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Linking life cycle sustainability assessment and the sustainable development goals – Calculation of goal achievement

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Abstract

In 2015, the United Nations General Assembly proposed seventeen Sustainable Development Goals (SDGs) intended to ensure sustainable development worldwide at the economic, environmental, and social levels. SDGs are now being used by some corporations in formulating and expressing business strategies. However, assessing the effects of corporate activities and products regarding their contribution to SDGs is difficult. In this paper, we have developed a method for linking life cycle sustainability assessment (LCSA) with the SDGs and calculating the contribution to SDG achievement. An essential part of this approach is the weighting of LCSA impact categories, which is typically done using equal weighting. This weighting method enables compensation of negative contributions by positive contributions in different impact categories but results in ambiguity in the results. This article identifies alternative weighting methods, integrates them into a computational approach, and determines their influence on the SDG contribution scores. The analysis shows that the use of alternative weights changes SDG contribution scores. However, the same product always has the highest SDG contribution score, regardless of the weighting method used. Nonetheless, the recommendations for action with regard to the total product alternatives would change depending on the weighting method.

Keywords: Sustainable development goals (SDGs); SDG quantification; Sustainable development; Life cycle sustainability assessment

1. Introduction

In 2015, the United Nations General Assembly adopted the seventeen Sustainable Development Goals (SDGs) and 169 targets to replace the earlier set of eight Millennium Development Goals [1]. These global goals are associated with the UN 2030 Agenda and are intended to ensure sustainable development worldwide at the economic, environmental, and social levels [2]. The main objectives of the SDGs are to highlight progress toward reducing disparities in living standards, creating equal opportunities, advancing economic growth, and the sustainable management of natural resources that ensure the preservation of ecosystems and strengthen their resilience [1]. The SDGs should provide guidance for sustainability efforts on the global and national levels and have been widely incorporated to highlight efforts regarding sustainable development. Corporations have also taken advantage of this in formulating and expressing business strategies. The aircraft manufacturer Airbus, for example, has adopted the SDGs to highlight their contribution to sustainable development. In doing so, they demonstrate how its corporate activities and products contribute to sustainable development in line with the SDGs [3].

However, there is a misalignment in the spatial, temporal, and demographic resolutions of corporate activities and SDGs,

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resulting in difficulties in assessing the effects of corporate activities and products regarding their contribution to SDGs.

Sustainability assessments of products and systems, in general, are common practice in academia and industry, and a variety of methods for environmental, economic, and social assessment are used. Environmental assessment methods include, for example, life cycle assessment, material flow analysis, and cumulative energy demand [4,5]. Examples of economic assessment include life cycle costing, discounted cash flow analysis, and techno-economic assessment [6,7]. The social impact assessment has become increasingly important, especially in recent years. In this context, methods such as social sustainability evaluation and social life cycle assessment are used to assess social aspects or products and processes [7,8]. Besides these sustainability dimension-specific assessment methods, integrated assessment methods such as the life cycle sustainability assessment (LCSA) enable an evaluation of all three sustainability dimensions [5,9,10]. The LCSA method for quantitative sustainability assessment is well established and widely used. However, all these methods were developed primarily to identify environmental and socio-economic impacts at the product or process level. Their correspondence to higher-level development goals, such as the SDGs, is unclear.

First scientific studies try to address this ambiguity by linking LCSA impact categories and SDGs. By doing so, SDG-based indicators for sustainability assessment have been developed, and potential contributions to specific SDGs have been determined (e.g., [11–16]). However, the existing studies leave uncertainties regarding the linkage procedure of LCSA impact categories and SDGs. Furthermore, the proposed approaches for quantifying the contribution to SDG achievement are highly simplified and result in a loss of information.

