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Integrated Life Cycle Assessment, Life Cycle Costing and Multi Criteria Decision Making for Food Waste Composting Management

R. Abu[1], Muhammad Arif Ab Aziz[1,2,*], Zainura Zainon Noor[1,3]

[1] School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[2] Centre of Hydrogen Energy, Institute of Future Energy, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[3] Centre for Environmental Sustainability and Water Security (IPASA), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia

ABSTRACT

The integrated models specifically designed to help decision-making in food waste (FW) composting management through the analysis of previous research studies are reviewed. The integrated models are built predominantly within three decision-supporting tools, which include life-cycle assessment (LCA), life cycle costing (LCC), and multi-criteria decision-making (MCDM). Different integrated models were discussed and their strengths, limitations, and crucial problems as well as their potential integration were evaluated. Apparently, there has been no in-depth analysis of its approaches and potentialities of combining harmonically the LCA, LCC, and MCDM analysis tools in the FW composting management which taking into consideration multiple stakeholders. Thus, the combined LCA, LCC and MCDM with cluster analysis (CA) is suggested. The concepts underlying the sustainable FW composting management model can be divided into several aspects in terms of environmental friendliness, financial profitability, and social acceptance. This gives an insight and facilitate to waste management sectors to decide on a preferable FW composting management.

Keywords:
Food Waste Composting Management; life-cycle assessment (LCA); life cycle costing (LCC); multi-criteria decision-making (MCDM)

1. Introduction

Throughout the last decades, the conventional goal of the waste research management sector focuses on the development of tools and techniques in helping decision-makers to make strategic judgments on waste treatment technologies. Decisions are the result of a decision-making process undertaken by decision-makers who formulate decision-making models employing particular structural and parameters to achieve an objective [1]. Regarding food waste (FW) composting management, most of the models have been developed primarily within the three frameworks for decision support, which are life-cycle assessment (LCA), life costing analysis (LCC), and multi-criteria decision-making (MCDM) [1- 4].

* *Corresponding author.*
E-mail address: m.arif@utm.my

Generally, FW past studies in most cases focused on the impacts on the environment using the LCA without showing the interconnection between cost and social outcomes. While different investigations implying the LCC have stressed the administration and finance, others have utilized the MCDM for quantifying preferences of the interested parties within the assessment instead of avoidance or valorization of specific flows. The consequences of having a single criterion assessment will result in the inherent inconsistency and sometimes conflicting nature of these parameters, which present major challenges to the implementation of treatment programs.

This review provides an analysis technique of a decision-making model that combines LCA, and LCC, and MCDM for FW composting management by discussing their strengths, limitations, and potential integration. This paper tries to highlight the areas where knowledge is scarce and value can be added to increase decision support performance and expansion. Although several types of research have been attempted to review the issue of decision support in the management of FW, nevertheless, their focus is not having a combination of environmental, economic, and social impacts. For instance, Bernstad *et al.,* [2] reviewed about LCA in FW management, while De Menna *et al.,* [3] focused in the LCC on FW study, and Shukor *et al.,* [5] reviewed MCDM sustainability requirements (environmental, social, economic, and technical) to choose the most suitable composting technology. A lack of studies on the combined decision support tool has contributed to a lack of formal comprehension of the relevant current literature and it hinders professionals and decision-makers from seeing which interventions have served in the past and which need to be prioritized in the future. The best management of waste sectors needs to communicate with environmental, financial, and public priorities [2-3, 5]. Thus, further views on future research through the integration of LCA, LCC, and MCDM-analytical hierarchy process (AHP) with cluster analysis (CA) were proposed.

2. Models developed to support decision making

The summarization models that have been developed to help decision-making in FW composting management is shown in Table 1. This content is presenting non-exhaustive list of update review of FW composting decision making process. The classified scopes were combined environmentally effective with socially acceptable, environmentally effective with economically affordable and socially acceptable within different frameworks. The reviewed findings from Table 1 has demonstrated the LCA with MCDM, and cost complementary hybrid framework implemented in integration tends to be among the most appropriate approach for this context at the frequency of usage 45%, and mainly the integration of LCA and AHP, the most frequently being used by an academic method (50%), due to its simple design and reliability for sustainable assessment in waste management systems as shown in Figure 1 [6 - 9].

