Normalization and weighting methods for precise and standardized sustainability assessment: recent practices in manufacturing

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Normalization and weighting methods for precise and standardized sustainability assessment: recent practices in manufacturing

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Abstract. To address the challenges of sustainable manufacturing, precise, transparent and standardized sustainability assessment is essential. In this regard, normalization and weighting approaches are key tools to improve the precision, transparency and robustness of sustainability assessment efforts. However, mostly, the available literature on sustainability assessment discusses less about normalization and weighting. Moreover, previously, most of the related sustainability assessment and review studies were based on normalization and weighting for life cycle assessment (environmental dimension) only. Thus, this paper aims to present the recent status quo of normalization and weighting practices for sustainability assessment in manufacturing. Unlike previous review studies, this paper includes all three dimensions of sustainability (environment, economy and society). In order to achieve this objective, recent sustainability assessment studies (published in last 10 years) were reviewed and analyzed, from normalization and weighting viewpoints. The results showed that a majority of the reviewed studies which considered all three dimensions of sustainability were based on internal normalization. In contrast, the environmental assessment based studies were mostly grounded on external normalization. In addition, most of the reviewed studies considering all three dimensions of sustainability were concerned with normalization of input and/or output indicators, whereas environment based studies were mostly normalized for impact indicators. For weighting purposes, the analytic hierarchy process method was used most commonly, whereas the Delphi method and others were less frequently employed. Overall, more future work is required to increase awareness and usage of normalization and weighting methods for sustainability assessment in manufacturing.

1. Introduction

Manufacturing activities and products affects all three dimensions of sustainability; environment, economy, and society throughout their entire life cycle [1]. In order to evaluate and improve the performance,

sustainability assessment is undertaken to support decision-making [2]. However, less literature is focused on how to make sustainability assessment efforts more precise, transparent, and standardized (comparable). Along with other reasons, the use of different and inconsistent normalization and weighting methods lead to differences and uncertainties in sustainability assessment results [3-5]. Moreover, most of the available literature on sustainability assessment discusses less clearly about normalization and weighting [3, 6], which makes it difficult to compare the results of different studies [7].

Due to inconsistent units of measurement, the data gathered for different indicators are not summed up together directly [8]. Resultantly, various normalization approaches are used which convert physical measurements into dimensionless scores. In this way, it increases the comparability of sustainability data and results, by transforming data into a compatible or comparable unique scale [3, 9]. Normalization is usually followed by weighting when relative importance of indicators or impact categories is needed [10]. If one indicator is more "important" than another, the former is assigned a higher weight than the latter [11]. Though, both normalization and weighting processes are challenging and complex tasks, they are crucial for more precise and more standardized sustainability assessment.

Previously, environment was the only concern for sustainability assessment studies which were normally based on life cycle assessment (LCA), etc. Because of this fact, most of the related review articles were also founded on normalization and weighting for LCA [5, 9, 10, 12]. However, the triple bottom line (TBL) concept of sustainability [13, 14] requires to consider all three aspects of sustainability, comprehensively. Moreover, previous studies were based on general discussions, whereas no study has reported the significance and application of normalization and weighting methods from the manufacturing viewpoint. Thus, this paper presents the review of these methods for sustainability assessment in manufacturing, from the TBL viewpoint. The objective is to present the status quo of normalization and weighting practices along with highlighting the usefulness of these approaches for more precise and more standardized sustainability assessment. For this purpose, sustainability assessment studies for manufacturing (published from 2009 to 2019) were reviewed and analyzed.

2. Review of normalization and weighting methods

Before presenting the review of various normalization and weighting methods, various related tools used in these studies are briefly described. Life cycle assessment (LCA) is used to assess the environmental burdens associated with a product, process, or service, etc. [15, 16]. The Eco-indicator 99 (H) V2.05/Europe EI 99 H/A method belongs to damage oriented impact assessment or endpoint methodologies (damage caused directly to human health, ecosystem and resources) [15], whereas the ReCiPe is a method used for both mid-point and end-point impacts' assessments [17].

Analytic hierarchy process (AHP) is especially suitable for complex decisions which involve the comparison of decision criteria (indicators) that are difficult to quantify. This gives a weighting for each criterion within a cluster (or level of the hierarchy) [18]. The Delphi method is effective in achieving consensus when there is uncertain information [19, 20] and identifying, selecting and validating factors and indicators [21, 22]. The reviewed studies were based on various types of indicators, such as input inventory indicators (material used, water used, energy used, etc.), output inventory indicators (emissions to air, emissions to water, etc.), and impact categories (midpoint, endpoint, etc.). The review of various normalization and weighting methods for sustainability assessment studies is presented in Table 1.

