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Tsalidis, G.A.

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Type I Social Life Cycle Assessments: Methodological Challenges in the Study of a Plant in the Context of Circular Economy

Georgios Archimidis Tsalidis [1,2,3]

[1] Biotechnology Department, Delft University of Technology, 2629 HZ Delft, The Netherlands; g.a.tsalidis@tudelft.nl
[2] Environmental and Networking Technologies and Applications Unit, Athena—Research and Innovation Center in Information, Communication and Knowledge Technologies, 67100 Xanthi, Greece; gatsalidis@athenarc.gr
[3] Department of Civil & Environmental Engineering, Brunel University London, Uxbridge Campus, Middlesex, Uxbridge UB8 3PH, UK; georgiosarchimidis.tsalidis@brunel.ac.uk

Abstract: Policymakers need to know where the social externalities of products occur in order to act at the macro level. The Social Life Cycle Assessment (S-LCA) method can contribute to the assessment of the social externalities of products; a necessary method supporting the European Union while they transitioning to a circular economy. This study follows the type I approach that explores how the S-LCA results of products manufactured by circular systems can be interpreted. A hypothetical case of industrial water production was designed comprising two product systems: a linear and a circular one. The S-LCA results are calculated using the Subcategory Assessment Method and aggregated or normalized to the number of organizations involved. Furthermore, allocation and weighting were applied to the circular system. The results show that the number of organizations involved in the system boundaries is crucial for the social performance score. Circular systems are expected to comprise more organizations than the existing linear systems. When the results are normalized by the number of organizations, the circular system provides social benefits, but the score values of each involved organization fall outside the score value range of the Subcategory Assessment Method, and they become challenging to interpret. Weighting the contribution of organizations to S-LCA results provides valuable insights, but it is unclear whether it should be performed on characterized inventory data or aggregated results. The application of the type I approach requires development, especially now that the circular economy systems are designed and constructed. The type I approach can be useful to organizations when selecting suppliers, but it is unclear how it can provide useful information to policymakers.

Keywords: subcategory assessment method; reference scale; SLCA; industrial water; social performance assessment; life cycle assessment; social sustainability

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1. Introduction

The circular economy is defined as "a regenerative system that aims to keep materials in a closed loop at their highest value" [1] while providing benefits to the environment, the society, and the economy. In contrast, the linear economy is based on traditional business models where raw materials are collected and transformed into products that consumers use until discarding as waste, with no concern for their ecological footprint or further consequences [2]. The EU aims to transition to a circular economy to make Europe cleaner and more competitive in the World Market. Thus, policymakers need to know where and to what extent the (social and environmental) externalities of products occur in order to act at the macro level [3]. Social Life Cycle Assessment (S-LCA) can contribute significantly to the policy making process by assessing these social externalities [4]. In saying that, social mechanisms continue to be complicated and unclear. This study follows the type I approach to explore how the S-LCA results of products manufactured by circular systems can be interpreted. What is important in this case is to explore whether the type I approach provides information to policy makers to help them achieve a circular economy.

The starting point of S-LCA was in 1993 when the Society for Environmental Toxicology and Chemistry aimed to account for socioeconomic aspects throughout the life cycle of a product [5]. However, the turning point was in 2009, with the publication of the first version of the S-LCA guidelines [6]. Since then, 76 S-LCA studies have been published [5], the *Handbook for Product Social Impact Assessments* was developed with the collaboration of academia and industry [7], and the Guidelines [8] have been updated, but S-LCA is still under rapid development [9]. As the latter one is yet to be standardized, it follows the environmental-LCA (E-LCA) framework [10], and aims to assess a broad range of social impacts within the life cycle of a product according to the six affected stakeholders.

The S-LCA guidelines target the Workers, the Local community, the Value chain actors, the Consumers, the Society, and the Children due to them being the affected stakeholders. It also presents two impact assessment approaches; type I or Reference Scale and type II or Impact Pathway. The type I (Reference Scale) approach aims to describe a product system according to social performance or risk. It assesses the social performance of organizational activities (i.e., practices [11]) in the product system based on the reference points of the expected activity (i.e., performance reference points or PRP) [8]. This approach employs an ordinal scale that is "low-high", "compliant- non-compliant", in order to scale the PRPs. In contrast, the type II approach aims to assess the consequences of a product system based on "cause-and-effect" relations (i.e., social mechanisms) [8]. So far, most studies have applied the type I approach because it is ambiguous how inventory data can be characterized by impact subcategories through social mechanisms [12].

A recent review [13] concluded that the most common approaches to the characterization of type I studies are the evaluations based on best practices and the socioeconomic geographical context. Various researchers [14–16] developed assessment frameworks for type I SLCA and the most widely applied is the Subcategory Assessment Method (SAM) [15]. The SAM uses qualitative, quantitative, and semiquantitative data, and converts them into semiquantitative data according to a PRP; this is called a basic requirement (BR). This way, the SAM compares different data types in a standardized way. It also assesses positive or negative organizational performance at four levels for each impact subcategory based on compliance with the BR and the organizational behavior of the peers.

