Life cycle assessment of a portable assembly biogas unit used for treating biowastes

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Abstract: The biogas unit under investigation is a specially designed portable assembly biogas unit and is sought to be widespread and commonly used in Egypt by the Egyptian Environmental Affairs Agency (EEAA). This unit is able to anaerobically treat different types of organic wastes, which are: food waste, kitchen waste, and waste from landscape. The main objective of this study is to perform an environmental impact evaluation of the implementation of this biogas unit. The specific greenhouse gas (GHG) emissions of using the produced biogas from the unit for electricity and heat generation were calculated, where the methodology of life cycle assessment (LCA) was applied. The results show the GHG emissions for each component of the biogas unit and each process within the biogas unit calculated in kg CO_2 equivalent per MJ electricity on year basis. It was concluded that the manufacturing of the portable assembly biogas unit causes the highest GHG emissions. In contrast, the operation of the biogas unit causes the lowest GHG emissions.

Keywords: life cycle analysis, biogas units, food waste, kitchen waste, landscape waste, greenhouse gases.

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1 Introduction

Life cycle assessment (LCA) or life cycle analysis is a methodology to carry out a cradle-to-grave investigation in to analyze and assess the energetic requirements and the negative environmental effects associated to all the stages of the lifespan of manufactured goods starting from the mining of raw materials through the processing, fabrication, handling, distribution, utilization, maintenance, repair, disposal, and recycling. Entrepreneurs deploy this methodology to support the evaluation of products. The LCA consists of the following: (1) creating databases of the energetic requirements as well as the used materials and relevant disposed materials to the environment, (2) evaluating the negative effects coupled with the input and output materials, (3) carrying out economic analysis of the entire industrial processes, and (4) elucidating the outcomes to support the decision making (Koido et al., 2018; Li et al., 2018; Pérez-Camacho et al., 2018; Ruiz et al., 2018). Furthermore,

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LCA is one of the thorough and exemplary means implemented for analyzing the negative environmental effects of novel technologies and products (Abdelsalam et al., 2019a; Hijazi et al., 2020a,b). Thus, LCA can be deployed as a technique for quantifying the greenhouse gas (GHG) emissions of the different processes in an industry (Nasution et al., 2018; Samer et al., 2021a,b).

The technology of anaerobic digestion (AD) is effective to process biowastes to generate biofuels, bioelectricity, and biological fertilizer in the course of the anaerobic digestion of organic materials (Samer, 2010; Samer, 2012; Santaolalla et al., 2020; Abdelsalam et al., 2021a,b,c; Moustafa et al., 2021; Attia et al., 2021,2022; Abdelqader et al., 2022; Saeed et al., 2022). The technical specifications of standard biogas plants in Europe were provided by Hijazi et al. (2016). The implementation of AD is a powerful emissions mitigation strategy to minimize the negative impacts of animal slurry on the environment. Compared to other techniques such as field application of manure and composting, AD holds substantial advantages such as generating energy, recycling slurry, and producing biological fertilizer (Safa and Samarasinghe, 2011; Samer, 2016; Wang et al., 2018; Abdelsalam and Samer, 2019; Abdelsalam et al., 2018, 2019b). Therefore, a life cycle analysis should be conducted to analyze the negative environmental effects and energy balance of biogas production (Ramírez-Arpide et al., 2018; Kral et al., 2020; Samer et al., 2021c).

Numerous studies carried out life cycle analysis in the area of biogas technology to accomplish diverse objectives, for instance: (1) analysis for specifying the correct period to install biogas technologies (Nikkhah et al., 2018), (2) analysis of diverse sizes of biogas units and systems (Van Stappen et al., 2016; Yasar et al., 2017; Wang et al., 2018; Ioannou-Ttofa et al., 2021), (3) environmental evaluation of biogas units and production systems (Ertem et al., 2017; Van Stappen et al., 2016; Styles et al., 2016; Li et al., 2017; Lijó et al., 2017; Pérez-Camacho et al., 2018), (4) feasibility study and economic analysis of electricity production (Li et al., 2017; Ruiz et al. 2018), (5) analysis of diverse techniques for the purification and upgrading of biogas (Collet et al., 2017; Cano et al., 2018), (6) analysis of biogas generation from diverse substrates (Giwa, 2017; Nasution et al., 2018; Ramírez-Arpide et al., 2018; Wang et al., 2016), and (7) analysis of resultant digestate (Pivato et al., 2016; Yasar et al., 2017).

Separately, a specially designed portable assembly biogas unit is sought to be spread and commonly used in Egypt by the Egyptian Environmental Affairs Agency (EEAA). Consequently, numerous questions and issues are raised: (1) is this an environmentally-friendly biogas unit? (2) what would be the environmental performance of this unit? and (3) further numerous questions concerning the energy consumption in comparison to the energy production using this unit, as well as the materials inputs and outputs.

The main objective of this study is to perform a LCA of the implementation of this portable assembly biogas unit. This main objective can be further elaborated into more specific objectives, as follows: (1) investigating the overall GHG emissions for electricity generation from the biogas unit calculated on year basis, (2) investigating the acidification potential for electricity generation from the biogas unit calculated on year basis, (3) investigating the eutrophication for electricity generation from the biogas unit calculated on year basis, (4) investigating the freshwater Ecotoxicity for electricity generation from the biogas unit calculated on year basis, (5) investigating the ozone Depletion air for electricity generation from the biogas unit calculated on year basis, and (6) investigating the human toxicity for electricity generation from the biogas unit calculated on year basis.

2 Materials and methods

2.1 Goal and scope definition

The aim of this study was to present the specific impacts on different environmental indicators of producing and utilizing biogas as an energy source from a portable assembly biogas unit.