To close these gaps, we have developed a novel approach for quantifying the contribution of products and technologies to achieving the SDGs [17]. Our approach can be divided into two parts: 1.) The linking of LCSA impact categories and the SDGs, and 2.) the calculation of so-called SDG contribution scores, which represent the contribution of a product to the achievement of an SDG. We demonstrate the applicability of this approach for product and technology assessment and open a new perspective on sustainability assessment in general.

However, there is still a need for research regarding the methodology for calculating SDG contribution scores. An equal weighting of the LCSA impact categories is commonly used to determine the SDG contribution score. However, this type of weighting allows for compensation of negative contributions by positive contributions in different impact categories, leading to ambiguity in the interpretation of the results. A more differentiated weighting method is needed to avoid this. For this purpose, three objective rank-based weighting methods are introduced, which can be used instead of equal weighting for calculating SDG contribution scores. An illustrative example is used to examine their impact on the contribution scores. In addition, the influence of the applied weighting methods is analyzed for different technologies to identify the extent to which technology-specific weighting methods are required.

The intended contribution to the scientific literature is twofold: First, we seek to determine the impact of alternative weighting methods on the calculation of the SDG contribution scores. For this purpose, we introduce and apply three rank-based weighting methods instead of equal weighting in the calculation procedure of the SDG contribution score. Second, we seek to derive insights regarding the impact of weighting methods on the SDG contribution scores of different technologies. Therefore, we calculate the SDG contribution scores for several technologies and investigate whether a technology-based weighting method is required.

The remainder of this article is structured as follows: The general approach for calculating the SDG contribution scores and the alternative weighting methods are introduced in Section 2. The SDG contribution scores resulting from using the alternative weighting factors for different technologies are analyzed in Section 3. In Section 4, the main findings of this article are discussed, and a conclusion and outlook are provided in Section 5.

2. Methods and materials

2.1. Approach for calculating the SDG contribution scores.

Our developed approach for calculating SDG contribution scores is based on the LCSA procedure according to ISO 14040/14044 standards [17]. The most important extension is the integration of a new phase, "*Evaluation of contribution to SDGs*", which follows the impact assessment. Furthermore, smaller extensions are needed in the upstream phases of the LCSA. In this context, a benchmark product is defined in the goal and scope definition phase, which relates to a state-of-the-art product. This benchmark product is analyzed and assessed in the same system boundaries, and inventory data is collected. In the new evaluation of the contribution to SDGs phase, the impact scores of each product alternative are compared to the impact scores of the benchmark in the first step, and the relative performance in the impact categories related to the same SDG are aggregated in the second step. In the following, the focus is exclusively on calculating the SDG contribution scores. Further information on the method can be found in our article [17].

We use the following notation in our calculation approach: The investigated product alternatives are described using the index $p = 1, \dots, P$ with $p = 0$ being defined as the benchmark. The index $i = 1, \dots, I$ represents the investigated SDG, and the index $h = 1, \dots, H$ is used to describe the LCSA impact categories. A set L_i of LCSA impact categories is used to characterize each SDG i, and $y_{p,h}$ represents the calculated impact scores for product p and impact category h.

The SDG contribution score $s_{p,i}$ of product p to SDG i is calculated via the weighted sum of the relative performance of the product compared to the benchmark (see Eq. (1)). The sum is taken over all impact categories h that are used to characterize the SDG i with the weighting factor $w_{h,i}$:

$$s_{p,i} = \sum_{h \in L_i} w_{h,i} \cdot c_{p,h}(y_{p,h}) \quad (1)$$

$c_{p,h}(y_{p,h})$ is the performance function, which describes the relative performance of a product p compared to the benchmark ($p = 0$) in terms of the impact score $y_{p,h}$. If the relative performance of the product equals the benchmark, it is defined as zero. If the relative performance deviates from zero, a case distinction must be made (see Eq. (2)): It is positive if the product's performance is better than the benchmark and negative if the performance is worse than the benchmark.

$$c_{p,h}(y_{p,h}) = \begin{cases} \frac{y_{0,h} - y_{p,h}}{y_{0,h}} & \text{, if smaller } y_{p,h} \text{ are preferable} \\ \frac{y_{p,h} - y_{0,h}}{y_{0,h}} & \text{, if larger } y_{p,h} \text{ are preferable} \end{cases} \quad (2)$$

The initial approach used equal weighting factors $w_{h,i}$ in Eq. (1). They are defined as $w_{h,i} = \frac{1}{|L_i|}$.

