CHAPTER I

INTRODUCTION

This chapter consists of the background of the project, problem formulation, research objectives, scope of problems, and final project report outline.

1.1 Background

Sustainability is defined as "*A development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). Sustainable development comprises of balancing the three pillars: environment, economy, and society. The Life Cycle Sustainability Assessment (LCSA) is considered the best approach to evaluate the environmental, economic, and social sustainability of production systems (Zamagni, 2012). LCSA embraces three techniques: environmental life cycle assessment (LCA), economic life cycle costing (LCC), and social life cycle assessment (S-LCA)(Klopffer, 2008).

LCA is the only tool already standardized by ISO 14040-44 (Environmental management- Life cycle assessment – Principles and framework), while several proposals and standardized definitions of LCC have emerged in recent years, such as the European standard DS/EN 15643 series on sustainability in construction and civil engineering and the international standard ISO 15686 (Service Life Planning, Part 5, Life-cycle Costing). There are no existing standardized methodologies for S-LCA as of now. However, as a step towards addressing the issue, is a guideline published by UNEP/SETAC Life Cycle Initiative. (UNEP; SETAC, 2009).

As concluded in a bibliographic portfolio of more than 100 published paper in applied LCSA studies conducted by Visentin et al. (2020), only 28% of the reviewed studies related to the application of existing methodologies while 42% of the reviewed studies related to the development of methodology and its application in a case study. LCSA conceptually consists of LCA + LCC + S-LCA, but in practice, there are two approaches to assess LCSA: Comparative Analysis, and Integrated Analysis. Comparative Analysis considered the life cycle results (LCA, LCC, and S-LCA) separately, comparatively concluding the result of sustainability. The second approach considers the results as an aggregation of the three life cycle analyses into a single life cycle sustainability score. Both approaches give birth to the development of many tools and methodologies to determine the sustainability of a variety of products ranging from electricity and heat production, agriculture, forestry, land usage, building, transportation and automobile, industrial, waste management, and other concerned sectors.

Comparative analysis methodologies such as the color-scale used by Corona and Miguel (2019), the color-coded diagram used by Kabayo et al. (2019), Sustainability Compass used by Moslehi and Reddy (2019), and Driver-Pressure-State-Impact-Response Framework used by Hannouf and Assefa (2017) have a weakness whereby the resulting assessment is either simplified too much or there is subjectivity in its analysis. Methodologies such as Life Cycle Sustainability Dashboard used by Valdivia et al. (2015), and Multidimensional Pareto Optimization used by Ostermeyer et al. (2013) have high data requirement or come with complexity in its procedure. A preview of the drawback comparison of comparative analysis methodologies can be seen in Table 1.1. Further detail can be seen in the **Appendix 1**.

In comparison, Integrated analysis methodologies aims to integrate the three pillars into a single aggregated score to describe the sustainability of the product. Eco-efficiency portfolio by Kicherer et al. (2007) requires a normalizing process and weighing factor that influences the result while the aggregation of the result does not provide enough information to identify hostpots for the improvement or any comparison to be made to the product. Methodologies such as Multi-Criteria Decision Making (MCDM) combined with multi-level analytical tools such as Analytic -

Table 1.1 Comparative Analysis Methodologies

No	Subject	Method	Author	Year	Assessment Component	Drawback
1	HYSOL Technology	Color Scale	Blanca Corona, Guilermo San Miguel	2019	Attributional and Consequential Life Cycle Assessment, Life Cycle Cost (LCC) Analysis and Multiregional input-output analysis (MRIO), and Social Life Cycle Asssessment (S-LCA), Social Hotspots Analysis	The color-scale method of Life Cycle Sustainability Assessment (LCSA) has a significant drawback in its oversimplification and subjective nature. By representing complex sustainability indicators using a color scale, this approach fails to provide a precise quantitative evaluation of environmental, social, and economic impacts throughout a product's life cycle. The absence of clear numerical values limits its ability to support evidence-based decision-making and hinders the comparability and consistency of results across different products or projects. Moreover, the color-scale method heavily relies on human interpretation, leading to potential biases and inconsistency in the assessments, making it less reliable and robust for guiding sustainable development strategies.
2	Energy Generation System in Portugal	Color-Coded Diagram	Jeremiah Kabayo, Pedro Marques, Rita Garcia, Fausto Freire	2019	Environmental Impact, Socioeconomic Impact	The color-coded diagram method in Life Cycle Sustainability Assessment (LCSA) has drawbacks due to its simplified visualization approach. While it offers an intuitive representation, it lacks depth and may oversimplify complex sustainability impacts. Its subjectivity in selecting color scales and boundaries can lead to inconsistent and potentially biased results, limiting its reliability for informing well-balanced sustainability decisions.

Hierarchical Process (AHP) used by Opher et al. (2018), VIKOR (multi-criteria optimization and compromise solution) used by Zheng et al. (2018), Three-Dimensional Coordinate Diagram used by Xu et al. (2017), Interval AHP used by Ren et al. (2018), Preference Ranking Organization Method for Enrichment Evaluation (PROMITHEE) used by Mahbub et al. (2018) relied heavily on weighting criteria from many possible sources such as the panel of experts and stakeholder. This means different perspectives will result in different Integrated Sustainability Scores and this will lead to bias and inconsistency in the resulting score. Another method such as Interval MCDM used by Ren and Toniolo (2017) had a potential complexity and huge computational burden, and Fuzzy Evaluation for Life Cycle Integrated Sustainability Assessment (FELICITA) Model used by Kouloumpis and Azapagic (2018) needed a precise definition of rules and membership functions which is affected by subjectivity and lacks standardized guidelines. Although drawback exists, the current established Integrated Analysis methodologies have followed the three pillar LCSA framework (LCA, LCC, S-LCA) and contributed to further development of the LCSA methodologies. The preview of the drawback of each methodology can be seen in **Table 1.2**. Further detail can be viewed in **Appendix 2**.

