable its users to assess the potential impact based on specific performance of the products on the achievement of the targets. It uses primary specific data collected directly from the supplying companies.

To assess the contribution to the targets, the methodological approach developed by Lindner (2016) for the impact assessment of biodiversity is adapted to S-LCIA. This has already been started by Kühnen et al. (2019) for the assessment of positive sustainability impacts of products and has been developed further in this study. The approach permits both quantitative and qualitative knowledge to be transformed into a numerical representation (Lindner 2016; Lindner et al. 2021). The method proposed by Lindner (2016) is used in biodiversity impact assessment (Lindner et al. 2019a, b, 2021) and uses fuzzy modelling, an approach that is used in a wide range of scientific fields, e.g. risk assessment (Singh et al. 2013).

2.4 Reference point approach

For the impact assessment, the performance reference point approach (Chipi-Shrestha et al. 2014; UNEP 2020) with the targets as references is used. This is coherent with the six main types of performance reference points for reference scales used in the UNEP Guidelines (2020), where the qualitative and quantitative reference can be based on specific norms, practices and best practices. At the same time, reference is made to a comparison with the sector average, which is also anchored in the UNEP Guidelines (2020).

Since the targets do not always specify a quantitative or quantifiable reference value, a systematic approach is chosen to derive a quantifiable reference value. The systematic approach consists of five steps to derive a reference value from the targets for the impact assessment. The first four steps are taken from the sustainable development report of the Sustainable Development Solutions Network (SDSN) and the Bertelsmann Stiftung (Sachs et al. 2021, p. 70). The report is the first worldwide study to assess where each country stands with regard to achieving the SDGs and has been published annually since 2015. The methodology described in the report of Sachs et al. (2021) has been developed and refined in several rounds of expert consultations and has been also used in prior scientific literature on SDG assessment (Sciarrà et al. 2021). Therefore, the chosen approach was deemed a convincing yardstick for deriving target-based reference values for the S-LCIA. As some aspects mentioned in the targets remain very difficult to quantify, a fifth step with a semi-quantitative assessment was added.

The following steps were used to derive reference values from the targets:

1. The priority is always to use absolute quantitative thresholds given to the target itself. This is the case, for example, with target 1.1 (By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.90 a day).

2. In the second priority, the guiding principle of the SDGs “Leave no one behind” is used: This states that all countries, peoples, individuals, etc. must be included in sustainable development and that no one must be left behind (United Nations 2018). This means, for example for target 1.3 (Implement nationally appropriate social protection systems and measures for all.) that all employees along the value chain should benefit from
certain benefits (e.g. social security) and none should be excluded.

3. The third priority is to use science-based targets to quantify the reference value to assess the impact on the target. This is, for example, used for target 2.5 (By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species…) to derive a reference value for the number of used breeds and varieties in agriculture.

4. In the fourth priority, the average of the top five performers is chosen which can be either companies or countries. This is, for example, used for target 9.5 (Enhance scientific research… and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending) to derive a reference value for the share of income spent on research and development.

5. As a last resort, if the definition of a reference value is not possible in the ways described above, the topic in question is included in an indicator on “Sustainability risk management”. The indicator contains how companies take up a specific topic in management and whether (a) goals, (b) measures and (c) responsibilities are defined. This semi-quantitative approach is taken from the Indicator 103–2 “Management Approach” of the Global Reporting Initiative (GRI 2016). This is, for example, used for target 14.1 (By 2025, prevent and significantly reduce marine pollution of all kinds…) to protect marine ecosystems since a quantitative assessment was not (yet) possible. Even though this step does not use quantitative data, it still assesses the actual performance of the company and not generic risk, e.g. based on a database.

2.5 Defining S-LCIA functions

The definition of the S-LCIA functions is based on the approach proposed by Lindner et al. (2021) for biodiversity impact assessment. According to this approach, first, measurable input parameters for the defined indicators and reference points are identified and, second, a contribution function is defined. The contribution function allows to quantify the contribution \( y \) of a parameter \( x \) to achieving the target for the defined indicators. To define each contribution function consistently, the following steps were taken. First, the contribution interval was set to be between +1 and −1, following the approach by Kühnen et al. (2019). +1 means that the product fully contributes to the achievement of the target and −1 means that the product has a negative impact on the achievement of the target. For the sustainability risk management (C2.3), the highest possible impact (+1) is achieved when all management measures (goals, measures and responsibilities) are covered. Each individual measure adds 0.33 to the contribution. The lowest impact (0) is assumed when no management measures are covered.

Next, the relationship between the parameter and its contribution is defined following the approach proposed by Lindner et al. (2021). The type of curve, describing the relationship, is based on expert knowledge and is furthermore discussed within an expert workshop (see Sect. 2.3). There are Gaussian and linear functions which determine the shape of the curve. The Gaussian functions have six constants\(^1\) \( \alpha, \sigma, \beta, \gamma, \delta \) and \( \epsilon \) which determine the shape of the curve. Once the curve type is defined, it is discussed with experts how the relationship is shaped. This is mapped accordingly via the six constants. The other type is a simple linear curve. To identify which type fits the contribution of a given parameter, three questions have to be discussed with experts, in order to be able to define the S-LCIA-functions (Lindner et al. 2021):

- First, the start and the end of the function are defined. This is done by discussing the relationship between the parameter \( x \) and the reference point. The related questions are as follows: Does more of the parameter lead to a higher contribution to achieving the target? Or is a lower proportion of the parameter a higher contribution to achieving the target? Where should “−1” or “+1” be set?
- Second, the overall shape of the curve is defined. This is achieved by discussing whether (a) the contribution to achieving the target is always higher (or lower) when more (or less) of the parameter is present, or (b) if it peaks and then drops again, or (c) if it reaches a plateau at some point, or (d) if there is a bend in the curve.
- Third, the curve is further refined by discussing for instance where exactly the plateau starts, how steep the slope/rise of the curve is to best refer to the targets’ reference point or at what point a positive contribution to the target could be expected.

