Anaerobic digestion of municipal solid waste produced by the city of Algiers using life cycle assessment

Sadia Zibouche, Rabah Bouarab, and Mohammed Amouri

Abstract− This study analyses the life cycle assessment of anaerobic digestion process of municipal solid waste management (MSWM) produced by Algiers city. Some keys parameters of the processes are then modified to analyze the "hot spots" and perform a sensitivity analysis to identify their influence on the results. Data for the inventory came from actual city facilities, and background process information came from Eco invent version 3.1 of *SimaPro 8.1* software. The analyzed process contribution indicates that the global warming potential is affected by the anaerobic digestion because of the NO_x and CO emissions from the thermal processes of biogas burning and fuel oil combustion for digesters heating. Furthermore, plastics recycling is environmentally beneficial because of net savings. The energy valorization of biogas produces the least amount of environmental damage, eliminating 403.06 kg CO_2 eq/ton of waste, saving 18.2 E+09 MJ/ton of fossil fuels, and producing 2.8 E+08 kWhel/year, or 6% of the city's annual electricity consumption.

***Keywords*− Anaerobic digestion, municipal solid waste, life cycle assessment, energy recovery, recycling.**

NOMENCLATURE

AD	Anaerobic digestion.
LCA	Life cycle assessment.
MSWM	Municipal solid waste management.
OFMSW	Organic fraction of municipal solid waste.
CHP	Combined heat power.
OD	Ozone layer depletion.
GHG	Greenhouse gas.
TA	Terrestrial acidification.
HT	Human toxicity.
GWP	Global warming potential.
FD	Fossil depletion.

I. INTRODUCTION

The daily per capita production of MSW in the city of Algiers doubled between 1980 and 2018, rising from an average of 0.63 to 1.25 kg per day per inhabitant. Similarly, the quantity of MSW produced by the city of Algiers increased dramatically, reaching 1,237,874 tons in 2018. In exchange, the waste management and treatment policy has not changed. The same mode of management inherited from the colonial period (landfill) is maintained. This choice is inappropriate for Algerian garbage since it mostly consists of organic waste (60 percent by weight), which produces a lot of CH4 and leachates, which are sources of pollution [1]. Additionally, there is opposition to the planning of new landfill sites, and dump capacities are decreasing, particularly in metropolitan areas [2]. Anaerobic Digestion (AD) or composting systems are the best ways to treat waste with high organic fractions [1]. Besides, anaerobic digestion is a well-proven technology to process municipal solid waste rich in organic fraction (OFMSW) [3]. The study conducted by Zibouche et al. confirms that anaerobic digestion seems to be more sustainable treatment alternative in terms of total CO_2 and total SO_2 saved for Algerian waste [4]. The same results are confirmed by multiple studies in different regions of the world. According to Edward et al., compared to existing waste management methods, anaerobic digestion has less of an influence on acidification, minimal capacity to deplete fossil fuels, and a reduced potential to cause global warming [5]. In addition to its positive effects on the environment, reports suggest that the AD process is commercially viable and has the potential to generate significant revenue. In this context, several authors have focused on in-depth studies of anaerobic digestion systems. Moreover, other research teams continue to work on anaerobic digestion to overcome obstacles and promote commercialization. Researchers need to examine anaerobic digestion at a systems level, taking into account its technological, economic, and environmental benefits [6]. Avangelisti et al. have conducted a sensitivity analysis on anaerobic digestion parameters to confirm the robustness of the results. In this regard, four parameters have been investigated: the sequestration of digestate carbon, emissions from digestate consumption, efficiency of the CHP unit, and fugitive methane emissions from the AD plant [3]. The findings verify that the most important presumption relates to the amount and quality of energy generated by the biogas. The optimization of the electricity produced by the biogas-fed cogeneration unit and the establishment of the future energy scenario in which the plant will be integrated are two crucial factors that influence the design and implementation of future anaerobic digestion plants. On that respect, Hadzik et al. investigate the influence of waste composition on the anaerobic digestion process. The findings indicate that waste composition affects recycling, thermal treatment of residual waste, and biogas production potentials and nutrient enrichment.

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The objective of this paper is to assess the anaerobic digestion of *MSW* by using life cycle assessment. This identifies the contribution of each subsystem on the investigated environmental impacts. Some processes key parameters are then modified to analyze the "hot spots" and perform a sensitivity analysis to determine their impact on the outcomes. In this context, life cycle assessment has been conducted for anaerobic digestion process composed of seven subsystems including site capital goods, sorting plant, waste pre-treatment, anaerobic digestion, leachate treatment unit, biogas valorization unit and transportation of construction and operating materials to the treatment unit, with an analysis of the influence of the subsystems on each of the five impacts studied. The intermediate categories (Midpoint) considered are; global warming potential (GWP), terrestrial acidification (TA), ozone layer depletion (OD), fossil depletion (FD) and human toxicity (HT).

II. Material and method

Case study

The nation's capital, Algiers City, will serve as the case study, because it is the city with the highest *MSW* generation. Indeed, it includes the most important concentrations of population, industries and large urban projects, the political and social institutions, the great economic and financial establishments.

