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Renewable biogas from anaerobic digestion of biomass: influence factors in life cycle assessment

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Abstract. Based on the current generation rate of 1 kg^{-1} $person^{-1}$, the production of organic waste in Malaysia is estimated to reach 9 metric tons per year by the year 2020. Components of these wastes, however, can be used to generate biogas, not only to decrease waste-related issues, but also to produce renewable energy. There is a growing interest in resource recovery and waste/energy integration through biogas generation from organic waste through anaerobic digestion method. However, due to the anaerobic digestion process varies in different facilities, thus proactive assessment on the status of biogas production and its effect on the environment through life cycle assessment is vital. The objective of this review is to assess factors that affect environmental performance results such as the system boundaries setting, the databases used and the life cycle impact assessment methods applied. This review underscores the fact that goal definition and scope, functional units, system boundaries setting, characterization and life cycle impact assessment methodology, as well as types of software and databases used influence and affects the life cycle assessment results. It suggests that for future cross study comparisons, all assessment guidelines should be addressed to avoid biased comparisons on climate performance between different alternatives.

1. Introduction

Biomass is classified as a renewable source that comprises of water and carbon dioxide, utilizing daylight as a source of energy. This contains food, harvested crop, trees, farm and forestry residues, aquatic plants, animal and municipal waste [1, 2]. The environmental benefits of using biomass are derived from its cycle of life. Output source on biomass could, in theory, biodegrade into carbon dioxide and water toward their finish cycle, preferably generating no “additional” carbon dioxide. Renewable biomass feed stocks are grains, oils, fats, proteins, and lignin’s from a chemical perspective [3].

Food waste (FW) is a source of biomass. It is the largest element of municipal solid waste (MSW) that comprises restaurants and canteen waste, households, as well as food processing plants. These large generations of FW brings about a wide range of environmental and sanitary problems, and this should not be ignored. It is expected that by 2025, FW volume in Asian countries will increase to 4.16 billion tons compared to the current 2.78 billion tons [4]. Every year, as stated by Xiao et al. [5], the foods produced are lost at about one-third over the whole food supply chain, and this is estimated to be around 1.3 billion tons of food. In 2018, FW in Malaysia reached nearly 16,700 metric tons on a daily basis. This includes 4000 metric tons that are still suitable for consumption, and should not be disposed [6]. Generally, MSW in Malaysia comprises 50% FW, of which, 70% is dumped in a landfill site [7].

Currently, several municipalities in Malaysia, like for example Petaling Jaya city council, have been utilizing anaerobic digestion (AD) dry continuous type (Cowtech technology) which is capable of processing approximately 500 kg-1ton/day of FW [8]. Other city councils such as Subang Jaya, Sepang, and Putrajaya are utilizing anaerobic waste digesting system facility to treat FW. The resulting biogas is used for direct heating in the kitchen, as well as generating electricity for lamps. According to Hoo et al. [9] production of biogas from FW is estimated at almost 60 Mm^3 of CH_4 that can be produced annually. This is equivalent to 16.3 MW of electricity, based on FW generated in 2010. The estimation is based on methane gas emissions derived from the Intergovernmental Panel on Climate Change (IPCC) biological treatment formula. The sale of electricity through the Feed-in-Tariff (F.i.T) scheme is expected to generate revenue of nearly Ringgit Malaysia 42 million. Nonetheless, due to the lack of a research facility, its real potential is not optimized.

FW has increased tremendously in line with the steady growth of the economy. It is an extremely unpleasant material that however, can be treated as a valuable potential source of bio methane, which can play a significant role in renewable and sustainable energy development. Hence, increasing consideration has been made towards technology advancement in this field. Apparently, AD has become the most effective way to treat energy-rich and high humidity organic substantial's [10]. It is relatively cost affordable and sustainable for long-term energy production that consistently becomes the most popular investigation trend. AD will be of value to both nutrient recovery and energy renewable. Hence, it is being investigated extensively because it offers favourable alternatives and has a high wastes valorisations value. Intensive explanations of the treatment methods, including landfilling, composting, incineration, integrated treatment, and anaerobic digestion can be concluded comprehensively in Table 1. These contents are used here to assist in evaluating the advantages, and disadvantages of each FW treatment method. Compared to landfill, AD requires less input energy for operation, fewer spaces and there is still potential for efficiency improvement [10-12].

Table 1. Results of the comprehensive evaluation of the different current methods FW Management.

		Landfill[a]	**Composting[a]**	**Incineration[a]**	**Integrated[a] Treatment**	**Anaerobic[b] Digestion**
Economy	Investment	Moderate	Moderate	Large	Large	Large
	Operating cost	Cheap	Medium	Expensive	Expensive	Medium
	Land Occupation	Large scale	Medium scale	Small scale	Small scale	Small scale
Ecology	Discharge gas	Biogas	Foul odour	Acid gas	Acid gas	Biogas
	Waste Water	Leachate	Little leachate	-	Little leachate	-
	Soil	Leachate Contamination	Heavy Metal Contamination	Gasses Pollutant Residues	Gasses Pollutant Residues	-
Technology	Requirement	All	Putrescible	High calorific waste	All	Putrescible
	Dependability	High	Medium	Medium	Medium	Medium
	Security	High	High	Medium	Medium	Medium
	Standard of control	Low	Medium	High	High	High
Community	Convenience	Moderate	Significant	Significant	Significant	Significant
	Resource	Little	Medium	Large	Large	Large
	Reduction	Nil	20% reduction	80% reduction	90% reduction	50% reduction

a [12][13] b [11]

