Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268 (Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 | No. 3 | pp. 1469-1479 | 2023
Original Research Paper
https://doi.org/10.46488/NEPT.2023.v22i03.032
Open Access Journal

A Master Plan Realization for an Integrated and Sustainable Management System for Household and Similar Wastes in Morocco's Landfills by Sizing a Methanation and Composting Unit

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 23-01-2023
Revised: 27-02-2023
Accepted: 03-03-2023

Key Words:
Household and similar wastes
Physicochemical characterization
Recycling and recovery
Methanation
Composting
Biogas

ABSTRACT

This work is a decision support contribution in Morocco's household and similar waste management. This management based on total waste landfilling leads to several environmental impacts, such as the use of large land areas, also the gaseous pollutants released, such as methane. Our first action was to collect reference data on the composition of this waste through a physicochemical characterization in the landfill in the city of Mohammadia. We sorted the waste generated by four types of populations with different living standards. A quantity of 500 to 2315 kg was treated, which allowed us to classify the household waste studied into nine main components. The sorting results are (organic matter 54.94%, plastic 15,18%, paper and cardboard 9,72%, textiles 7,46%, sanitary textiles 5,82%, metals 2,20%, glass 1, 89%, Wood 1,82% and Other 1,28%). Thus, these results revealed organic matter dominance and an increase in the plastic rate, which did not exceed 8% in the past. Added to this, the physicochemical parameters results are (volatile matter 60,26%, Humidity rate 59,05%, a total organic carbon (TOC) 33,47%, and a lower heating value (LHV) 1840,3 $kcal.kg^{-1}$). From these data, we can easily deduce that installing a sorting platform with a methanation and composting unit is the most suitable choice for recovering our waste. Therefore, we have chosen the methanation technology that meets the results obtained (dry batch and mesophilic) and sized this unit to assess its electricity production capacity that can be produced in our landfills. We carried out a scenario with a load factor of 0,9 and an electrical efficiency of 39%. The study results are 9 digesters to be built, 6.700 $MW.y^{-1}$ of electrical energy produced, 14.523 $tons.y^{-1}$ of refined compost, and 2.128.680 $m^3.y^{-1}$ of biomethane produced. By offering our own integrated and sustainable management system for household and similar waste, we have connected the landfill bins and the digesters to the same motor to avoid biogas leaks from the bins to the atmosphere and increase electrical efficiency by controlling the gas flow.

INTRODUCTION

The demographic growth that we are experiencing today requires urban expansion and industrial and socio-economic development at extraordinary rates. This impacts our lifestyles and makes us always push towards more consumption. Therefore, more waste is generated, particularly household and similar waste (HSW). According to the World Bank, in 2012, we generated 1,2 kg of waste per person per day, reaching 1,42 kg per person in 2025 (Hoornweg & Bhada-Tata 2012). Thereby, managing this waste represents a real challenge for all societies on Earth.

The planet is going through a critical stage with global warming conditions strongly linked to greenhouse gas (GHG) emissions. Despite the compromises adopted in 2015 at the Paris Climate Conference to limit the rise in temperature below 2°C, scientific evidence indicates that average temperatures are already reaching more than a one-degree increase in pre-industrial level (CLIMAT.BE 2018). The main cause of this phenomenon is the carbon dioxide emission. But there are also other gases, such as methane, which remain part of this major problem. With its warming power exceeding that of carbon dioxide by more than 20 times (EPA 2018), it is necessary to know that waste management is ranked among the four most important sources of its emission (Pierini & Ratto 2015).

HSW management requires many economic means and scientific and technological know-how, which developing countries (DCs) unfortunately do not have. Consequently, the environmental and economic impact of this lack of management results in life quality and public health deterioration. This has prompted these countries to take this problem very seriously by copying solutions that seem most suited to the nature of their waste. Despite this, these efforts did not lead to satisfactory results. Nevertheless, they proved the importance of focusing on the local context to create and adapt management systems and models.

In Morocco, controlled landfills are the national household waste program (NHWP) axis. This Program consists of ensuring the collection and cleaning of household waste to achieve a collection rate of 100% in 2022, carrying out controlled landfills for all urban centers, rehabilitating all existing wild dumps, developing the "sorting-recycling-recovery" sector to reach a recycling rate of 30% in 2030, generalize the master plans for all the provinces of Kingdom and train and sensitize all concerned actors. However, the targeted recycling and recovery rate will not reduce the severity of environmental impacts. The direct burial of our waste, which is very humid and organic, leads to methane emissions and too much leachate. Above all, we must change the landfill every 25 or 30 years. For this, Morocco must engage in a more innovative and daring approach to achieve the objectives of the NHWP.

This work falls within this perspective. The approach that motivates its development is realizing a system characterized by energy and financial autonomy in integrated and sustainable management (ISM). The term sustainability implies three dimensions: social, economic, and environmental. Its objective is to respond effectively to the many questions raised by implementing an ISM of HSW adapted to the specificities of our country.

