

**EVALUATING THE TRANSFORMATION POTENTIAL  
OF SRI LANKAN SUGARCANE INDUSTRY TOWARDS  
CIRCULAR ECONOMY; AN EMPIRICAL STUDY  
BASED ON LIFE CYCLE ASSESSMENT**

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198520P

Master of Science in Environmental Management

Department of Civil Engineering

University of Moratuwa

Sri Lanka

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Thesis submitted in partial fulfilment of the requirements for the degree

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August 2023

## DECLARATION OF THE CANDIDATE & SUPERVISOR

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The above candidate has carried out research for the Master's thesis under my supervision.

Name of the co-supervisor : Prof. Jagath Manatunge

Signature of the supervisor : .....

Date : .....

## ABSTRACT

In response to urgent global sustainability challenges, rapid action is imperative. The linear economy's resource depletion contrasts with the circular economy's resource optimization. As industries expand, thorough sustainability assessments, supported by versatile tools and concepts, become essential. This study delves into transitioning Sri Lanka's sugarcane industry to a circular economy, considering nationwide benefits. A comprehensive approach integrates diverse tools, aiming to boost the macro-economic performance of the sugarcane sector. The study's foundation rests upon existing sugarcane refineries in Sri Lanka. Objectives encompass evaluating the sugar and sugarcane industry's macro-economic performance, identifying local sugarcane biorefinery configurations, scrutinizing existing and potential biorefinery strategies, and analyzing material flow, circularity, and environmental life cycle performance of diverse configurations. Outcomes reveal the industry's subpar macro-economic performance compared to global and regional standards. Three biorefinery configurations emerge: one featuring sugar and ethanol production, another adding carbon dioxide capture, and a third integrating biogas and biofertilizer production. Analytical Hierarchy Process (AHP) identifies criteria for biorefinery selection, generating an alternative-ranked list. Material flow analysis underscores circularity potential, with the hypothetical configuration achieving 16.24% circularity, followed by the 3<sup>rd</sup> at 15.69%. Configuration one and configuration two show lower circularity, highlighting the value of additional pathways. Life cycle environmental performance is strongest in the hypothetical configuration, followed by the 3<sup>rd</sup>; the 1<sup>st</sup> exhibits higher impact. Human health, resources, and ecosystems are most affected. Enhanced configurations correlate with improved life cycle environmental performance. In conclusion, this study suggests promoting circular principles, diversifying by-product utilization, boosting local sugar production, and prioritizing comprehensive biorefinery setups as viable avenues for enhancing sustainability and environmental performance within Sri Lanka's sugarcane industry.

**Keywords:** Analytic Hierarchical Process, Circular Bioeconomy, Circularity, Environmental Life Cycle Assessment, Material Flow Analysis, Multi-Criteria Decision Making

## DEDICATION

*With deep affection, this dedication is extended to my cherished wife, **Sudari**; beloved son, **Yesh**; dear father, **Nimal**; and my two mothers, **Sujeewa** and **Sandya**, for their unwavering love and unconditional support...*