In correlation with different biofuels, biogas is progressively adaptable, since it tends to be created from hydrocarbons, proteins, and fats, including wet and secondary materials [14, 15]. Generally, biogas is generated from FW, sewage sludge and manure, but the biogas production method and arrangement is differed between regions, with various feedstocks, production, and use [16]. Thailand, Indonesia, Brazil, China, the United States of America and European countries for instance, deployed their accessible local timber and biomass resources to substitute coal and oil [17]. In Malaysia, biomass energy sources are acquired from timber waste and several cultivations i.e. palm oil, rubber, coconut, sugarcane, cocoa, rice paddy, animal waste and urban waste [18]. However, the biggest biomass energy is contributed by the palm oil industry due to its enormous plantation in Malaysia. Bruijstens et al. [19] stated that FW has higher methane content, which can reach nearly 85% compared to other wastes. A study conducted by Naesko Environment's Association [20], has shown percentage variation on the biogas yielded based on four types of waste. Compared to household waste (50-60%), all other wastes have a higher methane percentage (food waste 68%; agricultural waste 60-75%; wastewater treatment sludge 60-75%).

AD has numerous processes involving methanogenic archaea and bacterial actions. To assist the degradation of organic matter, four stages would be involved sequentially such as hydrolysis, acidogenesis, acetogenisis, and methanogenisis. During the treatment, macromolecular organic component is degraded into liquefy monomers which then to tinier molecules of short group fatty acid, pyruvic acid, amino acid, acetic acid and others. These eventually ingested into hydrogen and acetic acids and converted by methanogenic archaea into methane [4]. FW is highly considered suitable for AD bio methane potentiality approximated at range 200 to 670ml CH_4/g added Volatile Solids (VS).

During the AD process, organic waste might be altered into burnable biogas (principally methane, as well as gases variation, such as, hydrogen sulphide and hydrogen [5]. Parameters, for instance, volatile solids reduction and methane yield or so were employed to evaluate investigation efficiency. In the procedure to improve the quality of methane production, various aspects of AD are investigated such as additional supplementation, functional alternations, optimization of parameters and microbial behaviour. Besides biogas, the anaerobic digestion process transfers secondary products- bio fertilizer also known as digestate. As a large share of the source of nourishment content of the feedstock ends up in digestate, it can be used as bio compost contributing to improved soil nutrient management [21, 22].

However, as biomass transformation to bioenergy increases ecological issues, the subject on ecological sustainability assessment of bioenergy pathways has been extensively conducted. Consequently, a life cycle assessment (LCA) as a comprehensive method is used to determine and guarantee the environmental sustainability of the biogas. LCA is a holistic approach for surveying a system's environmental burdens by characterizing the fuel, materials utilized, and contamination discharged into the ecological system. As stated by Aziz et al. [23], particularly in Malaysia's biogas production there are less LCA studies have been conducted. This study aims to assess the biogas generation from biomass towards environmental impacts through LCA. This review highlights the influence factors that affect the life cycle assessment results, for example, goal determination and scope, functional units, boundary systems setting, characterization, assessment methodology on life cycle impact, impacts categories, finally the selection of software and databases.

2. LCA for biogas generation from anaerobic digestion of biomass

There is expanding attention in the assessment of the ecological impacts of biogas as a cleaner and more sustainable power source utilising approach of LCA. This reviewed paper discussed the investigations on LCA biogas generation from several countries with various characteristic points of view. The studies depended on the described LCA approach that stated in ISO 14040 and 14044. The consideration of the exhaustion of non-renewable energy source and the ecological issue, for instance, an a worldwide temperature alteration identified with ozone harming substance releases has incited an extension in examining at organic wastes biogas creation for a more feasible energy production.

Biogas processing from biomass products is highly cost saving for the creation of sustainable energy. This is because the abundance of ready feedstocks such as MSW, wastewater discharges, horticultural and animal waste can be exploited to generate energy. Reusing of natural wastes is likewise a better and more practical ecological expenditure that be able profit residents and the environment simultaneously. However, effect of feedstocks to lower ecological burden need to be defined; for example the use of straw, corn silage, or co generation between energy crop-agricultural residues with MSW food residue feedstock mixture [24]. Table 2 indicates 20 of the studies evaluated, 13 of which involved European countries such as Luxembourg, Germany, Italy, the United Kingdom, Switzerland, and Sweden. One study was from the African nation, Ethiopia and the other six were conducted in Asian nations (three in China, and one each in Vietnam, Singapore, Indonesia). Recently, the LCA research on biogas production has increases especially in Asian and North America regions. The developing concern for ecological assessment related to the generation and application of biogas utilizing LCA was to evaluate the environmental performance and the sustainability of the energy pathways [25].

Table 2 shows the summarized of 20 LCA biogas studies with different study context, the methodology used, and feedstock type, use of biogas and bio fertilizer, and the categories of environmental impacts. Referring to Table 2, the studies on life cycle assessment for AD plants in this review could have conducted out quite differently. Researchers found a number of importance influences in the way biogas by AD plants conducted. For example, the life cycle impact assessment method applied still play an important role in affecting the LCA results. The LCA results can be obtained much better, but there is stillroom for improvement especially complex systems that include assumptions and plenty of records. Many LCA results can be improved with appropriate system boundaries setting, the used of measurable functional unit (FU) as well as the robust databases selected. Difficulties can arise when there is more than one crucial element to be perceived. Thus, it is important to identify which elements have a larger influence on some of the other viable elements; and these may be described qualitatively. The following section addresses components and aspects such as goal definition and scopes, functional unit, system boundaries, use of biogas, use of bio fertilizers and categories of impacts that have been covered in the reviewed studies. As the LCA usage is likely to increase in the future, relevant LCA establishments were needed with the detailed guidelines provided. This is important for future potentiality on cross study comparisons and increasing the general quality in assessment.