Based on the physicochemical characterization of HSW, sizing of a methanation and composting unit, and based on some enlightening international experiences, this work provides four main elements of framing:

- The need to comply with the principles governing a desired integrated and sustainable waste management. In this sense, landfilling, however, controlled, is relegated to the status of an ultimate solution.
- The comparison between the different sectors and technologies must be multi-criteria and be based on all the aspects related to them. Without being limited to simple investment and operating costs, it must consider all the components: landfill lifetime, environmental risks, socio-economic impacts, etc.
- With more than 50% organic matter and 60% humidity in our household waste, we think directly of methanation, biogas, and composting as key elements for integrated and sustainable household waste management. In this sense, the sizing of a dry mesophilic anaerobic digestion and composting unit has been carried out.
- Dealing with the waste problem must rely on several treatment or disposal channels and ensure complementarity between these techniques (Yemadje 2013). In this sense, a management master plan with a technical feasibility study is carried out.

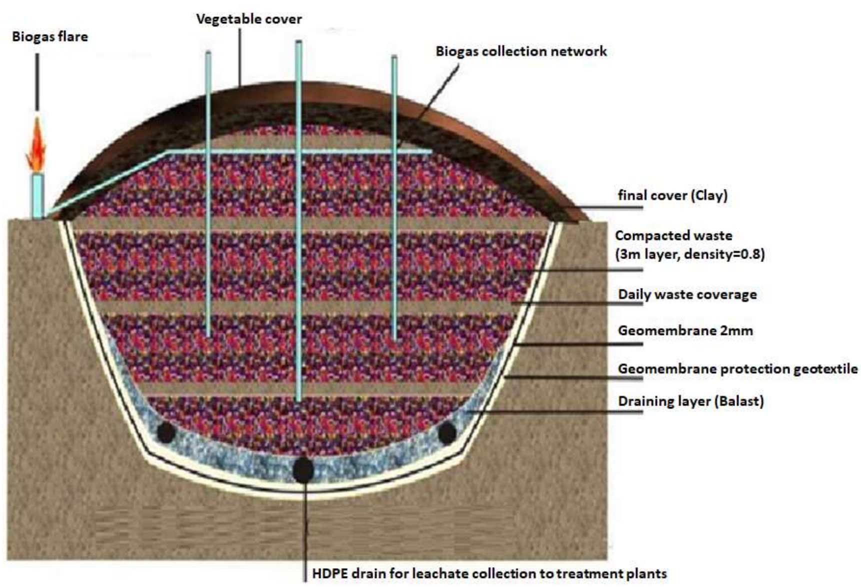

Fig. 1: Biogas Extraction directly from burial bins in controlled landfills.

THE GENERAL CONTEXT ANALYSIS AND BASIC DATA

The controlled landfill solution alone does not fit in efficiency or sustainability; it is considered an ISM system for HSW. We end up with large quantities of biogas seeking to spread into the atmosphere causing significant damage (Wellinger et al. 2013).

To solve this problem, decision-makers in my country have chosen to install duct systems and pipe networks to recover this biogas (Fig. 1).

The recovered biogas is sent to flares (wasteful), in the best of cases, as at the landfill of the city of Oujda, a combustion engine is installed to produce electricity.

This last solution has shown real potential for efficiency and profitability. However, we are faced with two major problems:

- Failure to control the amount of biogas produced.
- The fluctuation during the day of the biomethane rate composing this biogas.

As a result, we realized that we could never improve these two conditions by remaining dependent on landfill bins. Thereby, the addition of digesters becomes obvious to guarantee control over the necessary quantities of biogas and to eliminate the fluctuations of biomethane during the day if we want to maximize the performance of the cogeneration unit.

Today the HSW are directly buried after a mechanical treatment limited to compaction during the burial. Subsequently, the biogas is sucked by a pump to power a cogeneration engine to consume the biomethane that accumulates in the landfill compartments (Fig. 2).

As shown in Fig. 2, in a system of direct burial and biogas recovery from landfill bins, we are always:

- Limited quantity and quality of the CH4 used caps our electricity production and forces us to stabilize the engine on a moderately low output. Of course, this increases the production rate of other harmful gases.
- Depending on the seasons and the nature of the buried waste, which negatively impacts the triggering of the microbiological movement responsible for methanation.
- Limited if we want to optimize and improve the technical and financial performance of the unit. We cannot hope for an extension of the existing installation.
- Subjected to the production of excessive quantities of leachate for which we have neither the budget nor the technology to treat it.

To better understand the impact of these limitations and dependencies, an analysis was carried out on a cogeneration engine in a landfill that had 850 kWh of power and 39% efficiency. Table 1 shows the difference between what should be (simulation of normal operation) and what is produced in the landfill (actual production):

The difference between our calculations and reality is only the stability of our biogas source and the biomethane rate containing this gas. In the landfill, they are forced to lower the power and reduce the yield to not exhaust the

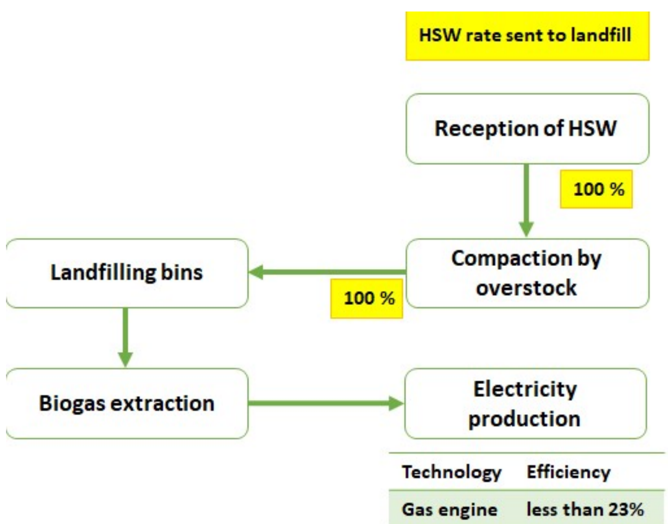

Fig. 2: Direct burial and biogas extraction from the landfill bins at the TLC in Oujda city.