2.2 Description of the Biogas unit

The biogas unit under investigation (Figures. 1 and 2; Table 1) is sought to be spread and commonly used in Egypt by the Egyptian Environmental Affairs Agency (EEAA) of the Ministry of State for Environmental Affairs. Figure 1 shows a sketch of the portable assembly biogas unit, while Figure 2 shows its photograph.

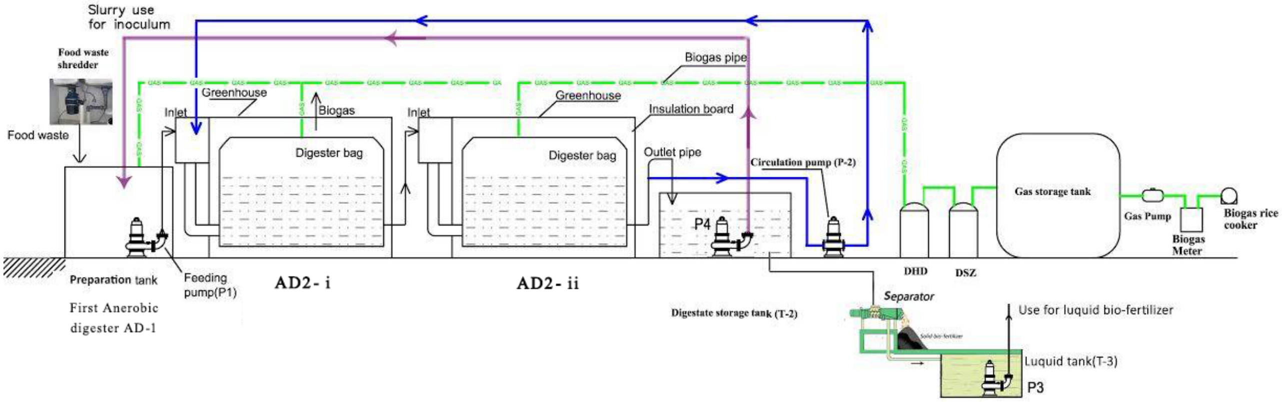


Figure 1 Sketch of the portable assembly biogas unit

This portable assembly biogas unit consists of two digesters, where each digester is composed of a greenhouse made with hollow sunlight sheet and aluminums alloy frame. The hollow sunlight sheet keeps the energy of sunshine, where the digester bag is installed inside the greenhouse. The membrane of digester bag has the characteristics of anti-aging, acid and alkali resistant. The biogas flows through the pipe to a separate gas bag. A stainless-steel tank for feeding and an outlet pipe for slurry discharge are installed (Figures 1 and 2).

Figure 2 The portable assembly biogas unit under investigation

Table 1 shows the technical specifications of the components of the biogas unit under investigation. This unit anaerobically treats a daily amount of 50-100 kg of organic wastes, which are: food waste (max. 30 kg per day), kitchen waste (max. 50 kg per day), and waste from landscape (max. 17 kg per day). Furthermore, the flow type is continuous flow. This unit produces an amount of 2200 m^3 biogas per year.

Table 1 Technical specifications of the components of the portable assembly biogas unit under investigation

No.	Item	Specifications	Weight of used materials as by GaBi® (kg)
1	Plastic pipes for drainage: used in cleaning	Length: 50 m Material: Polyvinyl chloride (PVC)	15 kg
2	Concrete slab: used to install the digesters and the equipment	Thickness: 15 cm Area: 4×5 m	7500 kg
3	Water tank (T1)	Capacity: 500 liter Material: High-density polyethylene (HDPE)	16 kg
4	Food waste shredder (FWS): used to shred food waste before introducing it into digester	Capacity: ≥100 L h^{-1} Motor speed: 5900 rpm Power: 0.75 kW Material: Stainless steel	9 kg
5	Sewage pump (P-1): used to feeding from shredder to digester	Flow: 12 m^3 h^{-1} Head: 8 m Pipe diameter: 50 mm Power 1.5 kW	11.5 kg
6	First anaerobic digester (AD-1): first stage of anaerobic digestion for 5 days	Capacity: 1000 liter Bag: Polyvinyl chloride (PVC) 1.0 mm with mesh yarn Greenhouse: polycarbonate sheets and aluminum frame	70 kg
7	Second anaerobic digester (AD-2): Second stage of anaerobic digestion for 40 days	Capacity: 1400 liter Bag: Polyvinyl chloride (PVC) 1.0 mm with mesh yarn Greenhouse: polycarbonate sheets and aluminum frame	98 kg
8	Circulation pump (P-2): used to circulate the digestate from 1st digester to 2nd digester	Capacity: 83 L min^{-1} Material: galvanized steel Power: 0.75 kW	9 kg
9	Centrifugal pump (P-3 and P-4)	Capacity: 83 L min^{-1} Material: galvanized steel Power: 0.75 kW	9 kg
10	Desulfurization unit (DSZ): Used to treat biogas from H_2S	Volume: 25 liter Capacity: ≤60 m^3 day^{-1} It can treat 5000 m^3 biogas Material: High-density polyethylene (HDPE)	25 kg
11	Desulfurizer pellets: agent used to fill the desulfurizer unit	Weight: 25 kg Material: Fe_2O_3	25 kg
12	Dehydration unit (DHD): used to treat biogas from H_2O	Capacity: 15 m^3 day^{-1} Material: High-density polyethylene (HDPE)	25 kg
13	Gas pump: used to pump biogas to gas storage	Capacity: 60 L min^{-1} Pressure: 32 kPa Power: 40 W	7 kg
14	Gas storage tank	Volume: 30 m^3 day^{-1} Material: Polyvinyl chloride (PVC) 0.85 mm	20 kg
15	Gas meter	Nominal flow rate, Q: 2.5 m^3 h^{-1} Maximum flow rate, Q_{max}: 4 m^3 h^{-1} Minimum flow rate, Q_{min}: 0.025 m^3 h^{-1} Maximum working pressure: 10 kPa Material: Mainly steel and a few plastics	1.5 kg
16	Digestate storage tank (T-2)	Capacity: 2000 liter Material: High-density Polyethylene (HDPE)	56 kg
17	Solid-liquid separator (SPTR): used to physically treat the digestate	Capacity: 10 m^3 h^{-1} Power: 7 kW Material: Stainless steel	27.5 kg
18	Liquid digestate tank (T-3)	Volume: 2000 liter Material: High-density polyethylene (HDPE)	56 kg
19	Liquid digestate tank (T-4)	Volume: 1000 liter Material: High-density polyethylene (HDPE)	29 kg