While equal weighting is one of the simplest weighting approaches, it allows for undesirable compensation of positive and negative contributions in different impact categories. Therefore, more differentiated weighting methods are required.

2.2. Alternative weighting methods

In the scientific literature, there are various approaches to determining weights in the presence of multiple criteria (e.g., [18,19]). However, these approaches are highly subjective and can usually be implemented with decision-makers interaction. More objective approaches to determining weights are rank-based methods. These are well-suited if there is missing or incomplete information about preferences [20]. This is also true for the described situation, where no information on preferences regarding the impact categories used to characterize the SDGs is available. For this purpose, three rank-based weighting methods that could be used instead of equal weighting are presented below: 1.) Rank sum weight method, 2.) Reciprocal weight method, and 3.) Rank-order centroid weight method. The notation for formulating the weighting methods follows the original model notation [17], presented in Section 2.1.

The first weighting method is the *rank sum weight method* (RS). This method is based on the initial idea that the weights are determined based on the individual ranks normalized by dividing them by the sum of all the ranks [20,21]:

$$w_{h,i} = \frac{|L_i| - r_{h,i} + 1}{\sum_{k=1}^{|L_i|}(|L_i| - r_{k,i} + 1)} \quad (3)$$

r describes the rank of the impact category, where $r_{h,i}$ is the rank of the addressed impact category with regard to SDG i.

Another weighting method is the *reciprocal weight method* (RP). Here, the reciprocal of the rank is normalized by dividing it by the sum of all reciprocals [20,21]:

$$w_{h,i} = \frac{\frac{1}{r_{h,i}}}{\sum_{k=1}^{|L_i|}\left(\frac{1}{r_{k,i}}\right)} \quad (4)$$

The third weighting method is the *rank-order centroid weight method* (ROC). The weight is calculated based on the idea of identifying the centroid of all possible weights maintaining the rank order of objective importance, which minimizes the maximum error of each weight [20,22]:

$$w_{h,i} = \frac{1}{|L_i|} \sum_{k=h}^{|L_i|} \left(\frac{1}{r_k}\right) \quad (5)$$

In addition, three aspects are relevant for determining the weights and linking them with our initial approach. First of all, the calculation of the weighting factors is carried out based on the benchmark product and the impact category in which the worst relative expression and, thus, the highest reduction potential exists, is assigned the highest rank, i.e., the highest importance. Second, since the impact categories are not comparable in principle, a normalization within each impact category based on the maximum must be carried out beforehand. Third, suppose the normalization based on the maximum results in indifference, and the same rank is assigned twice. In this case, to allow the calculation of weighting factors whose sum is not greater than one, a higher rank must be assigned to one product alternative and a lower rank to the other. The higher rank is assigned to the impact category for which the difference between the maximum and minimum, and thus the reduction potential, is the greatest.

2.3. Fundamentals of the case study

To examine the influence of different weighting factors on the SDG contribution scores, these are calculated for SDG 12 ("*Climate action*") as an example. SDG 12 can be characterized by three LCSA impact categories [17], which are presented in Table 1. The impact categories are based on the ReCiPe Midpoint (H) V1.13 method [23] and the Social Hotspots Database [24]. These are the environmental impact category, climate change (CC), and the two social impact categories, risk of non-communicable diseases (RNCD) and risk of occupational injuries and deaths (RCID).