Table 1: Engine output (reality) and output capacity (simulation) differences.

		Reality	Simulation
Electric power	KWh	500	850
Energy production per day	MWh	7,5	13,6
Yield achieved	%	23	39
Working hours	Day	15	16
Lower calorific value of Biomethane	$kWh.m^{-3}$	4,98	5,98
The biomethane amount per day	$m^3.day^{-1}$	6.548	5.802

landfill compartments and to produce all year round, even at 23% yield.

Based on the results of this analysis, we can easily deduce and frame the points for improvement and the objectives to be achieved by setting up our biogas recovery unit at the heart of landfills. This boils down to:

- Improving the efficiency and operating time of the cogeneration engine by controlling the quantity and quality of biogas produced.
- Improving the recycling rate of non-organic matter to reduce the landfilling rate of waste in the TLC and extend the lifetime of our landfills.
- The choice of the methanation process that best adapts to the nature of our waste to improve the biogas production and reduce the landfilling rate.
- Using a composting process for digestate recovery after methanation and diversifying the income sources for our TLC.

Basic Data

To develop an integrated and sustainable management system for household waste, the first thing to know is the physicochemical composition of this waste. The sampling operation must be representative and the sorting very selective to know the paths to follow while developing the sorting and recycling unit for non-organic matter (Sidi 2006).

The rate of organic matter, humidity, and pH will help us decide on the efficiency of methanation and the technology to use (Mata-Alvarez 2003). The lower calorific value will allow us to decide the incineration efficiency.

Tables 2 and 3 give us the rate of the physical components and the chemical parameters we need to carry out our plan.

From the results in Table 2, it is clear that organic matter is dominant. Thus, our plan should focus on recovering this organic part which exceeds 54% of all waste. But it should also be noted that plastic and cardboard represent more than 24% in a total of 38% of recyclable and non-organic matter.

Table 2: Average Rates of each recyclable fraction (Farhat et al. 2021).

Physical component	Average rates [%]
Fermentable waste	54,94
Plastics and rubber	15,18
Paper and cardboard	9,72
Textiles	7,46
Glasses	1,89
Metals	2,20
Wood	1,82

Table 3: Results of the physicochemical characterization of HSW (Farhat et al. 2021).

Chemical parameters	Value
pH	6,5
Density in the TLC $[T.m^{-3}]$	0,82
Humidity level [%]	59,05
TOC [%]	33,47
Volatile matter %]	60,26
Ashes [%]	39,74
LHV $[kcal.kg^{-1}]$	1840,3

Selecting a wet system is excluded from the analysis because this technology only accepts biomass with a maximum dry matter content of 15%. In comparison, the dry matter content of household organic waste is usually between 20 and 31%. The dominant organic matter, the pH and humidity, respectively at 6,5 and 59%, give us the certainty of the effectiveness of a dry and mesophilic discontinuous anaerobic digestion plan (Mata-Alvarez 2003).

The lower calorific value is average and insufficient to discuss an incineration block in our ISM system (Harzevili & Hiligsmann 2017). This value far exceeds the average of developing countries and is positioned in the range of industrial countries (1500-2700 $kcal.kg^{-1}$) (Yemadje 2013). This high LHV is due to a relatively high rate of plastic (15.18%).

MASTER PLAN FOR AN ISM SYSTEM FOR HSW AT LANDFILLS IN MOROCCO

After the physicochemical characterization and methanation process choice, we can present our ISM system, which has the following objectives: the extension of the landfills lifetime, the use of the stored biogas in the bins landfilling to avoid its spread in the atmosphere, making the landfill income-generating, as well as total energy autonomy. As shown in Fig. 3, our ISM system is based on inorganic matter

