Integration of Life Cycle Sustainability Assessment and Material Circularity Indicator for Circular Business: Case Study of Company XYZ Jakarta

Brigitta Ancelina, Amelia Santoso*, and Joniarto Parung
Industrial Engineering Department, Faculty of Engineering
Universitas Surabaya
Surabaya, Indonesia
s160318007@student.ubaya.ac.id, amelia@staff.ubaya.ac.id, and jparung@staff.ubaya.ac.id

Abstract

Along the years, sustainability concept has been increasingly relevant to tackle the problem of fulfilling the growing human needs with limited resources. Aside from it, Circular Economy (CE) has also been recognized as one of the initiatives to achieve sustainability. As the two concepts expand, researches that bridge both concepts and develop assessment tools keep flourishing. In this context, this research aims to suggest a framework integrating Life Cycle Sustainability Assessment (LCSA) and Material Circularity Indicator (MCI) to produce an aggregate index reflecting all aspects of triple bottom lines and circularity. Moreover, this research intends to implement LCSA for circular business. Literature review was done to build the framework by combining a couple existing methods. Following it, a study case was conducted to implement the framework. The study case's object was Company XYZ in Jakarta, a company leasing silicone containers as a substitute for single use plastic food takeaway packaging. The integrated framework produced single scores for the following aspects: environment (5.231), economy (0), social (0.534), and circularity (0.392). Through normalization and weighting, a final single score ranging from 0 (worst) to 1 (best) was constructed. Using this index, companies can attain easier communication and more straightforward comparison for all triple bottom lines and circularity, making it more convenient to design improvements. All things considered, the framework and index are more suitable for micro scale analysis due to its data intensiveness.

Keywords
Circular Economy, Life Cycle Sustainability Assessment, Material Circularity Indicator, measuring tool, integrated framework.

1. Introduction

As technology advances and human population grows, the human needs to be fulfilled also increases. On the other hand, Earth has a limit to sustain all those needs. According to Global Footprint Network (Lin et al., 2021), human needs 1.7 area of Earth to fulfill its needs in 2021. Earth Overshoot Day 2021 fell on July 29th, which on this very date human's annual needs equal the Earth's restore for one year. The reason why earth is so exhausted is because humans use too much resource too quickly. Humans also exploit nature, dispose a fully-functioning products, and produce many untreated wastes. It can be said the current society heavily adopts the linear economy, which follows the "take-make-dispose" process (Lacy et al., 2020). Linear economy is deemed wasteful and also causes several environmental damages such as climate change, air and water pollution, erosion, and loss of biodiversity (Liu and Ramakrishna, 2021).

Realizing the importance to make a change and innovate to avoid further damage as well as maintaining the earth's existence, numerous initiatives were done and new concepts emerged, including sustainability. Not only focusing on environmental well-being, being sustainable also considers economic and social well-being. These three pillars, better known as triple bottom line or 3P (people, planet, and profit) are connected and reinforce each other (Kuhlman & Farrington, 2010). Other emerging concept is circular economy (CE), the opposite of the unsustainable linear economy. Circular economy attempts to retain product's value and use as high and as long as possible, as well as maintain resource's purity and value (Stahel and McArthur, 2019). It aims to narrow, slow, close, and regenerate materials and energy flows of products and services (Konietzko et al., 2020). With its the advantages, CE is becoming an attractive and viable alternative to actualize sustainable development (Azevedo et al., 2017), making sustainability and circular economy two strongly related concepts. The emergence of sustainability concept in the last decades as well as circular economy has encouraged development and innovations, especially in terms of assessment methods to measure the sustainability and circularity of a product, company, or organization.

The most common sustainability assessment method is no other than Life Cycle Sustainability Assessment or better known as LCSA. LCSA was first formulated by Kloepffer in 2008 with the objective to include economic and social measurement to complement the environmental assessment done through Life Cycle Assessment (LCA). However, all this time LCSA has always been done only with a general guide (Life Cycle Assessment + Life Cycle Costing or LCC + Social Life Cycle Assessment or S-LCA), leading to a wide range of variation and room of improvement to further develop the current LCSA. Moreover, the majority of published LCSA works was implemented in linear businesses because the current LCSA has not yet incorporate circular economy in its framework. For example, Filho et al. (2022) did an LCSA to compare low-income building scenarios in Brazil using LCA, construction cost, community investment value, and multicriteria FAHP (Fuzzy Analytical Hierarchy Process) to compute one sustainability indicator. Bhambhani et al. (2022) also conducted LCSA for water sector resource recovery using LCA and LCC without S-LCA. Another example was shown by Lam et al. (2021) who did LCSA to compare several wind turbines by using LCA, LCC ISO 15686-5, and UNEP/SETAC 2009 framework, in addition to combining the three assessment results to one aggregate value.

The small number of LCSA for circular business provides a research gap to implement LCSA in a more circular setting. To do so, LCSA needs to be adjusted, one of the ways is to integrate it with one of the most widely used circularity assessment tool, Material Circularity Indicator (MCI) that was developed by Ellen McArthur Foundation in 2015. Another way is to adjust the three LCSA assessment tools to CE. Among the three assessment frameworks, LCA is broadly acknowledged (the same goes to S-LCA which has similar framework as LCA), while for economic aspect, there has been no LCC model that is agreed upon as the standard in industrial sector (Bradley et al., 2018), let alone a model that incorporates circular economy and its strategies. Hence, to consider the CE concept and the Value Retention Processes (VRPs) involved in the value creation process to observe the trade-off between cost and the possible gain from enforcing CE, Wouterszoon Jansen et al. (2020) developed the CE-LCC (Circular Economy Life Cycle Costing) specified for building components, which is the expansion of conventional LCC that accommodates the CE strategies and VRPs.