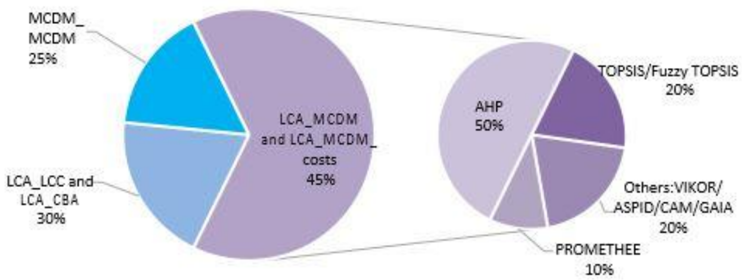

Fig. 1. Models developed to support decision making, and interrelationship of frequency used among the methods developed according to the Table 1 summary result

Table 1
Integrated decision support model in FW management in literary studies

Assessments criterion/Treatment alternatives (aerobic, anaerobic)	Summary decision support studies of combined LCA, LCC and MCDM									
	LCA: Environmentally effective				LCC: Economically affordable	MCDM: Socially acceptable		Types of analysis		Ref.
	FU	Software	LCIA	Impacts Assessed	Methods	Methods	Stakeholder	Complementary	Integral	
Recycled + Composting + Landfill, Recycled + AD						AHP/ ASPID	Municipal/Experts	√		[4]
Composting, Bio drying						PROMETHEE/ TOPSIS	Experts	√		[7]
Composting, AD	1t of SW of the campus	SimaPro 7.3	Eco-indicator 99	GWP, OD, EP		AHP	Experts		Cluster analysis	[8]
Dry AD	1t of source selected OFMSW	EASETECHDenmark/Eco-invent 3.0	ILCD	GWP, ODP, PM2.5, IR, POF, EU-F, EU-M, AP, EU-L, ET, AR, HT-Carc,HT-nonCarc		MCDA	Experts		VIP-analysis weighting	[9]
Composting, AD						AHP/ CAM	Municipal/ Experts/ Enterprise/NGO		Degree of consensus	[10]
AD centralized (continuous load digester), AD semi-centralized (continuous load digester, Centralized Takakura composting, Semi-centralized Takakura composting.	117.3 t of FW per year	SimaPro (Version 9.0.0.49)	ReCiPe 2016 midpoint method	GWP, LU, TA, FE, M-RS, F-RS, WC	E-LCC	AHP	Experts	√		[12]
Open Air Static Pile composting	200kg/d of FW+LW	SimaPro 9	TRACI 2.0	OD, GWP, S, AP, EP, C, n-C, RE, ET, FFD	Others	AHP	Experts	√		[13]
Composting, AD	500t of fruit saved from being wasted	Simapro 8.5	Environmental Footprint (version 2.0)		FW Prevention calculator		Experts	√		[14]
AD, In vessel Composting	Treatment of 1 ton of household FW	GaBi	ReCiPe 1.08	GWP, FD, MD, FET, MET, TET,	C-LCC			√		[15]

				HT, FE, ME, TA, PMF, POF, OD, ALO, ULO, NLT, IR, WD						
Centralized organic waste treatment (AD + Dewatering + Composting)	The management of 1t FW/15years lifetime of the operation of facilities	SimaPro 8.3	ReCiPe Endpoint	Resources, Ecosystem, Human Health	CBA			√		[16]
AD co-digestive	Annual production of grape seed oil	SimaPro 7	CML 2001	ADP, AP, EP, GWP100, ODP, HT, EF, ET, EM, EM-S, EF-S, Malodors air	E-LCC				Industrial symbiosis	[17]
Windrow composting	Per tons Fresh Matter in FW	EIO-LCA model	TRACI 2, IPCC	ODP, GWP, S, AP, EP, Carc, Non-carc, RE, ET, FF-use	Others			√		[18]
Composting, AD						TOPSIS/ VIKOR	Municipal/Experts	√		[19]
Composting, AD,	The management of annual food waste 82 generated by Danish households: 1,500,000 single-family housing (SFH) and 1,000,000 multi-family housing (MFH) units	EASETECHLCA model	ILCD midpoint	GW, POF	E-LCC			√		[20]
Integrated (MRF/Source separation/Composting/Incineration/Landfilling)	1t/d MSW of Isfahan	SimaPro 7	Eco-indicator 99	Carci, R-Carci, CC, IR, OD, ET, AP, EP, LU, AD		TOPSIS	Experts	√		[21]

