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Real large-scale waste management and electricity generation by incineration and methanation routes: methodologies and comparative investigation on local municipal waste landfills

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Abstract

Recent decades have dramatically increased energy demand due to globalization, rapid economic development, and rising urban populations. The emergence of climate change and global warming coincided with this increased demand, sparking even more discussion about the urgent need for an energy transition. Currently, a rising amount of biodegradable trash is burnt and then carried to landfills for disposal, which consumes a large amount of land and causes health issues due to a lack of regulation. Consequently, innovative and environmentally friendly recycling techniques are urgently required. This work aims to study real-case waste management and valorization conducted in El Berka Zerga's landfilling center (Annaba, Algeria), where two separate systems were implemented to provide electricity to the landfill and the surrounding urban zone. Two main methods were used for generating electricity from garbage: natural Methanation, which makes use of the full potential of the location under study, and waste incineration, which is based on a mathematical model that has been translated into MATLAB. Waste recovery showed a minimum power capacity of 11.6 kW associated with the center's steady-state emissions of natural methane and a maximum power capacity of 3.3 MW associated with the peak emissions achieved recently. The incineration process also showed a steady-state capacity of 10.04 MW, resulting in a daily burning of 500 tons. The production of valuable products from agro-industrial wastes is a low-cost and green process highly recommended by environmental and scientific communities.

Keywords: *Electrical; Energy transition; Circular bioeconomy; Municipal solid waste; Natural methanation; Renewable energy; Waste incineration*

1. INTRODUCTION

Traditional practices in the energy industry are to blame for the industry's lacklustre response to climate change. Although most changes take decades or even centuries to fully materialize, there has been a shift in recent years toward using renewable energy sources in the style of backyard gardens[1], [2]. Reduced greenhouse gas emissions and fossil fuel use will be a welcome relief for the planet's environment [3], [4]. Currently, biomass energy has risen to the position of the fourth-largest energy source in the world, following in the footsteps of coal, oil, and natural gas [5], [6]. Biomass is a fuel derived from different agro-industrial sources such as plants, animals, the food industry and so on [7]. In general, burning biomass wastes, like coal, leads to providing heat, which in turn can produce steam, whilst using this fuel for power generation still needs to be intensively investigated to scale it up [8]. The quantity of biomass is escalating at an alarming rate, causing disposal and governance issues [9]. It was reported that biomass can reach more than 1800 billion tons per year, presenting the largest worldwide renewable energy resource [10]. However, only 3% has been used on a large scale for different industrial applications. As a result, worldwide Environmental Commissions are pushing the scientific and industrial communities to seek green approaches to valorizing biomass waste into different high products [11]. In fact, this process is involved with the concept of circular economy, which enforces sustainable development through waste recycling and valorization [12], [13], [14]. It is essential to mention that biomass waste disposal, consumption, and management pose a severe problem for cities [15], particularly in developing countries [16]. Over the last decade, considerable interest from the scientific and industrial communities has been raised towards generating different high-value products from different biomass feedstock [10], [17]. Even though a lot of efforts have been made, most of the generated biomass wastes are left in the field to be decomposed slowly under natural conditions, even discarded in landfills, or for cooking or production of charcoal, ~~which~~ is associated with vast amounts of CO_2 emission [18], [19]. Textiles and wastepaper are substantial sources of municipal solid waste, although their recycling rates remain low. 5% of landfill waste comprises textiles, although only 13% are recycled globally, whereas wastepaper and cardboard recycling account for 58% [20], [21]. Most wastes are disposed of in landfills or incinerators, which have significant environmental effects due to groundwater contamination and the creation of greenhouse gases during decomposition [22]. Currently, a lot of approaches are under investigation to valorize wastepaper into different valuable compounds, such as biochar[12], bioethanol [23], cellobionic acid [24], and bio-oil and bio-hydrogen [25].

On the other hand, recovering valuable materials from wastepaper is considered one of the green technologies. Several materials can be obtained and directly recovered from wastepaper, including plasmonic cellulose textile fiber [26], [27], polyester fibers and glucose syrup raw materials as insulators and so on [28]. Based on the latest recommendations, to globalize the valorization of wastes valorization into different valuable products[29], local studies and techno-economic analysis are highly required since factors, including the type of waste and other particular circumstances, are different from one city to another[30].