20	Biogas pipe	Length: 150 m Diameter: 20 mm Thickness: 3 mm Material: High-density polyethylene (HDPE)	16.7 kg
21	Electrical control panel	consists of: - Six contactors - One circuit breaker - Six disconnect switches - One timer - Six On/Off switches - Seven indicator lamps Material: Steel and plastics	5 kg

2.3 Functional unit and system boundaries

The standardized methodology of LCA was followed using the GaBi® 6.0 tool (thinkstep AG, Germany). Therefore, useful energy was used as a functional unit. Different environmental impacts were assessed in this publication. The system boundaries are illustrated in Figure 3. Production of kitchen-, food- and organic- waste, use of liquid bio-fertilizer, and final use of produced energy are outside of our system boundary. For the biogas systems, the life cycle inventory (LCI) was compiled from primary data collected from the Faculty of Agriculture at Cairo University as well as Hijazi et al. (2020a,b).

2.4 Life cycle inventory

For characterizing the impact of the biogas systems on global warming, the main GHGs carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were taken into account, using CO_2 equivalence factors (mass basis) for a 100 year time horizon with a global warming potential (GWP) of 298 for N_2O (without considering climate carbon cycle feedback) and 25 for CH_4. For each exposure time length, a biogas production calculation was carried out based on the specifications (Hijazi et al., 2016) of standard biogas plants in Europe. Dependent on the values of biogas produced through each variant/scenario, the overall energy, heat energy and electrical energy were further calculated.

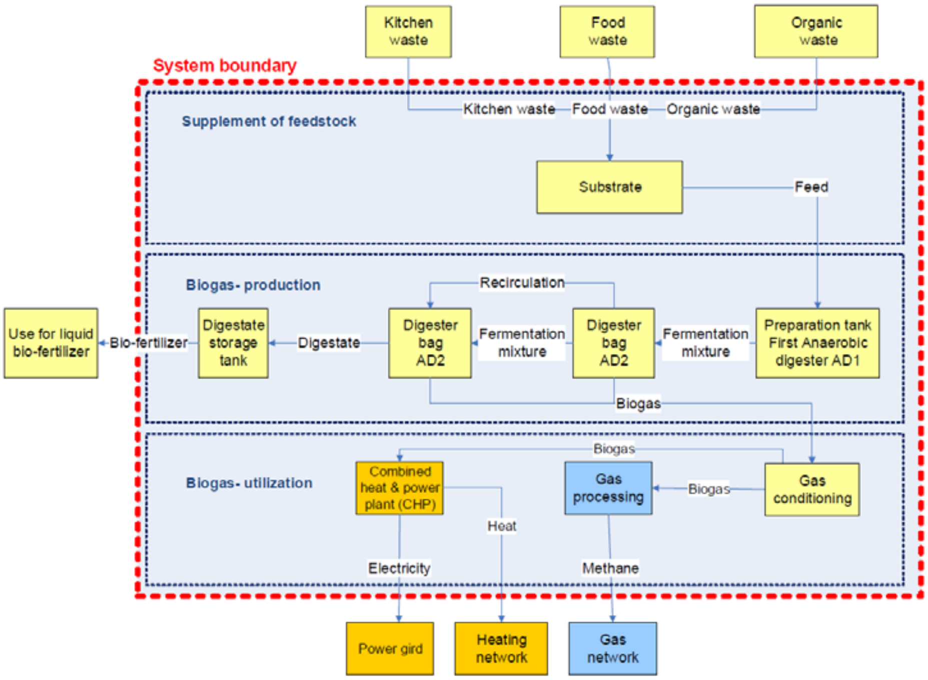


Figure 3 System boundary.

2.5 Investigation of environmental indicators

The following environmental indicators by electricity and heat generation from biogas has been considered in this LCA study: acidification, eutrophication, Freshwater ecotoxicity, ozone layer depletion potential, human toxicity potential and the specific GHG emissions.

2.6 Allocation of GHG emissions

Allocation of the total system GHG emissions between heat and power outputs has been a topic for never ending discussion. Several thermodynamic and economic methods are available to perform this allocation. In this study, the exergetic allocation method was implemented, where exergy is defined as that part of a system's energy content which can be transformed into mechanical work (Hijazi et al., 2020a,b).