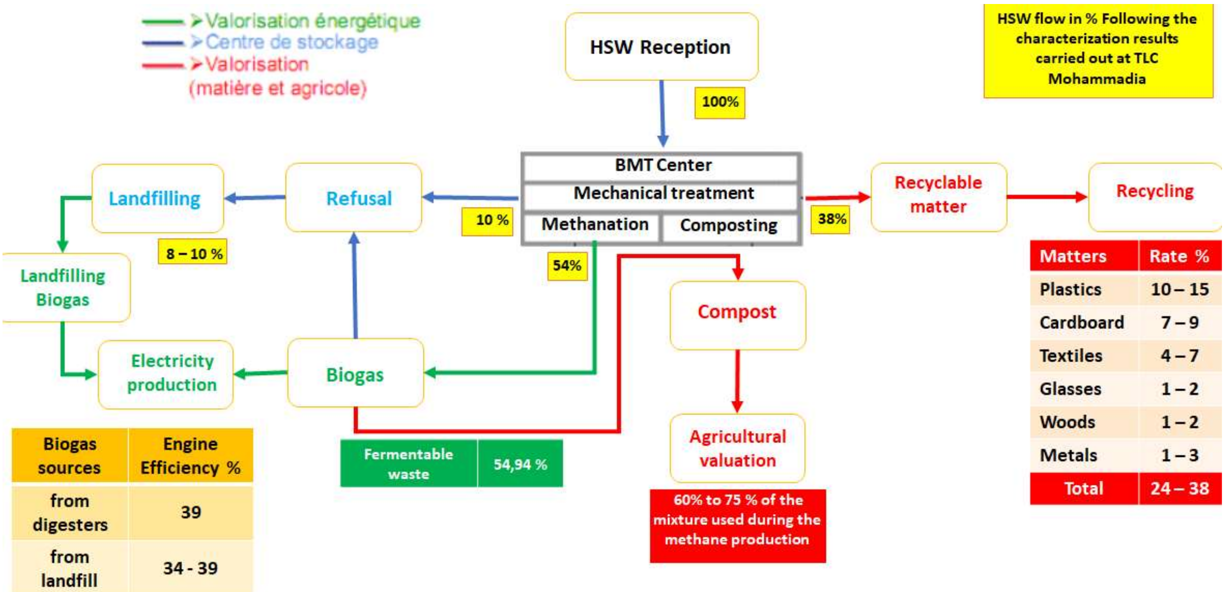

Fig. 3: ISM system with inorganic matter recycling, biogas recovery into electricity, and digestate transformation.

recycling, the methanation of organic fraction of household waste (OFHW), and the digestate composting generated after methanation.

The above system is a set of an ISM's most efficient municipal waste management processes. It focuses on reducing the rate of waste sent to landfill, starting with manual sorting of inorganic materials from HSW, allowing a recycling rate between 24 and 38%. Electricity production is ensured by transforming the biogas produced in our digesters and the landfilling bins (Fig. 4). Thus, OFHW is consumed in its entirety by our methanation and composting processes to further reduce the landfill rate.

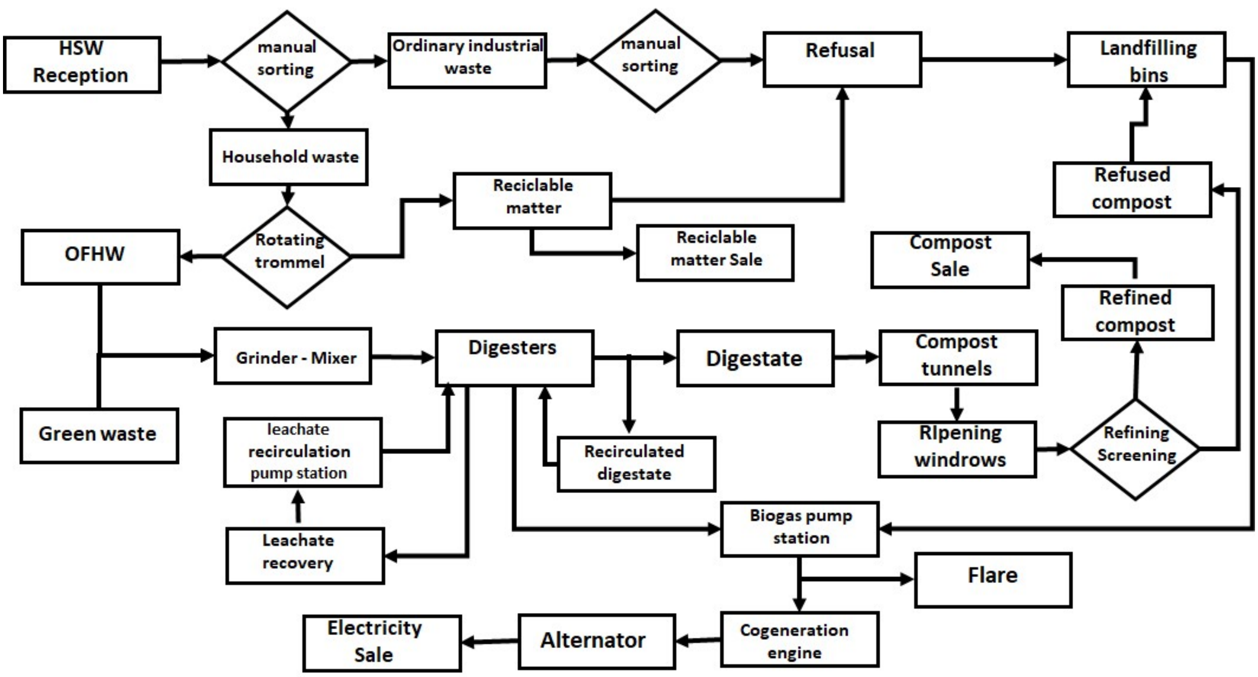

Fig. 4: Block diagram of the HSW recovery and recycling unit to be installed in our TLC.

This system gives us the possibility of recovering the shortcomings present in the management of our landfills and allows us to:

- Extending our landfill's lifetime by limiting the landfilling rate to 20% (maximum) of the waste quantities sent to burial.
- Improving biogas quality produced and increasing CH_4 quantity compared to harmful gases such as H_2S.
- Extracting and recovering the biogas accumulated in the landfill bins to prevent it from spreading into the atmosphere.
- Maximizing energy efficiency, and therefore improving our electricity and thermal production.
- Free our municipalities from the costs of processing and burying HSW through our ISM system's total energy and financial autonomy.
- Limiting the leachate quantities sent to recovery ponds.