Looking at the connection between sustainability and CE, although sustainability and CE are two related concepts, the relationship between the two is still ambiguous and underexplored (Kristensen & Mosgaard, 2020; Pauliuk, 2018; Verstraeten-Jochemsen et al., 2018) and there are only a few indicators that measures CE and the three pillars of sustainability at once (Kirchherr et al., 2017). That being said, a framework and indicator that measures both triple bottom line and circularity is also needed to enable more straightforward communication and decision-making process. According to the explained reasons, it is necessary to implement LCSA in circular economy setting to illustrate the connection between sustainability and circular economy in conjunction with carrying out assessments that aligns well with the circular strategies.

The advancement of sustainability and circular economy is also reflected by the growing number of circular businesses, one of them is Company XYZ in Jakarta, Indonesia. Company XYZ provides circular food packaging to encourage the transformation to circular economy as well as to minimize the use of single use plastic that eventually leads to smaller environmental impact. Established in 2021, Company XYZ has the aim to decrease the usage of single use plastic especially in the food and beverage industry by working together with food merchants and substituting the takeaway plastic containers with silicone food containers. Customers can borrow the silicone container, wash the container once used, and contact Company XYZ to return the container. Besides being used multiple times by multiple users, the silicone container can also be recycled at the end of its life cycle. Based on the circular business scale, Company XYZ is a suitable object for the study case to test and validate the proposed framework and indicator.

1.1 Objectives

Based on the described research gap, this research has the goal to implement LCSA for circular business and to develop LCSA to better suit the circular economy concept by considering the circularity assessment through (MCI), adjusting LCA to material circularity and circular strategies, and using CE-LCC instead of conventional LCC. Besides that, this research also intends to build an aggregate indicator that measures the triple bottom line of sustainability as well as circularity by normalizing the results from LCSA and MCI to attain easier communication and decision-making process.

2. Methods

This research implements LCSA in circular business by adjusting LCA ISO 14040 to circularity for environmental assessment, CE-LCC for economic assessment to better accommodate the circular strategies, and S-LCA based on UNEP/SETAC 2020 for the social assessment. This research will also measure circularity by using Material Circularity Indicator (MCI). Each assessment will result in a single score that reflects each assessed aspect and these scores will also be aggregated through weighting and normalization to produce a single score that indicates the sustainability (triple bottom line) and circularity performance. The methodology of this research is shown in the following Figure 1.