Table 1 shows 12 studies that applied SAM to various products of the linear economy, such as honey [17,18], milk [19], crude palm oil [12], etc. Among them, only [18] applied the social organizational-LCA, while the other studies applied the S-LCA. Table 1 also shows that most of the practitioners converted SAM levels into score (numerical) values. Ramirez et al. [15] suggested assigning the highest score to the best social performance (A = 4) and decreasing the score value to the worst social performance (D = 1). However, two studies [20,21] flipped SAM's scoring system (i.e., A = 1 and D = 4) to align it with the E-LCA results, where a higher impact score shows a worse environmental performance. Studies that used a numerical scale aggregated the data by impacting subcategories, stakeholder categories, or involved organizations. The former aggregation resulted in investigating the contribution of each involved organization to the social impact or stakeholder category. The latter showed whether the development of the BRs is based on laws or the willingness of the company to comply with the BRs [17]. All studies limited the system boundaries to the foreground organization(s) of the product's life cycle because collecting site-specific inventory data via interviews and questionnaires is time consuming and challenging [17]. There were no studies that applied S-LCA in a manner similar to E-LCA; no study assessed a reference system to compare it with the original under the study system. Therefore, each product was assessed independently and only the BRs can be considered as a "baseline" and provide context to the S-LCA results. The only exception would be do Carmo et al. [22] who applied S-LCA to compare four hypothetical suppliers. In general, these studies did not interpret the nature of the results, except for do Carmo et al. [22], but qualitatively analyzed the national context around them. For instance, Brenes-Peralta et al. [19] described why "Local employment" is relevant to Costa Rican agriculture sector and how it affects other indicators, such as "Social benefits / social security". In contrast, do Carmo et al. [22], recommended a scoring approach to convert qualitative classification levels of subcategory indicators into quantitative performance scores. To conclude this point, no studies considered multifunctional processes in the system boundaries of the S-LCA.

Table 1. Studies using the Subcategory Assessment Method.

Study	Product	Organizations in Boundaries	Scale Type
[12]	Crude palm oil	Five (5)	Alphabetical
[17,18]	Honey	Five (5)	Numerical
[19]	Green coffee	One (1)	Numerical
	Raw milk	One (1)	Numerical
	Leafy vegetables	One (1)	Numerical
[21]	Industrial water	One (1)	Numerical
	Textile	One (1)	Numerical
	Coal	One (1)	Numerical
	Silica	One (1)	Numerical
[23]	Sweater	One (1)	Numerical
[20]	Polyethylene	One (1)	Numerical
[24]	Egg	One (1)	Color-coded
[25]	Tomato	One (1)	Numerical
[26]	Textile	One (1)	Numerical
[22]	Biodiesel	One (1)	Numerical
[27]	Cocoa soap	Five (5)	Numerical

Despite the fact that many circular systems are designed and assessed with E-LCA, no type I S-LCA studies compared a circular system and a linear system that provides the same function. For instance, the type I studies mentioned above considered production systems of the linear economy, while some literature reviews focused on specific methodological S-LCA issues, such as cut-off criteria [28], classification of type I [13] and type II approaches [29], or the application of S-LCA to provide benefits in responsible research and innovation [30]. What is more, review papers that presented the past of S-LCA and its historic evolution did not mention the type I studies of circular economy systems [9,31,32].

This study aims to explore for the first time whether applying the type I S-LCA to assess whether a circular system's results can be absolute (stand-alone) results or results relative to the reference system. A case study inspired by the circular economy was designed, and S-LCA was applied to assess social performance with the SAM, while being based on (1) revenues and (2) working hours.

The results of this study show a step forward in the application of type I S-LCA to circular systems as well as the understanding of how decision makers can consider its results. Thus, this study contributes to the development of the application of the type I approach in SLCA studies on the circular economy.

This is how this study is structured; the second section consists of the methodology, including the goal and scope definition, the life cycle inventory, the assumptions, and the impact assessment. The third section presents and discusses the results of the circular and linear systems and it presents implications. The fourth section presents the limitations of this work, the conclusions, and the recommendations for future research.

2. Methodology

2.1. Case Study

The case study is hypothetical and was used to investigate the interpretation of the S-LCA results. The case study considered an assumptive industrial water production plant (called "linear plant" for the rest of the study) in Rotterdam, The Netherlands, which treats seawater with reverse osmosis. This is a typical linear economic process that consumes electricity and chemicals during operation. The reverse osmosis process produces wastewater that is disposed to the sea. The second hypothetical plant (called "circular plant" for the rest of the study) also produces industrial water and aims to replace the linear plant. The circular plant incorporates circular economy aspects to eliminate the saline wastewater disposal while aiming to recover magnesium at the same time, in the form of magnesium hydroxide. For this purpose, the circular plant employs higher amounts of chemicals and electricity.