2.1. Defining the Goal and scope of reviewed studies

The conducted LCA study is intended for its certain utility, the target audiences or for info dissemination. The utmost intention of using LCA on the biogas from AD is to assess on the environmental existence cycle effects of managing organic waste as they are achieved in those cases. In this segment, the plans of the LCA researches need to be described as clearly as possible. The classified scopes were ecological performance, ecological and economic performance, ecological and energy performance as well as resource efficiency. Fiez et al. [22] has assessed on environmental performance of FW biogas digesters that has carried out in Xiaoguwei Island, Guangzhou, China. The study was comparing the impacts on environmental of different waste treatment such as FW to biogas production (with upgrading to fuel, and with electricity production), incineration, landfill, and pig farms. The results indicated that the FW to biogas plant provides about 0.3MNm^3 bio methane and a reduction of greenhouse gas emissions of about 1780 tons of CO_2-eq each year.

Table 2. Goals, System Boundary, Functional Unit and Method LCIA of the Biogas from AD Treatment

Reference [a]	Country	Type of Waste	Goals	Aspects/System Boundary	Functional Unit	System of Reference	Database/software for LCA	Method LCIA	Midpoint	Endpoint	Biogas application	Bio fertilizer application
[22]	China	Treated Food Waste	Biogas potential, Climate performance	Cradle to gate	1 ton of Treated Food Waste	China condition	Monte Carlo Simulation	Calculation GWP_{100}			Biogas, electricity, vehicle fuel	Bio Fertilizer
[24]	Germany	Animal slurry, plant biomass, industrial waste/other	Environmental performance	Biogas production and utilization pathways	1 ton of feedstock mixture	German condition	SimaPro 7.2, Eco invent v2.1	ReCiPe	x	x	Bio methane, CHP	Fertilizer
[26]	Luxembourg	Plant biomass	Energy and environmental performance	Cradle to gate	1MJ injected into the natural gas grid	The imported natural gas system	Umberto 5.5, Eco invent 2.0	Impact2002, Eco-indicator 99	x	x	Injected into the natural gas grid	NA
[27]	Switzerland	Plant biomass, industrial waste/other	Environmental performance	Cradle to gate	1 ton of feedstock	Swiss condition	Eco invent v2.0,	Eco indicator 99, Ecological Scarcity 2006 method, IPCC 2007	x	x	Fuel, CHP	
[28]	Italy	Treated Food Waste	Environmental performance	Cradle to gate	1 ton treated Food Waste	Italy condition	SimaPro 7	CED, CML 2001	x		Bio methane upgrading into natural gas, CHP, vehicle fuel	Fertilizer
[29]	Sweden	Food Waste, Sewage Sludge	Environmental and economic performance	Cradle to gate	NA	NA	ORWARE Model	CML 2001 baseline	x		Vehicle purpose	Soil fertilizer
[30]	Vietnam	Animal slurry	Resource efficiency	Cradle to farm gate	Sum of products (the sum of 1 kg of each product delivered at the farm gate)	NA	ExFA, Eco invent v2.2 database	CEENE method	x		Household cooking	Base Fertilizer
[31]	China	Plant biomass	Environmental performance	Cradle to gate	1 ton of pre dried straw	NA	SimaPro, Eco invent database,	Eco-indicator 99 (H), IPCC 2007 GWP	x	x	Compressed LNG, CHP	Fertilizer
[32]	United Kingdom	Animal slurry, plant biomass, industrial waste/other	Environmental balance	Cradle to gate	1 Mg of dry matter feedstock input	NA	LCAD Eco screen tool, Eco invent v3.1	CML 2010	x		Bio methane, CHP	Fertilizer
[33]	Ethiopia	Animal slurry	Environmental performance	Gate to gate	The amount of energy needed to produce 1MJ heat	Dung combustion for cooking	GaBi Software, Eco invent v2.2	CML	x		Household cooking	Fertilizer, pastures
[34]	China	Animal slurry	Energy and environmental performance	Cradle to gate	2136 ton of manure	NA	Weighting method	Weighting method	x		Injected to the biogas grid, CHP	Fertilizer
[35]	Italy	Industrial waste	Environmental performance	Cradle to industry gate	1kg of tomato puree	NA	Sima Pro, Eco invent database	ILCD method	x		CHP	Organic fertilizer

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[36]	Germany	Plant biomass	The impact of regional factors	Cradle to grave	1 kg of fresh matter of maize, 1 kWh of electricity	NA	GaBi 4.4	GEMIS	x		CHP	Fertilizer
[37]	Italy	Animal slurry, plant biomass, industrial waste/other	Environmental performance	Cradle to grave	1.02 kWh of electrical energy, 10.92MJ of thermal energy, 1.86kg of compost	A real pilot plant system	Sima Pro, Eco invent 2.1 database	Eco Indicator 99	x		CHP	Soil Fertilizer
[38]	Germany	Animal slurry, plant biomass	Environmental and economic performance	Cradle to gate	$1kWh_{el}$ emission	Fossil reference system	Umberto 5.6, Eco invent 2.2 database	NA	x		CHP	Fertilizer
[39]	Norway	Industrial waste/other	Environmental performance	Cradle to gate	1MJ of electricity produced	Synthetic fertilizers and electricity from natural gas	ARDA v.1.8, Eco invent database	NA	x		CHP	Fertilizer, soil amendment
[40]	United Kingdom	Industrial waste/other	Environmental performance	Cradle to gate	1MWh of heat and electricity	AD-CHP system with electricity and heat geneartion	GaBi v4.4,	CML 2011	x		CHP	Fertilizer
[41]	Singapore	Food Waste	Environmental performance	Gate to gate	1000 ton of FW	NA	NA	NA	x		Electricity	Compost
[42]	Norway	Food Waste	Resource efficiency and environmental performance	Cradle to grave	1 ton Dry Matter mixed organic waste entering RBA	Value chain of Romerike biogas plant (RBA)	ARDA	ReCiPe	x	x	Liquefied Biogas	
[43]	Indonesia	Palm Oil Mill Effluent	Energy and environmental performance	Gate to gate	1 ton of fresh fruit bunch	NA	SimaPro, IPCC 2013	Impact 2002+	x		Electricity	Land application