Essentially, the landfill is a large hole in the ground. Its simplicity has made it the preferred technique of urban waste disposal globally, notwithstanding its crudeness. The gathered waste is dumped at the spot until the depression or hollow is deemed finished. The dumped damage is trampled over at that time, and the entire structure is left to settle. Over time, the site's organic matter will decay, generating CO_2 in the presence of air or methane in the absence of air. Many landfills produce methane as a common byproduct, which can continue for one to three decades after the site has been shut down. Many countries apply the waste landfill approach. However, other countries restrict such an approach because of the associated environmental issues and the low availability of land for waste burial. The effects of the mismanagement of waste and landfill disposal, such as pollution of soil and water supplies by toxic residues and air by methane emissions, have led to severe environmental problems. The rise of the 'zero waste' concept pushes the scientific and industrial communities to develop waste-to-energy technologies as a sustainable development. One of the challenges that face the transfer of this approach to worldwide application is the high cost of these technologies, and therefore, further studies are highly required to optimize the price and the effectiveness that fit the large-scale needs. Due to the specialized waste treatment and the necessity for comprehensive emission control systems to minimize air pollution, these plants are significantly more expensive to construct and operate than any other combustion power plant. These plants would never be built if they had to rely solely on power-producing earnings. ~~Fortunately~~, they must have supplemental income. Since waste must be disposed of in a regulated manner, waste disposal plant operators can charge a fee to accept trash. This price is generally referred to as the tipping fee. Tipping fees are the principal source of revenue for a power-from-waste facility. Any increased revenue from power generation will benefit the economy, but the plant may be able to exist without it.

The present work aims to study the feasibility of valorization of local urban biowaste potential as a controllable and flexible electricity residential power source in the city of Annaba, Algeria. This approach could be applied to study the valorization of wastes in other cities by considering the variables and circumstances. The main objective behind this analysis is to bridge the research on biomass valorization and the real-world implementation of this green technology towards energy production. Increasing the efficiency of biowaste conversion to power can lead to greater energy independence. The outcomes of this analysis serve as a focus for researchers, policymakers, and energy businesses as they determine the potential role that bio-waste could play in the energy transition, namely in providing inter-seasonal flexibility. Despite the use of actual historical data, the purpose of this hypothetical example is not for immediate adoption but rather to highlight and quantify potential future outcomes. Herein, we quantified the possible recovered energy from waste exploitation (Annaba data) using heat from waste in two manners, natural Methanation and incineration. (i) biogas recovery via Methanation, a natural process in which landfill waste will be fermented, producing Biogas containing a certain percentage of methane that will afterwards be used as a combustible. (ii) Rankine-Hirn cycle, a vapour cycle containing 4 main components to produce electricity out of heat: the pump, the boiler, the steam turbine, and the condenser. This study discusses the input parameters of an 11 MW and a 250 kW cycle and, most importantly, the results of the simulation conducted, the eventual power generated and the cycles' efficiency. After that, we simulated both power from waste by Methanation and incineration (for the incineration, we used the input parameters of 11 MW cycles).

2. MATERIALS AND METHODS

2.1. Frame of work

The El Berka Zerga landfill, where trash is disposed of buried in specified cases or pits, is located in the city of Annaba, northeast of Algeria. Its daily tonnage is 500 tons. Under the direction of the Ministry of Territorial Planning and the Environment, this public amenity commenced operations in 2014. A system is available to recover and incinerate methane and a device is available to collect leachate to prevent groundwater contamination [11].

2.2. Waste sources

There are two primary types of waste suitable for disposal in a power-from-waste facility: municipal solid waste (MSW) and industrial waste. MSW refers to municipal solid waste, which consists primarily of domestic waste. Some industrial trash has a comparable composition to municipal solid waste and can be treated similarly. Other industrial waste that contains hazardous or valuable materials must be treated differently. This study focuses solely on municipal solid waste and excludes industrial waste unless it can be co-combusted with MSW. The primary source of municipal solid waste is urban communities. The number and size of such communities are increasing exponentially.

2.3. Waste composition

The electricity generation from municipal solid waste (MSW) in the Annaba region significantly depends on its composition, underscoring the importance of waste estimation and pretreatment [31]. This composition varies with regional activities, seasons, and population, presenting materials across nine categories. As detailed in Table 1, the most common MSW components include putrescible waste, paper, textile, plastic, and others, each with specific calorific value, highlighting the potential energy recovery through appropriate management practices. Cheniti et al. (2020) reveal that organic matter constitutes the most significant portion (50%) of MSW in Annaba, followed by textiles (13.6%) and plastics (10%), with paper and paperboard, metals, and glass making up smaller fractions. This varied composition, including putrescible waste, textiles, plastics, and unique (dangerous) wastes, illustrates the complex nature of waste generated in the region, each contributing differently to the overall calorific value and, thus, the potential for energy generation [32].