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## TABLE OF CONTENTS

|                                                         |       |
|---------------------------------------------------------|-------|
| DECLARATION OF THE CANDIDATE & SUPERVISOR.....          | i     |
| ABSTRACT.....                                           | ii    |
| DEDICATION.....                                         | iii   |
| ACKNOWLEDGEMENT .....                                   | iv    |
| TABLE OF CONTENTS.....                                  | v     |
| LIST OF FIGURES .....                                   | x     |
| LIST OF PLATES .....                                    | xiii  |
| LIST OF TABLES .....                                    | xiv   |
| LIST OF ABBREVIATIONS .....                             | xv    |
| LIST OF SYMBOLS .....                                   | xvii  |
| LIST OF APPENDICES.....                                 | xviii |
| CHAPTER ONE .....                                       | 1     |
| 1. INTRODUCTION .....                                   | 1     |
| 1.1. Background of the Study .....                      | 1     |
| 1.2. Rationale to the study .....                       | 6     |
| 1.3. Research Problem.....                              | 10    |
| 1.4. Research Questions .....                           | 10    |
| 1.5. Research Objectives .....                          | 10    |
| 1.6. Significance of the Study .....                    | 11    |
| 1.7. Limitations of the Study .....                     | 11    |
| 1.8. Organization of the thesis.....                    | 11    |
| CHAPTER TWO .....                                       | 13    |
| 2. LITERATURE REVIEW .....                              | 13    |
| 2.1. Production of sugar from sugarcane.....            | 13    |
| 2.2. Sugarcane industry and environmental impacts ..... | 14    |
| 2.3. Challenges to the sugarcane industry .....         | 14    |
| 2.4. By-products of Sugarcane Processing.....           | 15    |
| 2.4.1. Sugarcane Trash (SCT).....                       | 15    |
| 2.4.2. Bagasse .....                                    | 16    |
| 2.4.3. Filter mud/press mud/ stillage.....              | 17    |
| 2.4.4. Molasses.....                                    | 18    |

|               |                                                                                                                                      |    |
|---------------|--------------------------------------------------------------------------------------------------------------------------------------|----|
| 2.4.5.        | Spent wash/ Vinasse.....                                                                                                             | 19 |
| 2.5.          | Circular Economy of Sugarcane industry .....                                                                                         | 20 |
| 2.6.          | Circular Bioeconomy of Sugarcane.....                                                                                                | 21 |
| 2.7.          | Concepts, tools and techniques used in sustainability assessments .....                                                              | 22 |
| 2.7.1.        | Material Flow Analysis (MFA).....                                                                                                    | 22 |
| 2.7.2.        | Environmental Life Cycle Assessment (E-LCA).....                                                                                     | 26 |
| 2.7.3.        | Social Life Cycle Assessment (S-LCA).....                                                                                            | 28 |
| 2.7.4.        | Life Cycle Costing (LCC).....                                                                                                        | 31 |
| 2.7.5.        | Life Cycle Sustainability Assessment (LCSA).....                                                                                     | 33 |
| 2.7.6.        | Material Flow Cost Accounting (MFCA).....                                                                                            | 35 |
| 2.7.7.        | Input-Output Analysis.....                                                                                                           | 37 |
| 2.7.8.        | Ecoefficiency .....                                                                                                                  | 39 |
| 2.7.9.        | Circularity Assessment .....                                                                                                         | 41 |
| 2.7.10.       | Environmental Footprints .....                                                                                                       | 42 |
| 2.7.10.1.     | Carbon Footprint Assessment .....                                                                                                    | 42 |
| 2.7.10.2.     | Water Footprint Assessment .....                                                                                                     | 43 |
| 2.8.          | Multi Criteria Decision Making in Sustainability Assessments and Transformations.....                                                | 43 |
| 2.8.1.        | Analytical Hierarchical Process (AHP) .....                                                                                          | 44 |
| CHAPTER THREE | .....                                                                                                                                | 46 |
| 3.            | METHODOLOGY .....                                                                                                                    | 46 |
| 3.1.          | Study site .....                                                                                                                     | 46 |
| 3.2.          | The general sugar refinery process in Sri Lanka .....                                                                                | 47 |
| 3.3.          | Descriptive analysis to evaluate the baseline performance of sugar and sugarcane industry in Sri Lanka .....                         | 49 |
| 3.4.          | Correlation analysis to evaluate the relationship between sugarcane crushed versus sugar production and the ethanol production ..... | 49 |
| 3.5.          | Establishing baseline biorefinery configurations for sugar refineries in Sri Lanka                                                   | 50 |
| 3.6.          | Establishing baseline macro-economic biorefinery configuration for the sugar refineries and associated industries in Sri Lanka.....  | 51 |
| 3.7.          | Biorefinery and management strategies adopted for by-products generating at each biorefinery configuration.....                      | 51 |
| 3.7.1.        | Existing biorefinery and management strategies adopted for by-products generating at each biorefinery configuration .....            | 51 |