Table 1. Environmental and economic impact categories

Dimension	Impact category	Unit
Environmental	Climate change	kg CO_2-equivalents
Social	Risk of non-communicable disease	Medium risk hour equivalents
	Risk of occupational injuries and deaths	Medium risk hour equivalents

Data from our previous study are used to calculate the SDG contribution scores and to allow for a comparison with the

Table 2. Environmental and social assessment results of the four LiS-ASSBs and four fuel alternatives, as well as their benchmarks

Impact category	Unit	Per 1 kWh pack capacity					Per 100 passenger kilometer traveled				
		Benchmark	*LiS-ASSB[Ge]*	*LiS-ASSB[Si]*	*LiS-ASSB[Sn]*	*LiS-ASSB[Cl]*	*Benchmark*	*Biokerosene*	*Syn. kero-sene(PEM)*	*Syn. kero-sene(SMR)*	*Syn. kero-sene(SOE)*
CC	kg CO_2-eq.	64.27	65.29	56.63	51.84	56.57	15.79	10.12	1.53	14.06	6.17
RNCD	Medium risk hour eq.	1329.64	1175.83	176.89	154.17	145.57	7.86	3.39	11.39	2.54	8.58
RCID	Medium Risk hour eq.	163.19	140.42	26.14	23.19	22.76	1.68	0.76	2.53	0.54	1.90

initial results [17]. The subjects of the study were different lithium-sulfur all-solid-state batteries (LiS-ASSBs). The LiS-ASSBs differ in terms of the solid electrolyte, which is based on germanium (Ge), silicon (Si), zinc (Sn), and chlorine (Cl). The choice of solid electrolytes leads to different specific energies. A state-of-the-art lithium-sulfur battery is used as the benchmark product.

In order to investigate whether the weighting factors lead to different results for different technologies and whether technology-specific weighting factors are required, data from another previous study are used, in which different types of fuel for aircraft were investigated [25]. These are bio-kerosene as well as three different types of synthetic kerosene. The feedstock of the synthetic kerosene is hydrogen which is produced using three different pathways: proton-exchange membrane electrolysis (PEM), steam methane reforming (SMR), and solid oxide electrolysis (SOE). Conventional fossil kerosene is used as the benchmark.

For the impact assessment, the previously mentioned methods of the ReCiPe Midpoint (H) V1.13 method [23] for the environmental impact assessment and a risk-oriented method related to the Social Hotspots Database for the social assessment [24] were used. The calculation model for the inventory analysis and impact assessment is implemented in Python using the Brightway2 framework [26]. The results of the sustainability assessment can be obtained from Table 2. They are scaled to 1 kWh pack capacity for the batteries, and 100 passenger kilometers traveled for the fuels.

Based on the sustainability assessment results, the weights for CC and the two social impact categories, RNCD and RCID, can be determined using the four weighting methods. The weights for the batteries and fuels are shown in Table 3.

Table 3. Sustainability assessment results

	Equal weighting		Rank sum weighting		Reciprocal weighting		Rank-order centroid weighting	
Impact category	*Battery*	*Fuel*	*Battery*	*Fuel*	*Battery*	*Fuel*	*Battery*	*Fuel*
CC	0,33	0,33	0,16	0,5	0,18	0,54	0,11	0,61
RNCD	0,33	0,33	0,50	0,33	0,54	0,27	0,61	0,27
RCID	0,33	0,33	0,33	0,16	0,27	0,18	0,27	0,11

3. Results

The SDG contribution scores are calculated based on the sustainability assessment results (see Table 2), and the weighting factors are calculated using different weighting methods (see Table 3). The resulting SDG contribution scores are shown in Figure 1.