High-value materials like textiles and plastics, alongside significant quantities of organic waste, indicate substantial opportunities for recycling and composting, potentially leading to biogas production. This detailed understanding of waste composition and calorific values is crucial for developing targeted waste management strategies. As suggested by spatial analysis, adequate segregation at the source is essential for maximizing the efficiency of these processes and mitigating greenhouse gas emissions from landfills and open burning, aligning with sustainable waste management and energy recovery goals in the Annaba region [33].

Table 1: The typical MSW composition and parameters in Annaba [31], [32], [33]

Waste Type	Calorific Value ***(MJ/kg)***	***x%***
Putrescible waste	***7***	***55.01***
Paper	***14.4***	***10.65***
Textile	***18.4***	***11.76***
Plastic	***35***	***16.51***
Non-Classified Combustible (NCC)	***14.4***	***1.67***
Glass	***0.14***	***0.86***
Metals	***0.7***	***2.52***
Non-Classified Incombustible (NCI)	***0.139***	***0.75***
Special waste (Dangerous)	***18.5***	***0.41***

2.4. Waste energy recovery modelling

As previously discussed in our case, waste is solely disposed of in the EL Berka Zerga's landfill. Therefore, to produce power, there needs to be a recovery system. The Rankine-Hirn cycle is the proposed system that recuperates the generated heat, either by the combustion of Biogas resulting from the natural process of Methanation or waste incineration. The heat generated is used as input heat to evaporate water in the thermodynamic cycle [34]; the evaporation-stemmed steam will rotate a steam turbine (ST), which generates electricity [35].

The typical transformations taking place in this cycle are:

- The first step is the compression of water within a pump that is considered isentropic,
- The second step consists of the isobaric heating of liquid water in the two economizers.
- The third would be the isotherm vaporization in the vaporizer.
- The fourth step is the isobaric superheating of the water vapour in the two superheaters.
- The fifth and last step in the cycle is the isentropic expansion of the vapour in the turbine.

In the first step, liquid water is supposed to be adiabatically compressed by the pump from P0 to P1 to a temperature of T_0=T_1. The work needed for this compression is represented by equations (1,2).

$$W_0 = h_1 - h_0$$

(1)

$$Q_0 = -W_0$$

(2)

h_1 and h_2 are the enthalpies before and after the compression expressed in (kJ/kg), read on the enthalpy-pressure water diagram according to the given pressures.

After the compression comes the second step, which consists of guiding the water through the 1st and 2nd economizers, heating it from T_1 to T_2; it should be noted that the water heating process is isobaric. The heat needed for such a process is expressed as follows:

$$Q_1 = \left(\frac{Cp_1+Cp_2}{2}\right)\times\ (T_2 - T_1) \quad (3)$$

Cp_1 and Cp_2 represent the Isobaric Heat Capacities of water at (T_1, P_1) and (T_2, P_2) respectively in (J/kg.K)

Concerning the third step, which comprises isotherm vaporization, a shift in the water's physical state from liquid to vapour by a pressure drop, the work needed for this transformation is as follows:

$$W_2 = -P_2 \times V_2 \times ln\left(\frac{P_3}{P_2}\right)$$

(4)

$$Q_2 = -W_2$$

(5)

For the fourth step, the water vapour goes through the primary and secondary superheaters, passing from T3 to T4 at a constant pressure. This step is represented by equations (6, 7).

$$Q_3 = \left(\frac{Cp_3+Cp4}{2}\right)\times(T_4 - T_3)$$

(6)

$$W_3 = -P_3 \times (V_4 - V_3) \quad (7)$$

With V3 and V4, the specific volumes are determined exactly as the enthalpies are in (m^3/kg).

Finally, for the last step, the obtained vapour enters the turbine and is expanded until P5. This expansion lets the turbine blades rotate, producing mechanical work expressed in equation 8.

$$Wtur = \left(\frac{Cv_4+Cv_5}{2}\right)\times(T_5 - T_4)$$

(8)

With: Cv_4 and Cv_5 representing Isochoric Heat Capacity corresponding to (T_4, P_4) and (T_5, P_5) respectively.