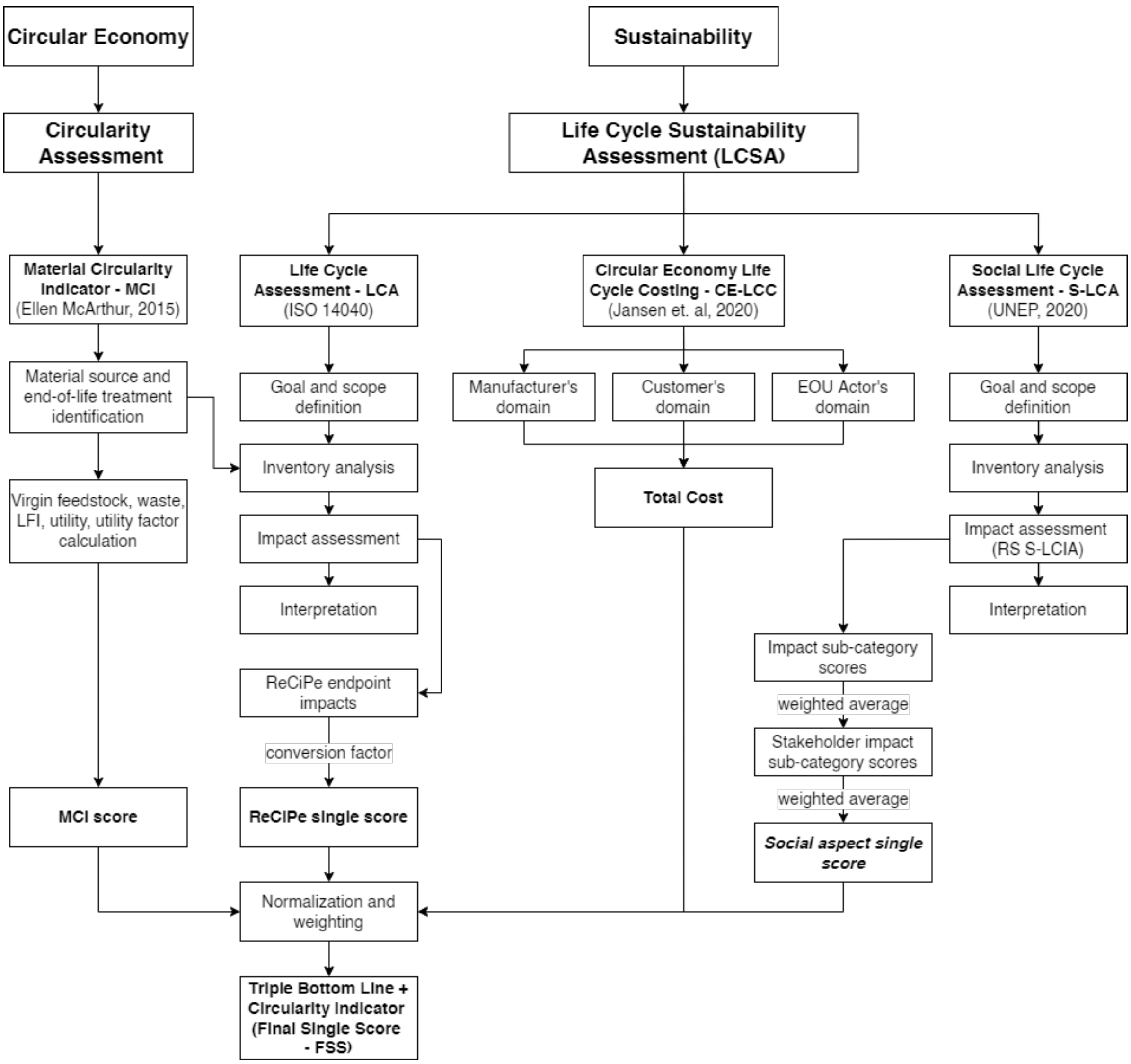

Figure 1. Research methodology

2.1 LCA

The environmental aspect assessment will be conducted using LCA according ISO 14040 2006 framework. The four major steps involved are goal and scope definition, inventory analysis, impact assessment, and interpretation. In this framework, the scope analysis will be cradle-to-cradle or cradle-to-grave. In inventory analysis, implemented R strategies is modelled linearly (to simplify calculation) and avoided product is analyzed. Considering MCI in LCA calculation, the raw materials used for the product is divided depending on their source (either from virgin raw material, recycling, reusing, or sustained production) and where the materials go at the end of its lifespan is also determined (either becoming landfill, recycled, reused, composted, or used for energy recovery).

The impact assessment method will be ReCiPe endpoint impact (comprised of human health, ecosystems, and resources), where it will further be normalized and weighted using conversion factor to be one score, ReCiPe endpoint single score. The conversion score according to the default weight is 400 for human health, 400 for ecosystems, and 200 for resources. The conversion from ReCiPe endpoint impacts to ReCiPe single score follows the following formula:

$$ES = HH \times C_{HH} + E \times C_E + R \times C_R \quad \text{Eq. 1}$$

where ES is the environmental impact score (ReCiPe endpoint single score), HH is the impact to human health score, C_{HH} is the human health's conversion factor (400), E is the impact to ecosystems score, C_E is the ecosystems' conversion factor (400), R is the impact to resource score, and C_R is the resources' conversion factor (200).

2.2 CE-LCC

CE-LCC breaks product down into components and break components down to parts. Each part is deemed to have different lifespan. CE-LCC also classifies cost based on product's lifecycle phase and its stakeholder, starting from manufacturing by manufacturer, use by customers, and end-of-use by end-of-use actors. By summing up the total cost of three stakeholders, product's total cost (TC) in net present value (NPV) during its lifespan will be obtained. Each stakeholder will as well have different interest rate.

In manufacturer's domain, the cost structure is divided into two, first use cycle cost and cost after first use cycle. First use cycle cost consists of material cost, material processing cost, manufacturing cost, transportation cost, and installation cost. The cost after first use cycle can be smaller or reduced from first use cycle cost by implementing R strategies such as reuse, recycling, and remanufacturing.

In customer's domain, manufacturer's total cost is considered alongside the manufacturer's profit margin to be customer's purchase cost. In this research, an adjustment regarding this cost component is made. Customer's purchase cost (and other costs that translates to revenue for manufacturer or company) is overlooked to prevent these two components (purchase cost and company's revenue) cancelling each other in normalization step that leads to cost always being larger than revenue. Customer's domain cost consists of consumption cost, maintenance cost, and waste disposal cost.

The final domain is end-of-use actor's domain that can implement some R strategies like refurbishment, repurposing, and energy recovery. The cost components in end-of-use actor's domain are refurbishment cost, repurposing cost, energy recovery cost, and waste disposal cost.

2.3 S-LCA

Applying the most widely-used and recently renewed social sustainability assessment, the S-LCA framework by UNEP/SETAC 2020 is used in this research. Similar to LCA, this framework is also comprised of four stages, from goal and scope definition to interpretation. Relevant stakeholders, assessment criteria, and criteria indicators are determined in the first stage. The impact assessment method used in this research is RS S-LCIA (Reference Scale Social Life Cycle Impact Assessment) which builds around a reference scale from 0 (worst performance) to 1 (best performance) with 0.25 interval. After each impact sub-category is scored based on the reference scale, each impact sub-category and stakeholder is weighted and weighted average method is employed to produce social aspect single score (SS) that shows the social aspect performance according to the following formula:

$$S_j = \sum_{i=1}^{n} (RS_{ij} \times w_i) \quad \text{Eq. 2}$$

$$SS = \sum_{j=1}^{n} (S_j \times w_j) \quad \text{Eq. 3}$$

where S_j is the weighted average of impact sub-category of stakeholder j, RS_{ij} is the reference scale score of impact sub-category of stakeholder j, w_i is weight of impact sub-category i. Whereas SS is social aspect single score and w_j is the weight of stakeholder j.

2.4 Material Circularity Indicator (MCI)

MCI was developed by Ellen McArthur Foundation in 2015 to assess product's circularity by looking at its material cycle. Due to its simplicity, MCI becomes one of the most used circularity assessment tools. MCI results in a score ranging from 0 (fully linear) to 1 (fully circular). MCI calculation process includes identifying virgin feedstock, waste, linear flow index, utility, and utility factor.

2.5 Aggregation: Weighting and Normalization

Aggregation is done to produce a final single score (FSS) ranging from 0 (not sustainable and circular) to 1 (very sustainable and circular). This step is conducted by aggregating three scores from each aspect in LCSA and the MCI score. Difference in calculation result scale and unit requires normalization to be performed beforehand. Normalization is done using the Min-Max method for environmental and economic aspect which results are not yet in the scale of 0 to 1.

As for now, there is no upper and lower limit for environmental impact for each industry and service sector, therefore acquiring the best and worst environmental impact result for comparison is quite challenging. To tackle this difficulty, environmental aspect normalization is done by comparing the previously calculated environmental impact score with environmental impact of similar product from the same industry that has not yet practiced circular strategies (still fully linear). The normalized environmental score (NES) is calculated through:

$$\text{Normalized ES} = \max\left(0;\ 1 - \frac{\text{ES}}{\text{ES}_{\text{ind}}}\right) \quad \text{Eq. 4}$$

where ES is the calculated environmental impact score and ES_{ind} is the environmental impact of linear similar product.