Table 1: Normalization and weighting methods for sustainability assessment in manufacturing

No.	Description of study	Normalization and weighting approaches	Reference
1	This research was based on sustainability evaluation, while considering technical, economic and environmental aspects for automotive coating technologies. The assessment was grounded on various input and output inventory indicators, along with some impact categories. However, the social dimension of sustainability was missed.	External normalization was done only for the environmental impacts that were based on the Singapore's population data, while using Eco-indicator 99 as an impact assessment method. The domain experts provided the relative importance (weight) of each indicator (criterion) and the weights were presented on a scale from 0 to 10. However, no details were provided on how these weights were calculated.	[23]
2	This study was based on the life cycle assessment (LCA) of a food manufacturing industry while including all life cycle phases.	LCA based impact categories were externally normalized. Normalization results were based on CML 2 baseline 2000 and Eco-indicator 99 (European	[15]

	The highest environmental burdens turned out to be from food ingredients and solid waste. However, economic and social dimensions were ignored.	data) as the reference points. The normalization was undertaken for both midpoint and endpoint impact categories. However, weighting of indicators or impact categories was not discussed.	
3	A methodology was developed for establishing Product Sustainability Index (ProdSI) for manufactured products based on all three dimensions of sustainability. It was tested for a fictitious case study while using equal weights.	Internal normalization was applied to convert measured data into dimensionless scores on a scale from 0 to 10. The score of 10 represents the best case and 0 shows the worst scenario. Only the input inventory related indicators were normalized.	[8]
4	This study reported the indicators based sustainability assessment approach for discrete manufacturing processes (grinding) while including all three dimensions of sustainability. The analysis was conducted for a quick comparison between different process variants.	The input and output inventory indicators were internally normalized whereas the impact categories were not discussed. Indicators were ranked based on degree of fulfillment from 1 to 10. The weights of the indicators were assigned in terms of percentage of their relevance, where all weights of the indicators add up to 100%.	[6]
5	LCA of wheat gluten powder and derived packaging film was reported in this paper. Results showed that the impacts of the wheat cultivation and gluten drying phase are significant in the ReCiPe midpoint assessment method.	External normalization of LCA based impact categories was undertaken. ReCiPe method was used for this purpose which was based on European data as a reference point. Normalization was conducted based on the percentage contribution of impact categories.	[24]
6	The LCA of cheese manufacturing was conducted in the USA, which overlooked the economic and social dimensions of sustainability. The results showed that aquatic ecotoxicity has the largest relative impact.	Impact categories which were measured through LCA were normalized with external reference. The reference data were based on the Impact 2002+ US midpoint assessment framework.	[17]
7	The paper was based on sustainability assessment for small-scale manufacturing: caddisfly jewelry production. All three dimensions of sustainability were included in order to investigate the performance of two manufacturing strategies.	Internal normalization was undertaken in which indicators were normalized in the form of a percentage. Both input and output inventory based indicators were included. However, the impact categories were not included. No weights were assigned to the indicators.	[25]
8	Sustainability indicators were used for finishing operations (material removal category) in order to assess the performance. All three dimensions of sustainability were considered along with quality as a fourth aspect.	Both input and output inventory based indicators were normalized. The approach was based on internal comparison of indicators. Normalization helped to plot indicators with different units in the same curve. The performance was normalized on a scale between 1 and 10.	[26]
9	The study reported the assessment for a production work cell while conducting impact assessment of all three dimensions of sustainability. The approach was tested for a representative machining work cell producing stainless steel knives.	Social impacts were normalized by evaluating the difference in performance and local standard. The endpoint approach (ReCiPe) was used to normalize impacts. For weighting, both an objective statistical method and subjective pairwise comparisons (AHP method) were used. Experts ranked indicators' weights from 1 to 9 and normalized them from 0 to 1.	[27]
10	The sustainability index of manufacturing was calculated at organizational and operational levels for a plastic manufacturing firm by using fuzzy analytic hierarchy process (fuzzy AHP). All three dimensions of sustainability were included for input and output indicators.	Input and output indicators were internally normalized on a scale from 0 to 10. A high score means that the company has a relatively higher performance. For weighting, a group of experts rated each indicator on a scale of 1–10 in the context of the fuzzy AHP methodology.	[28]
11	This study reported the sustainability assessment of manufacturing processes of boiler, requiring less detailed data, time, and expert knowledge. Indicators of all three dimensions of sustainability along with technological aspects were included for comprehensive assessment.	Indicators were assigned performance scores by the experts based on a 5-point Likert scale, which were later normalized on a scale from 0 to 1. It was an internal normalization which was based on an internal comparison.Weights of indicators were assigned using the AHP method on a scale from 1 to 9.	[29]
12	This research developed an integrated sustainability assessment method that includes both stochastic and fuzzy uncertainties for the Malaysian food manufacturing industry. It considers both quantitative and qualitative indicators for all three dimensions of sustainability.	Industry data were collected for all input and output inventory indicators. These data were normalized internally on a scale from 0 to 1. For weighting purposes the Delphi method was used in which experts ranked the indicators based on a Likert scale. The weights were calculated on a scale from 0 to 1 for all indicators.	[30]