The amount of *MSW* produced by Algiers city has increased dramatically between 1960 and 2018 to reach 1 237 874 tons of waste.

The management of wastes in Algiers district has long been limited to collection and transporting to dump sites. The two landfill units—HAMICI in the west, located at 36°39'29.99 "N, 2°49'14.33 "E, and CORSO unit in the east, located at 36°43'24.1 "N, 3°27'08.0 "E—are where the garbage is dumped.

Physical composition and chemical analysis

- The moisture (% M) is considered to 60% of the total volume of MSW.
- Of the waste that was taken into account for this study is made up of 15% other materials, 5% papers, 3% metals, 1% glassware, and 57% organic waste.
- With a 68% volatile matter content, 136 m3 of biogas are predicted to be produced for every ton of waste.
- The biogas produced is composed of 75% of CH_4, 21% of CO_2 and trace gases such as H_2S (59 ppm).
- The result of the study conducted by Nimaa et al. confirm that composts produced the urban solid residues in Algeria exhibit characteristics of organic amendments [7].

Anaerobic digestion unit

With reference to the fig. 1 schematic, below is a basic synopsis of the unit procedures. Pre-treatment, *AD*, biogas recovery unit, the digestate treatment unit, and the leachate treatment unit are the five primary subsystems that make up the *AD* unit under consideration.

Pre-treatment of MSW

Sorting procedures that can separate the waste into its organic and inorganic components are part of the pre-treatment. The organic fraction (about 50% of the original *MSW* weight) consists mainly of kitchen waste while plastics, wood, paper and cardboard, textiles that are not considered fermentable. This fraction represents 23% of the total composition. It is delivered to specific recycling facilities, which are usually located 30 km from *MSW* treatment plants.

Many studies have investigated the effect of recycling on different environmental impacts. When metals and plastics are sorted at material recovery plants before being converted to energy, the worldwide environmental impact is greatly increased [8].

Due to the high moisture content of the waste, in this case study, the paper and textiles are contaminated by wastewater from food waste and cannot be recovered or recycled [9].

The waste fraction retained for anaerobic digestion would be reduced in size to improve biodegradability. In this context, the data on the energy required for the grinding operations are taken from the study conducted by Fernandez-Nava et al [10]. The electricity consumption of the mixed waste sorting plant as well as the shredding operations is estimated at 58 kWh per ton of waste.

AD plant

Reactors for anaerobic digestion provide significantly improved control over the process, faster production of methane and biodegradation, and nearly total methane capture. Since AD is a renewable energy source, it may increase energy supply security and contribute to a decrease in greenhouse gas (GHG) emissions. In contrast to certain other renewable energy sources like wind and solar, which are more intermittent, it is also helpful as a source of energy that can be used whenever needed [11]. There are two primary digesters and one secondary digester installed in the anaerobic digestion unit under consideration.

The digesters used in this investigation are situated at BERRAKI's wastewater treatment plant in the city's center at 36°41'42.9 "N 3°06'25.1 "E. The retained fraction undergoes grinding, shredding and screening operations to reduce its size and reach a dry matter concentration of 50%, thus approaching the anaerobic digestion conditions used in the unit in question. After 25 days of residence at 37 °C and pH of 7.1, the anaerobic digestion reaction occurs, eliminating 50% of the organic matter by weight. The large range of applications and the high water content of the waste led to the selection of this wet digestion method. The primary digesters are continuously fed waste with a 50% dry matter concentration. Each digester has a 12,000 m^3 capacity. The waste has to be heated to compensate for heat losses and the arrival of fresh waste. It enters the exchanger on the opposite side to the hot water (counter-current heat exchanger). The hot water enters the exchanger at a temperature between 50 and 70°C. While the waste enters to the exchanger at 37°C and exits at 40°C.