For example for C2.1, first, the start and the end of the function were defined. The target 1.1 aims to “eradicate extreme poverty for all people everywhere” and defines that no one should earn less than the current UN poverty line of $1.90. Thus, it was first discussed with experts whether the target is achieved if more or fewer workers/employees earn below the UN poverty line and where “−1” should be set. The answer was that the fewer workers/employees

\(^1\) Constants of the Gaussian function: \( \alpha \) fixes the width of the plateau without affecting the width of the entire bell; \( \sigma \) determines the width of the bell, but not the plateau; \( \beta \) and \( \gamma \) shift the entire curve in either the \( x \)- or \( y \)-direction; \( \delta \) and \( \epsilon \) shift the top of the of the bell either in the \( x \)- or in the \( y \)-direction (Lindner et al. 2021; p. 3).
earn below the UN poverty line, the higher the contribution to the target. This means that the curve must run from the lower left to the upper right. It was defined together with the experts that the target is not achieved at all if no worker/employee earns above the UN poverty line. Thus, “−1” was set at 0% of workers/employees earning above the UN poverty line. Accordingly, the target is met when there are no workers/employees earning below the current UN poverty line and “+1” was set there. Second, the shape of the curve was discussed with experts. The result of the discussion for indicator C2.1 was that every single worker/employee who earns above the UN poverty line contributes to reaching the target and that the curve is therefore linear. Third, to refine the curve, it was discussed at what point a positive contribution to the target could be expected. The result of this discussion was that a positive contribution to the achievement of the target can be expected when more of analysed workers/employees earn above the poverty line than the national average. Accordingly, \( y = 0 \) (neither positive nor negative contribution) was set for the national average. Hence, a value above national average is always positive and a value below is always negative.

### 2.6 Validation through stakeholder and expert involvement

Furthermore, a stakeholder workshop with representatives from NGOs, companies, science, funding bodies and administration was held to discuss product-related targets, indicators and first ideas for the contribution functions. For the selection of stakeholders, a stakeholder analysis according to DIN 69901–5:2009: “Stakeholder analysis” was carried out. DIN provides for an “[…] analysis of the project stakeholders with regard to their influence on the project and their attitudes (positive or negative) […]” (DIN 69901–5:2009).

For this purpose, the following questions were asked for the selection of external stakeholders: (i) Which stakeholders are relevant for the project? (ii) What are the stakeholders’ expectations of the project? (iii) Who has an interest in the project goal being achieved? Who has an interest in it not being achieved? (iv) Who can influence the project positively or negatively? This analysis (see supplementary material) resulted in a shortlist of 40 stakeholders, of which 2 were from the funding bodies, 2 from the case study partners, 8 from other companies, including 2 LCA software providers, 6 from NGOs, 4 from administration and 9 scientists. Thirteen of the invited stakeholders participated in the workshop where, after an introduction to the topic, six discussion stations were used to discuss the selection of the product-related targets (1), on the proposal to define core and comprehensive indicators (2), on indicators for food (3), for cosmetics and hygiene products (4), for information technology (5) and for mobility (6) were discussed. There was also the opportunity to make general comments on the method. Participants were free to choose which of the six discussion stations they wanted to give input to. The input was collected and after an hour of discussion at the stations, and the results were discussed with all participants station by station. Common insights were extracted, and open questions were recorded. In addition, the participants also discussed the approach of defining contribution functions. The results of the workshop were used in the final selection of the product-related targets, and in the selection of the indicators which was done by experts.

Moreover, results were used in the ongoing discussion on the definition of the functions. The final discussion of the selection of the targets and indicators was held with a group of experts. Furthermore, the definition of the contribution functions was discussed according to the questions described in Sect. 2.5. This resulted in the defined S-LCIA functions, and their description as given in the supplementary material. In addition, a further expert was subsequently consulted with regard to the contribution functions in order to further validate them.

### 3 Results

In the following sections, the results of the described approach are presented. First, the identified product-related targets are analysed; second, the identified impact categories and indicators are shown; and third, some contribution functions are described in detail.

#### 3.1 Product-related targets

The analysis of the product-related targets based on two defined cases, (C1) whether the products along their life cycle have a direct impact on the achievement of the target and (C2) whether the companies along the life cycle that produce or offer the product have a direct influence on the achievement of the target through their activities (see Sect. 2.1), shows that a reference to products could be identified for 61 of the 169 targets, corresponding to 36% of the targets. This has been analysed especially with regard to food products. Targets belonging to all 17 SDGs were identified. 65.5% of the targets correspond to case C2, 19% to both cases and 15.5% to case C1. The highest fraction of targets with a product relation was found for SDG 6 “Clean Water and Sanitation”, where 6 out of 8 targets (75%) were identified, followed by SDG 15 “Life on Land” with 8 out of 12 (67%) targets. All identified relations to the targets, the used indicators and their assignment to E- and
S-LCA impact categories can be found in the supplementary material.

### 3.2 Suitable product-related indicators to measure the targets

After identifying the product-related targets and the parts of targets to which products can contribute, suitable indicators are derived from the GIF-SDGs, the EF framework, other sources or are added if no suitable indicator was available. The indicators are split into C1 impact indicators (Table 1), C1 inventory indicators (Table 2) and C2 impact indicators (Table 3). The respective impact categories, origin of indicators and targets are given. As the inventory indicators have no impact categories, there are no impact categories mentioned in Table 2.

The identified indicators belong to twelve environmental and six social impact categories (Tables 1 and 3). Regarding the environmental impact categories, not all impact categories proposed by EF are used in this framework (EC-JRC 2017; EC 2018). For example, the targets do not address ozone depletion. Therefore, this impact category does not appear in this study. On the other hand, the targets address the protection of biodiversity on land, in freshwater and in the oceans very prominently. Here, EF recommends assessing the impact on terrestrial biodiversity, but no concrete method has been proposed so far. Aquatic biodiversity is not yet addressed in EF, nor is ocean acidification, the reduction of which is explicitly mentioned in target 14.3. Concerning the social impact categories, all six categories proposed in the S-LCA guidelines (UNEP 2020) are reflected in the targets and all C2-indicators belong to social impact categories.

The first finding is that none of the indicators proposed in the GIF-SDG could be used directly to assess the potential contributions of products to the targets. The reason is that most targets and the corresponding GIF-SDG indicators address the policy level which is in line with the findings when identifying product-related targets. In particular, the targets focussing on ecological and health-related issues were addressed using indicators from the EF process as they focus especially on products. However, for 57% of the product-related targets, indicators from the GIF-SDGs could be used after they were slightly adapted to fit products. This is for example the case for the GIF-SDG indicator “1.1.1 Proportion of population below the international poverty line” which was adapted to “Workers earning below the UN poverty line”. Similarly, indicator 14.3.1 covers the “average marine acidity (pH) measured at agreed suite of representative sampling stations” which was adapted to measure the “marine acidification potential” of products with the E-LCIA method proposed by Bach et al. (2016).