Having the same circumstance as the environmental aspect, total cost does not have an upper threshold as well. Thus, the total cost from economic assessment will be compared with the generated revenue from all stakeholder along the lifecycle. Normalized total cost (NTC) can be calculated using the formula:

$$\text{Normalized TC} = \max\left(0;\ \frac{\text{Total revenue} - \text{total cost}}{\text{Total revenue}}\right) \quad \text{Eq. 5}$$

After each three aspects and MCI score are ranged from 0 to 1, each aspect is given weight that adds up to 100% or 1. Through simple weighted average, final single score (FSS) is obtained with the formula:

$$\text{FSS} = \text{NES} \times W_{ES} + \text{NTC} \times W_{TC} + \text{SS} \times W_{SS} + \text{CS} \times W_{CS} \quad \text{Eq. 6}$$

where W_{ES} is the weight of environmental aspect, W_{TC} is the weight of economic aspect, W_{SS} is the weight of social aspect, CS is the MCI score, and W_{CS} is the weight of circularity aspect.

3. Data Collection

The data collected in this research is all the data regarding Company XYZ related to the computation of LCSA, from LCA, CE-LCC, and S-LCA. Company XYZ is one of the first companies in Indonesia that pioneered the CE concept in its business. They provide a zero-waste packaging service to minimize single use plastic waste, specifically in food and beverage industry. Company XYZ partners with numerous food merchants across Jakarta, with the majority of them being a plant-based restaurants. They substitute the usual plastic take away container by lending their silicone container (Figure 2) to customers.

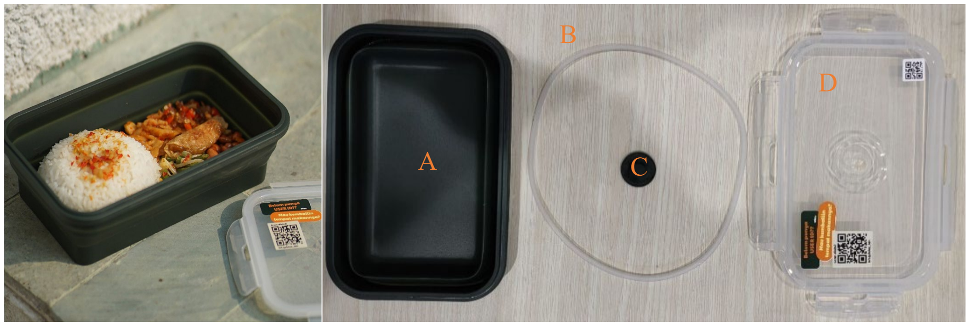

Figure 2. Company XYZ's silicone container and its parts. A: container, B: airtight rubber, C: valve, D: lid

Company XYZ offers their service: borrow, use, and return as seen on the business process in Figure 3. Once customers are done using the containers, customers wash them, and either schedule a container pick-up or return the container to the merchants. According to historical data, average container usage duration (the duration since container is borrowed until returned to cleaning hub) is 9.08 days.

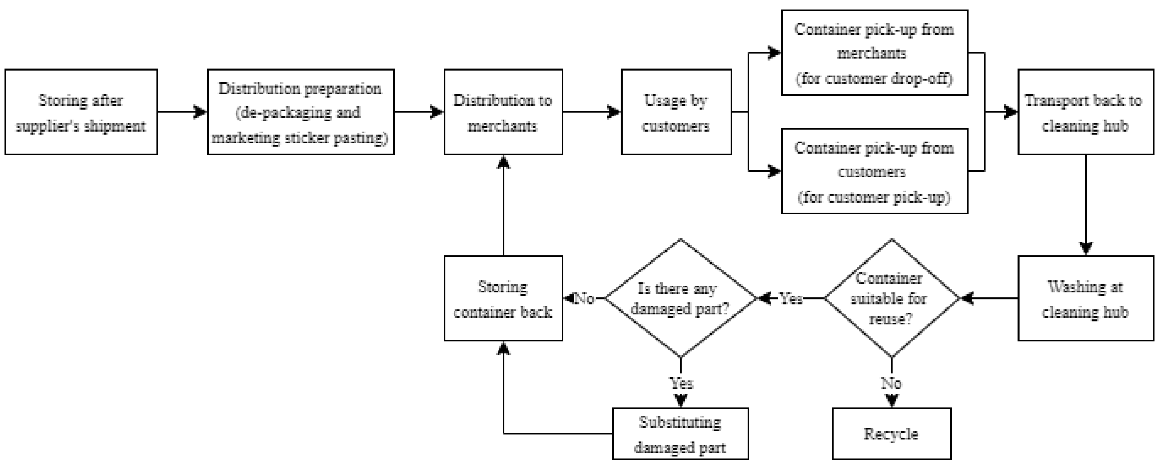

Figure 3. Company XYZ's business process

Company XYZ does their pick-up every Friday from 11AM to 3PM. At first, the pick-up was done using motorcycle, but now it is shifting to bicycle courier to lower the environmental impact. Once the used containers are collected, containers will be brought to the cleaning hub to be washed once again according to Company XYZ's standard to maintain container's hygiene, then stored back in the warehouse. If any merchants need container supply, Company XYZ will redistribute the container. At the end of its lifecycle, the silicone container is planned to be recycled. The components and materials of Company XYZ's silicone container (with the volume of 800 mL) is shown in Table 1 below.

Table 1. Company XYZ's silicone container specification

Part	Material	Mass (g)	Fraction from total mass
Container	Food grade silicone	113	63.48%
Lid	Polypropylene	58	32.58%
Valve	Food grade silicone	2	1.13%
Airtight rubber	Food grade silicone	5	2.81%
Total		**178**	**100%**

Another data needed for the calculation are: operational-related transportation (distributing samples, samples take back, container return to cleaning hub, container restock), transportation related to distribution to customer, transportation related to container pick-up, and container purchasing cost.