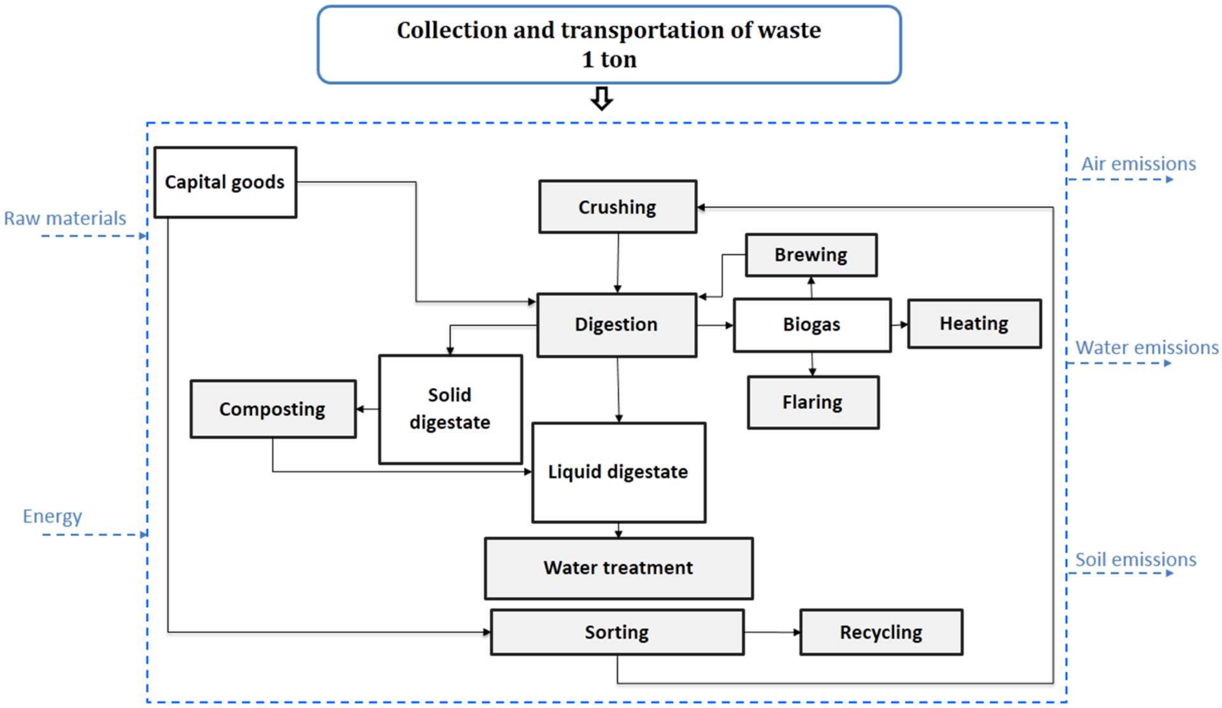

Fig. 1: Description of the unit processes of anaerobic digestion.

Use of biogas

The anaerobic digestion reaction produces 136 m^3 of biogas per ton of waste with composition of 75% of methane, corresponding to a net calorific value of 26 MJ/Nm^3. The biogas escapes upwards from the digesters and is stored in top of the digesters.
The compressor receives a portion of the biogas that is taken out of the digester's top. Once compressed, It is suppressed by the compressors and travels as bubbles at the bottom of the digesters to the sludge mixing rods. The biogas bubbles rise to the surface of the sludge, causing the sludge to move upwards. A water-cooling unit is associated with the compressors to prevent damage.
In addition, the biogas produced by anaerobic digestion is used to produce hot water for the process, using two boilers. When the gasometer level hits the high filling threshold of 35%, biogas is fed into the boiler burner. The burner uses fuel oil (diesel) if this level is below the 20% low threshold.

The gasometer is of flexible type with a double membrane, which has a storage capacity of 3000 m^3. These two membranes are made of a polyester complex and a PVC coating. The inner membrane is biogas-tight and has a high chemical resistance to biogas. The outer membrane has high mechanical strength and resistance to the outdoor climate. It is also biogas-tight enough to store biogas temporarily (for example, if the inner membrane breaks).
To prevent excessive biogas from leaking into the atmosphere, it is burned using a flare. When the gasometer's level is more than 80% of the overall level, it fires. The requirements for pre-treatment, the digesters' biogas mixing system, and digestate drying account for 3.24E-02 kWh of electricity usage.
Anaerobic digestion produces biogas, which is a sustainable and clean energy source that can be used to replace conventional energy sources that are producing ecological and environmental concerns while also depleting at a faster rate [12]. In most circumstances, without additional purification, it can be added to power gas engines (ideally in a combined heat and power (CHP) plant).

Furthermore, 4.42E+02 kWh of heat are produced, which meets the heat requirement needed to maintain the digester's temperature at 35 °C. The unit uses 3.73E+02 kWh of power generated, with the remaining energy being fed back into the public grid. The cogeneration unit's emissions from burning biogas are based on [13].

Use of digestate

In our study, a stage of digestate dewatering is considered. The compost is used as an organic fertilizer. The compost produced in Algeria has rates of N, P, K, C, organic matter, and a C/N ratio that satisfies the NFU 44 051 standard, according to a study by Nimaa et al. The elements metallic tracks have less content than the allowable limits. Furthermore, the outcomes of the phytotoxicity tests verify that the composts generated have the properties of organic amendments [13].

Leachate treatment unit

The quantity and characteristic of the MSWs and their leachates differ from one place to another [14]. The types of garbage in the landfill, as well as its residual moisture content, water infiltration, stage of degradation, and landfilling technology, are the primary factors influencing these variations in leachate composition.
The landfill site studied generates 200 m^3/day of leachate, of which:
- 80 m^3/day: treated at a membrane leachate of treatment plant.
- 120 m^3/day: treated at a reverse osmosis leachate of treatment plant.

Afterwards, the leachate's quality is presumed to meet the ISO standard standards for landfill pollution, after which it will be directly released into the city's sewer system. Table 1 lists the features of the leachate following treatment at the landfill under investigation [4].