The network of the Rankine-Hirn cycle is given as follows:

$$Wnet = Wtur - W0$$

(9)

The mechanical power delivered by the cycle is given as follows:

$$Pout = Wnet \times m \tag{10}$$

The turbine efficiency is agreed upon as follows:

$$\eta = \frac{Pout}{m \times (Q_1 + Q_2)}$$

(11)

The landfill at hand does not have any energetic valorization; therefore, we propose using the waste to generate heat, which will later be employed to produce electricity. This first proposition relies on the recuperation of Biogas ensuing from natural waste methanation, which is then combusted in the same manner as natural gas, producing heat entering as input at the Rankine-Hirn cycle.

2.5. Calculation Process

For this study, we use Biogas containing 65% of methane.

LHV (lower heating value) at 0° of Biogas = 9.94 kWh/m^3.

LHV (of a biogas with X% of methane):

$$LHV_m = LHV \times X\%$$

(12)

The Maximum Power Recuperated from Biogas:

$$P_{Max} = \mu_{Max} \times LHV_m$$

(13)

The Minimum Power Recuperated from Biogas:

$$P_{Min} = \mu_{Min} \times LHV_m$$

(14)

We determine the average CV for each waste type:

$$CV_i = CV \times x_i\% \tag{15}$$

Second, we compute the total CV for all the waste at hand:

$$CV_{Tot} = \sum CV_i \tag{16}$$

Finally, we estimate the heat generated from the incineration of waste QINC while keeping in mind that the daily tonnage entering the landfill *El Berka Zerga* is 500 tons. 30 % of this tonnage is water. In addition, to 21500 kg of residues from the purification of fumes from the incineration of household waste, 105000 kg of recyclable waste, and 25000 kg of ultimate waste:

$$Q_{inc} = CV_{Tot} \times tonnage$$

(17)

3. RESULTS AND DISCUSSION

The findings and analysis related to the potential energy recovery from waste exploitation using natural Methanation and incineration are depicted in Figure 1. This section discusses both methodologies' input parameters and simulation outcomes, including the generated power and cycle efficiency. A comparison of the two methodologies and their respective results is also provided.

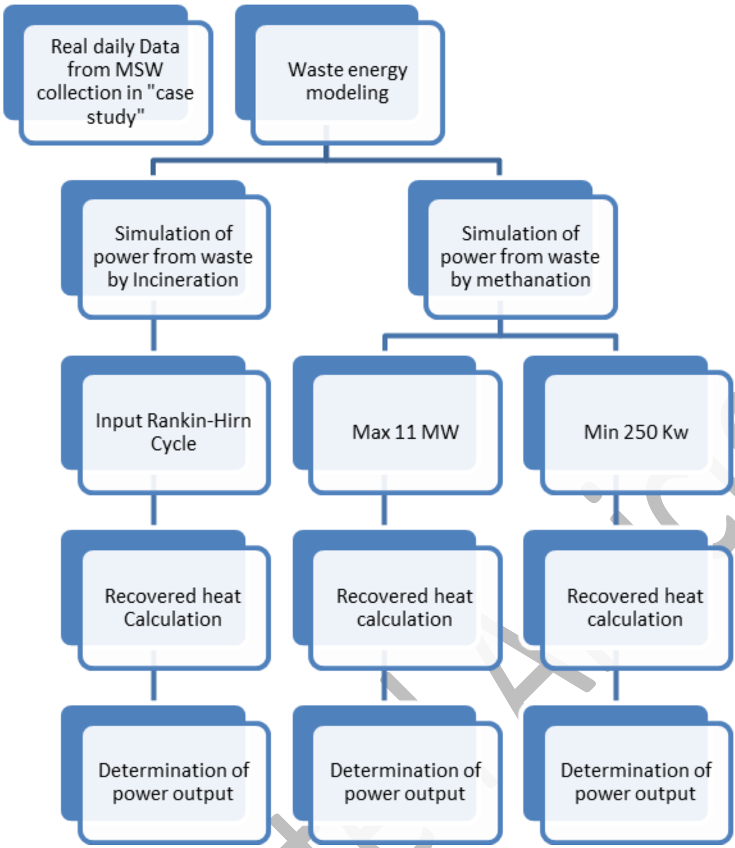

Figure 1. The main scenarios applied in this study towards biomass exploitation through different routes.