In terms of batteries, it can be seen that the SDG contribution score of SDG 12 increases by using rank sum weighting, reciprocal weighting, and rank-order centroid weighting instead of equal weighting. While the contribution score for LiS-ASSB[Sn] is 65% when equal weighting is used, it increases to 76% for rank sum weighting, 75% for reciprocal weighting, and 80% for rank-order centroid weighting. This is mainly due to three aspects: 1.) The relative impact of risk of non-communicable disease is the highest, and thus reduction has the highest priority. Accordingly, this impact category is weighted the highest. 2.) As seen in Table 2, the highest weight of the alternative weighting methods is always higher than that of the equal weighting. Accordingly, the impact category with the highest reduction potential is always weighted more heavily than with equal weighting. 3.) The deviation of the impact scores between the batteries and the benchmark within the impact categories is very high, resulting in a very high relative performance of the battery alternatives. A high weighting multiplied by a high relative performance ultimately results in a higher SDG contribution score. This is also shown in Figure 1, where the relative contribution of risk of non-communicable disease to the overall SDG contribution score increases by using the alternative weighting methods compared to equal weighting. Regardless of the weighting method used, LiS-ASSB[Sn] has the highest SDG contribution score, and the order of the batteries in terms of the highest SDG contribution score does not change.

Concerning fuels, the situation is different. While the SDG contribution score changes positively with respect to two fuel alternatives due to the weights resulting from the alternative weighting methods, it decreases for the other two fuel alternatives. For biokerosene, it is still 49% using equal weighting but then decreases to 46%, 45%, and 44% using rank sum weighting, reciprocal weighting, and rank-order centroid weighting, respectively. Similar results can be observed for synthetic kerosene (SMR). In contrast, the SDG contribution score for synthetic kerosene (PEM) is -2% when using equal weighting but then increases to 22%, 28%, and 37% when using the alternative weighting methods. A similar increase also occurs to synthetic kerosene (SOE). The main driver, in this case, is the impact category of climate change, which has the highest weighting factor. The relative share of climate change in the overall SDG contribution score increases accordingly by using the alternative weighting methods compared to the equal weighting. In contrast to the batteries, the deviation of the impact scores between the fuel alternatives and the benchmark is highly variable within the impact categories, which means that the relative performance is sometimes very high and sometimes very low or even negative. In this case, this can lead to a negative SDG contribution score becoming positive. Regardless of the weighting method used, however, biokerosene continues to have the highest SDG contribution score, but the order of the highest SDG contribution score changes behind it. Using alternative weighting methods could thus lead to different recommendations for action being derived.

4. Discussion

Overall, the analysis shows that using alternative weighting methods instead of equal weighting influences SDG contribution scores, and the SDG contribution score increases or decreases. In the example considered, the same product alternative always has the highest SDG contribution score, regardless of the selected weighting method. However, the order of the product alternatives behind it changes concerning the highest SDG contribution score. Accordingly, different recommendations for action would be given, depending on the weighting method applied. However, determining the most suitable weighting method in each case requires further research.

Integrating these more sophisticated weighting methods extends our original approach and helps mitigate compensation of positive and negative contributions in different impact categories.

However, this analysis results in some uncertainties. Alternative objective weighting factors were used instead of equal weighting to calculate the SDG contribution scores for multiple impact categories. This was done to prevent subjective perceptions of the importance of individual impact categories from influencing the determination of weights. However, it may make sense at this point to involve experts for the particular SDGs and determine the weights in cooperation with them. The experts could better assess the importance of individual LCSA impact categories for achieving SDGs and thus enable a more well-founded determination of the weights. At the same time, transparent disclosure of these aspects can strengthen trust in the methodology and the resulting recommendations for action.

Another key aspect is the integration of multi-criteria decision-making (MCDM) models. The LCSA impact categories used to characterize the SDGs are multiple criteria that are not, or only to a limited extent, comparable and, in some cases, conflict with each other. The integration of MCDM models lends itself to this case and can further improve the method.

A final aspect is applying the method for calculating SDG contribution scores to further products and technologies as well as other SDGs. The insights gained in this article are based on the analysis of two product groups and one SDG. In order to be able to derive generally valid statements and recommendations for action, it is necessary to calculate the SDG contribution scores for other product groups and SDGs as well. This will show whether a product alternative always has the highest SDG contribution score, regardless of the weighting method used, or whether product-specific weighting factors are required.