2.2. Social Life Cycle Assessment

2.2.1. Goal and Scope

The goal of the case study was to show how methodological choices affect the results calculated according to the type I approach of circular and linear industrial water production in The Netherlands. The system boundaries were cradle-to-gate, i.e., they were limited to the industrial water production organization (called Plant operator for the rest of the study) and its direct suppliers (see Figure 1).

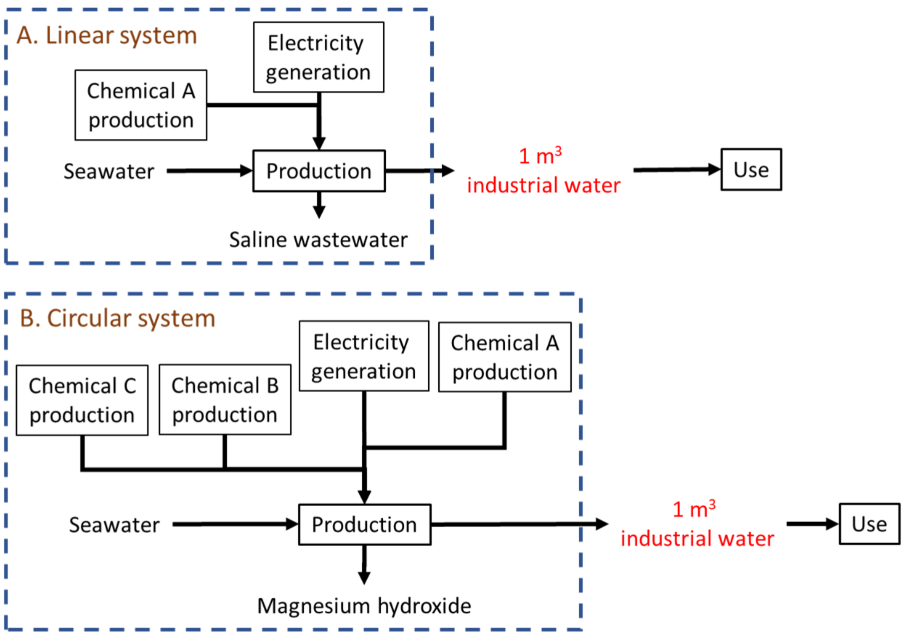

Figure 1. Flow diagram and system boundaries of the (**A**) Linear and (**B**) Circular systems.

The functional unit was 1 m^3 of industrial water. The Local community, the Value chain actors, the Workers, and the Society stakeholder categories were analyzed according to the Guidelines [8]. In total, four stakeholder categories, six subcategories, and 19 impact indicators were investigated (see Table S1). The selection of subcategories (and consequently stakeholder categories) was based on a literature review [33] and an online survey which was directly shared with more than 100 experts, and it was completed by 35 experts from multiple sectors (such as the water sector and the academic sector) [34].

The Guidelines suggest allocating social effects to the product under study when multiple coproducts are manufactured. The Guidelines also mention that performing allocation is not always needed due to the nature and scope of social data. For instance, allocation may be irrelevant when assessing indicators and impacts that are not measured at the product level (e.g., external effects, such as disrespect of indigenous rights, delocalization of local communities, etc.) or organization-wide issues [8]. In this study, two co-products were manufactured in a circular plant. Therefore, the inputs and outputs of the plant were allocated. Economic allocation was selected to handle multifunctionality according to the ISO standard [10] hierarchy for E-LCA. Table 2 presents the economic allocation factors for the circular system.

Table 2. Economic allocation factors for the circular system.

Co-Product	Economic Allocation Factor
Industrial water	30.2%
Magnesium hydroxide	69.8%

Weighting of the characterization results according to an activity variable occurs in S-LCA studies [8]. For instance, organizations that were deemed more important will have greater weights and will contribute more to the impact subcategory results. Even when this step is omitted, an implicit form of weighting is still applied, because all contributing organizations are assumed to be equally important [8]. The weighting factors were calculated on working hours and monetary flows of revenue. The weighting based on worker hours considered how long employees work to produce 1 m^3 of industrial water. Whereas weighting based on revenues was based on how much the suppliers charge the Plant operator for the provision of chemicals and electricity, and how much the Plant operator sells them to consumers. Table 3 lists the weighting factors for linear and circular systems.

Table 3. Weighting factors for involved organizations.