4. Results and Discussion

Through data processing and analysis, the LCSA and MCI result of Company XYZ study case is obtained. The data analysis and results of each sustainability assessment (LCA, CE-LCC, and S-LCA) and circularity assessment, as well as the indicator aggregation are explained in the following sub-sections.

4.1 LCA

In the study case, LCA is conducted with the scope cradle-to-grave (because the recycled silicone no longer enters Company XYZ's system nor other systems). The system boundary follows the company's business process as seen in Figure 3, which is from storing the container after supplier shipment until container recycling process. The functional unit used in this analysis is serving food up to 800 mL in one go. Inventory analysis and impact assessment were done using GaBi Education (for activities besides transportation) and Simapro with Ecoinvent database (for transportation modelling). In the end of its lifecycle, silicone container is assumed to be disassembled according to the material and end-of-life actions are taken as seen on Figure 4 below.

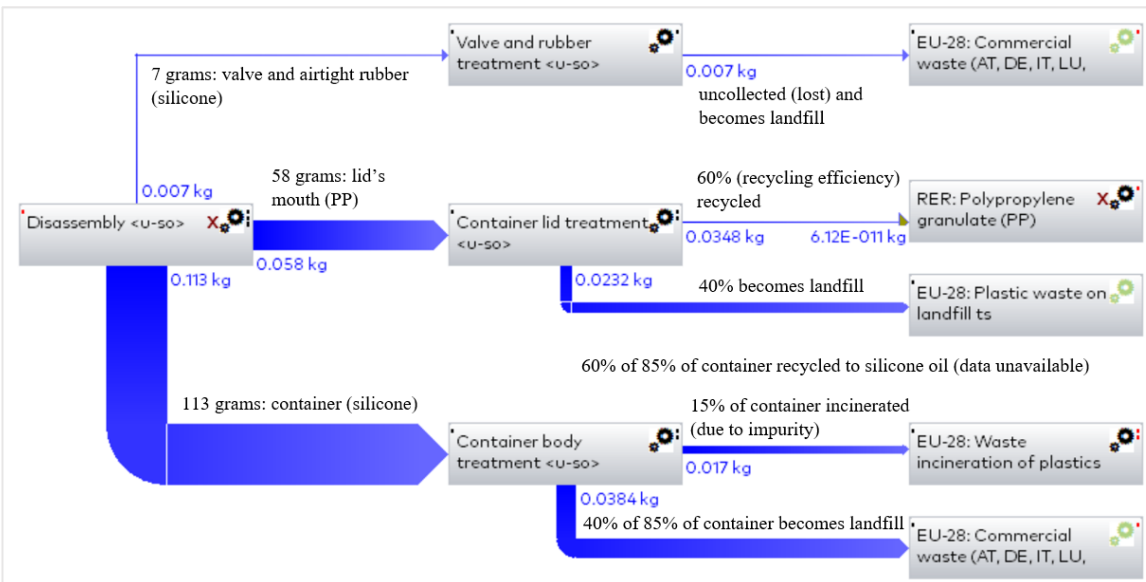

Figure 4. Company XYZ's container end-of-life scenario

The result of the impact assessment and the total point for each endpoint impact, as well as the ReCiPe endpoint single score is shown in Table 2.

Table 2. Endpoint impact for each activity and ReCiPe endpoint single score

Activity	Human health (pt)	Ecosystems (pt)	Resources (pt)	TOTAL (pt)
Silicone container production	0.00780	0.00032	0.00039	**0.00851**
Transport: Restocking	0.01824	0.00162	-0.01018	**0.00969**
Transport: Borrow	4.56202	0.16405	0.10531	**4.83138**
Washing at customers	0.00197	0.00009	0.00005	**0.00211**
Transport: Drop off to hub	0.14350	0.00647	-0.00706	**0.14292**
Transport: Pick-up to customer	-0.10311	-0.00401	-0.01402	**-0.12113**
Transport: Pick-up to hub	0.78621	0.02749	0.00491	**0.81861**
Washing at hub	0.00150	0.00007	0.00004	**0.00161**
EOU	0.00324	0.00015	0.00016	**0.00354**
Avoided production	-0.42757	-0.01768	-0.02065	**-0.46590**
TOTAL (pt)	**4.99380**	**0.17859**	**0.05895**	**5.23134**

Based on the impact assessment result, it can be seen that transport: borrow produces the most environmental impact, followed by transport: pick-up to hub. The high environmental impact was caused by the far distance in delivering the food while only a few portions (two to three portions) were ordered, making the attributed distance and impact for each container grew big. For easier understanding and analysis, the impact assessment result is illustrated in the graph in Figure 5.

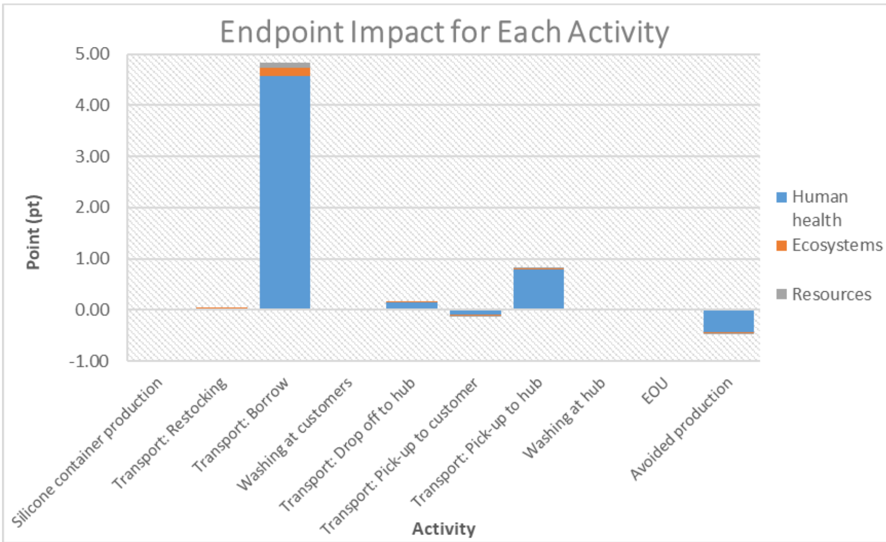

Figure 5. Environmental impact (ReCiPe endpoint impact in point) for each activity