Electricity is 100% exergy, and therefore, if exergetic allocation is performed, electricity shall bear the main part of the system's GHG emissions whereas the emissions share allocated to heat will remain small (Equations 1 - 3) after (Hijazi et al., 2020a,b):

$$EQ = Q \cdot (1 - TU / TQ) \quad (1)$$

$$AF_{Power} = W_{el} / (W_{el} + EQ) \quad (2)$$

$$AF_{Heat} = 1 - AF_{Power} \quad (3)$$

Where, AF_{Power}: Allocation factor for power

AF_{Heat}: Allocation factor for heat

W_{el}: Generated electrical power, MJ

EQ: Exergy of heat, MJ

Q: Lower heating value of biogas, MJ

TU: Ambient temperature, K (Reference temperature = 288 K)

TQ: Temperature of heat output, K

3 Results

3.1 Biogas production and energy generation

The results of biogas and methane production and energy generation calculations are presented in Table 1 which shows the computed values of overall, heat and electrical energies generation from biogas and methane production. The calculations were conducted for the portable assembly biogas unit, where its capacity is 2.4 m^3 with mixed food, kitchen and landscape wastes flow of 48.7 m^3 per year. Taking into consideration that the energy content in one cubic meter of biogas is 6.095 kW h m^{-3} (Kavitha et al., 2015). Additionally, data of dry matter content, organic dry matter content, methane content and methane production are also shown.

Table 2 Results of biogas production and energy generation from the portable assembly biogas unit calculated on year basis.

Parameter	Unit	Value
1st Digester and 2nd Digester	m³	2.4
Waste	m³	48.7
Water	m³	48.7
Substrate	m³	97.4
Dry Matter Content	%	12.5
Organic Dry Matter (percentage from Dry Matter Content)	%	80.4
Methane Production	m³	1174.8
Biogas Production	m³	2200.0
Methane Content	%	53.4
Average Energy in 1 m^3 Biogas	kWh m^{-3}	6.095
Overall Energy	kWh	13409.0
Electrical Energy	kWh	4827.2
Heat Energy	kWh	8581.8
Supplied Electrical Energy	kWh	4344.5
Supplied Heat Energy	kWh	6007.2
Consumed Electrical Energy	kWh	483
Consumed Heat Energy	kWh	2575

3.2 Environmental indicators

The different Environmental indicators from electricity production were estimated and presented (Figures. 4 - 6) and Table 3. Precisely, Figure 4 shows the overall GHG emissions for electricity generation from the portable assembly biogas unit calculated in kg CO_2 equivalent per MJ electricity on year basis. On the other hand, Table 3 presents the results of GHG emissions for each process in the portable assembly biogas unit calculated in kg CO_2 equivalent per MJ electricity on year basis. Further environmental indicators were investigated, which are: acidification, eutrophication, resource depletion, ozone layer depletion potential, and human toxicity potential from electricity production through the standard biogas production scenario and were presented in Figures 4 - 6, respectively.

Figure 4a shows the overall GHG emissions for electricity generation from the biogas unit calculated on year basis, where the manufacturing of biogas unit and the biogas utilization as well as the biogas production are responsible of the highest GHG emissions with a little effect of the plant operation. On the other hand, Figure 4b shows the acidification potential for electricity generation from the biogas unit calculated on year basis, where the manufacturing of biogas unit is responsible of the highest acidification potential. However, the plant operation and the biogas utilization have a little effect on the acidification potential, where the biogas production has no effect.

