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Estimated Production of Electrical Energy for the Controlled Landfill in Fez (Morocco) by the Land-GEM Model of US EPA

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Abstract: Throughout this article, we will present, in the case of the controlled landfill of Fes which first at the national level is it, even on the level of Africa, It makes it possible to control all the effluents, while preserving the environment of the city. The landfill it is the state of the places of production of electrical energy and thermal energy by the cogeneration. In this study, we used several techniques of calculation and modelling (IBM-Software SPSS, Technique of calculation for waste tonnage on the level the controlled landfill of Fes, Software Landfill Gas Emissions Model version 3.02 of the USEPA, Equation potential of production of electrical energy starting from the methane recovery of the landfill, Equation of the thermal power released by the thermal engines of generator). We will show that the quantity of the electrical energy estimated by the methanation (anaerobic digestion) of household wastes of the landfill of Fes is 65.5GWh/year, and then these quantities are currently available to the level of the landfill of Fes. This alternative allows a reduction of tonnage of accumulated waste.

Keywords: Controlled Landfill, Electrical Energy, Land-GEM Model, Methane Production

1. Introduction

Convention of the United Nations on the Climate changes was created in 1992 at the time of the Summit of Rio, it is the first attempt, within the framework of UNO (the United Nations), to better understand the climate changes and to suggest solutions to limit them. It meets annually at the time of world conferences to assess the projections as regards fight against the climatic upheavals.

The Convention of the United Nations on Climate changes (CCNUCC) joined 180 countries in Montreal, from 28 November to 09 December 2005, for two parallel events: its 11th session and the first session of the Reunion of the Parts of the Protocol of Kyoto. The conference of parts (COP) constitutes the supreme body of the CCNUCC and annually meets in order to negotiate and to supervise the implementation of Convention. Morocco has ratified the Protocol of Kyoto, on 16 February 2005. Since, twenty-and-a COP took place. The twenty-second will take place with Marrakech, in Morocco, from 07 November to 18 November 2016. Among the objectives of COP22 in Marrakech is to reduce and to develop household wastes by the construction of the controlled landfills, so our article will be a benefit currently.

The work program MDP (clean Mechanism of development) prepared by the FEC (Funds of Communal Equipment) in the field as of solid waste in Morocco is a innovating operation which illustrates the new approach fully that seeks to promote the Facility Carbon of Partnership (CPF) as regards Finance Carbon. This program is representative of a new way in the field of finance carbon where the challenge is from now on “to pass on the scale”, in order to mobilize resources on a sufficient level, and to be able to mobilize and combine various funding sources to fight against the climate change [1].

The current production of household wastes in urban environment in Morocco is at 5.3 million tons a year that is to say on average 0.76 kg per inhabitant per day, and in rural environment 1.47 million tons a year, is on average 0.28 kg per inhabitant per day. The rate of collection is of 80% relates to 90 contracts and 106 communes. With population growth, rapid urbanization and changes in consumption patterns, household waste production in Morocco is increasing. The rate of setting in controlled landfill is of 35%, this rate will have to reach 64% after the opening of several controlled landfills, which are in the course of construction [2]. Household waste in Morocco contains 65%-75% organic matter, so landfills in Morocco are one of the sources of biomass. According to the calculations of the energy potential of biomass, we can deduce that the amount of electricity that could produce by incineration of household waste from the Rabat region is about more hundred gigawatt-hours [3].

The multiplication of the not controlled landfills contributes to the contamination of surface and underground waters, to the propagation of the diseases and the degradation of the landscape. This situation also harms in a general way economic development of the country, in particular in the tourist sector. A study of the World Bank carried out in 2003 considered the economic costs of degradation of the environment in Morocco, bound mainly by the weak performance of the management system of solid waste [2].

The legal aspect relating to waste management solids that was reinforced in 2006 by the adoption of law n° 28-00. This law has the aim protect health from the man, fauna, the flora, water, the air, ground, the ecosystems, the sites and landscapes and the environment in general against the adverse effects of waste [4].

Beside the law of management of waste (law 28-00), one finds the strategy of National plan of Household wastes PNDM, This program was worked out by the Delegated minister in charge of the Environment and the Ministry for the Interior with the support of the World Bank. The PNDM aims primarily to [5]:

a. To ensure the collection and the cleaning of household wastes to reach a rate of collection of 85% in 2016 and 90% in 2020.
b. To carry out the landfills controlled and of valorization to the profit of all the landfills urban (100%) in 2020.
c. To develop the sector of “tri-recycling-valorization”, with pilot actions of sorting, to reach a rate of 20% of recycling in 2020.
d. To train and sensitize all the actors concerned on the problems of waste.