MBT	1t of treated/disposed SW	GaBi	CML 2001	GWP, AP, EP, OD, POCP		AHP	Municipal/Experts / Public/ NGO		Percentage analysis	[22]
Biological treatment of OFMSW + ER from RDF	1 kg of MSW treated in all cases		Calculation	Ecological Footprint (single indicator)		AHP/ PROMETHEE/ GAIA	Experts		Weighting analysis	[23]
AD + BMW, AD + MBT, Aerobic + MBT						AHP/ interval-valued fuzzy TOPSIS	Municipal/Public/ Experts/ Enterprise/ NGO	√		[24]
Integrated	1t of household SW	Calculation	Eco-Indicator 99	GWP	C-LCC	AHP	Municipal/Experts / Public/ NGO	√		[25]

Centralized composting, Home composting, Anaerobic co-digestion, In sink maceration, Separate AD, MBT (mechanical sorting + AD + in vessel composting)	Melton city council (CASE 1) provides waste services to 36,919 households. 10,461 Mg of residual waste, 8559 Mg of FW, 8125 Mg of GW, and 22,574 Mg of SS Sutherland shire council (CASE 2) provides waste services to 82,470 households. 33,280 Mg of residual waste, 17,920 Mg of FW, 13,000 Mg of GW, and 91,300 Mg of SS	SimaPro 8.0, Monte Carlo Simulation, Australasian Unit Process LCI Version 2015.3, Eco invent Database (3.1)	CML-IA (4.2), IPCC 2013 (GWP100)	ADP, FFDP, ODP, HT, POP, AP, ETP, GWP	E-LCC	√	[26]

MBT: Mechanical Biological Treatment, RDF: Refuse Derived Fuel; ER: Energy Recovery; FFW: Fuel from Waste: BMW: Bio Methane from Waste; FW: Food Waste; KW: Kitchen Waste; YW: Yard Waste; NA: Not Applicable; OFMSW: Organic Fraction Municipal Solid Waste
F.U: Functional Unit: LCIA: Life Cycle Impact Assessment; CML: Centrum voor Milieukunde Leiden; IPCC: Intergovernmental Panel on Climate Change, ReCiPe: RIVM and Radboud University, CML, and PRE' Consultants; EDIP: Environmental Design of Industrial Products; TRACI 2:
Reduction and Assessment of Chemical and Other Environmental Impacts; ILCD: International Reference Life Cycle Data System, GaBi: Ganzheitlichen Bilanzierung (German for holistic balancing)
Impacts assessment: AP: Acidification potential; EP: Eutrophication potential (EU-Fresh, EU-Marine, AP, EU-Land); GWP: Global warming potential; POF: Photochemical ozone formation; ODP: Ozone depletion potential; FEU: Fossil energy use; ETP: Eco toxicity potential; REU: Renewable
energy use; EU: Energy use; ADP: Abiotic depletion potential; HH: Human health; HTP: Human toxicity potential; HM: Heavy metals; HT(w): Human toxicity (water); HT(s): Human toxicity (soil); HT(a): Human toxicity (air) HT-Carc, HT-non Carc ; ET(wc): Eco toxicity (water chronic);
ET(wa): Eco toxicity (water acute); ET(s): Eco toxicity (soil); LU: Land use; WU: Water use; RU: Resource use. PM2.5: Particulate Matter; IR: Ionising Radiation; AR: Abiotic Resources S: Smog, FF: Fossil fuel used, AD: Abiotic depletion, ADFF: Abiotic depletion (Fossil Fuel), HT: Human
toxicity, FWA Ecotox: Fresh water aquatic eco toxicity, MA Ecotox: Marine aquatic eco toxicity, TEcotox: Terrestrial eco toxicity, POP: Photochemical oxidation potential
ALO: agricultural land occupation; FD: fossil depletion; FE: freshwater eutrophication; FET: freshwater ecotoxicity;