Table. 1
Characteristics of the leachate after treatment

Parameters	Unit	Reverse osmosis	Membrane leachate treatment	Limit values	Standard of analysis
Temperature	°C	13	19.3	30	/
pH		6.99	6.44	6.5-8.5	/
MES	mg/l	9	10	35	ISO 11923:1197
Kjeldahl Nitrogen	mg/l	12	17	30	ISO 5663:1984
Total phosphorus	mg/l	0.39	4.9	10	ISO 6878:2004
Phenol index	mg/l	0.1	0.1	0.5	ISO 6439:1990
DBO5	mg/l	58	14	35	ISO 5815:1989 (F)
DCO	mg/l	110	380	120	ISO 6060:1989
Oils and fats	mg/l	2	2	20	Rodier method
total hydrocarbons	mg/l	5	5	15	AST MD 1664
Aluminium	mg/l	1	1	3	ISO 120120:1997
Cadmium	mg/l	0.03	0.03	0.5	ISO 8288:1986
Lead	mg/l	0.2	0.2	0.5	
Copper	mg/l	0.1	0.1	0.1	
Nickel	mg/l	0.2	0.2	0.1	
Zinc	mg/l	0.03	0.03	2	
Manganese	mg/l	0.03	0.03	1	
Iron	mg/l	0.2	0.2	3	FD T90-112

1.1. Life cycle assessment

The life cycle assessment (LCA) methodology is used to evaluate various approaches to waste treatment. The four components of an LCA are as follows: (1) Goal and scope definition; (2) Life Cycle Inventory assumptions (LCI); (3) Life cycle impact assessment (LCIA); and (4) Interpretation, as outlined in ISO 14040: 2006 - Environmental management - Principles and methodology for LCA (ISO, 2006). The ensuing sections will provide an explanation and detailed guide to these steps.

1.1.1. Goal and scope definition

The objective is to evaluate and compare the environmental impacts of anaerobic digestion unit as management systems of solid waste of Algiers city and determine the critical parameters including the greatest influence on the environment impact and leads to the selection of the best system.

Recently the system of management of municipal waste in Algeria has been considered as a priority of the Ministry in charge of the environment. The findings of this study will raise decision-makers' knowledge, which may help to lessen future negative environmental effects.

Although the evaluation is intended to be conducted on the waste stream of the biggest city in Algeria, the final findings can be generalized to be reliable for the majority of cities across the country due to their comparable compositions of solid waste (MSW) [15].

1.1.2. Functional Unit

It is essential to establish the functional unit in order to compare the scenarios on an individual basis. One ton of waste was chosen as the functional unit for this study.

1.1.3. System boundary

To enable others to reproduce the work, each assumption will be stated as precisely as possible.

-The operations of construction, biogas emissions, leachate treatment and post closure are taken into account.

-The collection of waste and their transport to the treatment unit are not taken into account.

-The transportation of construction and operating materials to the treatment unit is taken into consideration.

- In this analysis, fugitive greenhouse gas emissions from the AD process are taken to be zero.

-The transportation of materials (steel, HDPE concrete, diesel, etc.) to the treatment units is considered. Calculations reveal a quantity of 1.09 tkm for the anaerobic digestion unit.

1.1.4. Data acquisition and assumptions

Based on real data, an inventory has been created. The life cycle inventory data was obtained from actual anaerobic digestion systems of BARRAKI sludge (36°41'43.85 "N, 3° 6'25.49 "E), while the background data came from scientific literature and the Eco-invent V3 database. Table 02 displays the system's primary input and output streams, normalized per ton of waste. This study takes into account data from several procedures, both direct and indirect.

1.1.5. Allocation method

In this paper, a system expansion of substitution strategy is applied to use power produced as a byproduct. The emissions created during waste treatment are removed from those produced by the "avoided" emissions produced by traditional energy generation. Credits are therefore given for substituting the same amount of power produced by burning fossil fuels.

1.1.6. Life cycle impact assessment

Selecting the appropriate software is crucial for determining and evaluating how waste management systems affect the environment, and the data it holds must be updated and validated on a regular basis. Knowing the effects of your actions in the first and second stages of the Life Cycle Assessment (LCA) can help you make informed choices about the databases and LCA methodologies to utilize [18]. The LCA approach needs to satisfy the study's objectives and requirements, although the process for choosing the latter is frequently disregarded [19].