5. Conclusions and Outlook

The study provides insights into the calculation of the contribution to SDGs achievement when using different weighting methods and extends our initial calculation approach. Here, the analysis shows that the use of alternative weights changes SDG contribution scores. However, the same product always has the highest SDG contribution score,

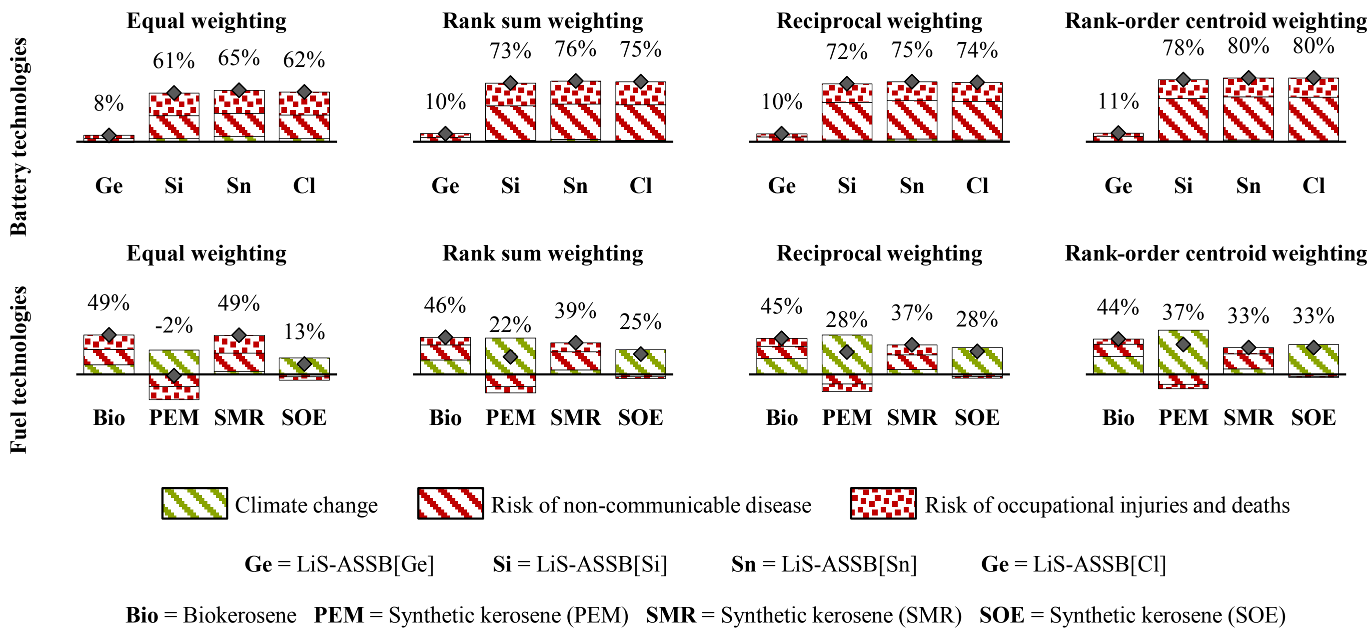

Figure 1. SDG contribution scores for different battery and fuel technologies using alternative weighting methods

regardless of the weighting method chosen. Nonetheless, the recommendations for action with regard to the total product alternatives would change depending on the weighting method. The findings obtained in this study extend the literature on determining the contribution of products and technologies to achieving SDGs and represent an extension of our original approach.

In future research, five aspects should be focused on: 1.) the integration of experts in the process of determining the weights in the SDG contribution score calculation, 2.) the incorporation of MDCM models in the calculation approach, 3.) the determination of the best suitable weighting method in each case, 4.) the analysis of further product groups and technologies, and 5.) the integration of more SDGs.

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