For 43% of the product-related targets, GIF-SDG indicators could not be adapted or modified to fit products. This is for example the case for GIF-SDG 5.1.1 “Whether or not legal frameworks are in place to promote, enforce and monitor equality and non-discrimination based on sex” because legal frameworks do not apply to specific products. Therefore, the indicator C2.10 “Equal wages

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| # | Indicator | Impact category | Origin of indicator | SDG |
|---|-----------|----------------|---------------------|-----|
| C1.1 | Soil quality index | Land use | EF 3.0 | 2.4 |
| C1.2 | Terrestrial biodiversity | Biodiversity | Lindner et al. (2019a) | 2.4, 15.9 |
| C1.3 | Accumulated exceedance | Eutrophication | EF 3.0 | 2.4 |
| C1.4 | Comparative toxic unit for human health: a: Cancer b: Non-cancer | Humantoxicity | EF 3.0 | 3.9, 11.6 |
| C1.5 | Photochemical ozone creation potential | Photochemical ozone formation | EF 3.0 | 3.9, 11.6 |
| C1.6 | Disease incidences | Particulate matter | EF 3.0 | 3.9, 11.6 |
| C1.7 | Comparative toxic unit for ecosystems | Ecotoxicity | EF 3.0 | 3.9, 6.3, 12.4 |
| C1.8 | P-equivalents | Eutrophication | EF 3.0 | 6.3 |
| C1.9 | Scarcity-adjusted water use | Water scarcity | EF 3.0 | 6.4 |
| C1.10 | Abiotic resource depletion: a: Minerals and metals b: Fossils | Resource depletion | EF 3.0 | 8.4, 9.4 |
| C1.11 | Global warming potential | Climate change | EF 3.0 | 9.4, 13.2 |
| C1.12 | Ionising radiation potential | Ionising radiation | EF 3.0 | 12.4 |
| C1.13 | N-equivalents | Eutrophication | EF 3.0 | 14.1 |
| C1.14 | Marine biodiversity | Biodiversity | To be developed | 14.2 |
| C1.15 | Marine acidification potential | Acidification | Bach et al. (2016) | 14.3 |
for men and women” was developed which compares the wages of women and men. As the corresponding target 5.1 states to “end all forms of discrimination against all women and girls everywhere” and does not include further genders, the indicator has been confined to men and women. Additionally, discrimination and equal opportunities were added as a topic for the sustainability risk management described in indicator C2.3 (the last step of the reference point approach).

In total, 45 indicators have been identified to be suitable for assessing the potential contribution of products to the 61 targets. This means that several indicators are used for the assessment of more than one target. However, for some targets, more than one indicator is necessary to map the potential contributions, e.g. target 5.1. 15 indicators assess the contribution to more than one target, 11 indicators assess the contribution to two targets, three indicators to three targets and one assesses the contribution to 26 targets (C2.3). However, most indicators (30) specifically assess the contribution to one target. All identified product-related indicators can be found in Tables 1, 2 and 3.

### 3.3 S-LCIA functions

The S-LCIA aims to assess the contribution of a product to the respective targets. The contribution is based on indicators that were identified using the approach specified in the method section. The expert and stakeholder discussions on the definition of contribution functions resulted in three types of curves:

- **Linear functions (15 out of 20):** Here, each unit more (or less) was considered a positive contribution to the target. In some cases, the slope of the curve depends on the national or the sector average which results in a piecewise linear function.
- **Bell-shaped functions (3 out of 20):** These were considered suitable for targets that address gender inequality and are based on Gaussian functions. Here it was discussed that inequality can occur equally for both genders considered. Therefore, both need to be assessed in the function. It was discussed that the maximum inequality for both genders is equally negative. In addition, it is very difficult to achieve exact equality, so that the slope at the peak (absolute equality) must be lower than when more inequality occurs. Hence, a symmetric bell-shaped function, resembling a downwards quadratic function was determined to be most appropriate.
- **Plateau functions (2 of 20):** This function expresses that the contribution y to the target increases rapidly with the parameter x at lower values but tends to reach a threshold at which the slope becomes smaller, resulting in a plateau. These functions are also based on Gaussian functions.

Other possible curve types described in Lindner et al. (2021) were not considered suitable by the experts for the impact assessment of the identified 20 indicators discussed here. Since it would be beyond the scope of the paper to discuss the impact assessment for each of the 20 C2-indicators, in the following, an example is given for each of the five priorities defined in the systematic approach to setting the reference value for the impact assessment. In line with the aim of this paper, functions were only developed for C2 indicators. As a first choice, the reference value for the impact assessment is derived directly from the target. This is the case for indicator C2.12 that is based on target 6.1 “By 2030, achieve universal and equitable access to safe and affordable drinking water for all”. The corresponding GIF-SDG aims to enhance the “proportion of population using safely managed drinking water services” and can be directly transferred to employees involved in the production and management of a certain product. The indicator captures the share of employees that have access to safely managed drinking water at work (input parameter). Result