Table. 2
Principal streams of input and output of anaerobic digestion

Energy and material	Unit	Value
Input flow		
Electricity	kWh	145
Diesel	kg	0.600
Fuel	kg	5.700
Steel	kg	0.018
Concrete	kg	6.120
Sand	kg	19.600
Gravel	kg	29.400
Water	kg	3.060
Reinforcing steel	kg	23.300
Cast iron	kg	0.009
Carbon Steel	kg	0.001
Galvanized steel	kg	2.05E-02
Ductile iron	kg	7.43E-03
coated polyester	kg	6.21E-03
Stainless steel	kg	7.53E-03
Aluminium alloys	kg	2.19E-04
Gravel	kg	29.4
Oil lubrication	kg	1.24E-04
Membrane Clean Osmacid-AC	kg	7.28E-04
Membrane Clean NE 10	kg	4.85E-05
Caustic soda (33%)	kg	4.52E-02
Phosphoric acid (50%)	L	2.43E-05
Sulphuric acid (96--98%)	L	1.31E-04
Sodium hydroxide 33 %	kg	3.40E-02
kleen Osmal	L	1.36E-03
Citric acid monohydrate	kg	1.94E-04
Output flow		
Air emissions		
CO	Nm^3	5.26E+01
N_2	Nm^3	5.44E+00
CO_2	Nm^3	6.35E+02
H_2S	ppm	8.02E-03
Water emissions		
Suspended matter	Kg	5.00E-04
Kjeldahl nitrogen	Kg	6.38E-04
Total phosphorus	Kg	2.07E-05
Phenol index	Kg	5.32E-06
DBO5	Kg	5.80E-02
DCO	Kg	1.10E-01
Oil and grease	Kg	1.06E-04
Total hydrocarbons	Kg	2.66E-04
Aluminium	Kg	5.32E-05
Cadmium	Kg	1.59E-06
Lead	Kg	1.06E-05
Copper	Kg	5.32E-06
Nickel	Kg	1.06E-05
Zinc	Kg	1.59E-06
Iron	kg	1.06E-05
Manganese	kg	1.59E-06

The software SimaPro@ was used to perform the modeling. There is no recommended impact assessment approach for use in the ISO 14040/14044 standard. The ReCiPe assessment approach is applied in this investigation because it combines the straightforward interpretation of ECO-99 results with the scientific rigor of CML2001, making it more intriguing and warranted for application. In addition, the ReCiPe approach takes into account 18 intermediate categories—eight more than the ECO-99—that are combined into the three primary categories of resource depletion, ecosystem quality, and human health. These categories represent domains in which policy and decision-making decisions are frequently made.

According to Yi et al., the midpoint analysis increases the comprehensiveness of impacts by including more endpoint effects [20]. Additionally, the endpoint approach—, which uses straightforward indicators—has been useful in summarizing the integration of interpretations. However, It has not been very successful in illuminating the harms associated with various environmental impact categories at various spatial scales. As a result, endpoints could be categorized into global, regional, and local scales to aid in their interpretation.

Although coverage of more impact categories represents a more detailed analysis, this study will consider the most important impacts. In the impact evaluation, 96% of the evaluated research covered the category of GWP, which is associated with the issue of climate change, according to the Iqbal review. Human toxicity potential (HTP) and the acidification and eutrophication of water resources were also examined in more than half of the studies [21]. Global warming potential (GWP), ozone layer depletion (OD), terrestrial acidification (TA), human toxicity (HT), and fossil depletion (FD) are the five impact categories taken into consideration in this study.

1.1.7. Sensitivity analysis

Sensitive analysis was done to identify uncertainties in the goal of observing the robustness and reliability of the anaerobic digestion process under study, as small adjustments to inputs and assumptions could cause fluctuations in LCA results, which would unintentionally cause confusion in decision-making [22]. Four parameters—the value of the biogas produced, the transportation of wastes, the composition of wastes and biogas, and fugitive emissions from the anaerobic digestion facility—were taken into consideration due to their significant contributions to the anaerobic digestion process. The range of variation of the input parameter for the sensitivity analysis is shown in Table 3.

Energy recovery

The identical *AD* unit established above is used here, but it is assumed that the biogas generates both heat and electricity through a combined heat and power unit.

In addition to the benefits to the economy, environment, and climate, renewable energy rules have fostered an increase in biogas production in the European Union, which reached 18 billion m^3 of methane (654 PJ) in 2015, accounting for half of the world's biogas production [23].

The electrical conversion efficiency of 38% and the thermal conversion efficiency of 45%, which are within the reported range of biogas power and heat generation employing engine technology, are the primary characteristics utilized to model CHP plants [24].

Table. 3
Sensitivity analysis key parameters

Parameter	Value
Wastes Transportation	Average transportation of 1 t of waste in the city of Algiers was estimated to be 25 km.
MSW composition and biogas production.	Waste composition data from a landfill site showed a 60% organic fraction, a difference from the 40% organic fraction average for Africa. Based on local statistics, the organic content of waste, which is 136 m^3/ton of garbage, determines the potential for biogas production. When 40% of the waste is organic, the value has been changed to 90.7 m^3/ton waste.
Biogas composition (% CH_4 and % CO_2 and others trace gas)	A value of 75% CH_4 is taken into account, which is supported by experimental findings from Saber et al. For sensitivity analysis, an average CH_4 content of 60% is utilized.
Fugitive emissions from anaerobic digestion facility	This research takes into account methane losses from the digestion process that range from 0% to 9%. According to published research, the highest loss from fugitive losses in digestive systems is predicted to be 9%.