HSW Sorting and Conditioning Unit

After receiving the HSW at the TLC, the sorting operation begins with manual sorting to collect all that is visible, large, and reachable, with the help of a loader-turner which turns all of this waste a few times. To reveal what remains buried at the bottom of the heap. After this initial sorting, non-hazardous industrial waste goes directly to landfill. Household waste is sent to the work-bag machine, then to the rotating trommel to continue the sorting operation (Fig. 5).

After the plastic bag shredding operation, the sorting team removes the rest of the large materials to pass the household waste through the rotating trommel. A second manual sorting team is positioned around the conveyor to scoop up what escaped the first team before the waste arrives at the trommel. The rotating screen with different meshes separates the waste according to its size. Waste with a diameter greater than the mesh constitutes rejects or a large organic fraction which will need additional grinding to make it homogeneous.

Smaller diameter waste will continue to a second manual sorting platform provided by another sorting team to recover all of the recyclable material and let the OFHW pass. this FODM at the end of the sorting operation is sent to a mixer. A percentage of green waste is added to this fraction, then mixed and transported to the digesters.

Methanation Unit

This process implements dry anaerobic fermentation through a concrete garage system with a steel overhead door. The number of tunnels can be adjusted according to the deposit. To obtain

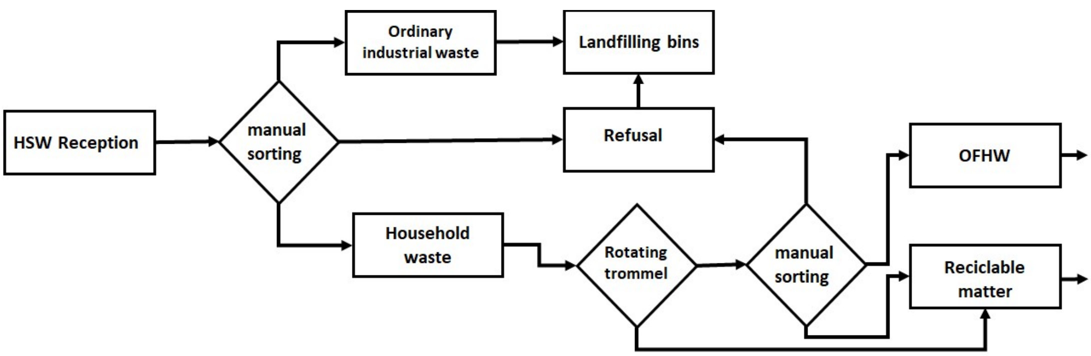

Fig. 5: Block diagram of the waste recycling unit received at the TLC.

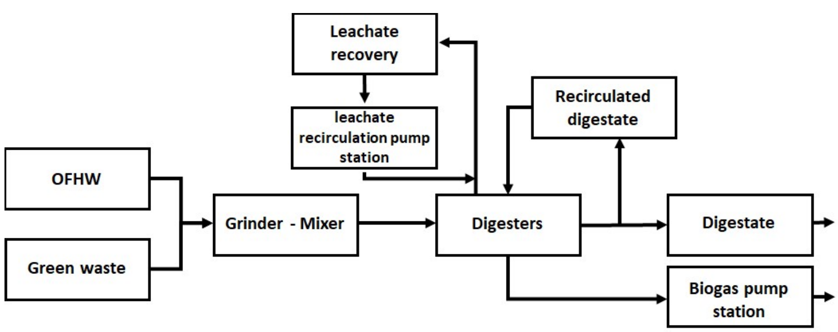

Fig. 6: Block diagram of the methanation unit of OFHW mixed with green waste.

Table 4: Calculation of the gross energy upstream of the engine and its quantity of substrate required from landfilling bins and the methanation digesters.

Energy balance		Landfill	Digesters
Electricity produced	KWh	850	850
Electrical efficiency	%	39	39
Operational hours	h	8	16
Energy produced per day	$KW.day^{-1}$	6.800	13.600
The engine's upstream energy	$KW.day^{-1}$	17.435	34.871
Organic fraction required to produce this energy			
Average biomethane content in biogas	%	50	60
LCV of biomethane	$KWh.m^{-3}$	4,98	5,98
The biomethane amount per day	$m^3.day^{-1}$	3.501	5.831
The biogas amount per day	$m^3.day^{-1}$	7.002	9.718
The biogas amount per ton of HSW	$m^3.ton^{-1}$	100	90
The substrate amount needed per day	$ton.day^{-1}$	70	108
The substrate amount needed per year	$ton.y^{-1}$	25.550	39.420

fresh matter, 15% of green waste is added to the total quantity of organic waste. To speed up the methanation process, 40% of the garage is filled with digestate, and the rest with fresh waste to be methanized (Fig. 6). The process is carried out under mesophilic conditions at 37°C for approximately four weeks. The percolate recirculation carries out a watering of the matter during the process recovered and heated to 37°C.

Sizing of the Biogas Unit

The dimensioning of our basic unit and the calculation of the number of digesters to be used are conditioned by the maximum power of our cogeneration engine.

To ensure the engine's functioning with its maximum efficiency using the biogas from the landfill, the quantity required upstream of the engine must be calculated (Table 4).

The results in Table 4 confirm the possibility of running the engine at full speed for 8 $h.day^{-1}$ all year round with the biogas extracted from the landfill. Also, the table gives us the quantity of substrate necessary with which we can start our anaerobic digestion unit sizing and calculate the number of digesters to be built. Table 5 gives us the quantities needed to start our methanation process:

To calculate the number of digesters needed, we must know the filling time and the number of cycles per year for each digester. The filling rate is 80%, and the substrate minimum density is 0,67 $ton.m^{-3}$. Tables 6 and 7 show the calculations made:

Table 5: Matter quantity needed to start the methanation process.