| #   | Indicator                                      | Origin of indicator      | SDG  |
|-----|-----------------------------------------------|--------------------------|------|
| C1.16 | Income per hectare – small-scale producers | GIF-SDG (adapted)       | 2.3  |
| C1.17 | Yield per hectare – small-scale producers    | GIF-SDG (adapted)       | 2.3  |
| C1.18 | Death rate due to road traffic injuries      | GIF-SDG                  | 3.6  |
| C1.19 | Water use                                     | GIF-SDG (adapted)       | 6.4  |
| C1.20 | Energy use:                                   | GIF-SDG (adapted)       | 7.2, 7.3 |
|      | a: Renewable                                 |                          |      |
|      | b: Non-renewable                              |                          |      |
| C1.21 | Food losses                                   | GIF-SDG (adapted)       | 12.3 |
| C1.22 | Waste generation (per fraction)              | GIF-SDG (adapted)       | 12.4 |
| C1.23 | Use of recycled material                      | GIF-SDG (adapted)       | 12.5 |
| C1.24 | Marine debris (incl. (micro) plastic)        | GIF-SDG (adapted)       | 14.1 |
| C1.25 | Share of by-catch in catches                  | GIF-SDG (adapted)       | 14.4 |
| #   | Indicator                                                                 | Impact category             | Origin of indicator | SDG          | Reference point based on          |
|-----|---------------------------------------------------------------------------|----------------------------|---------------------|--------------|-----------------------------------|
| C2.1| Workers/employees earning below the UN poverty line of $1.90 per day      | Working conditions         | GIF-SDG (adapted)   | 1.1          | Explicit SDG                      |
| C2.2| Coverage of social security support                                       | Health and safety          | GIF-SDG (adapted)   | 1.3          | Leave no-one behind               |
| C2.3| Coverage of product-related sustainability (risk) management              | Governance                 | Added               | 2.4, 3.6, 5.1, 6.5, 6.6, 7.3, 9.3, 11.6, 12.2, 12.3, 12.4, 12.5, 13.2, 14.2, 15.1, 15.6, 15.8, 15.9, 15.a, 15.b, 16.5, 16.a, 17.7, 17.11, 17.16, 17.17 | Sustainability risk management |
|     | **a:** Sustainable agriculture (SDG 2.4)                                 |                            |                     |              |                                   |
|     | **b:** Driver/passenger safety and reduction of accidents (SDG 3.6)      |                            |                     |              |                                   |
|     | **c:** Equal opportunities (SDG 5.1)                                     |                            |                     |              |                                   |
|     | **d:** Water use and scarcity (SDG 6.5, 6.6)                              |                            |                     |              |                                   |
|     | **e:** Natural resources (SDG 12.2)                                       |                            |                     |              |                                   |
|     | **f:** Food losses (SDG 12.3)                                             |                            |                     |              |                                   |
|     | **g:** Chemicals (SDG 12.4)                                               |                            |                     |              |                                   |
|     | **h:** Waste (SDG 11.6, 12.5)                                             |                            |                     |              |                                   |
|     | **i:** Climate change (SDG 13.2)                                          |                            |                     |              |                                   |
|     | **j:** Marine biodiversity (SDG 14.2)                                     |                            |                     |              |                                   |
|     | **k:** Terrestrial and freshwater biodiversity (SDG 15.1–15.5, 15.8)     |                            |                     |              |                                   |
|     | **l:** Patents on natural resources (SDG 15.6)                            |                            |                     |              |                                   |
|     | **m:** Corruption prevention (SDG 16.5)                                   |                            |                     |              |                                   |
|     | **n:** Human rights (SDG 16.a)                                            |                            |                     |              |                                   |
|     | **o:** Promotion of environmentally sound technologies in developing     |                            |                     |              |                                   |
|     |  countries (SDG 17.7)                                                     |                            |                     |              |                                   |
|     | **p:** Energy efficiency (SDG 7.3)                                        |                            |                     |              |                                   |
|     | **q:** Small-scale suppliers/industry borrowers in the supply chain (in  |                            |                     |              |                                   |
|     |  particular from least developed countries) (SDG 9.3)                     |                            |                     |              |                                   |
|     | **r:** Share of products/materials from developing countries              |                            |                     |              |                                   |
|     | (SDG 17.11)                                                               |                            |                     |              |                                   |
|     | **s:** Investments in conservation and sustainable use of biodiversity/  |                            |                     |              |                                   |
|     |  ecosystems (SDG 15.a, 15.b)                                              |                            |                     |              |                                   |
|     | **t:** Engagement in multi-stakeholder partnerships for sustainable       |                            |                     |              |                                   |
|     |  development (SDG 17.16, 17.17)                                           |                            |                     |              |                                   |
| C2.4| Number of used breeds/varieties                                           | Cultural heritage          | Lindner et al. (2019b) | 2.5          | Science-based                     |
| C2.5| Health insurance                                                          | Health and safety          | GIF-SDG (adapted)   | 3.8          | Leave no-one behind               |
| C2.6| Occupational injuries                                                     | Health and safety          | GIF-SDG (adapted)   | 3.9, 8.8     | Leave no-one behind               |
| C2.7| Access to protective clothing                                             | Health and safety          | GIF-SDG (adapted)   | 3.9, 8.8     | Leave no-one behind               |
| C2.8| Training in sustainability issues                                          | Governance                 | GIF-SDG (adapted)   | 4.4, 4.7, 13.3, 16.5 | Leave no-one behind               |
|     | **a:** ICT skills (e.g. technical and vocational) (SDG 4.4)               |                            |                     |              |                                   |
|     | **b:** Sustainability in general (SDG 4.7)                                |                            |                     |              |                                   |
|     | **c:** Climate change (SDG 13.3)                                          |                            |                     |              |                                   |
|     | **d:** Corruption and bribery prevention (SDG 16.5)                       |                            |                     |              |                                   |
| C2.9| Equal share of training for men and women                                  | Human rights               | GIF-SDG (adapted)   | 4.5          | Leave no-one behind               |
of the expert discussion was that the contribution to the target (reference value) is fully achieved ($C_{2.12} = +1$) when all workers/employees have access to safe drinking water at work (Fig. 1), and that there is a negative impact when none of the workers/employees have access to clean and safe water ($C_{2.12} = −1$). The impacts are assessed positively if the proportion of workers/employees who have access to safely managed drinking water is higher than the national average of the country in which the company is located. The impacts are assessed negatively, if the proportion is below the national average. If the company’s proportion of workers/employees who have access to safely managed drinking water at work is equal to the national average ($n$), $C_{2.12} = 0$. This is done for all steps in the value chain. The impact assessment equation is expressed as a piecewise linear function (Fig. 1, Eq. (1) [S-LCIA for indicator $C_{2.12}$]), as every additional worker/employee with access to drinking water at work is considered an improvement. Because of the piecewise definition dependent on the national average, the slope between $y = −1$ and $y = 0$ is prone to be different than the slope between $y = 0$ and $y = +1$.

$$
C_{2.12} = \begin{cases} 
1, & \text{for } n = 1 \\
\frac{x}{1 - n} - 1, & \text{for } x < n \\
\frac{x - \frac{1}{n}}{(1 - n)} - \frac{n}{(1 - n)}, & \text{for } x \geq n
\end{cases}
$$

where $x$ is the company specific value and $n$ is the national country average.

This approach of deriving the impact assessment directly from the target is also used for indicators $C_{2.1}$, $C_{2.13}$ and $C_{2.20}$. All of these indicators are defined as linear contribution functions.