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HT: human toxicity; MD: metal depletion; ME: marine eutrophication; MET: marine ecotoxicity; NLT: natural land transformation; OD: ozone depletion; PED: primary energy demand; PMF: particulate matter formation; POF: photochemical oxidants formation; TA: terrestrial acidification;
TET: terrestrial ecotoxicity; WD: water depletion; ULO: urban land occupation; DB: dichlorobenzene; NMVOC: non-methane volatile organic compounds
E-LCC: Environmental Life Cycle Costing; C-LCC: Conventional-Life Cycle Costing; CBA: Cost Benefit Analysis
MCDA: Multi-criteria Decision Analysis; TOPSIS: Technique for Order Preference by Similarity to Ideal Solution; PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation; ASPID: Analysis and Synthesis of Parameters Under Information Deficiency; ELECTRE
III: Elimination and Choice Translating Reality; VIKOR: VIseKriterijumska Optimizacija I Kompromisno Resenje, that means: Multicriteria Optimization and Compromise Solution); CAM: Consensus Analysis Model; VIP: variables interdependent parameters-analysis; **Complementary**: Cases of combining both tools existed mainly in separate forms, e.g. first an LCA on the objective and then an MCDM was performed separately on the same objective. **Integral**: We classify as an "Integrating" study those investigations where the LCA methodology is used as the main base and multi criterion techniques are included in any of its phases, otherwise it will be classified as a study with a “Complementary" approach [6].

2.1 An LCA with MCDM or LCA with MCDM with Costs Model

According to Hung *et al.,* [10] and Guzman *et al.,* [6], there are two decision-making models have often been used to facilitate decision-making in the field of waste management, multi-objective programming (MOP) and MCDM, as well as a framework of environmental impact, the LCA (Table 1). The most common MCDM-the AHP is known as the dominant method in the field of waste sectors and is primarily used to overcome FW composting treatments as it offers a useful insight of the inherent characteristics of decision issues and encourages the function of the multi stakeholders involved in decision-making processes [11]. The varied stakeholder group has diverse favorable treatment in the specific criteria groups; thus, it is complicated to obtain a consensus. In this analysis, it was noticed a simplified resolution was adopted in which preference was given to government or municipality stakeholder groups and experts (i.e. researchers in research institutes and universities, specialists in enterprises, non-governmental organizations-NGOs) rather than public or residents. It was further required to get stakeholders with enough information and was believed necessary to ensure that the panelists were knowledgeable with environmental effect (i.e. method of identifying and weighting the impacts categories) in present investigations administered.

A study that incorporate LCA and AHP, e.g. integration using cluster analysis (CA) performed by Ghazvinei *et al.,* [8] assessed two-dimensional aspects that were both environmentally efficient and socially appropriate. The study analyses approach to selecting effective solid waste management. A university-focused resource is selected as a case study. According to this integration for selecting the best alternatives within the same framework, it plotting standardization coordinate (x,y) in quadrant of Cartesian graph x-axis (AHP), y-axis (LCA). The possible solutions are to be found over the first quadrant. It indicates the significant performance between both LCA and AHP approaches. CA is the core method of classifying a "mountain" of information into real, controllable sets. It is, therefore, a method for data reduction by developing subgroups to handle data more efficiently than individual information. In the meantime, Abba [22] combines LCA and AHP as a case study into a percentage analysis of improvisational decision-making in solid waste in the city of Johor Bahru.

Another stud by Angelo *et al.,* [9] integrate the LCA study with the MCDA, by variables interdependent parameters-analysis (VIP-analysis). The study aims to identify the preferred environmental alternative for the domestic waste FW handling. Addition to its potential to manage problems with imprecise information, the VIP analysis is perfectly applicable in the aggregation of LCA data, improving the decision-making process. The VIP analysis software has been used to discover the appropriate alternative treatments for FW from among LCA results performed. This review has observed decision support tools by combining LCA, LCC, and MCDM techniques complementarily within the same decision-making objective [12-13]. Cases of combination of three methods occurred primarily in sequential ways, e.g. first the objective LCA and then the objective LCC as well as the multi-criterion were conducted separately within the same goal. However, this review has not yet discovered decision support tools by integrating LCA, LCC, and MCDM techniques harmonically within the same decision-making framework. In environmentally contexts, the LCA was calculated on municipal solid waste management system cases or FW in campus composting [13], [22] however, there is still less rigorous methodology for all scientific purposes pertaining to large-scale FW composting involving a range of environmental, financial or social impact factors for both aerobic or anaerobic conditions.