Organization	Factors Based on Revenue	Factors Based on Working Hours
	Linear system	
Chemical A supplier	5.1%	6.0%
Electricity provider	38.0%	22.2%
Plant operator	56.9%	71.8%
	Circular system	
Chemical A supplier	0.8%	1.8%
Chemical B supplier	2.6%	6.0%
Chemical C supplier	23.3%	54.3%
Electricity provider	23.3%	21.2%
Plant operator	50.1%	16.8%

During the design phase of the study, the following assumptions were made:

- Magnesium hydroxide was selected as the coproduct for the circular system. Magnesium is present in seawater at approximately 1300 ppm [35].
- All inventory data were generated with the random function of Microsoft Excel, except for "Local employment" and one indicator of "Public commitment to sustainability issues" of the Plant operator. These data were collected from a study by Tsalidis et al. [21]; these authors regarded an industrial water production plant in the Port of Rotterdam, The Netherlands, which was a good proxy for our study.
- It was assumed that the "working hours per €" of all employed chemicals were the same, even though they were supplied by different organizations.
- Proxy organizations were selected to calculate "working hours per €". These organizations are large and operate in The Netherlands. For electricity generation, EON [36] was selected, for chemical supply, Solvay [37] was selected, and for industrial water production, Evides Industriewater [38] was selected.
- To calculate the "working hours per €" of the electricity provider [36] and chemical suppliers [37], data were collected from annual corporate reports that referred to the entire group and not a specific plant in the Port of Rotterdam, The Netherlands.
- Because saline wastewater is generated by the linear system in the Port of Rotterdam, The Netherlands, it is disposed of in the sea [39].
- Realistic proxy numbers for the amounts of consumables (Table 4) were selected in both systems.
- The SAM score values represent ordinal data. However, they were treated as interval data to apply aggregation and averaging, as with the international literature [17,19].

2.2.2. Life Cycle Inventory

Inventory data for characterization in the impact assessment stage were not collected because of the nature of the case study. Normally, these data are collected from organizations involved through questionnaires and converted to SAM score values according to the BR. In juxtaposition, data for allocation and weighting were collected from the literature (see assumptions, Table 4 and Table S2). The linear system regarded a reverse osmosis plant that employs an antiscalant and electricity. Thus, it consisted of the Plant operator, a Chemical supplier A, and an Electricity provider. The consumables of the linear system were based on Harris et al. [40]. The circular system, although it regarded the same reverse osmosis plant, it expanded the study with processes to treat saline wastewater. Therefore, the latter consisted of the same Plant operator as the former, three chemical suppliers (Chemical suppliers A, B, and C), and the same Electricity provider. To sum up, there are three common organizations between the two systems, but the quantities of consumables differ. Table 4 presents the amounts of consumables and their prices normalized per functional unit.

Table 4. Life cycle inventory (normalized per functional unit).

Consumable/Product	Amount (Unit)	Price (€/Unit)	Reference
	Linear system		
Chemical A	0.03×10^{-3} m^3	8400	[40]
Electricity	6.67 kWh	0.12	[41]
Industrial water	1 m^3	2.5	[40]
	Circular system		
Chemical A	0.02×10^{-3} m^3	8400	[40]
Chemical B	0.02×10^{-3} m^3	18,400	[42]
Chemical C	0.008 m^3	500	[40]
Electricity	15.38 kWh	0.12	[41]
Industrial water	1 m^3	2.5	[40]
Magnesium hydroxide	3.85 kg	1.5	[40]

2.2.3. Life Cycle Impact Assessment

This was a type I study; thus, the reference scale approach was applied to assess social performance using a value scale [8]. SAM was selected for the characterization of data inputs [27]. The SAM includes various data types in a standardized manner and assesses organizational performance at four levels (A, B, C, or D) for each impact subcategory based on compliance with the BR. The SAM score values-per-level was flipped to align them with E-LCA (Table 5). Even though the BRs were not relevant in this hypothetical case study, they were established according to international agreements and industrial context conditions and practices. The impact assessment results (SAM score values) were generated using the random Excel function for each involved organization.

Table 5. Score values by organizational conduct.

Score Values	Organizational Conduct
D = 4	The organization does not comply with the basic requirement in a positive context
C = 3	The organization does not comply with the basic requirement in a negative context
B = 2	The organization complies with the basic requirement
A = 1	The organization has a positive and proactive behavior beyond the basic requirement

2.2.4. Interpretation

The S-LCA results are presented by subcategories. The characterization results were aggregated, averaged, and allocated by subcategories. Two types of weighting factors were used to understand how the S-LCA results of circular (multifunctional) systems should be viewed and presented.

3. Results and Discussion

3.1. Aggregated Results

Figure 2 presents the aggregated results by using subcategories. The circular system consists of more organizations than the linear system. Therefore, if the results are not normalized by the number of organizations, the circular system is expected to result in worse social performance. This would be the case even if all organizations were scored with a score value = 1 (i.e., going beyond corporate responsibility).