Used matters		Quantity
Organic fraction	$ton.y^{-1}$	33.507
15% Additional green waste	$ton.y^{-1}$	5.913
Total fresh matter	$ton.y^{-1}$	39.420
40% Recirculated digestate	$ton.y^{-1}$	26.280
Substrate	$ton.y^{-1}$	65.700

To calculate the cycle number carried out by a single digester during a year, we must first know the duration of a single cycle.

The number of digesters required is obtained by dividing the total volume of the substrate by the useful volume of a digester and the number of cycles at the same period (Table 8).

Composting Unit

The digestate obtained from the methanation of organic waste

Table 6: The volume of substrate for the methanation process.

		Data
The digester volume	m^3	980
the substrate amount	$ton.an^{-1}$	65.700
Density	$ton.m^{-3}$	0.67
Substrate volume per year	$m^3.y^{-1}$	98.060
Substrate volume per day	$m^3.day^{-1}$	269
filling time of digester per day	day	4

Table 7: Number of cycles per year carried out for a single digester.

	Data
Filling time (days)	4
Residence time (days)	28
Emptying time (days)	1
Digestion cycle time (days)	33
Cycles number of a single digester	11

Table 8: The digesters number calculation for 1 year of substrate.

		Data
Volume of substrate	$m^3.y^{-1}$	98.060
The digester volume	m^3	980
Cycles number per digester		11
Digesters Number		9

should undergo an aerobic process, such as composting, to improve its characteristics and efficiency during use. Green waste is added and mixed with the digestate before being introduced into composting tunnels (Fig. 7). The added green waste corresponds to 40% of the digestate volume (BEKON 2018b).

The process begins by mixing the digestate from the methanizers and the added green waste. Then the mixture is deposited in composting tunnels. We leave it in these tunnels for 10 days. Then, they are transported and deposited as windrows for 60 days for the maturation of the compost. During this period, the windrows are turned using a windrow turner to ensure oxygenation and inactivation of microorganisms still present in the compost before the last screening. The finished compost goes through a refining stage which consists of grinding the large particles to ensure the homogeneity of all the compost produced (Moletta 2009).

To calculate the tunnel number, the same methodology is applied as that carried out previously for calculating the digesters' number. Thus, the starting data is shown in Table 9.

The composting tunnel dimensions also depend on the BEKON (2017) process. We consider a filling rate of 40%, a residence time of 10 days, and an emptying time of 1 day (BEKON 2018b). The results presented in Table 10 relate to the operation of a BEKON composting tunnel:

In this way, the number of tunnels needed for the composting process is 8 tunnels, as shown in the Table 11.

Table 9: Input matter for the composting process.

		Data
Digestate after methanation	$ton.y^{-1}$	31.680
Digestate density	$ton.m^{-3}$	0,8
Digestate volume	$m^3.y^{-1}$	39.600
additional green waste rate	%	40
Additional green waste	$m^3.y^{-1}$	15.840
composting process mixture per year	$m^3.y^{-1}$	55.440
Composting process mixture per day	$m^3.day^{-1}$	152

Table 10: Composting tunnel dimensions and their operation based on the BEKON process.

The composting tunnel dimensions		Data
Long	m	20
Length	m	5,9
Height	m	5
Volume	m^3	590
Filling rate	%	40
Useful volume	m^3	236
The composting tunnel operation		
Filling time	day	2
Residence time	day	10
Drain time	day	1
Time for 1 composting cycle	day	13
Cycles number	$Cycle.y^{-1}$	28
Volume of mix processed	$m^3.y^{-1}$*tunnel	6.608

Maturation

After the stay in the tunnels, the compost is deposited in windrows to follow the maturation stage. A windrow should not exceed 3 meters in height, and its usual dimensions for width and length are 8 and 18 meters, respectively, giving a

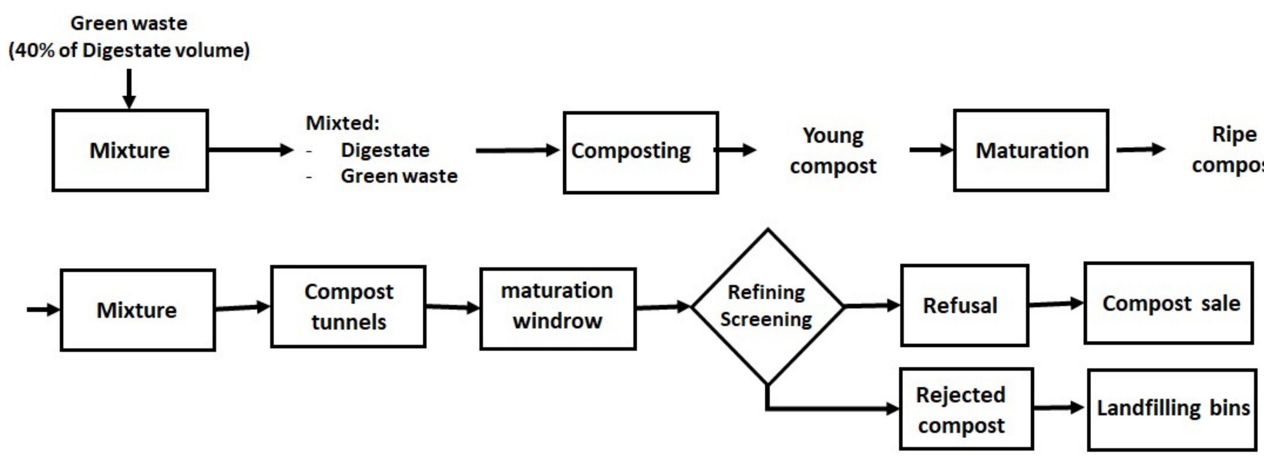

Fig. 7: The different stages of the composting process after anaerobic digestion.