Software CML: Centrum voor Milieukunde Leiden, , IPCC: Intergovernmental Panel of Climate Change, ReCiPe: RIVM and Radboud University, CML, and PRE' Consultants, CED:Cumulative Energy Demand; GWP100: Global Warming Potential (100years); NA: Not Applicable ; EDIP: Environmental Design of Industrial Products; TRACI 2: Reduction and Assessment of Chemical and Other Environmental Impacts; ILCD: International Reference Life Cycle Data System, CEENE: Cumulative Exergy Extracted from the Natural Environment; GEMIS: Global Emissions Model for integrated Systems; ORWARE: Organic waste research, GaBi:Ganzheitlichen Bilanzierung (German for holistic balancing), ReCiPe: RIVM and Radboud University, CML, and PRE′ Consultants

Biogas Application CHP: Combine Heat and Power, LNG: Liquid Natural Gas, LBG: Liquefied Bio Gas,

Other GWP: Global Warming Potential, CED: Cumulative Energy Demand, NA: Not Applicable

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Meanwhile in another study by Fiez et al [44] a multi-criteria method applied to evaluate the right quality of biogas feedstocks and the production of bio fertilizer was assessed. The study examined aspects of efficient costing, feasible technology, energy and ecological performance, accessibility, policy, competition and other relevant issues. The importance of the finding is to structure information relevancy for facilitating strategic overviews, informed decision making and communicating its result.

2.2. Functional units

FU has to be defined as the type of function or service the products' system delivers. The FU reason is to have a reference to which the inputs and outputs are related. The FU is essential to enable the similar cross study comparability between the LCA studies. Therefore, the FU itself needs to be measurable. Gradually, the options of the FU in biogas structures refer on power, distance, mass, volume or a hectare for land used. As shown in Table 2 the LCA studies of biogas manufacturing were having variation FU, for examples; ton [22,24,27-28,31,34,41-43], kg [30,35,36], Mg [32], m^3, MJ [26,33,39], kWh [37-38], MWh [40], ha and km.

2.3. Boundaries Setting

According to Fiez et al. [22] the effects of environmental and energy assessment are very dependent on the choice of system boundaries, assumptions and include effect categories. The boundaries setting indicate the system or process as well as the inputs and outputs of the system that to be included under the consideration for LCA evaluation purposes. There are 13 studies from total 20 reviewed LCA-studies took into consideration the system boundaries from cradle-to-gate [22,26-32,34-35,38-39,40], 3 studies from cradle to grave [36-37,42], 3 studies from gate to gate [33,41,43], and a biogas production and usage respectively [24]. The cradle-to-gate method consists of the complement of feedstock until the biogas production, and in a certain case focused effectively on unique stages within the system boundaries. In the general system, as illustrated in Figure 1, the dotted traces are the flows of energy and the solid traces are the flows of material. Definition system in Figure 1 is inclusion of feedstocks transportation, different processes waste, and the bio fertilizer product. In an extra correct system, biofertilizer products must also be covered in addition to the transportation of these flows and in a few cases, the fuel that is produced. Dependent on the substrate and/or the intended first-class of the products the need for different processes will vary. Five principal processes, AE, have been defined: - A: sorting- B: pre-treatment- C: anaerobic digestion- D: bio residual treatment — E: biogas usage and upgrading.

Bernstad et al. [45] discussed how variation in process parameters and boundary setting may influence the result of the LCA and made suggestions to improve interior equivalence within treatment options in a comparable LCA as well as among various LCAs. For example as reported by Chen [12] AD requires huge energy consumption (diesel provision) using larger trucks due to the process of collection, transporting collection to the waste treatment facility (electricity provision) and labourers' cost. The journey from the collection sites or small transfer station will release emission to air. Emission to air in AD process especially in collecting and transporting even in low concentration is considered as environmental burden.

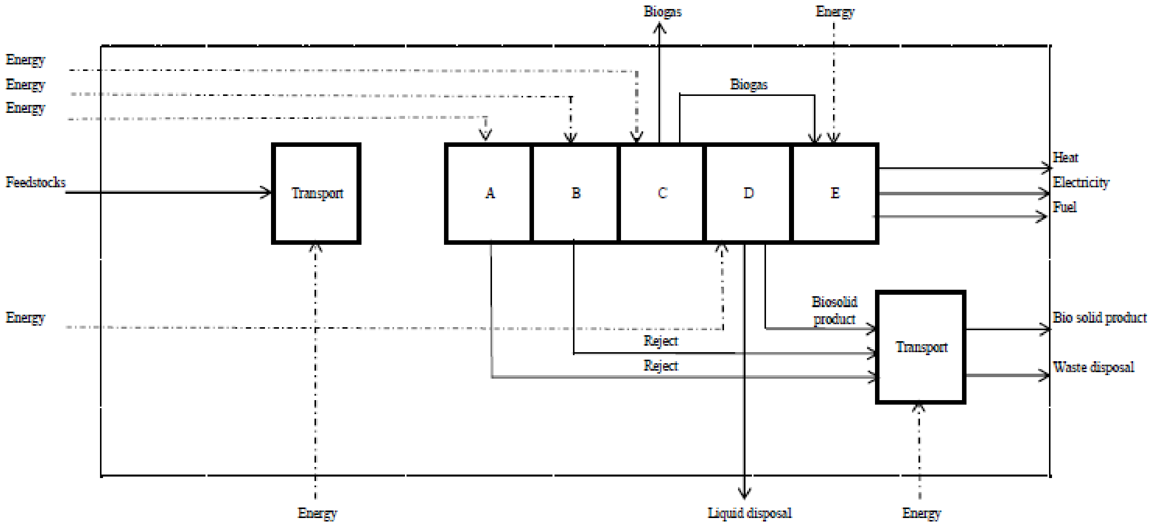

Figure 1. General value chains for biogas system definition [42].