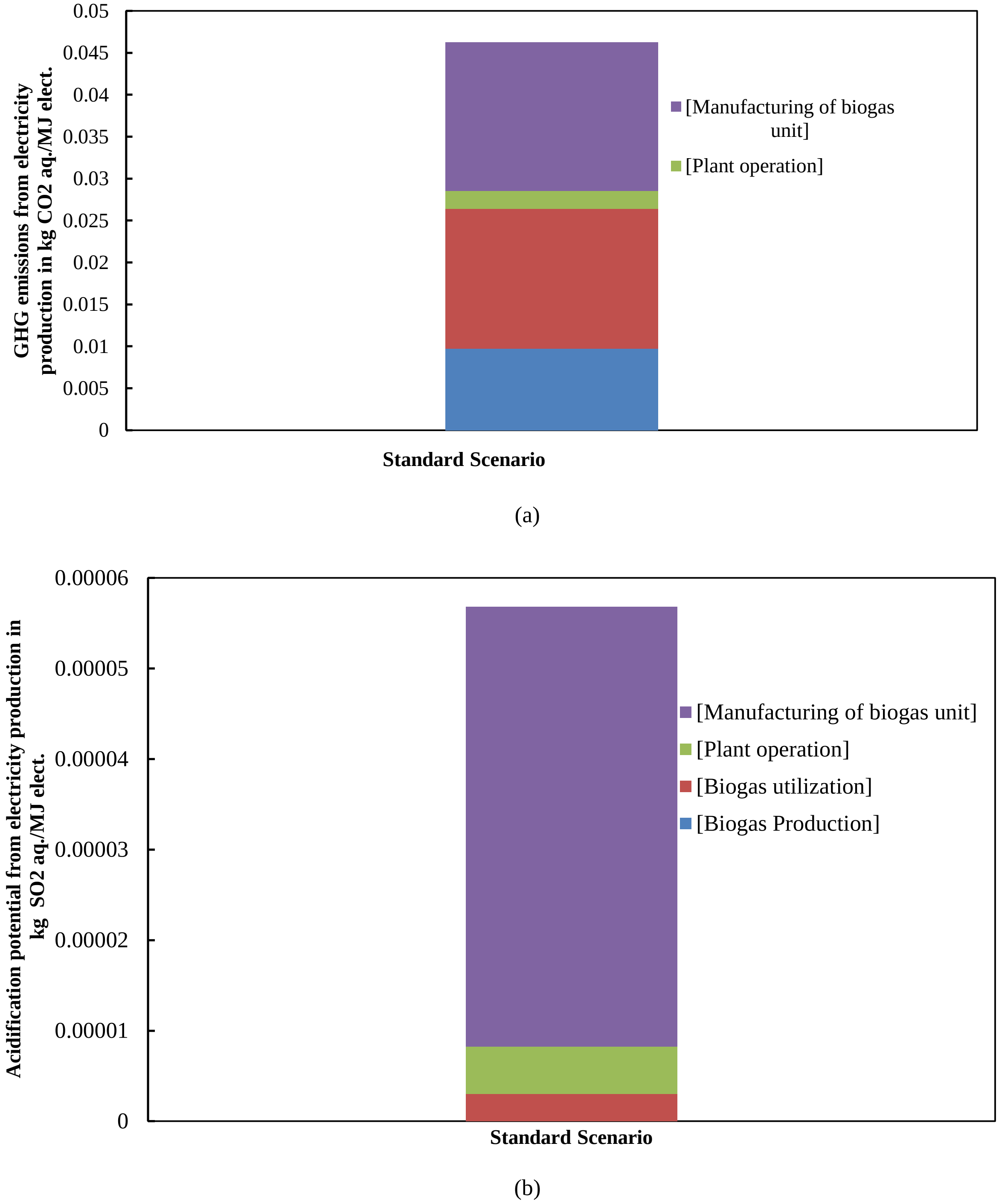
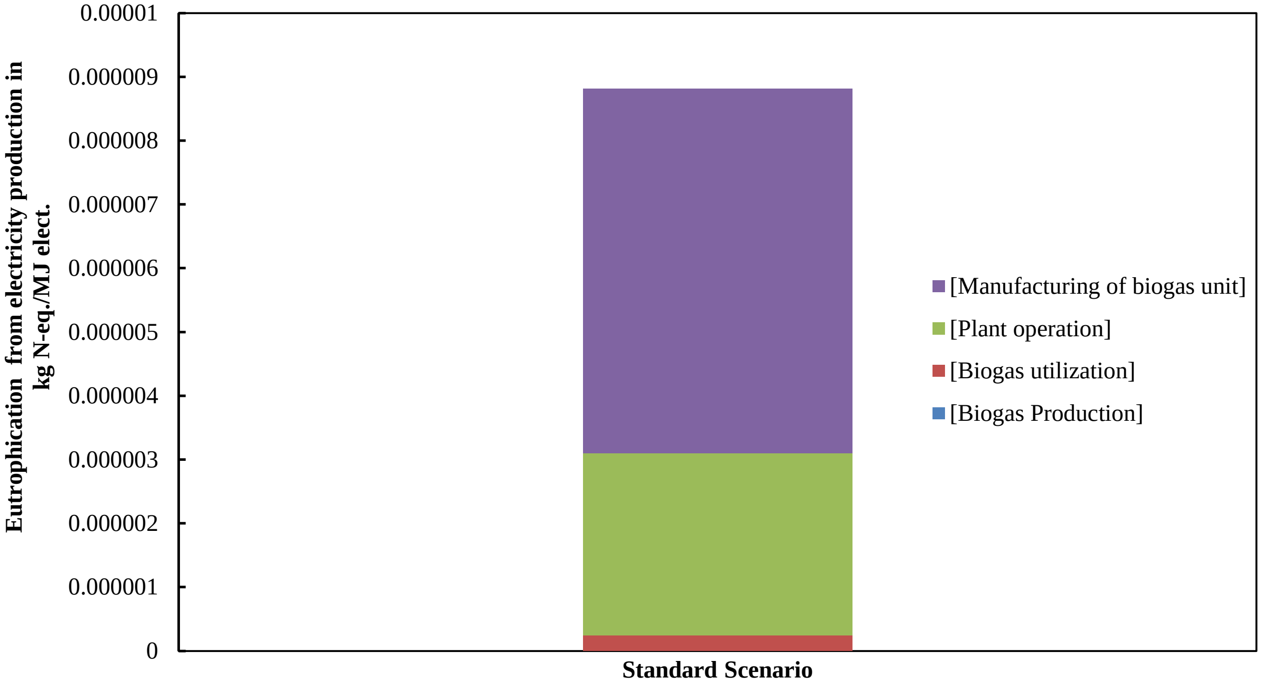
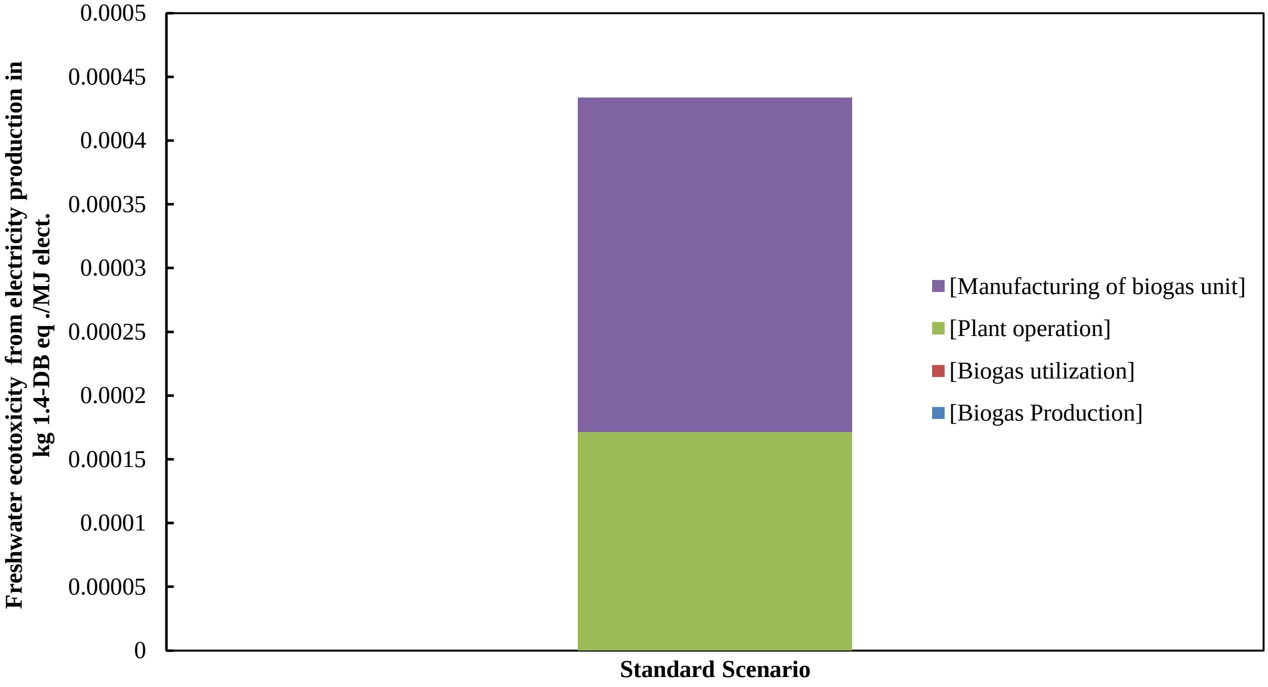