Furthermore, there is a need to provide methodological guidance and key sources for readers reference to implement LCA on FW composting management, so that misconceptions can be avoided due the variation of the item under analysis (waste) that is composed of various materials that can need different treatment options. In spite of the various technologies used, the analysis of a same composting functional unit (FU), the operating mode, the setting of the system boundaries, the databases used for example GaBi, SimaPro, EASETECH and life cycle impact assessment (LCIA) approaches, i.e. ReCiPe, Effect for 2002 +, EDIP and CML selection are indeed very essential in preventing bias in the comparison of climate reliability between different alternatives. The use of LCA databases and the inventory data collection are enabled by the inclusion of LCA databases in LCA software. Of the study analyzed, SimaPro has been widely used since it offers more open data in databases, which can offer very good visualization to reflect the results of the assessment [12-14].

Besides, the variation of the LCIA technique used may also have a major impact on the outcome; thus, it is necessary to understand each LCIA process, whether either midpoint or endpoint was chosen, or the mixture of methods used for comparative purposes. Midpoint has a reliable model and data that is known as a problem-oriented LCIA system. It can significantly contribute to accurate analysis and open possibility for comparison of various studies. However, the midpoint can also be more complex to interpret which includes a variety of abstract meanings, e.g. radiative force – acidification. Thus, the endpoint as the damage-oriented LCIA approach is an alternative to simplifying the interpretation of the LCIA. For example, endpoints (e.g. ReCiPe 3 and Eco Indicator 99) were determinants that demonstrated the environmental effect on human health, biodiversity, and, finally, resource scarcity at three higher aggregations. LCIA approaches such as ReCiPe [15-16], EDIP, and Impact 2002+ present greater categories of evaluation and comparison than CML [22], [26] and TRACI [18].

2.2 An LCA with LCC or LCA with Cost Benefit Model

Preventing, valorising and handling FW requires a clear combination of LCA and LCC to prevent trade-offs between environmental and economic impacts. The reason is simple; it is able to transform inventory and impact studies into metrics (dollars and cents) that business organizations understand. For many of these process and product development decisions, basic financial justification is a requirement for the approval of the proposed change. The LCC for facilities management frameworks presents a set of definitions and limits that the LCC community uses. Summing conventional company costs, plus less tangible, hidden, indirect company costs and external costs provide the overall cost of the product-all costs for which the company is responsible in view of current or expected market conditions and regulatory requirements. Although several LCA cases and LCC cases have been published so far, academic papers on cases of combining both methods occurred mainly in different ways, e.g. first an LCA on the target and then an LCC was conducted separately on the same target [20], [26] except by Zhu [17] within the same framework using industrial symbiosis. There are fewer cases with integrated methodology and cases, so does the analysis of the benefits and drawbacks of incorporating them. Second, a similar scenario emerges when the life-cycle approach of large-scale FW treatment is investigated in the literature.

De Laurentiis *et al.,* [14] presented the assessment framework and created the life-cycle prevention calculator, critically addressing how future interventions should be planned, tracked and reported, to ensure that adequate and appropriate data is made available to allow them to be properly assessed. It is important to note that this calculator has not been built to evaluate the value of FW valorisation actions. Edwards *et al.,* [26] addressed the analytical aspects of the system of LCA and LCC to FW, which primarily centred on the study of urban FW management studies. Although the LCA was determined on this case, there is still lacking a general methodology for all study purpose relevant, for example, to large-scale FW composting in the vessel for aerobics and composting in two stages. Most of the FW studies analysed could be categorized as E-LCC approaches while two cases have been used for C-LCC. The costing systems used by authors were defined by cost categorization typology, number of cost bearers, indirect allocation of costs, and discounts. Various approaches to costing lead to different applications and perceptions. For instance, C-LCC focused on economic viability or capital cost impacts and did not recognise environmental consequences. E-LCC was typically simultaneously as LCA and, unlike C-LCC, the distribution of net costs or savings across the supply chain could also be seen.