2.4. Characterization method and life cycle impact assessment

Life cycle impact assessments (LCIA) transform the life cycle inventory (LCI) results in a limited number of indicator scores, which are useful in defining the scores of indicators that show relative magnitude of impacts on the environment. As stated in Table 3, the LCA practitioners in biogas plants might have conducted the LCIA in a different way. The selection of the LCIA approach used can have a major impact on the outcome; however, no clear information or recommendations are available for general users to choose reasonable LCIA methods. Therefore, there is a need to understand each LCIA method or combination of methods used for purposes of comparisons. Furthermore, the findings can be used to elaborate the literature in future studies. These could be very useful when it is used in biogas plants with similar features. In addition, this analysis may also be part of future research on comparing biogas plants with other organic fractions treatments of AD from LCA perspectives.

The LCIA method is consists of two elements, midpoint and endpoint. Midpoint has lower uncertainties because the impacts that can be modelled are considered. Midpoint impact assessment has indicators that concentrate on a single environmental issue e.g. climate change or acidification. This will give a more concise overview of the system's impacts on the environment. The environmental impact results obtained using different LCIA midpoint approaches are identical for comparable categories. Moreover, the LCIA techniques such as ReCiPe, EDIP and Impact 2002+ offer greater assessment and comparative categories than CML and TRACI (as shown in Table 3) [46].

With respect to the definitions of global warming (called "Global Warming" in CML, TRACI, EDIP, and Impact 2002+ and "Climate Change" in ReCiPe Midpoint), expressed as kilograms of carbon dioxide equivalent (kg CO2 eq); it can be noted that there is almost the same relative result because the same reference was derived from the IPCC. Referring to Table 3, the midpoint studies using CML approaches conducted by Grosso et al; Eriksson et al; Styles et al; Lansche et al. and Whiting et al.[28-29,32-33,40], the results showed the best indication related to the potential for global warming reduction and improvement. Another type of environmental impact that can be correlated with different methods is the degradation of the ozone layer (called "Ozone Depletion" in ReciPe, TRACI and EDIP and "Ozone Layer Depletion" in CML and Impact 2002+, expressed as kilograms of chlorofluorocarbons equivalent (kg CFC-11 eq). Such quantitative analysis is not feasible for impacts such as eutrophication and toxicity that have different indicators of specific ecological compartments depending on the method selection. For acidifications, the findings are not convergent due to differences in spatially similar characterization variables and different models characteristics adopted according to each approach. An example of the differences in CML (acidification, as kg SO_2 eq), in ReCiPe (terrestrial acidification, as kg SO_2eq), EDIP (acidification as square meter) in TRACI (acidification as H^+ moles eq) and in Impact

2002+ looking at terrestrial acidification (as kg SO_2eq) and the aquatic acidification as (kgSO_2eq) is chosen [24, 26, 28]. Meanwhile, the GEMIS (Global Emissions Model for Integrated Systems) calculations have established the standard for contemporary assessments of the life cycle. GEMIS is a free lifecycle and material flow analysis tool for the public domain, which also provides a comprehensive database on energy carriers, materials energy, and material processes.

Midpoint have robust model and data, which is recognized as a problem oriented LCIA method. It may lead to reliable interpretation and open possibilities for comparisons between different studies. However midpoint can also be harder to interpret because it has too many abstract meanings e.g. radiative forcing - acidification. Besides, such features are not the only environmental effects of the emissions listed on LCI, but there are measures of the potential impact. Therefore, endpoint as damage oriented LCIA method is an alternative for simplification on the LCIA interpretation. For instance endpoint (e.g. ReCiPe 3 points and Eco Indicator 99) were indicators that showed the impact of the environment on three higher aggregations level on the effect on human health, biodiversity, and finally resource scarcity [24, 26, 27].

With regard to the single score, the relative contribution of the respiratory categories in organics in IMPACT 2002+ and Eco-Indicator 99 (H) methods and particulate matter formation in the ReCiPe endpoint (H) method can be compared [26,24,31]. Both categories are related to emissions of particulate, sulphur oxides, ammonia, and nitrogen oxides with some little differences in characterization steps and all of them are expressed in Disability Adjusted Life Years (DALY), at endpoint level. Another comparison can be made between the relative weight of land use in Eco indicator 99 (H) and Impact 2002+ methods [26, 27]. The Ecological Scarcity method presents no specific environmental impact category related to land [27]. The categories of Energy Resources in Ecological Scarcity, Fossil Fuels in Eco Indicator 99 (H) and Non-renewable energy in Impact 2002+ generally showed similar results, as exemplified by a comparison study conducted by Jury et al. and Stucki et al. [26, 27].

Table 3. Life cycle impact assessment (LCIA) methods [46].