Figure 4 (a) Overall GHG emissions for electricity generation from the biogas unit calculated on year basis, (b) Acidification potential for electricity generation from the biogas unit calculated on year basis.

Figure 5a shows the eutrophication for electricity generation from the biogas unit calculated on year basis, where the manufacturing of biogas unit and the plant operation are responsible of the highest eutrophication potential. On the other hand, the biogas utilization showed a little effect on the eutrophication potential. Besides, the biogas production has no effect on the eutrophication potential. Figure 5b shows the freshwater ecotoxicity for electricity generation from the biogas unit calculated on year basis, where the manufacturing of biogas unit and the plant operation are responsible of the highest freshwater ecotoxicity potential. On the other hand, the biogas utilization as well as the biogas production have no effect on the freshwater ecotoxicity potential.



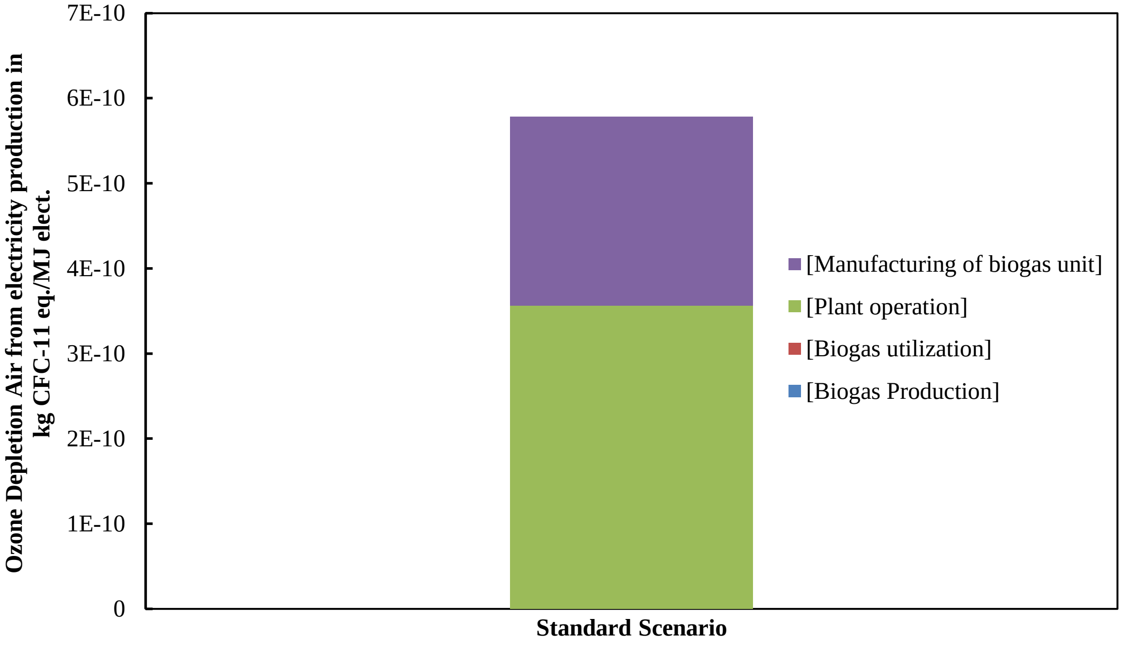
(a)



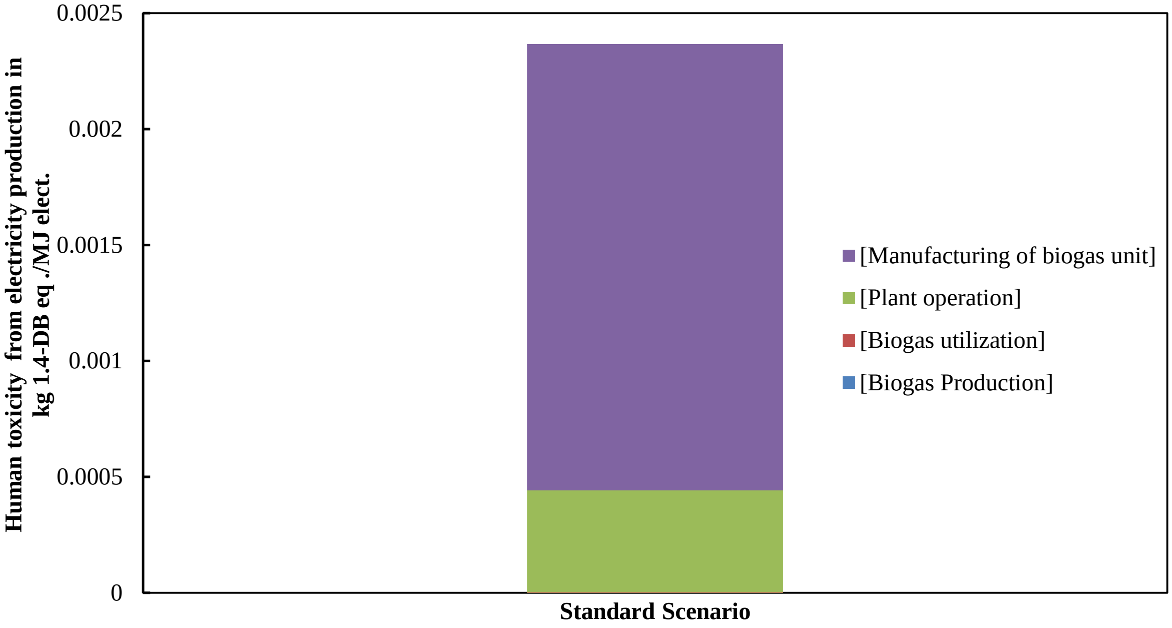
(b)