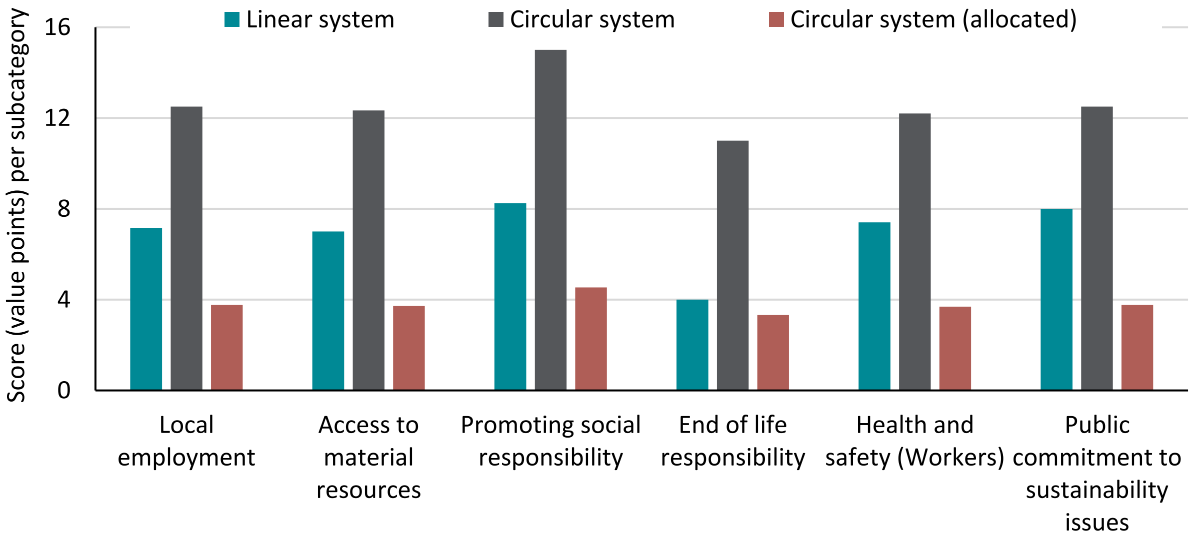

Figure 2. Aggregated results by subcategory.

The SAM suggests a four-level numerical score scale. As a result, the score of the linear system with three organizations ranges between three and 12 points, while the score of the circular system, with five organizations, ranges between five and 20 points. In particular, the difference between the two scores is due to the social performance of the additional organizations (Chemical suppliers B and C) in the circular system. However, the circular system is multifunctional because it comprises a process that produces two products. When the allocation is performed, its aggregated score is reduced to 30.2%. In this case, upon allocation, the score ranges between 3.3 and 4.5, with the latter being above the maximum of the score scale. Therefore, even though the circular system still comprises of more organizations, its performance is divided into its coproducts and performs better than the linear system for all subcategories.

The Guidelines mention that allocation is not always necessary or simple due to the nature and scope of social data [8]. In this study, we applied the type I approach, which assesses social performance due to organizational activities. According to the type I approach, should the inventory data of "Public commitment to sustainability issues", "Promoting social responsibility", and other impacts be allocated by coproduct? The answer lies in the type of data used. Data are qualitative or semiquantitative, i.e., organizational performance cannot be allocated for each coproduct. For instance, if two separate systems, that produce product A and B, were designed from the circular system shown in Figure 1B, the same data would be collected as these two new product systems (A and B) would comprise the same organizations. Therefore, allocation can be considered irrelevant because impacts are calculated organization-wide. In contrast, if part of the circular industrial water plant in Figure 1B can be subdivided by coproduct, then the new production systems (A and B) would consist of different organizations, and allocation (i.e., subdivision) could be relevant.

Aggregating results by subcategory is based on the assumption that the reference scale and the BRs are universal, i.e., other studies will use the same and deem the results of various S-LCA studies comparable as long as the system function is the same. Three studies [20,21,43] considered the BRs of the Methodological Sheets [44], while other studies [12,17,23,25,27] used the BRs according to Ramirez et al. [15].

So far, D'Eusanio et al. [17] aggregated the results by subcategory and organization, while do Carmo et al. [22] aggregated by subcategory and stakeholder category, and Brenes-Peralta et al. [19] aggregated by stakeholder category. Tsalidis et al. [21], D'Eusanio et al. [17], and Brenes-Peralta et al. [19] did not compare the two systems. Instead, they assessed the social performance of one system and identified hotspots that required improvement. Therefore, their results were treated in a standalone form, although they were normalized when SAM was applied. In contrast, do Carmo et al. [22] compared the social performance of four suppliers for decision-making purposes.

To date, without the use of weighting factors, it is assumed that all involved organizations contribute equally. What may happen then is that one organization may end up with the worst social score and have a marginal role in the system; an incident that can lead to it being easily replaced, or even omitted.