Then with the support of State (PNDM), the majority of the great urban areas currently have new controlled landfills and other landfills controlled are in the course of construction.

2. Methods

2.1. Controlled Landfill of the Town of Fes

The controlled landfill of Fes is of type classifies I, which makes it possible to collect only the comparable refuse domestic and waste. However, it is equipped by specific installations to receive waste of class II (tannery sewage sludge and scrap).

The landfill receives 100 trucks, on average, by day, which generates a quantity of waste equivalent to 700 tons. Most of wastes are the household wastes, transported by the trucks of collecting of the domestic buckets of refuse (BOM), and of comparable waste coming from the points from transfer of waste. The remaining part distributed between ordinary waste (Green wastes, Waste of demolitions, the ground) and of special waste (Sludge from the wastewater treatment plant and tannery waste).

Table 1. *Various types of waste codified in the controlled landfill of Fez.*

Types of waste	Code
Household wastes	DM
Green wastes	DV
Tannery scrap	DT
Mixed waste assimilated	DMA
Mixed wastes	DM
Industrial waste	DI
Waste of demolition	DD
Waste of sweeping	DB

The weighing of the waste takes place via a weighing bridge or also called the electronic flip-flop provided with six sensors underneath connected to an apparatus called the terminal, which allows the display of the mass on the weighbridge bridge, its capacity is 60 tons and its uncertainty is 20 kg per tons, this uncertainty considered negligible.

The terminal linked to a computer, which records the waste mass by the user and by software called Transistor, on the screen of the computer there are boxes, each box comprises information.

The user indicates the number of the truck coming installed on the weighbridge, the type of waste collected (household waste or similar household waste); the name of the carrier and the place of loading, and the computer displays other information concerning the masses.

Indeed, as soon as the truck installed on the weighbridge at the entrance, the gross mass or also called the input mass:

$$M_{entry} = M_{truck} - M_{carrier} - M_{waste}$$

M_{entry}: Mass of entry
M_{truck}: Mass of the truck
$M_{carrier}$: Mass of the carrier
M_{waste}: Mass of waste

The mass of entry displayed on the terminal then on the screen of the computer.

After the truck landfills, is installed on the weighbridge and there is displayed the mass of exit on the screen of the computer.

$$M_{exit} = M_{truck} - M_{carrier}$$

M_{exit}: Mass of exit

Therefore, we can deduce that the mass of waste is equal to the difference between the two masses.

$$M_{waste} = M_{entry} - M_{exit}$$

This calculation is carried out by the computer and gives the result directly, and then the user records this result to add the whole with the results of each day. This operation makes it possible to have the mass of the waste buried each day.

2.2. Land GEM model of the USEPA

Several types of mathematical models exist to estimate the production of biogas. They are generally based on decomposition kinetics of zero, of first order and second order. Others are of digital nature and have much precision, but their use requires several inputs that are not always at the disposal of managers [6].

First-order models are the most widely used in the world because of the compromise between accuracy and ease of use [7]. Among the first-order models, we distinguish the LandGEM model (Landfill Gas Emissions Model) [6].

The EPA's LandGEM (Environmental Protection Agency) is a Microsoft Excel-based software application that uses a first rate decomposition rate equation to calculate the methane estimate. LandGEM is the most widely used model of LFG (Landfill Gas) and is the standard for regulatory and non-regulatory applications in the US industry. Model defaults are based on empirical data from US landfills. Field test data can also be used instead of model default values when available. [8, 9].

LandGEM uses the first order decomposition equation below to estimate methane production. The model, in its double summation form, is represented by the equation [8]:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k * L_0 * \left(\frac{M_i}{10}\right) * e^{-kt_{i,j}}$$

Q_{CH_4} = Annual methane generation in the year of the calculation (m³.year⁻¹)

i = One-year time increments

n = Number of years calculated (year of the calculation - initial year of waste acceptance)

j = 0.1 year time increment (cutting the year into tenth)

k = Methane generation rate (year⁻¹)

L = Potential methane generation capacity (m³.Mg⁻¹)

Mi = Mass of waste accepted in the i^{th} year (Mg)

$t_{i,j}$ = Age of the j^{th} section of waste mass Mi accepted in the i^{th} year.