|                   |                                                                                                                                    |    |
|-------------------|------------------------------------------------------------------------------------------------------------------------------------|----|
| 3.7.2.            | Potential biorefinery strategies that can be adopted for by-products generating from sugar refinery process.....                   | 52 |
| 3.7.3.            | Identification of significant biorefinery strategies for by-products generating from sugar refinery process.....                   | 52 |
| 3.8.              | Performance Assessment of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka .....              | 54 |
| 3.8.1.            | Material Flow Analysis of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka.....               | 55 |
| 3.8.1.1.          | System definition for MFA .....                                                                                                    | 55 |
| 3.8.1.2.          | The system boundary for MFA .....                                                                                                  | 55 |
| 3.8.2.            | Circularity Assessment of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka.....               | 56 |
| 3.8.3.            | Life Cycle Environmental Assessment of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka ..... | 57 |
| 3.8.3.1.          | Goal and scope definition.....                                                                                                     | 57 |
| 3.8.3.2.          | The functional unit .....                                                                                                          | 57 |
| 3.8.3.3.          | System boundary .....                                                                                                              | 58 |
| 3.8.3.4.          | Inventory analysis .....                                                                                                           | 58 |
| 3.8.3.5.          | Impact Assessment.....                                                                                                             | 58 |
| 3.8.3.6.          | Interpretation of the results .....                                                                                                | 59 |
| CHAPTER FOUR..... |                                                                                                                                    | 60 |
| 4.                | RESULTS AND DISCUSSION .....                                                                                                       | 60 |
| 4.1.              | Results of descriptive analysis performed to evaluate the baseline performance of sugar and sugarcane industry in Sri Lanka .....  | 60 |
| 4.1.1.            | Local sugar consumption in Sri Lanka (2016-2022).....                                                                              | 60 |
| 4.1.2.            | Importation & local sugar production share of the total sugar consumption in Sri Lanka (2016-2022).....                            | 60 |
| 4.1.3.            | Sugar importation to Sri Lanka (2016-2022).....                                                                                    | 61 |
| 4.1.4.            | Local sugar production in Sri Lanka – total (t/year) (2016-2022) .....                                                             | 62 |
| 4.1.5.            | Local sugar production in Sri Lanka – contribution of each refinery (t/year) (2016-2022).....                                      | 62 |
| 4.1.6.            | Contribution from each sugar refinery to local sugar production (2016-2022)                                                        | 63 |
| 4.1.7.            | Sugar recovery in Sri Lanka – industry average (2016-2022) .....                                                                   | 63 |
| 4.1.8.            | Sugar recovery in Sri Lanka – performance of each refinery (2016-2022) ...                                                         | 64 |
| 4.1.9.            | Sugarcane cultivated area by sugar refineries of Sri Lanka (ha) (2016-2022)                                                        | 65 |
| 4.1.10.           | Share from each sugar refinery to total sugarcane area cultivated (2016-2022)                                                      | 65 |
| 4.1.11.           | Sugarcane yield in Sri Lanka – industry average (t/ha) (2016-2022) .....                                                           | 66 |
| 4.1.12.           | Sugarcane yield in Sri Lanka – performance of each refinery (t/ha) (2016-2022)                                                     | 67 |