2.3 An MCDM with MCDM Model

MCDM is also a widely used waste management problem solving tool. MCDM alone offers the required flexibility within the treatment of qualitative criteria on socially acceptable among different interested parties. Each MCDM tool uses a specific technique to perform a pairwise comparison. In addition, the choosing or combination of a suitable MCDM method is extremely important to support decision-making on sustainable management in the waste sector. Since none of the method is perfect, thus, a combined approach may sometimes be required [4], [7]. Hung *et al.,* [10] suggested a framework that incorporates MCDM-Fuzzy AHP with Consensus Model (CAM) analysis. CAM's primary feature is the evaluations of a level of agreement on alternative solutions among stakeholders. According the CAM proposed in this study, it appears that the stakeholders do not support landfilling and incineration. Again, when stakeholders discussed, the recommended treatment was AD, hog feeding, and composting.

Stefanovic *et al.,* [4] utilized AHP along with parameter analysis and synthesis under information deficiency (ASPID). As shown by this study, ASPID does have the ability to work with lack of knowledge, which might be the case in waste management, and could be adapted to the scenarios of waste management sustainability assessment. To use it, option ranking is performed utilizing AHP, and the results are compared with the results generated through ASPID. Four scenarios for waste treatment were formed based on Nis generated waste, and 9 indicators were assigned. The result obtained indicates that there is no substantial difference in the ranking of scenarios, irrespective of the method used, the AHP method or the ASPID method. The preferable waste management strategy is the scenario involving organic waste composting and inorganic waste recycling (39.3 per cent priority ranking).

Arikan *et al.,* [7] contrasting results among TOPSIS, PROMETHEE and FUZZY TOPSIS while Mir *et al.,* [19] using fuzzy TOPSIS and VIKOR in complementarily. These studies investigated and tried to establish the most practicable waste disposal evaluating thermal, biological and recovery methodologies, and proposed comparative analysis among MCDM frameworks. Pires *et al.,* [24] have combined two MCDA techniques (AHP-based interval-valued fuzzy TOPSIS) to enable decision-makers select waste management practices that take into consideration LCA results and general social, economic and operational indicators. However, integrating MCDM with MCDM models in the area of waste management, validating only possible strategies and not presenting any relevant data on waste minimization and waste prevention. Hence, the choice of more sustainable solutions is not being created.

3. Recommendation

The integral between LCA, LCC, and MCDM-AHP using CA within the same decision-making framework is suggested. The decision-maker needs to consider the evaluation measures required to make the right choice and to recognize the particular strengths and limitations of that judgment. It can minimize the error and risk probability of a procedure during the planning and execution phases of the project. In regards, the assessment actions help the decision-maker to analyze each technology suggested so that an optimized solution can be established. While the LCA provides a solid quantitative analysis of environmental aspects, the LCC provides the quantitative analysis of cost accounting systems, and the MCDM offers the required flexibility within the treatment of qualitative criteria on socially acceptable. Combining the strengths of both qualitative and quantitative methodology within the same framework, may be the most acceptable tool to attain a comprehensive sustainable analysis in FW composting system since a diverse variety of information that best offers a more complete understanding of assessment towards the sustainability of FW composting methods is of crucial necessary. Four methods will be employed to derive the framework for FW composting management: (i) LCA, a quantitative method for determining the environmental impact of a particular form of composting, (ii) AHP, a qualitative tool for collecting relevant information and determine experts preference, regarding composting approaches and their applicability, (iii) LCC, a quantitative method, to estimate the costing facilities of composting management and (iv) CA can incorporate the results from the previous three approaches by mapping three-dimensional coordinates. The proposed model should include thorough information and prevent bias against either a qualitative or quantitative approach.

4. Conclusions

The main objectives of this review are to analyze several integrated models developed to support decision making, based on composting literary studies. The finding underscored that the combined LCA with MCDM and cost complementary methods is the highest being studied at 45% in decision support tools. Furthermore, this review is intended to suggest a comprehensive methodology that incorporates diverse factors (i.e. environmental, economic and socially acceptable) involved in prioritizing the FW composting methods via CA integral. This gives opportunity for decision maker to select the most appropriate large-scale FW composting methods. Besides, the analysis presented can assist waste managers to determine LCA, LCC and MCDM-AHP of related waste management system considering their unique circumstances.

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