3.2. Averaged Results

Figure 3 presents the results of normalization to the number of organizations per product system. In this case, a higher number of organizations will not necessarily result in indifferent social performance in the circular system, but the final score values per organization can be even lower than A = 1. Averaged results can confuse the reader when the latter expects to read the score values based on Table 5. Furthermore, because both systems have three organizations in common, the difference in the results derives from the social performance of the additional organizations of the circular system. For "Local employment", "Access to material resources", "Promoting social responsibility", and "End of life responsibility", the additional organizations (Chemical suppliers B and C) performed worse than the organizations in common (Chemical supplier A, Electricity provider, and Plant operator). In contrast, for "Health and safety (Workers)" and "Public commitment to sustainability issues", the additional organizations of the circular system perform better on average than the organizations resulting in a different conclusion when compared with Figure 2.

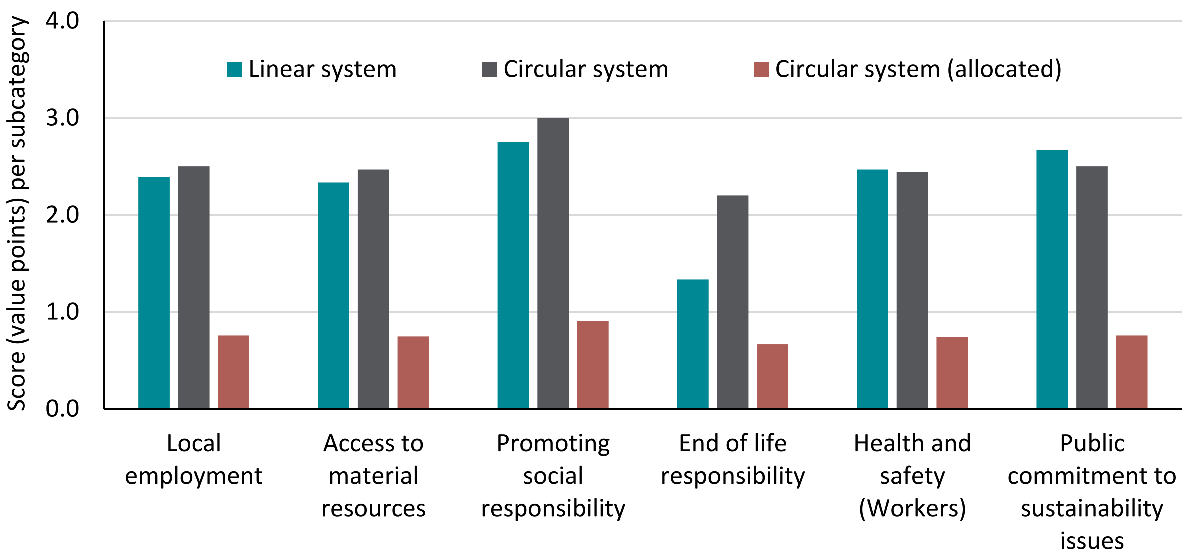

Figure 3. Normalized results by the number of organizations by subcategory.

In the case of the averaged results, allocation can be considered irrelevant because impacts are calculated organization-wide. This is the same concept as in the case of aggregated results because the inventory data was qualitative, it considered the organizational performance, and the impacts were calculated organization wide.

To date, no study has normalized the results by the number of organizations involved in the system boundaries because studies [20–22,24–26] considered only one organization in the system boundaries.

3.3. Weighting Characterized Data and Results

Figure 4 shows the aggregated results when weighting factors are applied to the characterized data of each organization in the circular system. Weighting resulted in an impact score very close to the averaged results (Figure 3) because it was applied to the characterized organizational data which range from A = 1 to D = 4. However, the total value scores are different in Figures 3 and 4. Choosing to apply weighting to the characterized data is based on the assumption that the "real" SAM results are the social performance per organization and subcategory, such as a score of B = 2 for Chemical supplier A for "End-of-life responsibility". In this case, the aggregated value scores change, and the contribution of the organizations involved changes, depending on not only the weighting factors but on the organizations' characterization data as well. For instance, the weighting factors based on working hours for Chemical supplier C and Electricity provider were 54% and 21%, respectively, but in the case of "End-of-life responsibility" their contributions were 71% and 9%, respectively. Therefore, their contribution to the S-LCA results is not necessarily greater than from when assuming equal weights.