|         |                                                                                                                                                       |    |
|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 4.1.13. | Local Ethanol Production (Million L/year) (2016-2022).....                                                                                            | 68 |
| 4.1.14. | Ethanol recovery in Sri Lanka – industry average (L/t) (2016-2022).....                                                                               | 68 |
| 4.1.15. | Ethanol recovery in Sri Lanka – performance of each refinery (L/t) (2016-2022)                                                                        | 69 |
| 4.2.    | Results of correlation analysis performed to evaluate the relationship between sugarcane crushed versus sugar production and the ethanol production . | 69 |
| 4.3.    | Baseline biorefinery configurations for sugar refineries in Sri Lanka .....                                                                           | 70 |
| 4.3.1.  | Sugarcane biorefinery configuration 1 .....                                                                                                           | 71 |
| 4.3.2.  | Sugarcane biorefinery configuration 2 .....                                                                                                           | 73 |
| 4.3.3.  | Sugarcane biorefinery configuration 3 .....                                                                                                           | 74 |
| 4.3.4.  | Macro-economic biorefinery configuration for the sugar refineries and associated industries in Sri Lanka .....                                        | 75 |
| 4.4.    | Biorefinery and management strategies adopted for by-products generating at each biorefinery configuration.....                                       | 78 |
| 4.4.1.  | Existing biorefinery and management strategies adopted for by-products generating at each biorefinery configuration .....                             | 78 |
| 4.4.2.  | Potential biorefinery strategies that can be adopted for by-products generating from sugar refinery process.....                                      | 79 |
| 4.4.3.  | Significant biorefinery strategies for by-products generating from sugar refinery process .....                                                       | 81 |
| 4.5.    | Material Flow Analysis of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka .....                                 | 86 |
| 4.5.1.  | The material flow analysis results of the biorefinery configuration 1 .....                                                                           | 87 |
| 4.5.2.  | The material flow analysis results of the biorefinery configuration 2 .....                                                                           | 88 |
| 4.5.3.  | The material flow analysis results of the biorefinery configuration 3 .....                                                                           | 89 |
| 4.5.4.  | The results of the material flow analysis of biorefinery configuration 4 (hypothetical scenario).....                                                 | 90 |
| 4.6.    | Circularity Assessment of baseline and hypothetical biorefinery configurations of sugar refineries in Sri Lanka .....                                 | 91 |
| 4.6.1.  | Circularity potential of the biorefinery configuration 1 .....                                                                                        | 91 |
| 4.6.2.  | Circularity potential of the biorefinery configuration 2 .....                                                                                        | 91 |
| 4.6.3.  | Circularity potential of the biorefinery configuration 3 .....                                                                                        | 92 |
| 4.6.4.  | Circularity potential of the biorefinery configuration 4 .....                                                                                        | 93 |
| 4.7.    | Life Cycle Assessment results of the sugarcane biorefinery configurations                                                                             | 94 |
| 4.7.1.  | Characterization results of the sugarcane biorefinery configurations .....                                                                            | 96 |
| 4.7.2.  | Damage Assessment results of the sugarcane biorefinery configurations .....                                                                           | 97 |
| 4.7.3.  | Normalized results of the sugarcane biorefinery configurations .....                                                                                  | 97 |
| 4.7.4.  | Weighted results of the sugarcane biorefinery configurations .....                                                                                    | 98 |

|                                                                                 |     |
|---------------------------------------------------------------------------------|-----|
| 4.7.5.    Single score results of the sugarcane biorefinery configurations..... | 99  |
| CHAPTER FIVE .....                                                              | 100 |
| 5.    CONCLUSIONS AND RECOMMENDATIONS .....                                     | 100 |
| 5.1.    Conclusions .....                                                       | 100 |
| 5.2.    Recommendations .....                                                   | 102 |
| REFERENCES .....                                                                | 104 |
| APPENDICES .....                                                                | 121 |