Without the need for additional purification, the biogas produced by AD is a clean, sustainable energy source that may be used straight in gas engines—ideally in a combined heat and power (CHP) plant.
Additionally, 4.42E+02 kWh of heat are generated, which is sufficient to meet the heat demand needed to maintain the digester's temperature at 35 °C. While the 3.73E + 02 meet the unit's internal needs kWh of electricity produced, the remaining energy will be fed back into the public grid. Based on Fruergaard and Astrup's assessment, the cogeneration unit's emissions from burning biogas [13].

Wastes Transportation

In the baseline scenario, waste collection and transfer to treatment units are not considered. According to the review conducted by Laurent et al. the most often tested parameters were those for collection and transportation [25]. The sensitive analysis studies the influence of transportation of the waste to an average transportation distance of 25 km per ton of waste.

MSW composition and biogas production

The sixth most tested criteria were the waste and biogas composition. It is strongly advised that practitioners incorporate waste composition in sensitivity studies since the variability of the treated materials frequently appears to be a substantial source of uncertainty [25]. In this case study, waste composition was provided from landfill facility to be 60 % of organic fraction and the variation was reported to the African average of 40 % of organic fraction. Biogas production potential is based on organic fraction, which is 136 m^3/ton waste according to local data. This value has been varied to be 90.7 m^3/ton waste in the case of 40% of organic fraction.
Regarding biogas composition, a value of 75 % of CH_4 is taken into consideration, which is confirmed by experimental results obtained by saber et al. A value of 60 % of CH_4 is used for sensitivity analysis as an average content of methane.

Fugitive emissions from anaerobic digestion facility

Recent research indicates that a number of sources, such as flares, feedstock storage, gas storage units, pipelines, safety valves utilized during digestion, and digestate storage, can leak methane during the anaerobic digestion process [26]. It is very difficult to estimate these emissions due to their variability from one site to another [3]. Significant amounts of fugitive methane emissions may originate from biogas plants. In general, fugitive losses at waste biogas facilities and whole-site farms are projected to have a maximum loss of 9%. This study takes into account methane losses throughout the digestive process that range from 0% to 9%.

III. RESULTS AND DISCUSSION

The Fig. 2 illustrates the contribution of each process studied in the anaerobic digestion process. The categories including human toxicity and terrestrial acidification are affected negatively by steel and iron used in the biogas facility because of the huge industrial installations built mostly in steel or cast iron (heating system, gasometer, unit of compression, boilers, etc.).

The methane bromotrifluoro-Halon 1301 is the main cause of the ODP [28]. Because of the rising need for fuel to heat reactors, ODP load is affected negatively (3.63E-05 kg CFC-11 eq by the emissions due to the fuel oil used to feed the boiler to produce hot water. this negative influence can be avoided by optimizing the anaerobic digestion process by feeding the two boilers with the biogas produced.
The global warming potential is widely affected by the anaerobic digestion because of the NOx and CO emissions from the thermal processes of biogas flaring and fuel oil combustion for digesters heating. The recycling of HDPE after the sorting operation displayed the greatest value of saving in three impact categories including global warming potential, fossil depletion and acidification potential. Recycling plastics saves the environment since it allows for net savings of -1600 kg CO2/ton of waste when virgin plastic is substituted [29].

Sensitivity analysis

The figure 3 illustrates how each parameter's fluctuation contributed to the impacts studied.
-Biogas valorization in CHP unit
Biogas power generation has positive effects and reduces the impact due to the replacement and conservation of non-renewable energy in all damage categories. The valorization of biogas in CHP unit as defined in the sensitivity study, allows to obtain less environmental impacts. Since it allows to eliminate 403.06 kg of CO_2 eq. per waste, to save fossil fuels with a net avoidance of 18.2 E+09 MJ per waste and to produce 2.8 E+08 kWhel/year of electricity, which covers 6% of the electricity needs of the city.