Figure 5 (a) Eutrophication for electricity generation from the biogas unit calculated on year basis. (b) Freshwater Ecotoxicity for electricity generation from the biogas unit calculated on year basis

Figure 6a shows the ozone depletion for electricity generation from the biogas unit calculated on year basis, where the plant operation and the manufacturing of biogas unit are responsible of the highest ozone depletion potential. On the other hand, the biogas utilization as well as the biogas production have no effect on the ozone depletion potential. Figure 6b shows the human toxicity for electricity generation from the biogas unit calculated on year basis, where the manufacturing of biogas unit and the plant operation are responsible of the highest human toxicity potential. On the other hand, the biogas utilization as well as the biogas production have no effect on the human toxicity potential.



(a)



(b)

Figure 6 (a) Ozone depletion for electricity generation from the biogas unit calculated on year basis, (b) Human toxicity for electricity generation from the biogas unit calculated on year basis

Table 3 presents the results of the different environmental indicators for each process in the biogas unit calculated on year basis, which are the global warming (kg CO_2 eq./MJ elect.), acidification (kg SO_2 eq./MJ elect.), eutrophication (kg N-eq/MJ elect.), freshwater ecotoxicity (kg 1.4-DB eq./MJ elect.), ozone depletion (kg CFC-11 eq./MJ elect.) and human toxicity (kg 1.4-DB eq./MJ elect.).

Table 3 Results of Environmental indicators for each process in the biogas unit calculated on year basis.

Process	Environmental indicators					
	Global warming	Acidification	Eutrophication	Freshwater Ecotoxicity	Ozone Depletion	Human toxicity
	kg CO_2 eq./MJ elect.	kg SO_2 eq./MJ elect.	kg N-eq/MJ elect.	kg 1.4-DB eq./MJ elect.	kg CFC-11 eq./MJ elect.	kg 1.4-DB eq./MJ elect.
Biogas Production	0.0097138	0	0	0	0	0
Biogas utilization	0.01668592	3.0278E-06	2.4306E-07	9.1738E-09	0	1.86416E-06
Plant operation	0.00213906	5.2538E-06	2.8596E-06	0.00017157	3.56301E-10	0.000440297
Biogas pipe	0.00011458	2.1109E-07	2.2618E-08	1.4389E-06	1.98646E-16	5.18914E-06
Centrifugal pump	8.31E-05	2.8131E-07	0	0	0	0
circulation pump	0.00010624	3.5945E-07	2.433E-08	1.7205E-07	4.8022E-16	9.40374E-06
concrete slab	0.00335638	5.5886E-06	3.1088E-08	2.20E-07	6.13614E-16	1.20159E-05
Dehydration unit	0.00017152	3.16E-07	1.4766E-06	0.00014872	1.11356E-10	0.000433284
Desulfurization unit	1.72E-04	3.16E-07	3.3859E-08	2.154E-06	2.97374E-16	7.76818E-06
Desulfurizer pellet	8.45E-05	4.447E-07	3.3859E-08	2.154E-06	2.97374E-16	7.76818E-06
digestate storage	3.84E-04	7.0783E-07	3.1403E-07	6.2059E-05	1.10597E-10	0.000131272
Electrical control	4.62E-05	1.5628E-07	7.5845E-08	4.8249E-06	6.66117E-16	1.74007E-05
First anaerobic Fermenter	0.00063902	9.7065E-07	1.3517E-08	9.5582E-08	2.66789E-16	5.2243E-06
Food waste shredder	2.54E-04	8.5956E-07	1.4904E-07	3.2611E-06	5.63772E-14	1.9831E-05
Gas meter	8.31E-05	2.8131E-07	7.4341E-08	5.257E-07	1.46734E-15	2.87337E-05
Gas pump	6.47E-05	2.188E-07	2.433E-08	1.7205E-07	4.8022E-16	9.40374E-06
Gas storage Tank	0.00018258	2.7733E-07	1.8923E-08	1.3381E-07	3.73504E-16	7.31402E-06
Liquid digestate tank 1000 lit	0.00019896	3.6656E-07	4.2583E-08	9.3175E-07	1.61078E-14	5.66601E-06
Liquid digestate tank 2000 lit	0.0003842	7.0783E-07	3.9277E-08	2.4986E-06	3.44954E-16	9.01109E-06
manufacturing CHP	0.01016194	3.4382E-05	7.5845E-08	4.8249E-06	6.66117E-16	1.74007E-05
Plastic pipes	0.00013693	2.08E-07	2.9736E-06	2.1028E-05	5.86936E-14	0.001149346
Second anaerobic digester	8.95E-04	1.3589E-06	3.1938E-08	6.9881E-07	1.20808E-14	4.2495E-06
Sewage pump	8.31E-05	2.8131E-07	2.0866E-07	4.5656E-06	7.8928E-14	2.77634E-05
Solid liquid separator	1.39E-05	4.6885E-08	2.433E-08	1.7205E-07	4.8022E-16	9.40374E-06
Water tank	0.00010977	2.0224E-07	4.055E-09	2.8674E-08	8.00367E-17	1.56729E-06
Total	0.04626392	0.000057	0.0000088	0.00043	0.0000000006	0.00236