LCIA methods	Midpoint/ Endpoint	Number of impact categories evaluated	Single score damage categories	Regional validity	REF.
CML 2001	Midpoint	10	NA	World, excluding acidification and photo oxidants (Europe) production.	[28], [29], [32],[33], [40]
Impact 2002+	Midpoint	15	NA	The simplest version of Europe. Calculations were performed for the intake fraction (toxicity effect category) for a European spatial model based on a grid of 200x250 km. A multi-continental version of this model was made available to test pollution inventories across all continents.	[26],[43]
	Endpoint	13	i-Human health ii-Ecosystem quality iii-Climate Change Resources		
EDIP 2003	Midpoint	19	NA	Europe (factors with a European average value for up to 44 regions or countries within Europe). Global for the categories of global impact.	[NA]

Eco Indicator 99	Endpoint	11	i-Human health ii-Ecosystem quality iii-Resources	Global environmental climate, ozone depletion and resource affect categories. European model for other types of effects: It is presumed that all emissions occur in Europe. Damage that happens outside Europe is also taken into account when using the European impact situation, if the lifetime of the atmosphere is long (some toxic substances, radioactive substances, etc.). Dutch model-based acidification/eutrophication, land use is driven on the Swiss model.	[26],[27],[31],[37]
TRACI 2	Midpoint	9	NA	Emissions in the United States, impacts for acidification, eutrophication, and smog development in North America, and ozone depletion and global warming around the world. Human and eco-toxicity is not a common location in TRACI, but in the United States. EPA standards are used for human health factors and recommendations for risk assessment	[NA]
ReCiPe	Midpoint	18	NA	Europe. Global climate change, degradation of atmospheric layers and resource.	[24],[42]
	Endpoint	17	i-Human health ii-Ecosystem iii-Resources	Europe. Global climate change, degradation of atmospheric layers and resource.	
Ecological Scarcity	Endpoint	7	NA	The original method for Switzerland has been established. Different versions of the Ecological Scarcity approach for other countries or regions of the world were established.	[27]
Others					
Calculation GWP_{100}	Midpoint				[22]
ILCD	Midpoint				[35]
IPCC 2007	Midpoint				[27],[31]
CED	Midpoint				[28]
CEENE	Midpoint				[30]
Weighting					[34]
GEMIS					[36]

CML: Centrum voor Milieukunde Leiden, , IPCC: Intergovernmental Panel of Climate Change, ReCiPe: RIVM and Radboud University, CML, and PRE' Consultants, CEENE: Cumulative Exergy Extracted from the Natural Environment; CED:Cumulative Energy Demand; GWP100: Global Warming Potential (100years); NA: Not Applicable ; EDIP: Environmental Design of Industrial Products; TRACI 2: Reduction and Assessment of Chemical and Other Environmental Impacts; ILCD: International Reference Life Cycle Data System, GEMIS: Global Emissions Model for Integrated Systems

Poeschl et al. [24] indicated that single scores using ReCiPe methods could show the most significant outcomes when comparing variation on technologies of small scale and large-scale biogas plant, and identifying the 'hot spot' potential where it is possible to achieve further reduction of environmental impacts. The outcome indicates preference for small plants. Tri-generation would be the most promising path for sustainable biogas use; compared to the generation of electricity only. Tri-generation combined heat and power (CHP) could be reduced the overall impact on the environment by almost 200%. Cavalett et al. [46] extended the debate whether and to what degree the efficiency of the system is influenced by using of the various Life Cycle Impact Assessment (LCIA) presented throughout the research study of the Brazilian environmental impact analysis of bio refinery. The assessment considered the following LCIA methods: CML 2001, Impact 2002+, EDIP 2003, Eco-indicator 99, TRACI 2, ReCiPe, and Ecological Scarcity 2006. Although there is a consensus on the outcomes of similar categories of environmental impact using different midpoint LCIA measures, when considering single-score metrics, the use of various techniques of LCIA could results in different interpretations. However, ReCiPe was indicated as the best endpoint method to evaluate environmental impact as shown in the summarized framework in Figure 2.

Life cycle assessment (LCA ReCiPe)								
Life cycle inventory (LCI)				**Life cycle impact assessment (LCIA)**				
Product processes		**Life cycle inventory results**		**Categories of Impact**	**Characterization factor**	**Unit**	**Categories of Damage**	**Single score**
System process 1 System process 2 System process 3 System process 4	⇨	Water Energy CO_2 CO CH_4 NO_x SO_2 NMVOC PM_{10} N_2O Etc. Air, water, and soil contaminants.	⇨	Climate change	Global warming potential	kg CO_2 eq	Human health (DALY) Ecosystem Diversity (species.yr) Resources availability ($) Normalized: (person*yr)	Points (Pt)
				Ozone depletion	Ozone depletion potential	kg CFC-11 eq		
				Terrestrial acidification	Terrestrial acidification potential	kg SO_2 eq		
				Freshwater eutrophication	Freshwater eutrophication potential	kgP eq		
				Marine eutrophication	Marine eutrophication potential	kgN eq		
				Human toxicity	Human toxicity potential	kg1,4-DB eq		
				Photochemical oxidant formation	Photochemical oxidant formation potential	kgNMVOC		
				Particulate matter formation	Particulate matter formation potential	kgPM_{10} eq		
				Terrestrial ecotoxicity	Terrestrial ecotoxicity potential	kg1,4-DB eq		
				Freshwater ecotoxicity	Freshwater ecotoxicity potential	kg1,4-DB eq		
				Marine ecotoxicity	Marine ecotoxicity potential	kg1,4-DB eq		
				Ionizing radiation	Ionizing radiation potential	kgU235 eq		
				Agricultural land occupation	Agricultural land occupation potential	m^2a		
				Urban land occupation	Urban land occupation potential	m^2a		
				Natural land transformation	Natural land transformation potential	m^2		
				Water depletion	Water depletion potential	m^3		
				Metal depletion	Metal depletion potential	kgFe eq		
				Fossil depletion	Fossil depletion potential	kg oil eq		

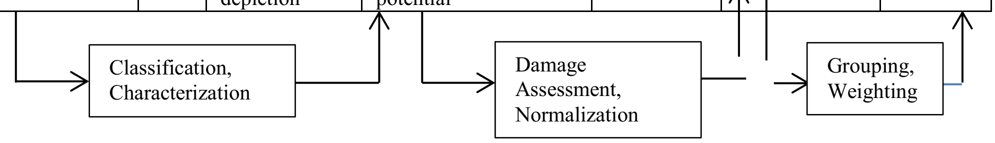

Figure 2: Summarized LCIA ReCiPe framework [24].