## LIST OF FIGURES

|                                                                                                                                        |    |
|----------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 1.1: Planetary Boundary Framework.....                                                                                          | 1  |
| Figure 1.2: The Linear Economic model .....                                                                                            | 3  |
| Figure 1.3: The Circular Economy Model .....                                                                                           | 4  |
| Figure 1.4: Technical and biological recovery cycles of CE .....                                                                       | 5  |
| Figure 2.1: Basic sugar production process and resulting by-products .....                                                             | 13 |
| Figure 2.2: Relationship between bioeconomy, bio-based economy, green economy,<br>and circular economy .....                           | 22 |
| Figure 2.3: Micro, meso and macro level application of MFA.....                                                                        | 23 |
| Figure 2.4: Life Cycle Assessment Framework.....                                                                                       | 26 |
| Figure 2.5: Circularity Indicators .....                                                                                               | 41 |
| Figure 3.1: Main sugarcane growing regions and the locations of operational and<br>non-operational sugar refineries in Sri Lanka ..... | 46 |
| Figure 3.2: Conceptual Framework of the Study .....                                                                                    | 48 |
| Figure 3.3: Web platform of the Sugarcane Research Institute for Statistics of the<br>sugar and sugarcane industry in Sri Lanka .....  | 49 |
| Figure 3.4: Preview 01 of the AHP web-based tool .....                                                                                 | 54 |
| Figure 3.5: Preview 02 of the AHP web-based tool .....                                                                                 | 54 |
| Figure 3.6: Interface of STAN 2.7 .....                                                                                                | 56 |
| Figure 3.7: The life cycle assessment framework.....                                                                                   | 57 |
| Figure 3.8: Midpoint and Endpoint impact categories.....                                                                               | 58 |
| Figure 3.9: Interface of SimaPro 9.4 faculty version .....                                                                             | 59 |
| Figure 4.1: Local sugar consumption and per capita sugar consumption in Sri Lanka<br>(2016-2022).....                                  | 60 |
| Figure 4.2: Share of sugar importation & local sugar production to the sugar<br>consumption in Sri Lanka (2016-2022) .....             | 61 |
| Figure 4.3: Sugar importation to Sri Lanka (2016-2022) .....                                                                           | 61 |
| Figure 4.4: Local sugar production (Total) (2016-2022).....                                                                            | 62 |
| Figure 4.5: Local sugar production (Contribution of each refinery) (2016-2022).....                                                    | 62 |
| Figure 4.6: Contribution from each sugar refinery to local sugar production (2016-<br>2022) .....                                      | 63 |
| Figure 4.7: Sugar Recovery in Sri Lanka – Industry Average (2016-2022).....                                                            | 64 |
| Figure 4.8: Sugar recovery of each sugar refinery (2016-2022).....                                                                     | 64 |

|                                                                                                                             |    |
|-----------------------------------------------------------------------------------------------------------------------------|----|
| Figure 4.9: Sugarcane cultivated area by sugar refineries of Sri Lanka (ha) (2016-2022) .....                               | 65 |
| Figure 4.10: Share from each sugar refinery to total sugarcane area cultivated (2016-2022) .....                            | 66 |
| Figure 4.11: Sugarcane yield in Sri Lanka – industry average (2016-2022) .....                                              | 66 |
| Figure 4.12: Sugarcane yield in Sri Lanka – performance of each refinery (t/ha) (2016-2022).....                            | 67 |
| Figure 4.13: Local Ethanol Production (Million L/year) (2016-2022) .....                                                    | 68 |
| Figure 4.14: Ethanol recovery in Sri Lanka – industry average (L/t) (2016-2022) ...                                         | 68 |
| Figure 4.15: Ethanol recovery in Sri Lanka – performance of each refinery (L/t) (2016-2022).....                            | 69 |
| Figure 4.16: Sugarcane biorefinery configuration 1 .....                                                                    | 72 |
| Figure 4.17: Sugarcane biorefinery configuration 2 .....                                                                    | 73 |
| Figure 4.18: Sugarcane biorefinery configuration 3 .....                                                                    | 74 |
| Figure 4.19: Macro-economic biorefinery configuration for the sugar refineries and associated industries in Sri Lanka ..... | 77 |
| Figure 4.20: criteria and sub-criteria for selecting biorefinery pathway.....                                               | 81 |
| Figure 4.21: Consolidated priorities of criteria considered in the AHP.....                                                 | 83 |
| Figure 4.22: The material flow analysis results of the biorefinery configuration 1...                                       | 87 |
| Figure 4.23: The material flow analysis results of the biorefinery configuration 2...                                       | 88 |
| Figure 4.24: The material flow analysis results of the biorefinery configuration 3...                                       | 89 |
| Figure 4.25: The material flow analysis results of the biorefinery configuration 4...                                       | 90 |
| Figure 4.26: Circularity potential of the configuration 1 .....                                                             | 91 |
| Figure 4.27: Circularity potential of the biorefinery configuration 2 .....                                                 | 92 |
| Figure 4.28: Circularity potential of the biorefinery configuration 3 .....                                                 | 92 |
| Figure 4.29: Circularity potential of the biorefinery configuration 4 .....                                                 | 93 |
| Figure 4.30: Block diagram of biorefinery configuration 1 .....                                                             | 94 |
| Figure 4.31: Block diagram of biorefinery configuration 2 .....                                                             | 94 |
| Figure 4.32: Block diagram of biorefinery configuration 3.....                                                              | 95 |
| Figure 4.33: Block diagram of biorefinery configuration 4 (Hypothetical Configuration).....                                 | 95 |
| Figure 4.34: Characterization results of the LCA .....                                                                      | 96 |
| Figure 4.35: Damage assessment results of the LCA .....                                                                     | 97 |