4 Discussion

In this study, the environmental impact was evaluated by considering the GHG emissions, global warming potential, biogas utilization (energy consumption), biogas production and net energy. This methodology agrees with the methodology applied by Nasution et al. (2018), where GHG emissions were further considered by Nikkhah et al. (2018) as the main indices for the installation of biogas production systems. On the other hand, electricity generation was considered to be a part of the function of the biogas system, where the other part is heat generation. This is more applicable and mimics the real biogas plants and, therefore, this approach disagrees with that applied by Ruiz et al. (2018) which admirably assumed that power generation is the only function of the biogas system to allow expanding the boundaries of the system to include more functions for their study. The concept of this study was to apply a comparative LCA to evaluate the life cycle environmental impacts of using a portable assembly biogas unit in order to investigate the avoided GHG emissions in CO_2-equivalent, where the same concept was previously adopted by Pérez-Camacho et al. (2018). On the other hand, an increasing interest in conducting technical assessments as well as implementing software programs (Samer et al., 2019, 2020), where these can be covered by implementing the life cycle analysis approach (Ioannou-Ttofa et al., 2021).

In terms of carbon emissions, it was found that the 100-year global warming potential, an indicator that is easy comprehended by decision- and policymakers and the public, for producing 2200 m^3 of biogas using the portable biogas unit under rural Egypt's conditions amounts to 0.046 kg CO_2 eq. per one MJ electricity. The Global Warming Potential (GWP) is used to compare results based on CO_2 eq. emissions and is a standard indicator of environmental relevance that allows a more direct dissemination of the results to the general public. Even though the comparison cannot be direct, the identified environmental footprint was around twice as high as this of biogas produced by large biogas plants operating in Europe and the developed world. Another issue is that it seems that the usage of digestate as a crop biofertilizer could be a promising approach to enhance the observed environmental sustainability of the portable biogas unit. Depending on the digestate storage system and conditions, a substantial reduction on the total environmental footprint can be achieved; however, more research is required towards this end. This is in line with the findings of Roubík et al. (2018, 2020) as well as Ioannou-Ttofa et al. (2021).

Apart from biogas, digestate, a process residue that can also act as a co-product through its utilization as a crop fertilizer, is also produced. Similarly, to cattle manure, the digestate could be used as an alternative to the chemical fertilizers that are largely employed in the agriculture industry, provided that it does not contain high levels of pathogens and heavy metals which could negatively affect both humans and crop yield (Ioannou-Ttofa et al., 2021). As such, the use of the digestate as a crop fertilizer could possibly improve the environmental sustainability of the AD process. It should be mentioned that after collection, and before being applied to the field, the digestate is typically shortly stored and during this time the digestion process continues generating relevant emissions (Giuntoli et al., 2014).

It should be noted that fossil fuel extraction, refining, transportation, and combustion release toxic materials, such as heavy metals, sulphurous compounds, and polycyclic aromatic hydrocarbons (PAHs) to the environment (Ioannou-Ttofa et al., 2016). These directly affect the (eco) toxicity impact categories. The relatively high score on the eutrophication impact categories can be traced back to fossil fuel mining activities, where sulphate introduction, through mining activities, can increase the availability of nitrogen and phosphorus through internal eutrophication (Masindi et al., 2018). In addition, fossil fuel combustion emits nitrogen oxides, which directly impact marine eutrophication, while phosphate emissions from fossil fuel mining (e.g. coal) directly affect freshwater eutrophication (Ioannou-Ttofa et al., 2016). This is also the case with the digestate emissions to soil and water, which directly affect freshwater eutrophication and marine eutrophication. During the fertilizer stage of the animal feed, nitrogen and phosphorus from excess chemical fertilizers leaches into groundwater or become transported with sediment by runoff, thus polluting freshwater and marine aquatic ecosystems, and promoting eutrophication. The lower score of marine eutrophication (nitrogen enrichment of seawater), compared to freshwater eutrophication (phosphorus enrichment of freshwater) impact category, can be attributed to the fact that marine ecosystems are more resilient than freshwater ecosystems to eutrophication stresses (Chatzisymeon et al., 2017). This is in line with the findings of Ioannou-Ttofa et al. (2021) as well as Ilyas et al. (2019).

5 Conclusions

The environmental sustainability of portable assembly biogas units used for treating food, kitchen and landscape wastes and operating under rural Egypt's conditions was examined herein. To this end, actual LCI data of this technology were obtained through field visits and interviews and was then used for environmental modelling, by means of the software program GaBi® 6.0. The environmental sustainability of the system was examined using the life cycle impact assessment (LCIA) method. It was found that the 100-year global warming potential, an indicator that is easy comprehended by decision- and policymakers and the public, for producing 2200 m^3 of biogas per year using the portable biogas unit under rural Egypt's conditions was 0.046 kg CO_2 eq. per one MJ electricity. Additionally, is that it seems that the usage of digestate as biofertilizer can be an auspicious strategy to boost the environmental sustainability of the portable biogas unit.

According to the results of this study, it can be concluded that the manufacturing of the portable assembly biogas unit causes the highest GHG emissions. In contrast, the operation of the biogas unit causes the lowest GHG emissions. On the other hand, the biogas utilization causes high GHG emissions but slightly lower than the manufacturing of the unit due to the fact biogas utilization requires some equipment which is considered in the calculation of GHG emissions.

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