2.5. Impact categories

Some research that focused mainly on greenhouse gases and energy balance assessed greenhouse gas emissions, potential for global warming (GWP), and greenhouse gas mitigation potential (GMP), Cumulative energy demand (CED), cumulative exergy demand (CExD), net energy gain (NEG) and primary energy demand (PED). In several studies, these metrics were calculated to assess the energy efficiency of biogas production. Based on Bosch et al. [47], CED and CExD offered a reliable energy efficiency evaluation of the production of biogas system compared to the method of natural gas. Many biogas production studies have shown that biogas-generated energy contributes to greenhouse emissions reductions compared to fossil fuel [26, 48, and 49].

Bacenetti et al. [50] explained that the using of cogenerated heat effectively and reduce methane emissions at the side of strength self-consumption have been the primary factors to enhance the results of the CED and GHG emissions. In the LCA conducted by Seldal et al. [42], the GWP had the point of interest. It was observed that biogas plant from the AD value chain had an overall impact on GWP of 455kg CO_2-eq/FU. By the defined processes, the household waste collection had the greatest effect. When adopting the value chain compared to using alternative options such as chemical fertilizer and diesel, a burden of 747 396 kg CO_2-eq can be averted.

AD treatment releases emissions that direct from the digestive process or indirect from transient emissions of valve malfunction or transitory and this concept has developed by Gentil et al. [51] occurs during the upstream-operation-downstream, which all relevant processes were accounted for. Besides, the produced biogas is necessary to be enhanced, compressed/liquefied and transferred. The fugitive emissions from anaerobic digestion plants may emit CH_4 during treatment and upgrading which may largely affect the general Global Warming Potential (GWP) from the treatment chain. Such discharges change between different technologies and, as stated by Eggleston et al. [52], range from 0 to 10 vol. percent of the biogas generated, but close to 0 percent in plants with unexpected discharges. According to Börjesson and Berglund [53] and Møller et al. [54], both studies noted that the outlawed discharge of methane is a key parameter in connection with Greenhouse Gas (GHG)-outflows from AD systems (in both cases allowing discharges equal to 0–3 vol. percent of methane delivered). While others [55-58] do not consider these discharges at all in their assessments, Bjarnadottir et al. [59] and Ia Cour Jansen et al. [60] consider fugitive methane discharges compulsory.

In the meantime, Lantz et al. [61] and Pertl et al. [62] indicate that during the technology upgrade decision and the consequent fear of CH_4-outflows, the total treatment chain GWP may be significantly affected. As stated in the IPCC rules, the ignition of recovered biogas is minimum in connection to a worldwide temperature alteration since CO_2 emissions are of biogenic starting point (and along these lines GWP neutral) and the outflows of CH_4 and N_2O are insignificant (IPCC, 2006), whereas Ia Cour Jansen et al. [60] states that biogas discharges is necessary be considered. Biogas outflows from ignition rely upon the kind of gas engine, and lean-burn gas engines, commonly utilized at AD plants, often produce higher CH_4 in contrast with different gas engines [63]. While the use of LCA is likely to increase in this area in the near future, it is rather important to develop up more standards that are comprehensive in order to improve the overall consistency of assessments as well as the possibility of cross-study comparisons.

2.6. Software's/databases

Software is also one of the influencing factors in the LCA results. The AD system may look simple at one glance, of reality; however, any technology must be carefully modelled. The version of the waste management program requires a substantial amount of information that includes characteristics of waste, system of collection, different choices for treatment, background structures, and so forth. Such changes were introduced for future trends update, offering future portions of waste, fuel expenses, electricity mixes, and lots of others. Since used software varies for example SimaPro, Gabi, ORWARE, EaseTech etc. the most important of software selection is its databases. GaBi for instance has more than 20,000 accessible databases and this will provide very good visualization to represent assessment results compared to other software which only used common database provider i.e. Eco Invent (13,300 databases) [64].

There is an extensive division among popular LCA applications as with SimaPro, GaBi, Team, Umberto and the programs specifically designed for use in a particular area. In waste treatment schemes, for example: ORWARE (organic waste research), IWM-2 (integrated waste management II), WISARD (waste – integrated systems for assessment of recovery and disposal), WRATE (waste resources assessment tool for the environment), and EASEWASTE (environmental assessment of solid waste systems and technologies). GEMIS (Global Emissions Model for Integrated Systems) is a free lifecycle and material flow analysis tool for the public domain, which also provides a comprehensive database on energy carriers, resources, energy and material processes. Such software will be used to assess the present and further to version-new waste management systems. Figure 3 showed the databases used for LCA reviewed studies in biogas plant by AD.