Table 11: Calculation of the number of composting tunnels.

		Data
Volume of the mixture for 1 year	$m^3.y^{-1}$	55.440
Volume of mixture treated for 1 year	$m^3.y^{-1}$*tunnel	6.608
Tunnels number	tunnels	8

Table 12: Dimensions of a maturation windrow and its residence time.

Windrow dimensions		
Long	m	18
Length	m	8
High	m	3
Volume	m^3	432
Operation of a windrow		
Filling time	day	4
Residence time	day	60
Drain time	day	1
Time for 1 maturation cycle	day	65
No. of Cycles	$cycle.y^{-1}$	6
Volume that can be treated	$m^3.y^{-1}$*windrow	2.592

Table 13: Calculation of the necessary maturation windrows number.

Volume of young compost for 1 year	m^3y^{-1}	44.824
The volume of young compost treated per windrow	$m^3.y^{-1}$*windrow	2.592
Windrows number	Windrow	17

volume of 432 m^3. The values used for the maturation process are shown in Table 12.

In this way, the calculated number of windrows necessary for the compost maturation coming out of the tunnels is 17 windrows, as indicated in the Table 13.

The surface required calculation is based on the same principle as that carried out previously for the digesters and the composting tunnels. Thus, the calculated surface is 2.448 m^2, but taking 20% of the necessary space for circulation, we obtain a total surface of 2.938 m^2.

Refining

Since the pretreatment in discontinuous systems is not demanding, the compost particles obtained will have heterogeneous sizes, which requires a refining process that separates the large particles with a sieve.

Based on experience in similar processes, it is estimated that after the refining stage, 50% of the compost is rejected, and 50% is considered valid for its use (Table 14).

Table 14: Refining the resulting compost.

		Data
Ripe compost	$ton.y^{-1}$	29.046
Refined compost	$ton.y^{-1}$	14.523
Refused compost	$ton.y^{-1}$	14.523

The fresh organic matter used at the start of the methanation process may contain contaminants such as heavy metals or inorganic matter due to poor sorting at the source, which reduces the quality of the compost and may limit its use.

Energy Production

The average biogas yield value is 90 m^3 per ton of substrate. To calculate the amount of biogas produced, we base ourselves on the amount of substrate used in the digesters (Table 15) (BEKON 2018a).

Table 15: Biogas and biomethane estimated production by anaerobic digestion.

		Data
Fresh matter	$Ton.y^{-1}$	39.420
Biogas production yield	$m^3.ton^{-1}$	90
Biogas produced	$m^3.y^{-1}$	3.547.800
Biomethane content	%	60
Biomethane produced	$m^3.y^{-1}$	2.128.680

To remain realistic, we will not work 100% of the year. Our load factor is 0,9. This means that 10% of our products will be burned in a torch, as shown in Fig. 8:

Considering the lower calorific value of biomethane at 5,98 $KWhm^{-3}$ (Engineering ToolBox 2003). The amount of energy that can be obtained by cogeneration is shown in Table 16.

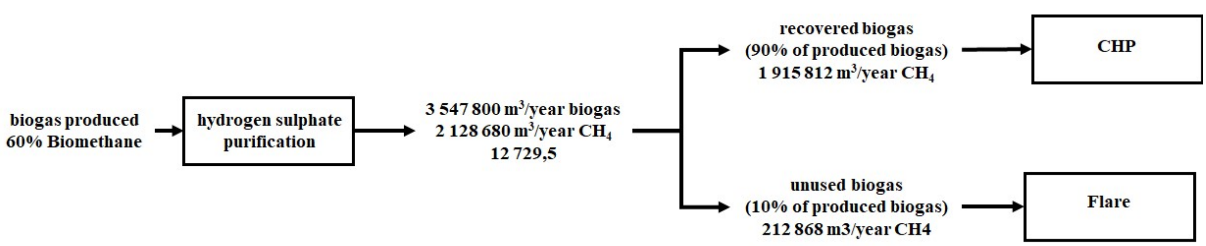

Fig. 8: The biogas recovery unit energy balance for one year of production.

Table 16: Energy contained in biogas available from digesters.

Energy contained in biogas		
Biomethane available	$m^3.y^{-1}$	2.128.680
Biomethane LHV	$KWh.m^{-3}$	5,98
Energy contained in biogas	$MWh.y^{-1}$	12.729
Valorization by cogeneration		
CHP electrical yield	%	39,2
Electric energy	$MWh.y^{-1}$	4.990

Table 17: Total electrical energy produced by the cogeneration engine.