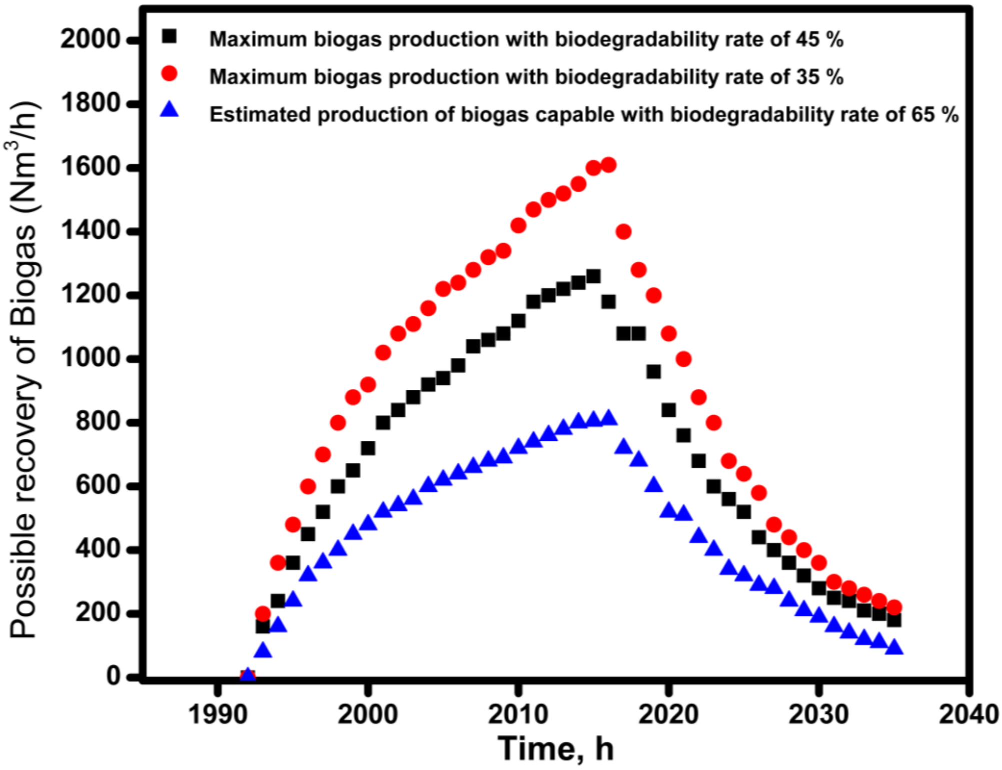

Figure 2. Estimated Biogas Recovered at the landfill of EL BERKA ZERGA

3.1. Simulation of power from waste by Methanation

Methanation is a natural process in which landfill waste is fermented, producing Biogas containing a certain percentage of methane. As indicated in the previous chapter, this Biogas will be used as a combustible and explored as a heat source to produce electricity. However, before we utilize this power source, we will estimate its production at the Landfill of *El Berka Zerga, which* will be calculated as shown in Figure 2.

It can be observed that there is a certain progression in the process of biogas recovery over time, laying the grounds for a maximum of about $1600(Nm3/h)$ and a minimum of approximately $50(Nm3/h)$. The two limit values will be the base of our calculations. It is important to mention that the produced Biogas contains 65% methane.

Table 2. The data collected from the minimum and maximum methanation process

Parameter	*Value*
Methane percentage in Biogas	***65%***
LHV	***9.94 (kWh/m³)***
LHV_m	***6.46 (kWh/m³)***
μ_{Max}	***1600 (N.m³/h)***
μ_{Min}	***50 (N.m³/h)***
P_{Max}	***10337.6(kW)***
P_{Min}	***323.05(kW)***

The maximum and minimum estimated heat power generated will be exploited in a Rankine-Hirn cycle, an 11 MW cycle and 250 KW corresponding to both the 2 limit values. However, before introducing the heat, we present the two cycles. The Rankine-Hirn cycle, as previously established in the prior chapter, is a vapour cycle containing 4 main components to produce electricity out of the heat: the pump, the boiler, the steam turbine, and the condenser. We will present the input parameters of an 11MW and a 250 KW cycle, the results of the simulation conducted, and most importantly, the eventual power generated and the cycles' efficiency. This cycle will be utilized in the calculation as a proposed model exploiting the maximum generated heat power from the natural methanation process to produce electrical power. The input parameters and results are presented as follows:

Table **Error! No text of specified style in document.**. The input parameters of an 11 MW Rankine-Hirn cycle used for Max heat generated by Methanation

Input Parameters	*Value*
P_{in}	***10337600 W***
MH2O	***0.018 (Kg/mol)***
P_0	***14000 (Pa)***
P_1	***7300000(Pa)***
P_2	***7300000(Pa)***
P_3	***6500000(Pa)***
P_4	***6500000(Pa)***
P_5	***1300000(Pa)***
R	***8.31 (J/mol.K)***
T_0	***325 (K)***
T_1	***325 (K)***
T_2	***553(K)***
T_3	***553(K)***
T_4	***773(K)***