Secondly, the reference value can be derived from the principle “leave no one behind”. For example, target 1.3 aims to “implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the

$$
\begin{array}{|c|}
\hline
\# & Indicator & Impact category & Origin of indicator & SDG & Reference point based on \\
\hline
C2.10 & Equal wages for men and women & Human rights & GIF-SDG (adapted) & 5.1, 8.5 & Leave no-one behind \\
C2.11 & Equal managerial positions for men and women & Human rights & GIF-SDG (adapted) & 5.5 & Leave no-one behind \\
C2.12 & Drinking water at work & Health and safety & GIF-SDG (adapted) & 6.1 & Explicit SDG \\
C2.13 & Adequate sanitation at work & Health and safety & GIF-SDG (adapted) & 6.2 & Explicit SDG \\
C2.14 & Wastewater treatment & Health and safety & GIF-SDG (adapted) & 6.3 & Top 5 (countries) \\
C2.15 & Employees under 24 years & Socio-economic repercussions & GIF-SDG (adapted) & 8.6 & Leave no-one behind \\
C2.16 & Fulfilment of ILO conventions: a: Child work and minimum age, forced labour b: Freedom of association, discrimination, collective bargaining for all employees, equal remuneration of workers & Working conditions & GIF-SDG (adapted) & 8.7, 8.8 & Leave no-one behind \\
C2.17 & Investments in R&D & Governance & GIF-SDG (adapted) & 9.5 & Top 5 (companies) \\
C2.18 & Relative poverty rate & Working conditions & GIF-SDG (adapted) & 10.2 & Leave no-one behind \\
C2.19 & Income spread & Working conditions & GIF-SDG (adapted) & 10.3 & Science-based \\
C2.20 & Product-related sustainability information & Governance & GIF-SDG (adapted) & 12.6, 12.8, 14.4 & Explicit SDG \\
\hline
\end{array}
$$
vulnerable”. The requirement for the corresponding GIF-SDG is to analyse the “proportion of population covered by social protection floors/systems [...].” If the principle “leave no one behind” is applied to target 1.3, the reference value can be set to let all employees along the product life cycle benefit from all types of social security (C2.2 = +1; Fig. 2). A neutral impact on the target (C2.2 = 0) is assumed if the average coverage of the company’s employees with social security equals the average coverage of employees in the country concerned. If none of the employees is covered by any type of social security, a negative impact of C2.2 = −1 is assumed.

To define a social security system, the definition of the International Labour Organisation (2017, p. 168) was used, which includes the following types of social security: (a1) child and family benefits (e.g. benefits in form of periodic cash or housing, holidays, help); (a2) maternity protection (e.g. paid leave or leave with adequate social security benefits); (a3) unemployment support; (a4) employment injury benefits; (a5) sickness benefits; (a6) health protection; (a7) old-age benefits; (a8) disability benefits; (a9) survivors’ benefits (e.g. earnings-related periodic cash benefits and funeral grants to survivors of deceased workers). The contribution is first assessed for all nine types of social security independently (y1 to y9) and then summed up to an equally weighted average C2.2. Since the average coverage with social security varies within the different countries and also for the different types of social security systems, the x axis intercept can occur at different values of x. Figure 2 shows an example of this for y1 and y2. The impact assessment equation is expressed as a linear function (Fig. 2, Eq. (2) [S-LCIA for indicator C2.2]), as every additional worker/employee with access to one or more of the nine different types of social security is considered an improvement. Since the national averages regarding social protection systems are different for different countries and thus y1 = 0 is varying, this also results in different slopes of the functions as displayed in Fig. 2.

$$C_{2,2} = \frac{1}{9} \cdot \sum_{i=1}^{9} y_i$$

where $y_i = \begin{cases} 1, & \text{for } n_i = 1 \\ a_i \cdot \frac{1}{n_i} - 1, & \text{for } a_i < n_i \\ a_i \cdot \frac{n_i}{(1-n_i)} - n_i, & \text{for } a_i \geq n_i \end{cases}$

(2)

where $a_i$ is the share of employees benefiting from social security support, $a_1$ is the child and family benefits, $a_2$ is the maternity protection, $a_3$ is the unemployment support, $a_4$ is the employment injury benefits, $a_5$ is the sickness benefits, $a_6$ is the health protection, $a_7$ is the old-age benefits, $a_8$ is the disability benefits, $a_9$ is the survivors’ benefits and $n_1$ to $n_9$ is the national country average of related coverage $a_1$ to $a_9$.

The approach of using the principle “leave no one behind” is also used for the indicators C2.5, C2.6, C2.7, C2.8, C2.9, C2.10, C2.11, C2.15, C2.16 and C2.18. However, due to the different issues addressed by the other indicators, the indicators C2.9, C2.10 and C2.11 are expressed with quadratic functions, whereas the other indicators mentioned are also expressed with linear functions. All functions are given in the supplementary material.

The third choice is to use science-based targets to quantify the reference value to assess the impact on the target. The basis for the indicator C2.4 is target 2.5 which states “By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals [...].”
The requirement for the GIF-SDG 2.5.1. (United Nations 2021) for this target is to report on the genetic resources in conservation facilities and the proportion of local breeds being at risk of extinction which, in the view of the involved experts and stakeholders, cannot be transferred to products. Since the reference value can also not be derived directly from the target and the principle “leave no one behind” does not hold here, an assessment based on science-based targets was adopted. A suitable assessment was developed by Lindner (2016) and has already been used in case studies on the assessment of biodiversity impacts (Eberle 2018; Eberle and Lindner 2015; Lindner et al. 2019a). The indicator describes agrobiodiversity and assesses the number of breeds/varieties grown (input parameter). Which and how many different breeds/varieties are cultivated is based on the agricultural practice of the cultivating farm. The more different breeds or varieties are cultivated, the better for the agricultural practice of the cultivating farm. The more different breeds/varieties are cultivated is based on breeds/varieties grown (input parameter). Which and how many different breeds/varieties are cultivated is based on the agricultural area hectare (ha) and \( t \) is the number of years (a).

As a fourth choice, the reference value for the impact assessment can be based on the average of the five top performers which can be either companies or countries. C2.17 illustrates such an indicator which is based on target 9.5 “Enhance scientific research, upgrade the technological capabilities of industrial sectors […].” The potential contribution of companies is to raise the share of income spent on R&D. The GIF-SDG 9.5.1 proposes to measure research and development expenditure as a proportion of GDP which is adapted to products. The maximum impact on the target (C2.17 = +1) is reached when the share of income spent on R&D (input parameter) is equal to the average of the five branch leaders in the sector (\( r_2 \)). However, an expense above the average of five industry leaders does not lead to a value above +1. There is a neutral impact on the target (C2.17 = 0) when the expenses spent on R&D are equal to the national country-branch average (\( r_1 \)). The impact is set as C2.17 = −1 when there are no expenses for R&D. The function is expressed in linear terms until the spending of the five industry leaders is reached, as each additional resource spent on R&D represents a positive contribution to the achievement of the target (Fig. 4, Eq. (4) [S-LCIA for indicator C2.17]).