4.2 CE-LCC

The silicone container is consisted of four components that can not be broken down into parts, which are the container, lid, valve, and airtight rubber. Each of the components is assumed to have the same lifespan (no broken parts have been reported) and is used as one entity. It is also assumed that each container lasts for 3 years with 40 usages per year (according to the average usage duration). In manufacturer's domain, only reuse strategy is implemented. Repurpose and energy recovery are implemented in end-of-use actor's domain. The cost structure of each stakeholder during container's life is shown in Table 3. An interest rate of 2.5% is applied for the manufacturer's domain and end-of-use actor's domain, whilst the rate of 3.5% (according to Bank Indonesia) is applied for the customer's domain.

Table 3. Company XYZ's CE-LCC result for each container

Manufacturer's domain			
Cost component	**Year 1**	**Year 2**	**Year 3**
Container purchase cost	IDR54,759.49	-	-
Initial transportation cost	IDR818.29	-	-
Monthly operational cost	IDR266,578.59	IDR266,578.59	IDR266,578.59
Cost after first use cycle	IDR383,774.25	IDR328,196.,46	IDR328,196.46
Total	**IDR383,774.25**	**IDR328,196.46**	**IDR328,196.46**
NPV_{MAN}	**IDR1,016,348.04**		
Customer's domain			
Consumption cost	IDR194,513.72	IDR194,513.72	IDR194,513.72
Maintenance cost	IDR2,038.60	IDR2,038.60	IDR2,038.60
Total	**IDR196,552.31**	**IDR196,552.31**	**IDR196,552.31**
NPV_{CUS}	**IDR569,941.62**		
End-of-use actor's domain			
PC_{EUA}	-	-	IDR8,427.00
NPV_{EUA}	**IDR8,020.94**		
TOTAL COST (TC)	**IDR1,594,310.60**		

The largest cost emerged from manufacturer's domain due to the large monthly operational cost, especially marketing and research cost. Initiative that can be taken to minimize the total cost is increasing the number of containers borrowed in a month so the monthly operational cost allocated for each container can be lowered.

4.3 S-LCA

In this study case's S-LCA, there are five involved stakeholders namely: worker, value chain actors, consumers, local community, and society. Each stakeholders have different impact sub-categories with different indicators. Each impact sub-categories will have a reference scale ranging from 0.00 (worst) to 1.00 (best) with the interval of 0.25. Each impact sub-categories and their indicators as well as the descriptions for each reference scale are based on several references such as UNEP/SETAC 2020, Product Social Impact Assessment (Goedkoop, M.J., et al, 2020), and preceding researches. The weighting of each impact sub-categories is obtained from interviews with Company XYZ. The score of each impact sub-categories, weighting, and the social single score (SS) are shown in Table 4 below.

Table 4. Company XYZ's S-LCA result

Impact sub-categories	Score	Weighting	Sj	SS
Stakeholder: Worker		**0.15**		
Work health and safety	0.50	0.20		
Forced labor	0.50	0.05		
Underaged labor	0.50	0.05		
Discrimination	0.50	0.10	**0.650**	
Freedom of association and discussion	1.00	0.30		
Remuneration	0.50	0.15		
Working hours	0.50	0.15		
Stakeholder: Value chain actors		**0.10**		
Healthy competition	0.50	0.35	**0.412**	
Promotion of social responsibility	0.25	0.35		
Supplier relationship	0.50	0.30		**0.534**
Stakeholder: Consumers		**0.30**		
Consumer health and safety	0.50	0.25		
Consumer privacy	0.50	0.25	**0.625**	
Affordability	0.50	0.25		
Feedback mechanism	1.00	0.25		
Stakeholder: Local community		**0.225**		
Safe and secure living condition	0.50	0.25		
Access to material and non-material resources	0.50	0.20	**0.425**	
Community involvement	0.25	0.30		
Local employment	0.50	0.25		
Stakeholder: Society		**0.225**	**0.500**	
Contribution to economic growth	0.50	1		

Calculation produces the score of 0.534 for social single score, showing an almost neutral score from 0 to 1. In can be concluded that Company XYZ has given neither positive nor negative social impact to their stakeholders. The highest score was attained from worker, followed by consumers, while the three other stakeholders' scores were at 0.40 to 0.50. This shows that Company XYZ still mainly focuses on their "major" stakeholders, which are worker and consumers. They have not yet done much impactful activities that involve the other stakeholders.

4.4 MCI

MCI calculation showed that virgin feedstock (container's raw material which is not from recycle, reuse, and sustained production) amounts for 178 grams, which equals to Company XYZ container mass. The unrecoverable waste equals to 41.2 grams and linear flow index (LFI) amounts to 0.681. To compute the utility and utility factor, eco-clamshell (plastic container made from PP with cafeteria reuse system) was chosen as the similar product to compare with. According to Institute for Sustainable Futures (2018), eco-clamshell can be used for 360 times during its one year lifespan. Calculation resulted the container utility of 1.008 and utility factor of 0.893. Lastly, Company XYZ scored 0.392 MCI score which means they are still transforming from linear to circular, but is still leaning towards linearity.