Electrical energy from digesters		
Electricity produced	kWh	850
Electrical efficiency	%	39,2
Operating hours number	H	5.256
Energy produced by the motor	$MW.y^{-1}$	4.467
Electrical energy from bins landfilling		
Electricity produced	KWh	850
Electrical efficiency	%	39,2
Operating hours number	H	2.628
Energy produced by the motor	$MW.y^{-1}$	2.233
Operating hours total	H	7.884
The total electrical energy produced by the motor	$MW.y^{-1}$	6.700

To calculate the cogeneration unit power, we use the biogas energy, the electrical engine efficiency, and the operational hours according to our load factor (Table 17).

The Electrical Fraction Energy Balance

It is expected that a fraction of the electrical energy obtained from the cogeneration unit will be used to meet the energy needs of the digesters. A balance sheet of the energy fraction tells us the net quantity of energy that can be obtained from this biogas plant (Table 21).

Electricity consumption is mainly included in these three stages: (1) pretreatment from the arrival and preparation of waste (Table 18), (2) methanation, and (3) post-treatment (Table 19), including the green waste digestate mixer.

For the pretreatment step, we use the operating capacity of the equipment in this step and their electrical power (bag opener, trommel screen, feed, and dosing hopper with decompactor (FDHD)).

For the methanation step with the BEKON process, the electricity consumption of the digesters is 10% of the electricity produced by the cogeneration unit.

The equipment used in the post-treatment stage is the green waste digestate mixer, the rotary screen after maturation, and the windrow turner during the compost maturation stage. This equipment is not all electric. We chose to use gas-powered mobile equipment during the composting stages to save on the movements of the loaders and to work where the windows are installed. Therefore, the only electrical equipment is the green waste digestate mixer.

Table 18: Power consumption of pretreatment equipment.

		bag opener	trommel screen	FDHD
Pretreatment process				
Powerful	kW	52	30	33
Operating capacity	$Ton.h^{-1}$	40	25	7
organic waste quantity	$ton.y^{-1}$	33.507	33.507	39.420
Operating hours	$h.y^{-1}$	838	1.340	5.631
Electrical consumption	$MWh.y^{-1}$	43	40	186
Total electricity consumption	$MWh.y^{-1}$	269		

Table 20 presents the electricity consumption of the entire installation:

The cogeneration unit operates with a load factor of 0,9. Consequently, during the engine stoppages hours, it will be necessary to buy electricity from the network to ensure the operation of the rest of the equipment. The quantity of this auxiliary electricity is equal to

Table 19: Power consumption of post-processing equipment.

		Mixer
Post-processing process		
Powerful	kW	102
Operating capacity	$m^3.h^{-1}$	108
organic waste quantity	$m^3.y^{-1}$	55.440
Operating hours	$h.y^{-1}$	514
Electrical consumption	$MWh.y^{-1}$	52

Table 20: The biogas unit's electricity consumption.

		Data
Pretreatment process	$MWh.y^{-1}$	269
Methanation process	$MWh.y^{-1}$	670
Post-processing process	$MWh.y^{-1}$	52
Total electricity consumption	$MWh.y^{-1}$	991

Table 21: Electrical balance of the biogas plant.

		Data
Total electricity consumption	MWh/year	991
Auxiliary electricity	%	10
Auxiliary electricity	$MWh.y^{-1}$	99
CHP electricity	$MWh.y^{-1}$	6.700
Total electricity consumption	$MWh.y^{-1}$	- 991
Net electrical energy	$MWh.y^{-1}$	5.808

10% of the total electricity consumption of the biogas plant.

The net electricity is injected into the national electricity grid, which will improve the number of renewable energies produced in Morocco, ensuring an annual and stable income to cover the expenses.

CONCLUSION

To achieve the NHWP (national household waste program) objectives set by 2030, Morocco must develop an HSW management model adapted to its deposits and problems. For this purpose, dry methanation appears to be an adequate technological solution. However, this approach is underdeveloped and only represents methanizers processing agricultural products. To obtain a Moroccan anaerobic digestion model, it is necessary to identify and study the scientific and technological obstacles relating to the dry process.

The work presented in this article has endeavored to provide a reference database with which the choice of the process becomes obvious. Batch and mesophilic dry methanation is the solution for Morocco to develop its own model of integrated and sustainable management of household and similar waste.

Based on the sorting results, the waste studied is characterized by the dominance of fermentable matter, which presents a significant fraction of the deposit's overall mass. It varies between 42,75% and 64,20% (averaging 54,94%). This reflects the priority of establishing a recovery method for this type of waste.

Therefore, the choice of dry and mesophilic anaerobic digestion is the one that uses the simplest technology with the most stable parameters. Added to this is the investment amount. We should create a system for municipalities that do not have large budgets, so discontinuity seemed to be the exact answer. With a discontinuous and mesophilic dry methanation process, we can make our landfills capable of self-financing by producing energy and compost. The technological level of the solution is acceptable, and the digesters number can increase according to our investment budget.

This plan fills all the gaps in a strategy based essentially on total landfilling: Extend the landfills lifetime, eliminate methane leaks into the atmosphere, increase the operating time of the biogas processing unit, ensure acceptable sorting, and improve the working environment for scavengers, remove the ceiling on the quantity produced of biogas and electricity.

This master plan connects biogas extraction from the landfills to our network of digesters to operate 24 hours a day all year round. We avoid sending the digestate to a landfill by adding a composting process. So, we built a unit that can even be installed in our transfer centers and save the daily trips between these centers and our controlled landfills.

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