The reference value based on the five best performers is also used for C2.14. C2.14 relates to the amount of wastewater treatment, uses the top five performing countries as reference point and is also expressed as a linear function. Both indicators are adapted from the GIF-SDG.

\[
C_{2.17} = \begin{cases} 
1, & \text{for } x > r_2 \\
\frac{x}{r_1} - 1, & \text{for } x < r_1 \\
\frac{1}{(1-r_1-r_2)} - \frac{1}{r_1-r_2}, & \text{for } r_1 \leq x \leq r_2 
\end{cases}
\]  

(4)

where \( x \) is the share of investments in R&D based on income, \( r_1 \) is the national country-branch average and \( r_2 \) is the average share of 5 industry leaders in the sector.

As a fifth choice, a product-related topic addressed in a target can be included in the sustainability risk management if a quantitative assessment is not (yet) possible. An example of an impact assessment based on sustainability risk management is target 5.1 which aims to “End all forms of discrimination against all women and girls everywhere”. The indicator C2.10 “Equal wages for men and women” was developed which compares the wages of women and men which can be further amended for minorities. However, not all kinds of discrimination can be covered using wages as proxy. Therefore, discrimination was added as a topic for the sustainability risk management. Whether a certain issue is covered comprehensively in the sustainability (risk) management...
of the company is based on the management approach developed by GRI (2016). Summing up the requirements, comprehensive sustainability risk management can be proven by (a) agreeing policies/goals and targets, (b) defining responsibilities/allocating resources and (c) planning concrete actions/measures. Each risk management measure can either be addressed (e.g. C2.31 = 1) or not (e.g. C2.31 = 0). The highest possible positive impact on preventing discrimination (C2.3a = +1) is achieved when all management measures (policies/goals and targets; responsibilities/resources; specific actions/measures) are covered. No positive impact (C2.3a = 0) is assumed when no management measures are covered. Equation (5) (S-LCIA for indicator C2.3a) gives details on the measurement of the indicator regarding discrimination C2.3a.

$$C_{2.3a} = x = \sum_{j=1}^{3} C_{2.3j}$$  \hspace{1cm} (5)

where C2.3 is a Boolean operator (value either 1 or 0) for management measures against discrimination covered, C2.31 is the policies/goals and targets, C2.32 is the responsibilities/resources and C2.33 is the specific actions/measures.

The approach of using the sustainability risk management is also used for other topics addressed in the targets such as C2.3b: driver/passenger safety/reduction of accidents (target 3.6); C2.3c: equal opportunities (target 5.1); C2.3d: water use and scarcity (target 6.5, 6.6); C2.3e: natural resources (target 12.2); C2.3f: food losses (target 12.3); C2.3 g: chemicals (target 12.4); C2.3 h: waste (target 12.4, 12.5); C2.3i: climate change (target 13.2); C2.3j: marine biodiversity (target 14.2); C2.3 k: terrestrial and freshwater biodiversity (target 15.1–15.5, 15.8); C2.3 l: patents, on natural resources (target 15.6); C2.3 m: corruption prevention (target 16.5); C2.3n: human rights (target 8.7, 8.8, 16.a); C2.3o: promotion of environmental sound technologies in developing countries (target 17.7); C2.3p: energy efficiency (target 7.3); C2.3q: small-scale suppliers/industry borrowers in supply chain (particular from least developed countries) (target 9.3); C2.3r: share of products/materials from developing countries (target 17.11); C2.3 s: Investments in conservation and sustainable use of biodiversity/ecosystems (target 15.a, 15.b); C2.3t: Engagement in multi-stakeholder partnerships for sustainable development (target 17.16, 17.17).

These topics (C2.3a-t) are all assessed using the same approach as described for C2.3a. They are then summed up and equally weighted, to give an overall result for indicator C2.3 (Fig. 5, Eq. (6) [S-LCIA for indicator C2.3]).

$$C_{2.3} = x = \frac{1}{60} \cdot \sum_{j=a}^{t} \sum_{j=1}^{3} C_{2.3_{ij}}$$  \hspace{1cm} (6)

where C2.3_{ij} is the Boolean operator (value either 1 or 0) for each management measure (policies/goals and targets, responsibilities/resources, specific actions/measures) covered, for each of the 20 topics.

The interval for all indicators was set between −1 and +1, except for C2.3 and C2.4. Both indicators range only between 0 and +1. For C2.3, no negative impact on the achievement of the target is considered if the mentioned topics are not managed comprehensively. C2.4 is science-based and the range has been adopted directly from the literature (Eberle and Lindner 2015; Lindner et al. 2019b).

4 Discussion

The agenda 2030 with the 17 SDGs poses a powerful frame to guide the world in fostering sustainable development. However, the 169 targets focus mainly on government roles, ignoring the role of businesses and their products (Spangenberg 2016). The main contribution of this paper is to propose a coherent method to measure the contribution of products to the 169 targets. The method involves a systematic approach to identify targets that are related to products, to derive suitable indicators from existing frameworks and to develop an S-LCIA method for the C2-indicators using the targets as a performance reference point. This contributes to science and practice as previous literature has analysed that to date companies often cherry-pick the SDGs they want to focus on (PwC 2015), researchers tend to select the S-LCA indicators mainly on previous studies or on gut feeling (Kühnen and Hahn 2017) and that a method to measure the contribution of products to the SDGs has been lacking in both research and practice. The paper also contributes to the scientific discussions on S-LCIA methods, in particular to the performance reference point approach. Furthermore, the paper contributes to corporate practice as choosing the targets
of the SDGs as reference points allows linking the companies’ activities in sustainability management to the SDGs. In the following, the main constituents of the method are discussed.