|                                                   |    |
|---------------------------------------------------|----|
| Figure 4.36: Normalized results of the LCA.....   | 97 |
| Figure 4.37: Weighted results of the LCA.....     | 98 |
| Figure 4.38: Single score results of the LCA..... | 99 |

## LIST OF PLATES

|                                                                                                                                                  |    |
|--------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Plate 3-1: Sugar refinery process in Sri Lanka.....                                                                                              | 47 |
| Plate 3-2: Industry Expert consultation during the study.....                                                                                    | 50 |
| Plate 4-1: Potential biorefinery strategies that can be adopted for by-products<br>generating from sugar refinery process (Expert opinion) ..... | 79 |

## LIST OF TABLES

|                                                                                                                                                           |    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 4.1: Pairwise Pearson Correlations: Sugarcane crushed vs sugar production..                                                                         | 70 |
| Table 4.2: Pairwise Pearson Correlations: Sugarcane crushed vs ethanol production<br>.....                                                                | 70 |
| Table 4.3: Existing biorefinery and management strategies adopted for by-products<br>.....                                                                | 78 |
| Table 4.4: Potential biorefinery strategies that can be adopted for by-products<br>generating from sugar refinery process (Expert opinion - ranked) ..... | 80 |
| Table 4.5: Decision Hierarchy of AHP criteria.....                                                                                                        | 82 |
| Table 4.6: Decision hierarchy with consolidated priorities for selected criteria.....                                                                     | 83 |
| Table 4.7: Selected alternatives for sugarcane by-products for AHP .....                                                                                  | 84 |
| Table 4.8: Consolidated priorities for selected alternatives .....                                                                                        | 85 |
| Table 4.9: Biorefinery options that are not incorporated into any of the existing<br>biorefinery configurations.....                                      | 85 |

