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RESEARCH ARTICLE

EVALUATION OF BIOGAS RECOVERY AT THE OUJDA LANDFILL

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ABSTRACT

The organic waste is recycled in several ways, including incineration, composting and biomethanation. Controlled landfills are gradually built into the different regions of Morocco as they are considered a solution to avoid greenhouse gas emissions (GHG) and allow recovery of biogas as a renewable source to produce electricity. However few studies have evaluated the cost of waste management and the emissions balance sheet as equivalent Carbon emissions Reduction from these facilities. In this study we present an estimate of the kWh price in Dirhams (Dh) and of the Carbon credits and we establish two formulas than can facilitate their calculations in different sites according to different parameters

INTRODUCTION

Currently, energy recovery from biomass has become both an environmental necessity and an economic opportunity because it allows opening new ways for a sustainable development, creating jobs and alleviating constraints on the economy. Landfills are gradually built in different parts of Morocco, under pretext that it is a solution to avoid greenhouse gas emissions (GHG) and to recover the biogas as renewable energy to produce electricity, however little studies have estimated the cost per 3kWh produced, the cost of waste management, the emissions balance sheet as Carbon equivalent of these facilities and the impact on the environment.

In Europe, policy and strategy development of renewable energy are clear and progressive. Indeed, their part in energy consumption has increased from 6.5% in 2005 to 10% in 2010 and is expected to reach 20% in 2020. In Morocco, the strategy for development of renewable energy began with the creation in 1982 of the Center for Renewable Energy Development (CDER), which became the National Agency for the Development of Renewable Energy and Energy Efficiency (ADEREE) in 2010 and the promulgation of the law 28-00 on waste management and the 13-09 law in 2009 for renewable energy and the creation of several institutions: in 2010, the new Moroccan Solar Energy Agency (MASEN) and the Society of Energy Investment (SEI), and in following year the Institute for Research in solar Energy and in New Energy (IRESEN).

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In 2010, the share of renewable energy in Morocco was less than 1% (mostly hydro) while the country's goal is to reach 42% in 2030.

In this study we evaluate the performance of landfills - called controlled landfills - to show that other more profitable options should be considered in Morocco. Official data (**Annuaire statistique du Maroc, 2010)** shows that in Morocco, the collection rate is around 80% and the rate of fermentable organic matter is around 65%, the theoretical potential of household waste could be determined on the basis of an average of 0.7 kg / capita / day, yielding more than 6 million tons / year, mostly landfilled. In 2010, most of the existing landfills in Morocco were wild.

Cogeneration from biogas

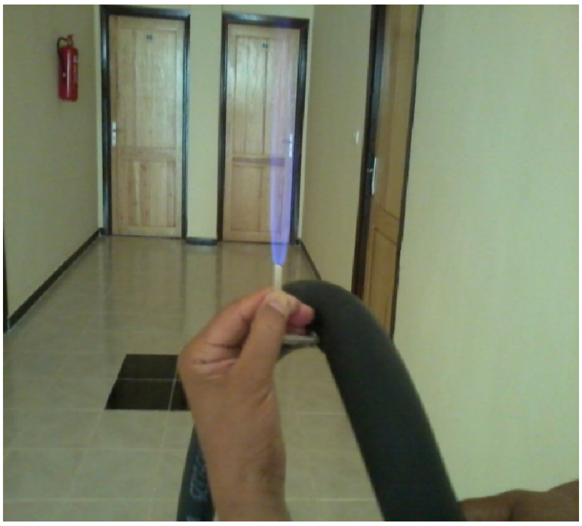
Table 1 shows that landfills produce biogas poor in methane compared to bioreactor technology. This is illustrated in the following Figure 1:

(a) at a pilot bioreactor installed at the University of Oujda
(b) at landfill of Oujda.

We see that the two fermentations do not give the same flames.

Table 1. Biogas composition (http://www.aile.asso.fr/wpcontent/uploads/2012/11/revue-technologie-en-francais.pdf)

parameters	Bioreactor biogaz	Landfill biogaz	Natural gas(Danish)
Methane (%V)	60-70	35-65	89
Other hydrocarbons (%V)	0	0	9,40
Hydrogene (%V)	0	0-3	0
Carbon dioxyde (%V)	30-40	15-50	0,67
Nitrogen (%V)	Up to 1	5-40	0,28
Oxygen (%V)	Up to 0,5	0-5	0
Hydrogen sulphide (ppmv)	0-4000	0-100	2,9
Ammonia (ppmv)	Up to 100	Up to 5	0
Lower calorific value (kWh/m^3)	6,5	4,4	11



(a)

(b)

Fig. 1. Flame biogas

Indeed, analyzes at the landfill of Oujda, indicate that the rate of methane in the biogas reached only an average of 44%. A Biogas pilot bioreactor installed at the University of Oujda has a higher Methane rate (75%), therefore providing better energy recovery with greater energy efficiency (electricity, heat, ...).