4.5 Indicator Aggregation: Normalization and Weighting

Normalization is done for the environment and economic aspect. To normalize the environmental impact score, the environmental impact of similar product that has not yet implemented R strategies needs to be identified. In this analysis, this similar product is takeaway plastic container made from PP with the volume of 750 mL and the mass of 30 grams. The inventory of this plastic container are adjusted from the research done by Gallego-Schmid et al. (2019). Through data analysis, the ReCiPe endpoint single score for 121 plastic containers is 5.366 and following Equation 4, normalized environmental score (NES) is equal to 0.025 which translates to Company XYZ is still not environmentally sustainable because no significant impact difference was seen between two containers.

As for the total cost, it is necessary to calculate the revenue generated from all stakeholders during the container's lifecycle. With the total revenue of IDR1,043,138.17 per container received by Company XYZ, partner merchants and bike couriers, and end-of-use actors, the normalized total cost is 0 (not sustainable) because total cost is bigger than the revenue. This is due to the reason that Company XYZ is still at its early development stage, making the current condition still economically disadvantageous for Company XYZ. Company XYZ still needs to spend more on marketing and promotion as well as personal branding to gain more customers as well as partner merchants.

Through interview and discussion, Company XYZ gives 30% weight for circularity aspect, 25% for each environment and economic aspect, and the weight of 20% for social aspect. Using the normalized environment score of 0.025, normalized total cost of 0, social aspect single score of 0.534, and MCI score of 0.392, through the calculation with Equation 6, the final single score for Company XYZ is 0.231, meaning that Company XYZ is still relatively far from being sustainable and circular. The main reason for the low FSS is because Company XYZ is still a new and growing company, resulting in the not yet significant environmental impact decrease, revenue generation, and positive social impact. To increase the overall performance, Company XYZ needs to gather more customers to increase the number of containers used per month and number of container usage along its lifecycle. Other than that, Company XYZ also needs to expand its partner merchants to minimize the travel distance from merchant to customers, as well as to provide more food choices for customers.

4.6 Discussion

The LCA done in this research assimilates the material circularity from MCI by doing a material break down for raw material and end-of-life scenario in inventory analysis. Avoided product and R strategies are also considered in the system modelling and inventory analysis. But, the degree of detail in doing it might differ from one analysis to another. It can be improved by adding indicators or steps that guarantee the same degree of detail and understanding, as well as guarantee that circularity is assessed in any conducted LCA. Compared to the conventional LCC, CE-LCC is describing product as components and parts that have different lifespan during its lifecycle. CE-LCC also build cost classification based on the stakeholders and each stakeholder's cost components are explained in great detail. The biggest strength of CE-LCC is that the framework incorporates nine R strategies in its calculation. Though the application is slightly more complicated than the conventional LCC, the advantages outweigh its slight complexity. Compared to the other two aspects, social aspect is perhaps the aspect that has the least CE-related development. It can be seen that not much framework variations exist for social aspect because social aspect itself is hardly considered in CE assessments. For future research, S-LCA development to better suit CE has a great potential, from development from the framework itself or the related impact sub-categories and indicator in the current framework. Some improvements can also be made for the aggregated indicator proposed in this research. The normalization step is quite time-consuming because environmental impact assessment needs to be re-done for another product (because there is no threshold for the ReCiPe single score) and revenue along the lifecycle also needs to be calculated. The normalization step can be simplified or a threshold on environmental impact can be constructed. The indicator itself can also be perfected to be used more simply and straightforward by choosing some major and influential sustainability and circularity indicators instead of having to do all four assessments.

5. Conclusion

In this research, LCSA was implemented in circular business while adapting it to a more circular setting by integrating it with MCI, adjusting the LCA with material circularity, as well as replacing the conventional LCC that has not yet considered circular strategies with the CE-LCC. The assessment of the other two sustainability pillars, environment and social, was carried out using the standardized LCA ISO 14040 and S-LCA by UNEP/SETAC 2020 with the RS S-LCIA impact assessment method. Through data processing and analysis, four single scores from each assessment were obtained. In addition, these four scores were then normalized and weighted to generate a single aggregated score (final single score) that reflects the sustainability and circularity performance in the range of 0 (not sustainable and circular) to 1 (very sustainable and circular).

The object of study case in this research is Company XYZ in Jakarta, Indonesia that leases silicone container as a substitute for single-use takeaway plastic container used by the partner merchants. Company XYZ mainly implement the reuse strategy in its business by picking up the silicone container after being used by customers to be washed and used again by another customers. According to the conducted LCA, Company XYZ scored 5.231 point in environmental aspect (ReCiPe single score). CE-LCC calculation showed a total cost of IDR1,594,310.60 per container during its assumed 3 years lifespan. On the other hand, Company XYZ scored 0.534 on social assessment and 0.392 in circularity assessment done with MCI. Through normalization and weighting, each aspect's score was normalized to: 0.025 for environment aspect, 0 for economic aspect, 0.534 for social aspect, and 0.392 for circularity. The final single score of 0.231 was also acquired, which means that Company XYZ still relatively far from being sustainable. This is due to the fact that Company XYZ has just been established, meaning that Company XYZ is still at its very early stage and has a huge room for improvements, either in increasing the number of customers or partner merchants across Jakarta or even Indonesia.

There are some limitations occurred in this research that might be considered for improvements of upcoming researches. The first limitation is related to the availability of environmental impact database and threshold, which in this research is needed during the normalization step. The second limitation is related to study case's object's scale and industry. This LCSA and aggregate indicator are more suitable for micro-scale analysis due to the data intensiveness and relatively time consuming. It is also more preferable to have a manufacturing industry as the study case object rather than a service industry because the assessment frameworks under LCSA are mostly more suitable for manufacturing industry. Other suggestions are compiling preceding LCA results and building a database to simplify impact comparison and compliance, also polishing the normalization and weighting method (for environment and economic aspect which have no constant threshold) to be easier and more straightforward.