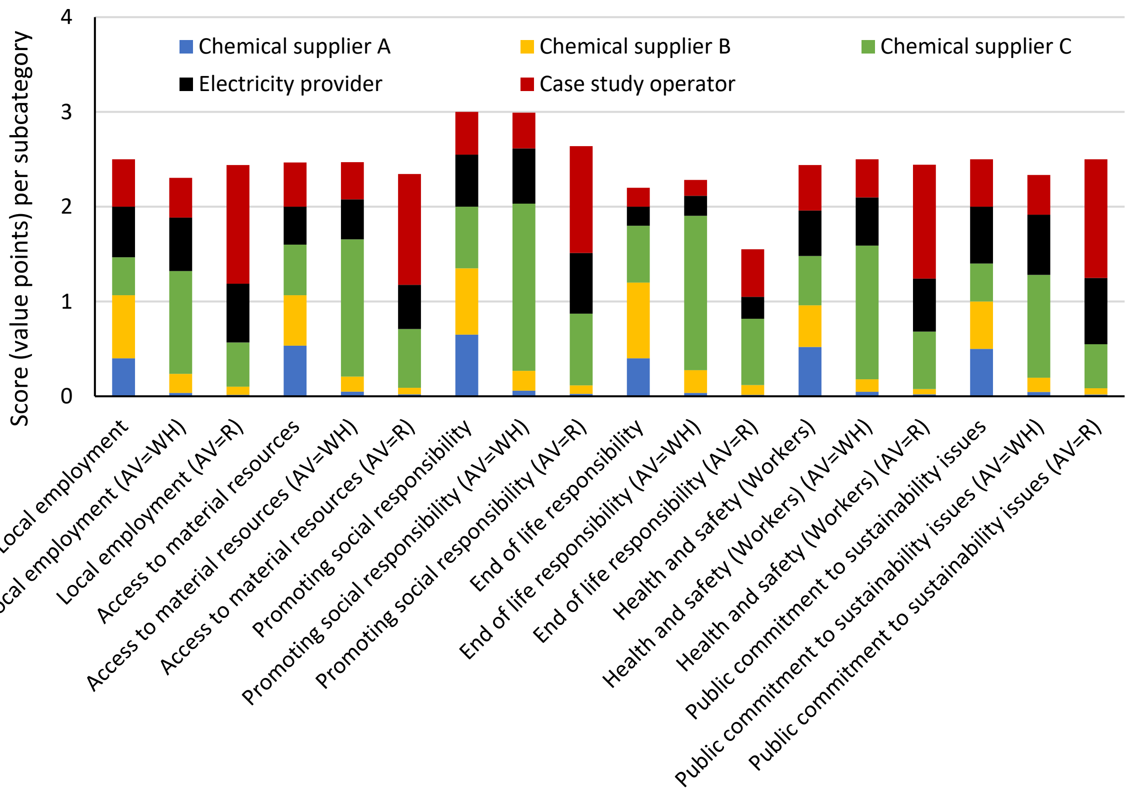

Figure 4. The effect of weighting characterized data per organization involved presented with normalized results, WH = worker hours, and R = revenues.

Figure 5 shows the results when weighting factors were applied directly to the aggregated results by impact subcategory. In this case, the weighting resulted in an impact score very close to the aggregated results (Figure 2). This calculation assumes that the aggregated results by subcategory are the "real" SAM results and should not change after weighting; the aggregated score of 11 for "End-of-life responsibility" for example. That shows that the contributions of the organizations involved depend solely on the weighting factors. For instance, the weighting factors based on working hours for the Chemical supplier C and the Electricity provider were 54% and 21%, respectively. Therefore, their contribution to S-LCA results is greater than from when assuming equal weights.