### 4.1 Identification of product-related targets

To filter the product-related 169 targets of the SDGs, an approach using two questions was developed. Using this approach to identifying the product-related targets, only 36% of the targets were found to have a reference to products. However, this must not be the case for all products and the authors propose to always screen the 169 targets of the SDGs based on the defined cases regarding the specific product to be analysed. This finding corresponds roughly with the findings of Vermeulen (2018) who analysed that 54% of the goals are formulated as plans, projects or regulations for policy outputs or policymaking. Herrera Almanza and Corona (2020) found that only 17% of the targets were related to the product of their analysis, but they only included social targets as they focused solely on S-LCA. Lisowski et al. (2020) focused their analysis exclusively on ecological indicators used in the GIF-SDG that can be linked to the automotive sector and found that 12.5% of the indicators had a direct relation. Since in this work both environmental and social targets were addressed, a comparison with previous work that focused on either social goals or on environmental indicators is difficult. Previous studies also focused on other products which prohibits a further comparison.

### 4.2 Selection of suitable indicators

To measure the impact of products on the targets, the GIF-SDG was used as a primary source for reliable and generally accepted indicators. However, the policy focus of the targets also applies to the indicators formulated in the GIF-SDG. Only for 57% of the product-related targets, the GIF-SDG indicators can at least be partly related to products and almost all of them had to be adapted for this purpose. Some targets address topics more broadly than the corresponding GIF-SDG and hence had to be complemented with further indicators to address the diverse aspects of these targets and improve the assessment (e.g. target 6.6). For other targets, product-related indicators were drawn from the EF process, from other sources or were defined specially to assess the potential impact on the respective target (see Tables 1, 2, and 3). The selection of indicators from the EF process is considered to contribute positively to the assessment of the targets, as they address the environmental impact on the targets more directly (e.g. target 2.4). Additional indicators were used or defined in cases where neither the GIF-SDG nor the EF framework provided sufficient coverage.

Even if for 43% of the product-related targets, indicators were taken from the EF framework, other sources or defined especially to assess the potential impact on the respective target, they have the advantage of being oriented as far as possible to a globally accepted reference framework and are not based on any normative goals of their own. This addition of objective indicators is a major contribution to the field of S-LCA, as Kühnen and Hahn (2017) analysed that the indicator selection to date is based mainly on previous studies or on gut feeling of the researcher or practitioner. This study has examined the targets exhaustively for foods. Future research should critically examine these indicators and adjust them for the particular product and aim of the respective study. Additionally, it should be considered whether it would be worthwhile to establish a product-related indicator framework for the SDGs (PIF-SDG) that stakeholders worldwide could agree on, analogous to the GIF-SDG.

### 4.3 The development of a quantitative S-LCIA method

This study develops a quantitative S-LCIA method taking the SDGs as a normative reference point and following the S-LCA guidelines (UNEP 2020). The method enables its users to assess the potential impacts of products on the targets of the 2030 Agenda, which can support companies in assessing their contribution. The S-LCIA can also help to detect corporate cherry-picking of the targets. Some previous studies have analysed product- or sector-related SDGs and have linked existing indicators to the SDGs (e.g. Herrera Almanza and Corona (2020); Lisowski et al. (2020)). However, the authors are not aware of any other publications that have tried to measure the contribution of products to the SDGs which underlines the novelty of the work. The S-LCIA method is based on an E-LCIA method for biodiversity (Lindner 2016, Lindner et al. 2019a, b; 2021) and allows for assessing a product’s impact on the targets. Following this approach, for the 20 S-LCIA indicators, the relevant input parameters were identified and contribution functions were developed to quantitatively assess the impact of products. Since many targets are not precise and the reference value cannot be set precisely, an approach using five different steps to derive a quantitative reference value was adopted. The first four steps are taken directly from the sustainable development report of the SDSN and the Bertelsmann Stiftung (Sachs et al. 2021). As the difference between these steps relates only to the approach to derive a quantitative reference value and the contribution interval was set to be between +1 and −1, the impact assessments of these steps are directly comparable. The fourth step to use the average of the five top performers which can be either companies or countries might cause suspicion, as even the most advanced
companies might not be very advanced in some regards. In this study, only one indicator to measure the expenses in R&D (C2.17) uses the approach to benchmark against the five top companies in the sector. Since expenses in R&D are a common business measure, the suspicion of setting the bar too low was deemed neglectable. However, some targets are too vague and a quantitative reference value could not be derived. Therefore, the fifth step of the S-LCIA method uses a semi-quantitative approach to assess whether the topics addressed in the targets are integrated into the company’s sustainability risk management. Whether an issue is comprehensively covered is reviewed based on the management approach developed by GRI (2016). This allows a semi-quantitative assessment for those aspects where a quantitative assessment is not (yet) possible. Since the logic adopted here is different from the first steps, the assessments are not directly comparable. In future studies, more quantifiable assessments should be sought for these indicators to make the assessments comparable.

This is for instance the case for target 5.1 which aims to “End all forms of discrimination against all women and girls everywhere”. The indicator C2.10 “Equal wages for men and women” was developed which compares the wages of women and men, which can be further amended for minorities in general. However, not all kinds of discrimination can be covered using wages as proxy. Therefore, discrimination was added as a topic for the sustainability risk management. Other targets directly address issues related to minorities like target 10.2 which aims to “empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status”. However, companies in many countries are only under special circumstances allowed to collect data regarding ethnicity or religious beliefs. Measuring the contribution of products to target 10.2 is therefore in many countries not allowed and cannot be included in the S-LCIA. Future research could further test the proposed indicators and examine the feasibility as well as the logic of the proposed approach. For instance, a study from the OECD (2019) uses a four-step approach to measuring the SDGs and uses reference values from other international agreements (e.g. reduce particulate matter pollution to the recommendations of the World Health Organisation) as a second step. The approach of using reference values from international agreements could be reviewed in future studies with the aim to further substantiate the approach adopted in this paper.

Fourteen out of 20 C2 indicators and their reference value derived in this research are not used in the sustainable development report (Sachs et al. 2021). This is because the sustainable development report focuses mostly on the policy and state level, while the C2 indicators focus on products. The remaining 6 indicators and their matching reference point in the sustainable development report are described in the following. Both C2.1 (Workers earning below the UN poverty line of $ 1.90 per day) and C2.17 (Investments in R&D) use the same reference point approach as the sustainable development report. For indicator C2.10 (Equal wages for men and women) and C2.14 (Wastewater treatment), the sustainable development report uses the technical optimum as a reference point approach which is not given as an official step to derive target values (Sachs et al. 2021, p. 70). As the report does not give an indication of when to use the technical optimum, this approach was not adopted and the reference points differ for these two indicators. For indicator C2.15 (Employees under 24 years) and C2.18 (Relative poverty rate), the sustainable development report uses the average of the top performers while in this research the principle “leave no-one behind” is applied as it has higher priority (see Sect. 2.4). Hence, even though the approach to setting the reference point is similar to the sustainable development report, the results differ a lot.