T_5	*423(K)*
Cp_0	*4180.1855693661 (J/kg.K)*
Cp_1	*4163.8142344165 (J/kg.K)*
Cp_2	*5090 (J/kg.K)*
Cp_3	*5100(J/kg.K)*
Cp_4	*2400(J/kg.K)*
Cp_5	*1993(J/kg.K)*
V_0	*0.001013004728 (m3/kg)*
V_1	*0.001009787523 (m^3/kg)*
V_2	*0.0013 (m^3/kg)*
V_3	*0.0013 (m^3/kg)*
V_4	*0.0521 (m^3/kg)*
V_5	*0.00108994872 (m^3/kg)*

Table 4. The Simulation results of an 11 MW Rankine-Hirn cycle used for Max heat generated by Methanation

Output Parameters	*Value*
P_{out}	*3305307.650483443(W)*
Q_0	*-6.25× 103 (J/kg)*
Q_1	*1.055× 106(J/kg)*
Q_2	*-1.10× 103(J/kg)*
Q_4	*862500(J/kg)*
Q_5	*0(J/kg)*
W_0	*6.25× 103(J/kg)*
W_1	*-2.12× 103(J/kg)*
W_2	*1.10× 103(J/kg)*
W_3	*-330200 (J/kg)*
W_{net}	*6.01× 105(J/kg)*
W_{tur}	*6.07× 105(J/kg)*
h_0	*217070.56 (J/kg)*
h_1	*223315.56 (J/kg)*
m	*5.50 (m3/kg)*
η	*31.97%*

Inducting the maximum flow rate of Biogas as a heat source in an 11 MW Rankine-Hirn cycle results in a 3,3 MW electrical power output and a vapour cycle efficiency of 31,97%. Just as the previous cycle, this one is used to model the exploitation of the minimum generated heat power from the natural methanation process to produce electrical power. The input parameters and results for this system are presented as follows:

Table 5. The input parameters of a 250 KW Rankine-Hirn cycle used for Min heat generated by Methanation

Input Parameters	***Value***
$\boldsymbol{P_{in}}$	***323050 (W)***
MH2O	***0.018 (Kg/mol)***
$\boldsymbol{P_0}$	***14000 (Pa)***
$\boldsymbol{P_1}$	***5200000(Pa)***
$\boldsymbol{P_2}$	***5200000(Pa)***
$\boldsymbol{P_3}$	***4700000(Pa)***
$\boldsymbol{P_4}$	***4700000(Pa)***
$\boldsymbol{P_5}$	***1300000(Pa)***
R	***8.31 (J/mol.K)***
$\boldsymbol{T_0}$	***325 (K)***
$\boldsymbol{T_1}$	***325 (K)***
$\boldsymbol{T_2}$	***553(K)***
$\boldsymbol{T_3}$	***553(K)***
$\boldsymbol{T_4}$	***713(K)***
$\boldsymbol{T_5}$	***423(K)***
$\boldsymbol{Cp_0}$	***4180.19 (J/kg.K)***
$\boldsymbol{Cp_1}$	***4168.46 (J/kg.K)***
$\boldsymbol{Cp_2}$	***3780(J/kg.K)***
$\boldsymbol{Cp_3}$	***3450(J/kg.K)***
$\boldsymbol{Cp_4}$	***2360(J/kg.K)***
$\boldsymbol{Cp_5}$	***1993(J/kg.K)***
$\boldsymbol{V_0}$	***0.001013 (m^3/kg)***
$\boldsymbol{V_1}$	***0.001010 (m^3/kg)***
$\boldsymbol{V_2}$	***0.0402(m^3/kg)***
$\boldsymbol{V_3}$	***0.0457(m^3/kg)***
$\boldsymbol{V_4}$	***0.0665(m^3/kg)***
$\boldsymbol{V_5}$	***0.00109(m^3/kg)***

Introducing the minimum flow rate of Biogas as a heat source in a $250\ KW$ Rankine-Hirn cycle results in an $11{,}6\ KW$ electrical power output and a vapour cycle efficiency of 35,95%.