The LandGEM software is an automated tool for estimating emission rates for total landfill gas, Methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from solid waste landfills.

LandGEM offers the value of constant k and the potential value of methane production L_o, both CAA (Clean Air Act) and the other for AP_{42} standards (USEPA, 1998). It is recommended to use standard AP_{42} standard values for landfills (US-EPA, 2004).

The default methane content in the landfill gas is 50%, which are both the industry standard value and the default value recommended by LMOP (Landfill Methane Outreach Program) [9].

3. Results

3.1. Fez Waste Tonnage

The table below shows the quantities of waste received by the controlled landfill of Fez, as from the year of opening of the landfill in 2004 until 2016:

Table 2. *Tonnage of waste (in ton) in the controlled landfill of Fez (2004-2016).*

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Tonnage	135,700	153,665	171,550	189,435	207,320	225,205	243,090	260,975	278,860	296,745	314,630	332,515	350,582

From this table (table 2) we see the increase in the quantities of waste according to the years, due to population growth in the Fez region.

According to the results of the general population and housing census of 2014, the prefecture of Fez containing 1,150,131 inhabitants, with the rate of increase equal to 1.63% [10].

The figure 1 shows the evolution of waste tonnage of the Fez landfill as a function of the years, a regression model given by the SPSS software can approximate these points.

Then, this model of regression is equal:

$$T = 17\,893.637 * Y - 35\,723\,113.253$$

T: Tonnage

Y: Year

According to this model, one can make a forecast for the quantities of waste of the next years, since the contract of the company that is responsible for waste management with the prefecture of Fez will completed in 2034 (table 3). In 2034, the annual waste will be of 672,544 ton.

Table 3. *Forecast of waste quantities for next years at Fes landfill (in ton).*

Year	2018	2020	2022	2024	2026	2028	2030	2032	2034
Tonnage	386,246	422,033	457,821	493,608	529,395	565,182	600,970	636,757	672,544

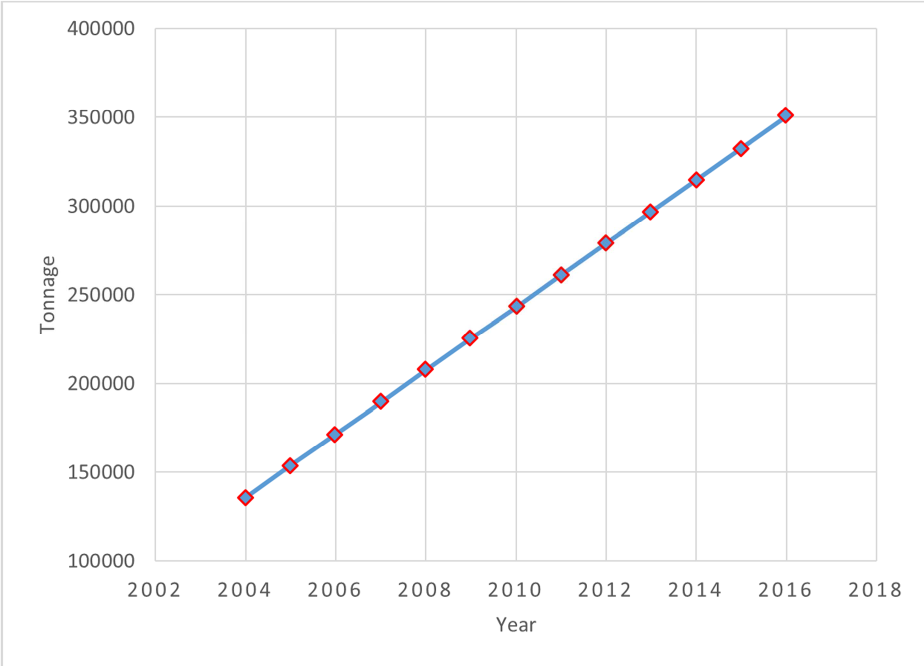

Figure 1. *Evolution of tonnage waste (in tons) of the controlled landfill in Fez.*

3.2. Estimated Production of Electrical and Thermal Energy in the Fez Landfill Using Land GEM of the USEPA

Our objective of this model is to introduce the quantity of annual methane estimated by the waste in the controlled landfill of Fez.