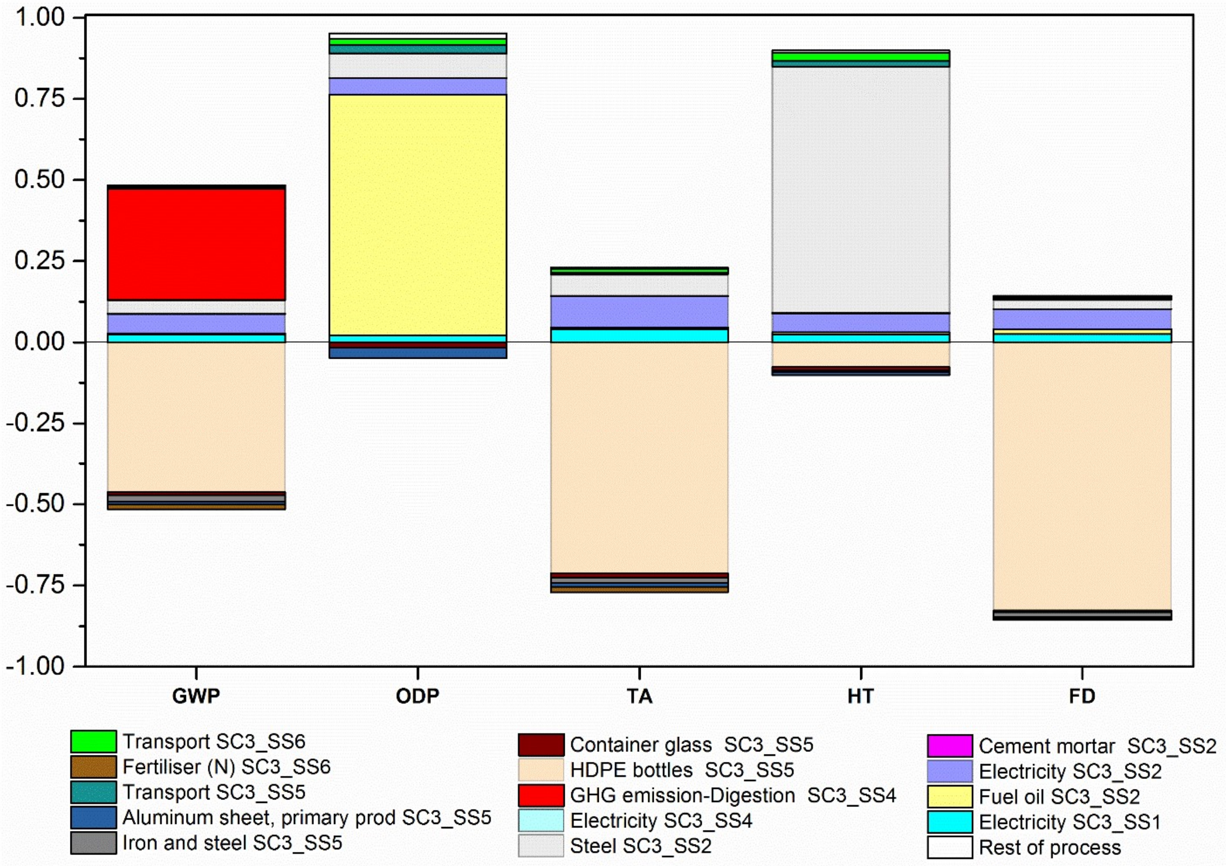

Fig .2: Contribution of each process in the anaerobic digestion process.