Table 6. The Simulation results of a 250 KW Rankine-Hirn cycle used for Min heat generated by Methanation

Output Parameters	***Value***
P_{out}	***11613.83 (W)***
Q_0	***-4.45 × 10^3 (J/kg)***
Q_1	***9.06 × 10^5 (J/kg)***
Q_2	***-2.11 × 10^4(J/kg)***
Q_4	***464800(J/kg)***
Q_5	***0(J/kg)***
W_0	***4.45× 10^3(J/kg)***
W_1	***-2.04 × 10^5(J/kg)***
W_2	***2.11 × 10^4(J/kg)***
W_3	***-9.78 × 10^4(J/kg)***
W_{net}	***4.93 × 10^5(J/kg)***
W_{tur}	***4.97 × 10^5(J/kg)***
h_0	***217070.56(J/kg)***
h_1	***221517.31 (J/kg)***
m	***0.24 (m^3/kg)***
η	***35.95%***

3.2. Simulation of power from waste by incineration

As previously mentioned, the second method to recover heat from waste is by incineration; in this process, waste and, more specifically, Annaba MSW will be evaluated to deduce the heat generated from this method. The following Table 7 illustrates the results of this procedure, concluding with a value of the heat power generated.

NB: The CV_{avg} below corresponds to the exact order in Table 1.

The same 11 MW Rankine-Hirn Cycle model used previously is also applied to offer results of this procedure, as shown in Table 7.

Table 7: Parameters of the heat recovery from the waste procedure, the input parameters of an 11 MW Rankine-Hirn cycle used for the incineration process of waste and the Simulation results of an 11 MW Rankine-Hirn cycle used for the incineration process of waste

Heat Recovery Parameters		***11 MW Rankine-Hirn Cycle Inputs***		***11 MW Rankine-Hirn Simulation results***	
Parameter	***Value***	***Input Parameters***	***Value***	***Output Parameters***	***Value***
CV_{avg1}	***3.8507 (MJ/kg)***	***Pin***	***31389780.1 (W)***	***Pout***	***10036457.24 (W)***
CV_{avg2}	***1.5336 (MJ/kg)***	***MH2o***	***0.018 (Kg/mol)***	***Q0***	***-6.25 × 10^3 (J/kg)***
CV_{avg3}	***2.16384 (MJ/kg)***	***P0***	***14000 (Pa)***	***Q1***	***1.06× 10^6(J/kg)***
CV_{avg4}	***5.7785 (MJ/kg)***	***P2***	***7300000(Pa)***	***Q2***	***-1.11× 10^3(J/kg)***
CV_{avg5}	***0.24048 (MJ/kg)***	***P3***	***7300000(Pa)***	***Q3***	***862500(J/kg)***
CV_{avg6}	***0.001204 (MJ/kg)***	***P4***	***6500000(Pa)***	***Q5***	***0(J/kg)***
CV_{avg7}	***0.01764 (MJ/kg)***	***P5***	***6500000(Pa)***	***W0***	***6.25× 10^3(J/kg)***
CV_{avg8}	***0.0010425 (MJ/kg)***	***R***	***1300000(Pa)***	***W1***	***-2.12 × 10^3(J/kg)***
CV_{avg9}	***0.07585 (MJ/kg)***	***T0***	***325 (K)***	***W2***	***1.10× 10^3(J/kg)***
CV_{tot}	***13.6628565 (MJ/kg)***	***T1***	***325 (K)***	***W3***	***-330200 (J/kg)***
Tonnage	***198500 (Kg)***	***T2***	***553(K)***	***Wnet***	***6.010× 10^5(J/kg)***
Q_{inc}	***2712077.015 (MJ)***	***T3***	***553(K)***	***Wtur***	***6.07× 10^5(J/kg)***

T4	***773(K)***	***h0***	***217070.56 (J/kg)***
T5	***423(K)***	***h1***	***223315.56455763 (J/kg)***
Cp0	***4180.19 (J/kg.K)***	***M***	***16.6973 (m^3/kg)***
Cp1	***4163.81 (J/kg.K)***		
Cp2	***5090 (J/kg.K)***		
Cp3	***5100(J/kg.K)***		
Cp4	***2400(J/kg.K)***		
Cp5	***1993(J/kg.K)***		
V0	***0.0010130 (m^3/kg)***		
V1	***0.0010098 (m^3/kg)***		
V2	***0.0013 (m^3/kg)***		
V3	***0.0013 (m^3/kg)***		
V4	***0.0521 (m^3/kg)***		
V5	***0.0010899 (m^3/kg)***		

Table 8. Comparison of methanation and incineration routes towards the valorization of biomass waste

Biomass Exploitation type	*Recovered Heat*	*Output power (Electrical)*	*Efficiency*	*Environmental issues*
Methanation	***Min 250 kW Rankine-Hirn***	***11,6 KW***	***35.95%***	***No***
	Max 11 MW Rankine-Hirn	***3,3 MW***	***31.97%***	***No***
Incineration	***11 MW Rankine-Hirn***	***10,04 MW***	***31.97%***	***Yes***

Introducing the heat recovered from waste incineration as a heat source in an 11 MW Rankine-Hirn cycle results in a 10,04 MW electrical power output and vapour cycle efficiency of 31,97%.