The percentage of methane is reflected in the price per kWh, which is why we study the price per kWh at the Oujda landfill.

We must distinguish the estimates reflect an average global and the actual cost which mainly depends on local conditions, hence the need for reliable studies integrating all parameters.

We should also distinguish between the price of energy production and the overall cost, which takes into account the cost of transport and distribution. For example, in France the installation of a power line that allows serving an isolated customer costs 20,000 euros per Km, on the other hand, the cost of fossil fuels and electricity increases sharply in scattered settlements (mountains for example) because of transportation costs. In these circumstances, the best solution is to produce energy on site, which offsets the cost of investment in renewable energy and helps develop the local economy and achieve energy self-sufficiency even by using only renewable energy source (**Belakhdar *et al.,* 2014**).

Production costs include all investment costs, operation, fuel, cleanup and decommissioning of facilities when they arrived at the end of life. Not to mention the costs that are not borne by the producer but by the local community. This is for most of the costs related to the impact on the environment and health (**Elasri O.et Afilal, 2014**).

Estimates of cost of production depend on the values chosen and calculation methods.

Production COST

Table 2. Energy price depending on the source (Alain, 2008)

Energy type	Price of MWh
Individual photovoltaic	300 €
Collective photovoltaic	200 €
Biogas	63,5 €
Earth Wind Turbines	43 €
Hydropower plant	39 €
Waste incinerator and biomass	33€

Table 2 shows the probable cost of electricity from various sources in 2015 (**Alain, 2008**). Waste incineration is more profitable, although requiring investment in big incinerators. In Morocco this solution is limited by the fact that our household wastes are wetter and therefore their PCI is lower.

The incineration of one ton of garbage produced 0.15 Tep (PCI, 1 Tep = 11628 kWh). Representing a potential of 1744 kWh / tonne.

Methane fermentation of one tonne of organic waste in a suitable bioreactor is giving 600 kWh (**Afilal *et al.,* 2007; Afilal *et al.,* 2009**), so the price per kWh will depend on the investment much higher costs for an incinerator than for a suitable bioreactor.

COST CalculATION OF kWh générated by Oujda's landfill

The price P (in Dh / kWh) is given by the following formula:

$$P = \frac{C_t}{P_{el} \times D_v}$$

Where C_t is the total cost (Dh), P_{el} is the electrical power (Wh / year) and D_v is the life of the landfill (year).

However, the total cost C_t is given by:

$C_t = D_v \times \{(P_{tr} + P_{gst}) \times P_d\} + C_{inv}$

Where P_{tr} is the price of transporting waste, P_{gst} is the cost of waste management, P_d is the potential waste (t / year) and C_{inv} is the cost of investment (in Dh).

We deduce then:

$$P = \frac{D_v \times \{(P_{tr} + P_{gst}) \times P_d\} + C_{inv}}{P_{el} \times D_v}$$

Numerical application with data from Oujda:

D_v = 20 years, P_{el} = 2.5 GWh/year, P_{tr} = 100 Dh/t, P_{gst} = 50 Dh/t, P_d = 200000 t/year, C_{inv} = 46.000.000 Dh

Whence: P = 12,9 Dh/kWhe

Since the cost is high compared to the purchase price by the ONE who is 1Dh / kWh, we believe that other methods could improve economic performance. We propose, for example the installation of a suitable and optimized bioreactor for putting the biodegradable wastes (70% of household waste) in a yield of 100 m3 biogas / tonne at 75% methane (**Afilal *et al.,* 2010**).

The proposed scenario will produce 10.24 Million m^3 / year equivalent to 15.3 GWhe, so the kWhe cost 0.98 Dh and the balance sheet after 20 years of operation would be positive and will save more than 7.5 MDh / year in savings from the current cost of 28.9 MDh / year.

The carbon bilan

These calculations allow us to determine the reductions in pollution (in terms CO_2-equivalents) when using biogas obtained from waste.

If methane is used to produce thermal energy, we have to see where it will be installed, what it will replace: a gas heater or an electric heating or other thing, in order to compare the amount of CO_2 reduced. Same thing if methane is used to produce electrical energy, we must know what it will replace: oil or solar or other, because if for example the electricity is produced by solar energy, we know that it does not generate CO_2. Sometimes biogas is more polluting in terms of CO_2 per kWh than coal or oil, especially if the generator used is with low profitability and the biogas produced is with low percentage of CH_4:

Let's take for example the case where each electric kWh produces by biogas gives 1.1 Kg of CO2, and a thermal KWh produces by biogas gives 0.7 Kg. Of another side, each electric KWh produced by coal produces 0.96 Kg of CO2 (this is less than this is produced by biogas, because it is made in larger power stations whose performance is maximal ~40%), and the thermal KWh produced by coal produces 0.6 Kg of CO2. One can say therefore, that the production of the energy by the biogas or by the coal produces about the same quantity of CO2, and that the one and only gain as using the biogas is to avoid the broadcast of methane in the air that is 21 times more harmful (**Afilal *et al.,* 2013**).