The S-LCIA functions developed in this work represent a first proposal on how the contribution to the targets can be measured. The results show that 75% of the contribution functions are linear functions, all of them linked to social impacts on single individuals. Based on the principle to “leave no-one behind”, every individual is valued the same, resulting in a rather simple function where every increment in the input parameter results in a change in contribution to the achievement of the target by the same amount. Other types of functions would deviate from this basic principle. Additionally, the types of curves, describing the relationship of the functions, were the result of discussions with experts. On the other hand, linear functions in most cases do not reflect complex side effects, which could amplify or dampen the impact. As the functions represent a first proposal, more complex functions are subject to further research.

As discussed earlier, not all targets formulate quantitative objectives, which makes it difficult to define the reference value. Nevertheless, the procedure described by Lindner et al. (2021) for defining contribution functions for impact assessment in biodiversity can be transferred very well to social indicators. However, the functions defined here have so far been discussed with a small circle of stakeholders and experts and should be discussed with a wider group of stakeholders in the future to further refine them. It would also be of great interest to conduct these discussions in an international setting to exclude a national bias in the definition of the functions. Such a process was already started by Kühnen et al. (2019) and has been continued within the research presented here. However, this should be expanded, as the contribution functions also contain a normative component that is rooted in the guiding principle of sustainable development.
### 4.4 S-LCIA in supply chain management

The S-LCIA method presented here carries out the impact assessment at the level of the actors involved along the value chain (e.g., agricultural enterprises, food processing, retail, transport) and then aggregates their respective contributions according to the functional unit taking working hours as reference flow. With this approach, however, it is not only possible to carry out an S-LCIA at the product level, but also to conduct a social organisational life cycle impact assessment (SO-LCIA). Thus, the presented S-LCIA method is a contribution to both S-LCIA and SO-LCIA. As companies can increasingly be legally prosecuted if they fail to meet their responsibilities along the supply chain, such impact assessment tools will become increasingly important. For instance, Germany has just passed a supply chain law. In France, such a law is already in force, and also the Netherlands and the UK incorporate aspects of it, e.g., no child labour or modern slavery in law. The Council of the European Union has just requested the EU Commission to launch an EU action plan by 2021 that focuses on the sustainable design of global supply chains and promotes human rights, social and environmental due diligence standards. The UN Treaty on Business and Human Rights discussed by the UN Human Rights Council could also give human rights due diligence at the international level a legally binding instrument to regulate the activities of transnational corporations and other business enterprises in terms of human rights. Nevertheless, this is currently very controversial.

Nevertheless, the method still requires further validation and application in case studies to substantiate its practicability and scientific foundation. In line with the approach of Lindner et al. (2019b), one limitation is that the stakeholder involvement was limited to a small circle. In the future, the function development should be supplemented by further expert consultations and by broader stakeholder discussions. Selected case studies have been conducted for individual indicators of this method (Kühnen et al. 2019), but no full case study has been carried out yet. Another limitation is that the targets are examined exhaustively only for foods. Future research could examine the indicators for further branches and test their applicability. Furthermore, it is necessary to consider whether and, if so, how the results at the level of the targets can be aggregated into an overall contribution to the respective SDG, e.g., the indicators C2.1 and C2.2 both contribute to SDG 1 of reducing poverty. Additionally, LCC and its possible use for assessing corporate contributions to the SDGs should be considered in further research. Another limitation is that some aspects mentioned in the SDGs could so far not be translated to quantifiable indicators but have been added as issues to be managed in the sustainability (risk) management (C2.3). Future research could try to further quantify these issues to make the assessments comparable.

### 5 Conclusion

The approach developed in this paper contributes to the literature by proposing a coherent method to measure the contribution of products to the 169 targets. It enables the implementation of the SDGs at the company level by selecting the targets which can be influenced by products. This can help to detect cherry-picking of the SDGs (and related “SDG-washing”) and can guide researchers and practitioners in selecting targets of the SDGs that are relevant for companies and their products. In line with the UNEP Guidelines for S-LCA (UNEP 2020), the study focuses on developing a method to assess social performance using a reference scale approach (Chhipi-Shrestha et al. 2014). The identified indicators can guide researchers and practitioners in their search for a set of product-related SDG-indicators. Furthermore, the paper adopts a quantitative S-LCIA method.

There is little research on how the 17 SDGs and their 169 targets can be used to assess the social and environmental impacts of products. However, since the SDGs were adopted by all UN member states and thus represent the normative framework for sustainable development worldwide, this is an important avenue for further research. The translation steps that are necessary to make use of the SDGs in S-LCA, because the targets of the SDGs were not explicitly formulated for this purpose, are provided in this paper. All 17 SDGs and 61 of the 169 targets (36%) were evaluated as product-related while the rest are on a policy level. For 57% of the product-related targets, indicators from the GIF-SDGs could be used after slight adaptations, while for the remaining 43% of the product-related targets, indicators had to be added or were taken from the EF framework. In total, 45 indicators have been identified to be suitable for assessing the potential contribution of products to the 61 targets. An S-LCIA method was developed that translates the targets into conditions beneficial or damaging to the achievement of the target to estimate the socio-economic impact of the product using a scale from +1 to −1.

The SDGs are part of the 2030 Agenda and are to be achieved by then. This means that the reference point used here will then become obsolete. Nevertheless, it can be assumed that the international community will set new sustainability goals. The three-step approach presented here (identification of product-related targets, identification of indicators, development of the impact assessment) offers the methodological framework to integrate the newly agreed targets into an impact assessment. This is an important first step to measure the contribution of products to the
SDGs. However, further research to examine the proposed method, the derived indicators and the impact assessment both theoretically and in case studies is strongly encouraged. Especially, there are several targets for which no quantitative assessment has yet been developed and which can therefore only be addressed in the sustainability risk management using the GRI management approach (GRI 2016). Further research could try to find ways to quantify these targets using the suggested approach of this paper.

Concerning the ecological impacts of products, further research could intend to estimate the contribution to the SDGs with the method presented. This would require a further normative “translation step”. The targets for sectors and products presented by the Science-Based Targets Initiative (2020) could possibly fill this gap and be used in the further development of the method for the identified ecological indicators.

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Data availability The authors declare that all data supporting the findings of this study are available within the article and its supplementary material.

Declarations

Conflict of interest The authors declare no competing interests.

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