References

Azevedo, S. G., Godina, R., & Matias, J. C. de O., Proposal of a sustainable circular index for manufacturing companies. *Resources*, vol. 6, no. 4, pp. 1–24, 2017.

Bhambhani, A., van der Hoek, J. P., & Kapelan, Z., Life cycle sustainability assessment framework for water sector resource recovery solutions: Strengths and weaknesses. *Resources, Conservation and Recycling*, vol. 180, pp. 106-151, 2022.

Bradley, R., Jawahir, I. S., Badurdeen, F., & Rouch, K., A total life cycle cost model (TLCCM) for the circular economy and its application to post-recovery resource allocation. *Resources, Conservation and Recycling*, vol. 13, pp. 141–149. 2018

Filho, M. V. A. P. M., da Costa, B. B. F., Najjar, M., Figueiredo, K. V., de Mendonça, M. B., & Haddad, A. N., Sustainability Assessment of a Low-income Building: A BIM-LCSA-FAHP-based Analysis. *Buildings*, vol. 12, no. 2, 2022.

Gallego-Schmid, A., Mendoza, J. M. F., & Azapagic, A., Environmental impacts of takeaway food containers. *Journal of Cleaner Production*, vol. 211, pp. 417–427, 2019.

Goedkoop, M.J.; de Beer, I.M; Harmens, R.; Peter Saling; Dave Morris; Alexandra Florea; Anne Laure Hettinger; Diana Indrane; Diana Visser; Ana Morao; Elizabeth Musoke-Flores; Carmen Alvarado; Urs Schenker; Thomas Andro; Jean-François Viot; Alain Whatelet., *Product Social Impact Assessment- Social Topics Report – 2020*. Amersfoort, 2020.

Institute for Sustainable Futures, *Feasibility Study: Reusable food containers for takeaway food in the Sydney CBD. June,* 2018.

Kirchherr, J., Reike, D., & Hekkert, M., Conceptualizing the circular economy: An analysis of 114 definitions.

Resources, Conservation and Recycling, vol. 127, pp. 221–232, 2017.
Kloepffer, W., Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95). *International Journal of Life Cycle Assessment*, vol. 13, no. 2, pp. 89–95, 2008.
Konietzko, J., Bocken, N., & Hultink, E. J.,. Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, vol. 253, 2020.
Kristensen, H. S., & Mosgaard, M. A., A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, vol. 243, 2020.
Kuhlman, T., & Farrington, J., *What is Sustainability? 2*, pp. 3436–3448, 2010.
Lacy, P., Long, J., & Spindler, W., *The circular economy handbook*, Palgrave Macmillan UK, 2020.
Lam, W. C., de Regel, S., Peeters, K., & Spirinckx, C., Applying life cycle sustainability assessment to maximise the innovation potential of new technologies for critical components in wind turbines. *Journal of Physics: Conference Series*, vol. 2042, no. 1, 2021.
Lin, D., Wambersie, L., & Wackernagel, M., *Estimating the Date of Earth Overshoot Day 2021 Overview: Earth Overshoot Day Calculation The Need for Nowcasting Methodological Overview: Accounting for Biocapacity*. Available: https://www.overshootday.org/2021-calculation/?__hstc=104736159.f999c0391c62dab708fef264bc1a851c.1626599156314.1626599156314.1626599156314.1&__hssc=104736159.1.1626599156314&__hsfp=2200279348, October 20, 2021.
Liu, L., & Ramakrishna, S, (Eds.), *An Introduction to Circular Economy,* Springer Nature, 2021.
Pauliuk, S., Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resources, Conservation and Recycling*, vol. 129, pp. 81–92, 2021.
Sillanpää, M., & Ncibi, C., *The circular economy: Case studies about the transition from the linear economy*, Academic Press, 2019.
Stahel, W. R., & MacArthur, E., *The circular economy: A user's guide,* Routledge, 2019.
Verstraeten-Jochemsen, J., Keijzer, E., Van Harmelen, T., Kootstra, L., Kuindersma, P., & Koch, R., IMPACT: A Tool for R&D Management of Circular Economy Innovations. *Procedia CIRP*, vol. 69, pp. 769–774, 2018.
Wouterszoon Jansen, B., van Stijn, A., Gruis, V., & van Bortel, G., A circular economy life cycle costing model (CE-LCC) for building components. *Resources, Conservation and Recycling*, vol. 161, 2020.

Biographies

Brigitta Ancelina is an Industrial Engineering graduate from University of Surabaya, Indonesia. She takes a great interest sustainability-related topics such as Circular Economy and Green Supply Chain Management.

Amelia Santoso is an Associate Professor of Industrial Engineering at the University of Surabaya, Indonesia. She received her Master's and Ph.D. degree in Industrial Engineering from Institut Teknologi Bandung (ITB), Bandung, Indonesia, and her Bachelor's degree in Statistics from Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia. Her research interests are production, distribution & transportation systems; supply chain engineering; and humanitarian logistics in disaster operations and management.

Joniarto Parung is a professor of Supply Chain Management of Industrial Engineering Department, University of Surabaya, Indonesia. He graduated from Universitas Hasanuddin-Makassar, obtained his Master's degree from ITB Bandung, Indonesia and Ph.D. from University of Strathclyde, Glasgow, UK. His research interests include logistics & supply chain management and application of digital technology on this area, decision sciences, and performance analysis. He is a member of the board of Indonesian Supply Chain & Logistics Institute (ISLI) and Association of Indonesian Logistics (ALI), East Java Chapter, member of the Institute of Electrical and Electronics Engineers (IEEE) and European Operations Management Association (EUROMA). He has presented some of his research and has delivered invited seminars around the world and around Indonesia.

Acknowledgements

The authors would like to thank LPPM Universitas Surabaya for supporting and providing funding for this research through the research grant.