Table 4. *Estimated annual production of methane in the landfill in Fez Land-GEM from 2004 to 2016.*

Year	Annual Estimate of Volume Production of Methane ($m^3/year$)	Annual estimate of mass production of methane ($kg/year$)
2005	1 128 000	756 775.2
2006	2 350 000	1 576 615
2007	3 661 000	2 456 164.9
2008	5 057 000	3 392 741.3
2009	6 534 000	4 383 660.6
2010	8 087 000	5 425 568.3
2011	9 713 000	6 516 451.7
2012	11 410 000	7 654 969
2013	13 170 000	8 835 753
2014	14 990 000	10 056 791
2015	16 880 000	11 324 792
2016	18 820 000	12 626 338

From this table, it is shown that the volume and mass of methane increase with the years, due to the increase in waste tonnage from the Fez landfill. The amount of methane accumulated in this landfill is $18\,820\,000\ m^3$. (The numerical density value of methane is $0.6709\ kg \cdot m^{-3}$).

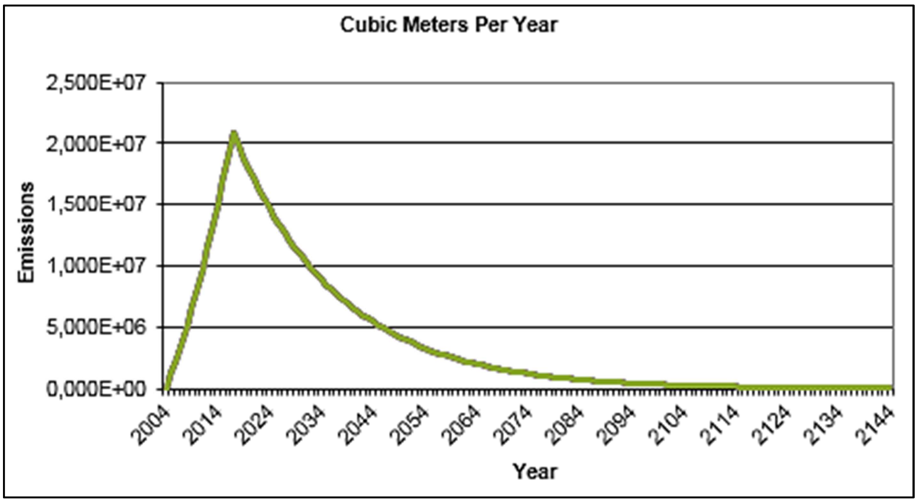

Figure 2. *Curve of the annual estimate of methane production (in $m^3/year$) in the controlled landfill of Fez by the Land-GEM model.*

According to the graph in top, we observed that the pace of the graph contains two intervals:

If $2004 \leq t \leq 2018$: The quantity of methane increases with a significant slope up to $22 \cdot 10^6\ m^3$ of methane.

If $t > 2018$: The quantity of methane decreases exponentially as a function of the years until a value of zero.

3.3. Annual Estimation of Electrical Energy by the Fez Landfill

The production of electrical energy from controlled landfill methane is a most common application of beneficial use. Electricity can be produced by the combustion of methane in a Gas generator set, a gas turbine or a microturbine. (Electrical system)

The potential for producing electrical energy from the methane recovery from the landfill was estimated using the following equation:

$$E_{el} = LCV * r_{elec} * Q_{CH_4}$$

E_{el}: Annual production of electricity in $(kWh\ /\ year)$

LCV : Lower calorific value of methane from landfill: 9.94 kWh/m^3

r_{elec}: Efficiency of the facility producing electricity from methane from the landfill, the efficiency of these systems generally varies between 30% and 40%, Depending on the properties of the engine or gas turbine installed. Efficiency of the electrical system at the level of the controlled dump of Fez equal to 35%.

Q_{CH_4} : Annual methane generation in the year of the calculation $(m^3 \cdot year^{-1})$.

From this equation, we now calculate the annual estimate of production of electric energy by the controlled dump of Fez.