3. Analysis and Discussion

An analysis of the reviewed studies is presented in Table 2. Table 2 shows that comparatively the sustainability assessment studies were more focused on the environmental dimension of sustainability than the social or economic dimension. With respect to internal or external normalization, an interesting fact was observed. Except for [27] which was based on all three dimensions of sustainability and used external reference for normalization, all TBL based studies were grounded on internal normalization. For internal normalization, the performance data of an indicator were internally compared with the performance of other indicators. However, all the reviewed studies which were concerned with environmental assessment only, were based on external normalization.

The reason for this might be comparatively, external reference data were more readily available for environmental assessment, but they were normally not available for economic and social assessments. From the viewpoint of indicators' type, most of the TBL based reviewed studies were based on normalization of input and/or output indicators. However, the environment based assessment studies were generally normalized at the impact indicator level. In addition, with respect to normalization, comparatively the normalization scale from 0-1 and 0-10 were used more frequently than the other scales.

From the weighting viewpoint, several reviewed studies used the AHP method to assign weights to indicators. Only two reviewed studies employed the Delphi method and/or consultation approach in order to assign weights to indicators. Overall, not all the reviewed studies used weighted indicators. There were various reviewed studies which did not consider the weighting scheme (equal or not equal). Additionally, in the reviewed studies, four different scales (0-1, 1-9, 1-10 and percentage) were used for weighting of indicators. However, from the repeatability and consistency viewpoint, no scale was used more than twice.

Table 2. Analysis of reviewed studies for normalization and weighting methods

No.	Reference	Sustainability dimensions			Normalization									Weighting									
					Reference point		Type of indicators			Scale				Approach		Scheme		Scale					
		Environment	Economy	Society	Internal	External	Input	Output	Impact	0-1	0-10	Percentage		Delphi method	Consultation/ AHP based	Equal	Not equal	0-1	1-9	1-10	Percentage		
01	[23]	√	√			√			√					√			√			√			
02	[15]	√				√			√														
03	[8]	√	√	√	√		√				√					√							
04	[6]	√	√	√	√		√	√									√				√		
05	[24]	√				√			√			√												
06	[17]	√				√			√														
07	[25]	√	√	√	√		√	√															
08	[26]	√	√	√	√		√	√			√												
09	[27]	√	√	√		√	√	√	√	√					√		√		√				
10	[28]	√	√	√	√		√	√			√				√		√			√			
11	[29]	√	√	√	√		√	√		√					√		√		√				
12	[30]	√	√	√	√		√	√		√				√			√	√					
Total frequency		12	9	8	7	5	8	7	5	3	3	1		2	3	1	6	1	2	2	1		

Overall, for sustainability assessment in manufacturing the normalization and weighting approaches are not clearly described and commonly used and their usage is quite inconsistent. This inconsistent and infrequent usage of normalization and weighting methods in manufacturing, in a way pinpointed various challenges to achieve precise, transparent and comparable sustainability assessment. There is still considerable discussion on how normalization and weighing should be done.

4. Conclusions

Normalization and weighting approaches can play a significant role to make sustainability assessment more precise and more standardized. However, for sustainability assessment based research in manufacturing, these approaches have not been given due attention. So, this study is aimed to highlight the importance of these approaches and present a review of various normalization and weighting methods for sustainability assessment in order to provide a comprehensive analysis and recent picture of normalization and weighting trends and their applications in manufacturing.

This study showed that from the normalization viewpoint, the majority of the reviewed studies were based on internal normalization, especially the studies considering all three dimensions of sustainability. However, the studies based on environmental assessment were mostly grounded on external normalization. This might be because most of the approaches for environmental assessment (LCA, etc.) were more mature and carried external reference data. From the indicators viewpoint, most of the TBL based studies were concerned with normalization of input and/or output indicators, whereas the environment based studies were generally normalized at the impact category level. For weighting, the AHP method was used more frequently than the Delphi or other methods. Overall, more future work is required in order to increase the awareness and usage of normalization and weighting methods to enable more precise and comparable sustainability assessment in manufacturing.

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