As concluded by Todorov et al. (2011), there have been numerous ways of representing sustainable development in a model that encapsulates this extremely complex concept and a new way of thinking. One of the more popular models is using Venn Diagram to visualize the sustainability pillars as composed of three overlapping circles, with each circle representing a separate dimension (O'Riordan, 1998, as cited in Moir & Carter, 2012). In this case, sustainability is described as the intersection of environmental, economic, and social impact. Such representation can be seen in **Figure 1.1**.

Table 1.2 Integrated Analysis Methodologies

No	Subject	Method	Author	Year	Assessment Component	Drawback
1	Combining Life Cycle Assessment and Life Cycle Costs via Normalization	Eco-efficiency Portfolio	Andreas Kicherer, Stefan Schaltegger, Heinrich Tschochohei, Beatriz Ferreira Pozo	2007	LCA, LCC	Normalizing and weighting leads to subjectivity and influence the result. The resulting score also offers little aid in identifying hotspots that might be crucial in improving or comparing products.
2	Urban water reuse	MCDA (AHP)	Tamar Opher, Eran Fiedler, Aviad Shapira	2018	LCA,LCC, SLCA	A potential drawback of this approach lies in the time and effort required to elicit accurate and reliable pairwise comparisons in AHP. The process of assigning subjective weightings to criteria and alternatives can be challenging, especially when involving multiple stakeholders with diverse perspectives. If not carefully managed, inconsistencies and biases in the pairwise comparisons may lead to unreliable results and undermine the credibility of the decision-making process.
3	Pavement Maintenance Alternatives	MCDA (AHP + VIKOR)	Xiaoyan Zheng, Said M. Easa, Zhengxian Yang, Tao Ji, Zhenliang Jiang	2018	C-LCA (Life Cycle Cost Analysis), Environmental Life-Cycle Assessment (E-LCA), Social Life-Cycle Assessment (S-LCA)	A drawback of this hybrid approach lies in the potential subjectivity of AHP's pairwise comparisons, which can influence the final VIKOR rankings. The accuracy of the outcomes heavily depends on the consistency and reliability of the AHP judgments.

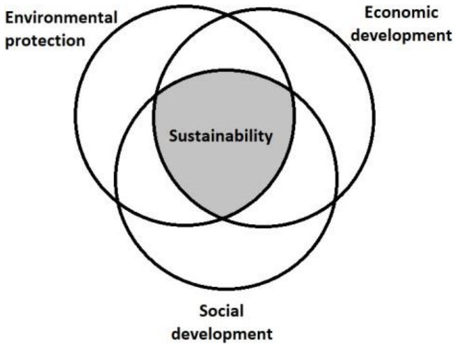

Figure 1.1 Sustainability Model using Venn Diagram

The weakness of the existing methodologies drives the need to have a better and easier-to-use framework to assess LCSA. With the help of the Venn Diagram, a probability model can be developed to analyze life cycle sustainability by determining each impact proportion and using a goodness-of-fit test to determine the probability distribution that best fits the dataset. The union of the proportion of the impact gives the aggregated value of the impact for the pillar of sustainability, likewise, the union of the proportion of the impact of the pillar of sustainability gives the aggregated value of the sustainability impact of the product. As such, this paper will study how to integrate Probability Distribution theory to perform a life cycle sustainability assessment and contribute toward furthering the development of LCSA methodologies.

1.2 Problem Formulation

Based on the background of the final project, it can be inferred from previous research and literature that there are drawbacks in existing methodologies, most prominent of them includes subjectivity in analysis. There is a need to develop method that overcomes this problem.

1.3 Research Objectives

The proposed objectives of this final project are the following:

1. To formulate a mathematical model used to determine the LCSA aggregated score.

2. To design a procedure in order to execute the aforementioned mathematical model.

1.4 Research Scope & Assumption

The scopes of this project are:

1. Analysis conducted using the gate-to-gate system boundaries.
2. Types of cost considered are electricity cost, labor cost, maintenance cost, fuel cost, and operational cost.
3. Environmental impacts considered are the impact resulted by the manufacturing operation of the product.
4. S-LCA is not considered for case study because the lack of inventory data and database pertaining social aspect of sustainability.

The assumption underlying this project is that the LCSA pillars are treated as independent of each other.

1.5 Outline of Final Project

The outline of this report is the following:

CHAPTER I INTRODUCTION

This chapter covers the background, problem formulation, the objectives, scopes, and outline of this final project.

CHAPTER II LITERATURE REVIEW

This chapter covers some theories and literatures relate to LCSA and Probability Distribution Method. These theories derived from sources such as books and journals.

CHAPTER III RESEARCH METHODOLOGY

This chapter explains the procedure in carrying out this project and it is also ilustrated in a research flowchart.

CHAPTER IV Results and Discussion

This chapter covers the results of the method that consists of the findings of the CDFs of selected impact categories, model verification, and model verification that used a case study in PT. Batanghari Barisan. This chapters also covers the discussion regarding the results that has been obtained.

CHAPTER V CONCLUSION

This chapter covers the conclusion and suggestion of this final project.