In the transformation CH4 + O2 -> CO2 + 2 * H2O, each kg of CH4 produced 2.75 kg of CO2, then in the calculation of carbon balance sheet is removed the CO2 equivalent when converting biogas into electricity, in burning biogas by a motor, accordingly, the amounts produced carbon dioxide are reduced by the equivalent that would be produced by conventional energy by the generator: because producing 1MWh of oil emits 315 kg CO2 equivalent. For comparison, 205 kg and 473 kg equivalents are obtained respectively with the natural gas and the coal. The electricity in Morocco produces 750 g / kWh.

The oil Substitution with biogas saves 315 kg of CO2 equivalent per 100 m3 of methane. In fact, whatever the method used the fermentation of biomass induced its degradation in CO2 (**Afilal *et al.,* 2014**). Given that a kilogram of CO2 contains 0.2727 kg of carbon, the emission of one kilogram of CO2 is then equivalent to 0,2727kg carbon equivalent:

1 carbon equivalent = 1 CO2 equivalent x 0.2727.

To calculate the reductions in pollution (in terms of equivalent CO2 and carbon balance) when using biogas, it must determine the performance in biogas of the differents wastes, as also the methane percentage.

So in summary, in the case of an electrical valorization in Morocco:

The carbon balance is in T/year :

= (Qtté of CH4 Kg /year) x (21 + r*11.2 - 2.75) x0,2727
= (Qtté of CH4 m3/year) x 0.67Kg/m3 x (21 + r*11.2 - 2.75) x 0,2727
= Qtt CH4 m3/yearx0.67Kg/m3x(5+3*r)
= 100 m3 biogas / T x quantities of wastes x 60% x 0.67Kg/m3x (5+3*r)
= Qtt of wastes in T/year x (0.2+0.12*r)

For generators with profitability r = 0.3 we have: The carbon balance = Qtt of wastes in T/year x 0,236
For generators with profitability r = 0.45 we have: The carbon balance = Qtt of wastes in T/year x 0,254

The theoretical potential of Morocco in various fermentable organic wastes and residues amounts to 95.7 million tons (**Afilal *et al.*, 2013; Afilal *et al.*, 2014**). The potential is 41.2 million tons with an energy equivalent of 3.9 million toe / year and an equivalent of 10 MT carbon balance / year (36.7 Million ton CO2 equivalent). Among the benefits of the introduction and adaptation of biogas technology in Morocco, over 90 billion Dh / year (based on a feed-in tariff for electricity to 10 c€ / kWh, with a carbon credits premium estimated at 50 € / ton of carbon equivalent, and 10% of the quantities of waste that remain for composting with 1 € / kg).

It is noteworthy that when the rate of purchase will be promulgated in Morocco, the electrical biogas will be very attractive to investors. The management and recovery of energy from organic waste in Morocco, by biogas technology must be done through an integrated energetic policy and implementing decrees of law 13-09 on renewable energy, to meet the needs sustainable development. In the case of controlled landfill, to calculate the carbon balance between the production rate and quantities avoided compared to conventional treatment (discharge wild), we use the following formula:

Net emissions = (GHG emitted by installation (bioreactor / discharge)) + (GHG emitted by transporting the waste and digestate) – (GHG avoided from reference treatment of wastes) – (GHG avoided by the transport of reference processing) – (GHG avoided by the substitution of produced energy) = (tonnage * EF) + (tonnage*km*EF) – (tonnage*EF) – (tonnage*km*EF) – (kwh*EF).

Where GHG is GreenHouse Gas and EF is Emission Factor.

It is not possible to directly measure the GHG emissions resulting from a given action. The only way to estimate these emissions is often to obtain them by calculation, from data called activity data: number of trucks used and distance, the primary energy used to make a kWh at the exit of the central, etc. The carbon balance is the measure of the total emissions emitted directly and indirectly all emissions associated with their activity. The use of renewable energies can reduce CO2 emissions from fossil fuels. The gain depends on the amount of fossil CO2 emitted by non-renewable energy normally used. Of all the solutions, anaerobic digestion is the best solution, in terms of energy yield and in terms of the balance sheet Carbon, with compost recovery for soil fertilization

Emissions of greenhouse gas can be calculated by the following formula:

$$REa = X (ESRa) - Y (EPa)$$

Where :

REa Emission reduction of the landfill (in tCO2eq) 2013
X(ESRa) Emissions in the baseline scenario (in tCO2eq) 2013
Y(EPa) Emission of landfill (in tCO2eq) = Y(controlled landfill or bioréactor) 2013

For numerical calcul, an overall estimate shows that the controlled landfill of Oujda yields savings in GHG of 15795 tCO2 equivalent / year, while the installation of the bioreactor as improvement scenario will save more than 110228 tCO2 equivalent / year.

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