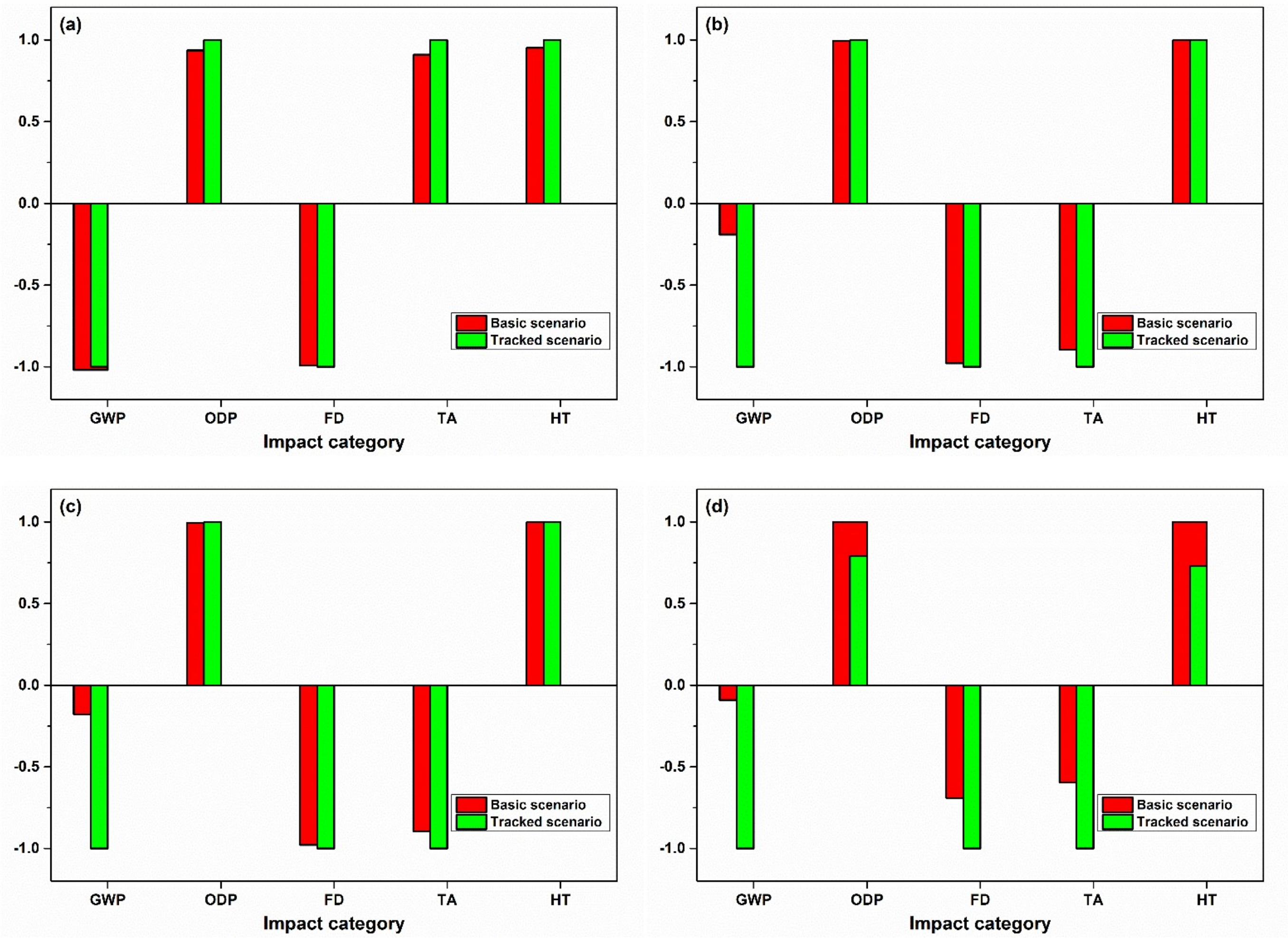

Fig. 3 Contribution of variation of each parameter in the studied impacts, (a) transport, (b) waste composition, (c) biogas composition and (d) energy valorization.

The emissions "avoided" by the conventional production of this energy are subtracted from the emissions generated by the waste treatment. As a result, credits are provided for substituting the equivalent quantity of power produced by burning fossil fuels. Fossil depletion refers to the use of fossil fuels, the results show that both anaerobic digestion scenarios do not contribute to the depletion of fossil fuels due to the valorization of the biogas produced. Significant environmental savings are obtained by energy recovery, according to Rana et al. [30], which explains the overall negative score obtained in the other two scenarios that show savings from fossil fuels. With a net avoidance of 453 kg oil equivalent per waste (18.2 E+09 MJ) from the valorized biogas scenario and 139 kg oil equivalent per waste (5.6 E+09 MJ) from cogeneration, the biggest savings are observed in this scenario.

Waste transportation

The most often evaluated parameters were those for collecting and transportation, though research typically concluded that their influence on the outcome was minimal [25]. Actually, there is raising concerns on environmental burden from waste collection and transportation indicating that more attention should be paid on this parameter [22].
The analyses show that the transport process does not imply a significant variation in the effects on the environment, with the exception of a slight increase in the terrestrial acidification and effects of ozone depletion due to greenhouse gas emissions.
Because of the efficient waste transportation to the treatment plant in the city of Algiers, it was discovered that the transportation process only contributes 2% of the total GWP for all scenarios examined.

Waste composition and biogas composition

The effects of changing the composition of the biogas yield results that are comparable to those of changing the waste composition. A decrease in the amount of organic matter in waste and a drop in the methane content of the biogas primarily suggest a decrease in the amount of energy generated in both cases. The anaerobic digestion system is significantly impacted by the greenhouse gas emissions released by biogas engines, as demonstrated by each process's contribution. For this reason, when compared to baseline assumptions, a decrease in the methane biogas content or the waste organic portion permits a reduction in the possible environmental effects of global warming.

Fugitive emissions

Based on this study, the GWP increases by more than 30 times when the methane losses of the digestion process are varied from 0% to 9%. This results in a contribution of 75.85 kg CO_2 eq/ton, instead of the avoided -36.70 kg CO_2 eq/ton of waste. This clearly shows the need of emission monitoring and management in biogas production, since fugitive losses have a major effect on the overall environmental performance of a biogas production system.

IV. CONCLUSION

This work aims to evaluate and analyses the environmental impacts of anaerobic digestion of MSW in the city of Algiers. The ozone depletion is primarily caused bmethane because there is a greater need for fuel to heat reactors. This detrimental effect can be prevented by maximizing the anaerobic digestion process to produce more biogas to the boiler. Because of the NOx and CO emissions from the thermal processes of biogas flaring and fuel oil burning for digester heating, anaerobic digestion has a significant impact on the global warming potential. However, HDPE recycling following sorting process demonstrated the highest value of savings in three impact areas, including the potential for global warming, acidification, and the depletion of fossil fuels. Sensitivity analysis reveals that biogas valorization stands out environmentally and helps to mitigate the effects of all the harm categories taken into consideration. It enables the production of 4.42E+02 kWh_{th}/ton of waste, meeting the necessary heat requirement. Utilizing the created biogas will enable the production of 2.8 E+08 kWh_{el}/year of electricity, which when injected to the public grid will satisfy the electricity requirements of 6% of the city's total population. In comparison to baseline assumptions, the results for the variance in the composition of waste and biogas indicate a decrease for energy produced. This allows lowering the potential environmental effects of global warming. The results of this study can be applied to other Algerian cities as well as cities around the world with comparable sociological and climatic circumstances. Evaluating and discussing the three pillars of sustainability requires integrating the findings with social (by social life cycle assessment) and economic (via life cycle costing) components.

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