Table 5. *Annual estimated production of electric energy by the controlled dump of Fez.*

Year	Annual estimate of volume production of methane $(m^3/year)$	Estimated annual production of electricity $(kWh\ /year)$
2005	1 128 000	3 924 312
2006	2 350 000	8 175 650
2007	3 661 000	12 736 619
2008	5 057 000	17 593 303
2009	6 534 000	22 731 786
2010	8 087 000	28 134 673
2011	9 713 000	33 791 527
2012	11 410 000	39 695 390
2013	13 170 000	45 818 430
2014	14 990 000	52 150 210
2015	16 880 000	58 725 520
2016	18 820 000	65 474 780

From this table, we can plot the evolution of the annual estimated electric power generation for Fez landfill from 2005 to 2016 (figure 3).

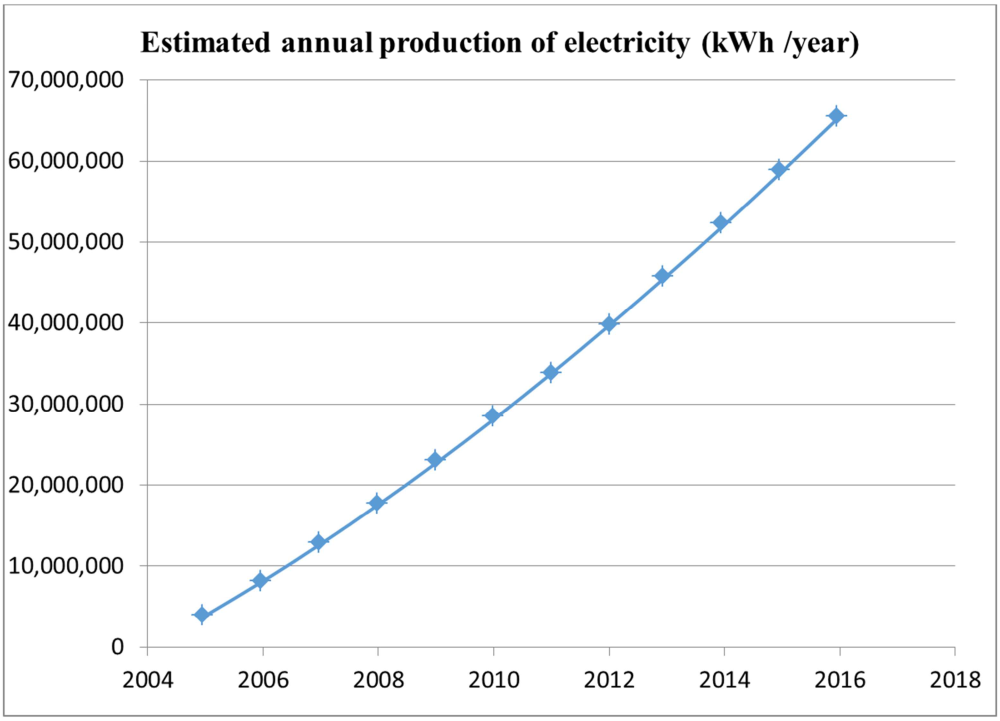

Figure 3. *Annual estimated electric power generation for Fez landfill from 2005 to 2016.*

From this result, it is observed that the production estimate of electrical energy increases with the growth of quantity of methane. For 2016, the estimate for the production of electrical energy in the Fez landfill is 65.5 $GWh/year$.

4. Discussion

The prefecture of Fez containing 1,150,131 inhabitants in 2014, with waste production of 314,630 ton (0.75

kg/inhabitant/day). According to the regression model, one can make a forecast for the quantities of waste of the next years. In 2034, the annual waste will be of 672,544 ton.

According to the LandGEM model, the volume and mass of methane increase with the years, due to the increase in waste tonnage from the Fez landfill. The amount of methane accumulated in this landfill is 18 820 000 m^3. From 2004 to 2018, the quantity of methane increases with a significant slope up to $22 \cdot 10^6\ m^3$ of methane. Then, the production of methane decreases exponentially as a function of the years until a value of zero.

The production estimate of electrical energy increases with the growth of quantity of methane. For 2016, the estimate for the production of electrical energy in the Fez landfill is 65.5 $GWh/year$.

5. Conclusion

The use of controlled landfill waste to generate electricity is a promising approach in terms of energy conservation; it is also a good technology for reducing air pollution. The LandGEM software is an automated tool for estimating emission rates for total landfill gas, Methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from solid waste landfills. We have shown that the estimated current electrical energy in the Fes landfill was 65.5 GWh for the year 2016. Therefore, it can be concluded that the Fez landfill is a good source for energy production and can be used to move fossil fuels.

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