As summarized in **Table 8**, according to the findings, waste methanation presented two opportunities for heat recovery, specifically a minimum of 250 kW and a maximum of 11 MW when employing the Rankine-Hirn cycle. The choice that included the most negligible heat recovery resulted in an output power of 11.6 kW and an efficiency of 35.95%, while the option with the most heat recovery resulted in an output power of 3.3 MW and an efficiency of 31.97%.

However, it is essential to highlight that the methanation process calls for a specific progression in the biogas recovery process; this could potentially limit how quickly it could be used. In contrast, trash incineration presented a single alternative for heat recovery with a capacity of 11 MW utilizing the Rankine-Hirn cycle. This cycle led to an output power of 10.04 MW with an efficiency of 31.97%. It was discovered that using this strategy resulted in serious environmental problems.

In light of the findings, waste methanation using the minimal recovery heat option is the most effective strategy for exploiting the energy contained in biomass, achieving an efficiency of 35.95%. This discovery is consistent with the findings of prior research that showed the promise of waste methanation as an environmentally friendly and effective process for converting organic waste into electricity. This is consistent with the findings of prior research that showed the promise of waste methanation as an environmentally friendly and effective process for converting organic waste into electricity [36], which highlights Methanation's role in minimizing environmental consequences while maximizing energy recovery efficiency from organic wastes. Furthermore, it was discovered that waste methanation had no adverse effects on the environment. Because of this, trash methanation is more appealing than waste incineration, which substantially negatively impacts the environment [37].

However, the decision between the two approaches, waste methanation and combustion, extends beyond mere technical considerations and delves into economic feasibility, resource availability, and broader societal and environmental impacts. [38] emphasizes the economic aspects, asserting that the costs associated with establishing and operating waste treatment technologies significantly influence the choice between Methanation and combustion. This perspective is crucial, especially considering the initial investment and ongoing operational expenses inherent to Methanation, which might hinder its rapid deployment[38]. Furthermore, the process of Methanation requires a specific progression in biogas recovery, potentially delaying its quick exploitation. Conversely, waste combustion offers a more immediate method of resource extraction, though with its environmental and social ramifications. [36] highlight the ecological consequences of these technologies, advocating for comprehensive research to assess their long-term sustainability and practicality in diverse settings. Additionally, the review by Porta et al. (2009) [39] on the health effects associated with waste management practices underscores the importance of considering social and environmental consequences in the decision-making process. These studies collectively indicate the necessity for additional research to thoroughly evaluate both approaches' practicability and long-term viability in various contexts, considering the complex interplay of economic, environmental, and social factors.

4. CONCLUSIONS

This study served as a case study of the landfill of El Berka Zerga, exploring the possibility of exploiting Annaba MSW as an energy source compared to an already well-established renewable energy source in the form of photovoltaics. The valorization of local biomass waste was studied via two routes, namely natural Methanation and waste incineration, and modelled by a Rankine-Hirn cycle to achieve the vapour cycle and, most importantly, the output power for each method. It was concluded through study that the waste incineration process is far more efficient and yields better results than the natural methanation process, in addition to being more consistent, which guarantees the consumer's electrical power stability. In retrospect, the waste incineration process produced approximately 3 times greater electrical power output than the maximum of the natural methanation method did. The waste incineration process can solve a long-term landfill problem since urbanization is prevalent in most countries, including Algeria.

The rates of MSW are overflowing the landfills and exceeding their projected age, which is what waste incineration will help unravel by reducing the amount of landfilled remains to about 5%. The Algerian MSW is a great energy source on the path towards an energy transition towards renewables and a great pillar in the fight against global warming and climate change. Bettering its quality by reducing moisture levels, integrating waste treatment techniques and encouraging active recycling can strengthen its position, raise it above other well-known renewable energies, such as photovoltaics, and increase the amount of electrical power generated. The outcomes of this analysis serve as a focus for researchers, policymakers, and energy businesses as they determine the potential role that bio-waste could play in the energy transition, namely in providing inter-seasonal flexibility. Despite the use of actual historical data, the purpose of this hypothetical example is not for immediate adoption but rather to highlight and quantify potential future outcomes.

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