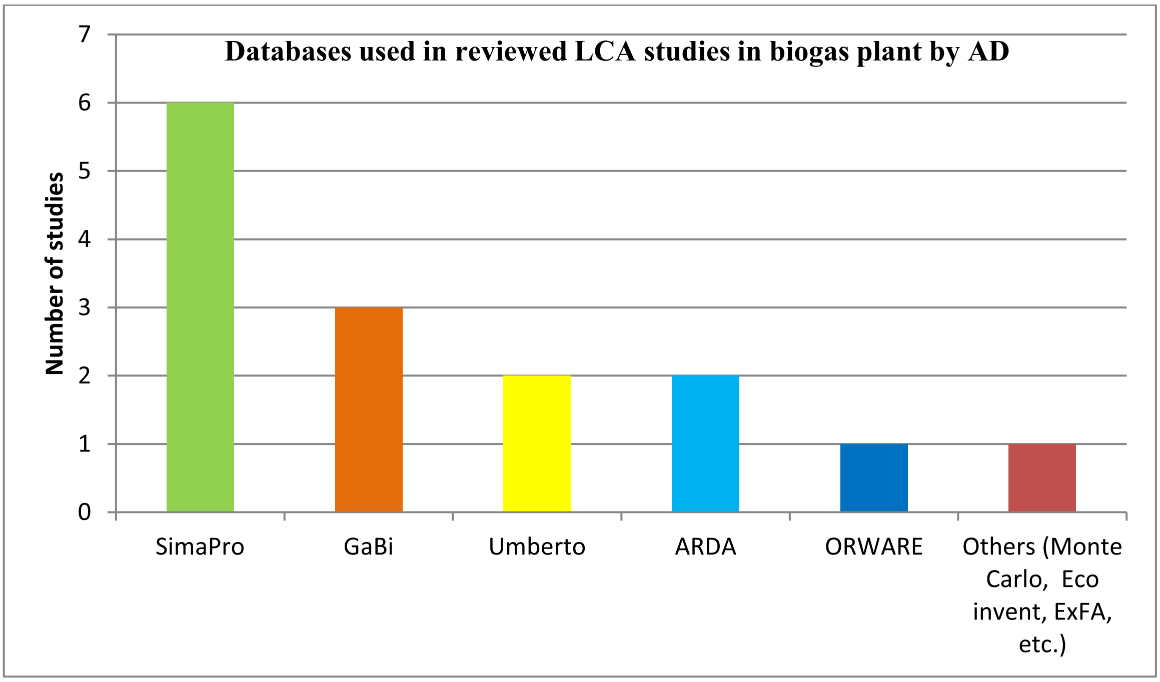

Figure 3: Databases for LCA reviewed studies in biogas plant by AD.

Kulczycka et al. [65] stated that differences among the research in the assessment are associated to technical assumptions with input data, form of technology, used inventories and data production. It is also determined that the models are subject to special assumptions are especially associated with various times after the information system has been developed (e.g. assumptions for the time horizons for landfill emissions). Further optimization of these tools to geographical situations will have an extra impact on the consequences. Nevertheless, each of the LCA programs can display a few benefits and downsides if assessed strictly from the waste management perspectives. The common LCA programs frequently encompass complete databases; however, they are now not continually specific for the waste treatment systems and suitable for national/regional situations [65].

Nonetheless, compared to a standard LCA model, the concept of ORWARE is designed to capture the waste characteristics control applying an SFA method and additionally include estimates of the economy. The use of a version unlike ORWARE, the concept of the district heating system has been popular and is in addition defined by Eriksson et al. [29], ORWARE is to an excessive volume feasible to adapt to the system studied precisely. ORWARE is beneficial due to (1) its potential to each treatment of environmental and biological wastes efficiently and (2) the potential of the new model procedures.

3. Recommendations

It is recommended that the modelling performed on to biogas plants from AD treatment be improved to give better results such as by defining a system with more processes to produce more equal results, thus more processes and more reliable inputs and outputs are needed to be included. So, the result with much lesser uncertainty will be generated by a system. Secondly, is by comparison of the value chain with relevant literature studies. It is strongly suggested to LCA practitioners to perform both a Material Flow Analysis and LCA for robust analysis [42]. Finally, a selection of suitable database to model the study system on, for example by using GaBi which has 20,000 accessible data plus Eco invent databases 13,300 data for the foreground processes to reduce uncertainties. This means the impacts that can be modelled are will be considered to have with robust model and data, and finally could lead to accurate analysis and open comparability between different studies [64, 65]. Regarding the AD alternatives for organic waste treatment the single stage dry continuous as well as single stage wet high rate digestion system can effectively handle organic waste. Both technologies are capable of significantly reducing the water consumption and energy expense. However, in high generation of organic waste in urban area with fewer spaces available, dry continuous system is more preferable because it has a small reactor, cheap pre-treatment, very little wastewater production, composting waste well applied and less heat needed. This is supported by Poeschl et al. [24] which indicated that small scale AD technologies is the promising approach to reduce impact on the environmental. The two-stage AD systems with separation of hydrolysis and methanogenesis in separate reactors could have shorter processing times and higher organic loading levels (up to 50 kg-COD/m3/d) than the single-stage systems, but their Total Solid > 20%, the dilution of the waste stream causes a substantial increase in the energy needed for heating, pumping and expanding reactors. Meanwhile, the performance of the three-stage digestion systems has more complex operation, more costly investment, more maintenance and operating resources compared to two-stage AD systems, and the large-scale three-stage system is not currently a good option [66].

4. Conclusions

LCA has much to offer regarding decision-making aid for a preference towards a cleaner AD process. This is beneficial because the identification of the GWP contributing inventory of AD is of crucial importance. Such determination is helpful to lead to the mitigation procedure to decrease the GWP of AD. Since direct energy use in AD plants changes generally, it ought to as per all surveyed rules, be tended to especially during the treatment, biogas utilization and upgrading. Despite different facilities used, the analysis of the same functional unit of biogas, operation mode, system boundaries setting, databases used and life cycle impacts assessment method are also very relevant to avoid biased comparisons on climate performance between different alternatives. Extra investigation and study on various AD scales, waste streams, and process systems are fundamental to better understand their impacts on explicit and GWP in general.

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