## LIST OF ABBREVIATIONS

|        |                                                |
|--------|------------------------------------------------|
| AD     | Anaerobic Digestion                            |
| AHP    | Analytical Hierarchical Process                |
| AWG    | Anthropocene Working Group                     |
| BOD    | Biochemical Oxygen Demand                      |
| CBE    | Circular Bioeconomy                            |
| CE     | Circular Economy                               |
| CFA    | Carbon Footprint Assessment                    |
| CI     | Circularity Indicator                          |
| COD    | Chemical Oxygen Demand                         |
| CR     | Consistency Ratio                              |
| CSE    | Circular Sugarcane Economy                     |
| CTI    | Circular Transition Indicator                  |
| DMC    | Direct Material Consumption                    |
| DMFA   | Dynamic Material Flow Analysis                 |
| DMI    | Direct Material Input                          |
| EIOA   | Enterprise Input-Output Analysis               |
| EIP    | Eco-Industrial Parks                           |
| E-LCA  | Environmental Life Cycle Assessment            |
| EPR    | Extended Producer Responsibility               |
| EW-MFA | Economy-wide Material Flow Accounts            |
| GHG    | Greenhouse Gases                               |
| GTS    | Geological Time Scale                          |
| GWP    | Global Warming Potential                       |
| ICS    | International Commission on Stratigraphy       |
| IOA    | Input-Output Analysis                          |
| IS     | Industrial Symbiosis                           |
| ISO    | International Organization for Standardization |
| ISO    | International Sugar Organization               |
| LCA    | Life Cycle Assessment                          |
| LCC    | Life Cycle Costing                             |
| LCSA   | Life Cycle Sustainability Assessment           |
| MCDM   | Multi Criteria Decision Making                 |
| MCI    | Material Circularity Indicator                 |
| MFA    | Material Flow Analysis                         |
| MFCA   | Material Flow Cost Accounting                  |

|       |                                                    |
|-------|----------------------------------------------------|
| ODP   | Ozone Depletion Potential                          |
| PCA   | Principal Component Analysis                       |
| PE    | Polyethylene                                       |
| PET   | Polyethylene terephthalate                         |
| PP    | Polypropylene                                      |
| RECP  | Resource Efficient Cleaner Production              |
| SDGs  | Sustainable Development Goals                      |
| SFA   | Substance Flow Analysis                            |
| S-LCA | Social Life Cycle Assessment                       |
| SME   | Small & Medium Enterprises                         |
| SRI   | Sugarcane Research Institute                       |
| TMC   | Total Material Consumption                         |
| UNEP  | United Nations Environment Program                 |
| UNIDO | United Nations Industrial Development Organization |
| WBCSD | World Business Council for Sustainable Development |
| WFA   | Water Footprint Assessment                         |

## LIST OF SYMBOLS

|                   |                           |
|-------------------|---------------------------|
| %                 | percentage                |
| µg                | micro gram                |
| µl                | micro liter               |
| Km                | Kilometer                 |
| m                 | meter                     |
| m <sup>3</sup>    | cubic meter               |
| Min               | minute                    |
| ml                | milliliter                |
| mm                | millimeter                |
| mm                | millimeter                |
| msl               | mean sea level            |
| nm                | nanometer                 |
| °C                | degree centigrade         |
| r                 | radius                    |
| s                 | second                    |
| SD                | Standard Deviation        |
| t                 | time                      |
| λ                 | Wavelength                |
| µg/m <sup>3</sup> | microgram per cubic meter |
| π                 | pie                       |

## LIST OF APPENDICES

|                                                                                                          |     |
|----------------------------------------------------------------------------------------------------------|-----|
| <b>Appendix I:</b> Process flow diagram of the general sugar production process .....                    | 121 |
| <b>Appendix II:</b> Sugar Milling Process (Expanded) .....                                               | 122 |
| <b>Appendix III:</b> Bagasse Processing (A) .....                                                        | 122 |
| <b>Appendix IV:</b> Rotary vacuum filtration.....                                                        | 123 |
| <b>Appendix V:</b> Molasses Processing (C) .....                                                         | 123 |
| <b>Appendix VI:</b> Data collection sheet to obtain sugarcane by-product utilization pathways.....       | 124 |
| <b>Appendix VII:</b> Consolidated Weights of Alternatives (AHP – Step 02 Results)...                     | 125 |
| <b>Appendix VIII:</b> Input-Output Tables for LCA Data Collection (Agricultural Stage) .....             | 126 |
| <b>Appendix IX:</b> Input-Output Tables for LCA Data Collection (Sugarcane Transportation).....          | 127 |
| <b>Appendix X:</b> Appendix IX: Input-Output Tables for LCA Data Collection (Sugarcane Processing) ..... | 128 |