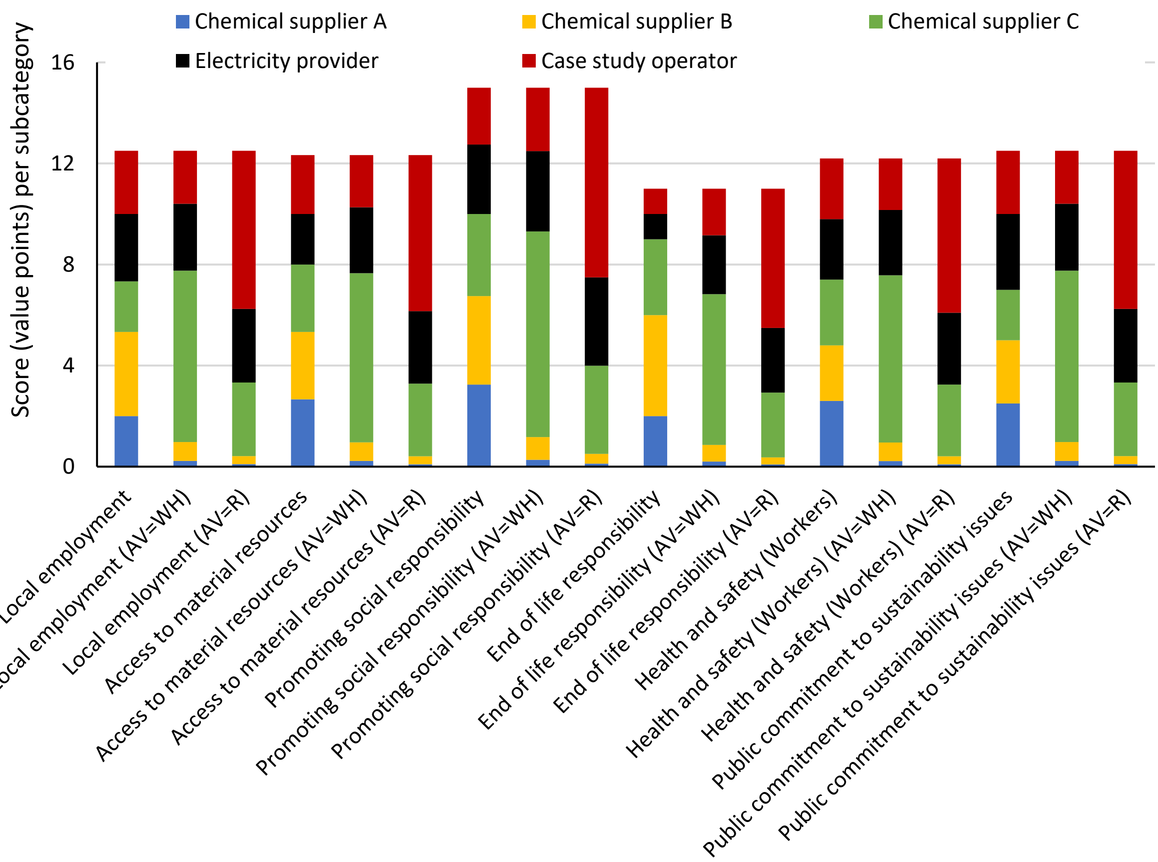

Figure 5. Effect of weighting aggregated subcategory results, WH = worker hours, and R = revenues.

The applications of weighting factors may result in different conclusions concerning the organizations that contribute the most. For instance, concerning "End-of-life responsibility", Chemical supplier C contributes 45% when characterized organizational data are weighed, or 23% when aggregated results by subcategory are weighed. To date, no study has weighted the contributions of organizations as many studies [20–22,24,26] considered one organization within the system boundaries. It is unclear which way to weigh organization performance results is more reliable, but weighing characterized data per organization results in affecting the S-LCA result which is likely to be expected from a weighting procedure.

3.4. Limitations

The results of this study provide added value to the interpretation of type I S-LCA results of circular systems. One limitation of the study is the sources of inventory data. Most of these data were produced randomly, which limited the results' interpretation in terms of suggestions to the Plant operator. Furthermore, SAM score values are ordinal data which in this study were aggregated and averaged, and each impact subcategory was assumed to be weighed equally during aggregation. However, according to do Carmo [22], a linear scale score of SAM values should not necessarily be associated with each classification level of the subcategory indicators.

4. Conclusions

This study aimed to explore whether applying the type I S-LCA to assess a product, manufactured by a circular system, results in absolute (stand-alone) results or results relative to the reference system. For this purpose, a hypothetical case study was designed according to circular economy principles to investigate allocation and weighting.

This study advances existing research on the S-LCA method by discussing several methodological decisions during its application on circular systems. Indeed, this study has an exploratory nature and aims to fill a gap in the literature: the social assessment of products manufactured by circular systems and their reference products manufactured by linear systems with type I S-LCA. Type I S-LCA is suitable for the identification of positive effects and social aspects of products manufactured by circular systems, but type II S-LCA may be more suitable to capture the social benefits upon transition from a linear economy to a circular economy.

A major finding was that it was still unclear how to compare two systems with a large difference in the number of organizations involved according to the type I approach. This aspect is particularly important for assessing the social benefits of circular products for existing products. Thus far, it seems that the type I approach fits better for the decision-making of organizations, such as the selection of suppliers. In this case, allocation or averaging can be irrelevant.

In addition, normalizing impact scores to the number of organizations should be avoided because the final score values can differ from the scale values of the applied impact assessment method, and they also do not show which organizations comply with the PRP/BRs. On the other hand, aggregating characterization results appears straightforward, but in the case of circular systems, allocation needs to be performed. Practitioners should subdivide processes (/organizations) into coproduct systems.

The results of the type I approach can stand alone only when the BRs of the impact assessment method are universal in studies. Therefore, it is recommended to develop universal BRs per region and company size according to international agreements, national regulations, and the best practices to reduce the subjectivity of the results. Lastly, it is recommended to limit type I S-LCA to decision-making on an organizational level and further develop type II S-LCA for policymaking.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142215031/s1, Table S1. Stakeholders, subcategories, and indicators. Table S2. Amount of worked hours for consumables

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Conflicts of Interest: The author declares that there is no conflict of interest.

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