PRODUCTION OF ELECTRICITY FROM MUNICIPAL SOLID WASTE IN KOS

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ABSTRACT

In this paper, a methodology of transforming the waste management of Kos, an island of 34,280 inhabitants in south-eastern Greece, in a third generation waste management stream with recovery of energy is presented.

Initially, the amount of waste disposal in the island of Kos is taken under examination, according to data obtained from the existing landfill, in order for the annual biodegradable fraction of the Municipal Solid Waste to be estimated.

The next step includes a detailed research on the optimum waste to energy (WtE) technology between combustion, gasification and anaerobic digestion. By assuming that the biodegradable fraction of the municipal solid waste (MSW) would be separated through a sorting in the source system, and taking into account the probable amount of that fraction, along with its chemical composition and moisture percentage; a model for each different waste to energy technology was constructed, estimating in that way the total amount of the thermal and electrical energy that could be produced.

Afterwards, a financial analysis takes place, again for each WtE technology, according to the current economic conditions and the existing legal framework. The obtained results are compared and the optimum selection is proposed.

The only alternative that adds positive value in financing terms is anaerobic digestion with NPV of 2,465,203 €. Gasification is the most efficient route and for the same feedstock has the highest installed capacity of electrical power (2 MW) while combustion has the highest thermal power capacity (2.7MW). The highest installation cost and installation cost per MWh come from gasification: 14,392,202 € and 904 € respectively and the lowest installation cost from anaerobic digestion (2,490,400 €) while combustion stands in between (4,415,820 €). In environmental terms, combustion has the highest CO_2 emissions 14,900 tons per year. Although gasification presents the lowest environmental impact per MWh of installed capacity (905 kg/MWh), it doesn't contribute to any positive value in financial terms.

Keywords: Municipal Solid Waste, Renewable Energy Source, Anaerobic Digestion, Combustion, Gasification, Waste to Energy.

1. Introduction

The production of municipal solid waste has been increased significantly the last decades, due to the consumerism that characterizes the western world after the second half of the 20th century, along with the industrialization of the developing countries. It is a phenomenon expected to expand rapidly in the future, making the problems of waste disposal and waste management, key issues for present and future generations.

Since the production of municipal solid waste is growing with an ever increasing rate, its accumulation is becoming a major problem and the creation of a sustainable waste management stream is vital for every region. The existing waste management streams could be classified/ categorized into three generations. The first generation deals with the uncontrolled waste disposal site the second one with the sanitary landfills and the third generation with an integrated waste management stream with energy recovery.

Nowadays, due to environmental, financial and social aspects, a more rational waste management stream is considered necessary. The willingness to minimize the accumulated waste along with the increased energy demand, led to the development of the third generation waste management systems. Such systems are the Waste to Energy facilities which are considered friendly for both the environment and the society.

In relation with what was mentioned above, the main purpose of this paper is to examine which is the optimum technology in financing and environmental terms between combustion, gasification and anaerobic digestion in the island of Kos, a typical Mediterranean island in the south-eastern Greece. Kos is not interconnected to the country's main electrical grid and has an intensive touristic period during the summer, as is the case with the large majority of the other Greek islands. Although, an integrated and sustainable waste management stream is indicated, the research focuses in the recovery of energy through the waste.

Initially, the technologies taken under consideration are briefly analyzed, along with the feedstock estimation. Subsequently, a program has been developed in order to illustrate which is the most appropriate WtE technology. The algorithms used for program development are based on university lecture notes by Marnellos (2013) and the financing tables are based on the book of Damodaran (2011). A parametric analysis has been conducted by examining the influence of some variables in the viability of the projects, using the NPV of the project as the main indicator.

2. Methodology

2.1. Feedstock Estimation

The total amount of waste for the year 2012 is 31,291 tons (Municipality of Kos, 2012). The percentage of the biodegradable fraction of the (MSW) in Kos is 45.1 % (Bourtzalas, Themelis and Kalogirou, 2011) Therefore, the biodegradable fraction of the (MSW) is 14,112 tons. Figure 5 illustrates the seasonal distribution of the waste in Kos, which is mainly related to the high increase of population during the summer period caused by tourists.

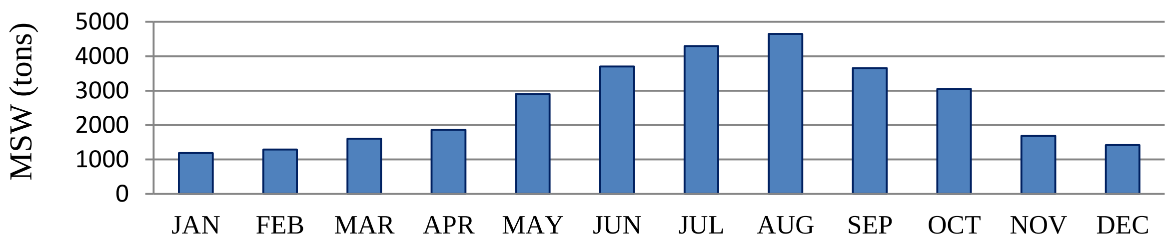

Figure 1: Total amount of waste in Kos per month (2012).

2.2. Performance Models

Not many programs with the capability of simulating the performance of various biomass technologies exist. Due to that fact, a software tool with the ability to estimate the performance of several WtE technologies and to conduct basic project valuations has been developed.

Three performance models have been developed for the three technologies taken under examination: combustion, gasification and anaerobic digestion. In every model the required inputs are the annual amount of the available feedstock, the chemical composition of the dry ash free feedstock and the percentages of moisture and ash of the feedstock.

The combustion performance model is based on the fluidized bed combustor. Additional variables for that model are the temperature of the exhaust gases, the percentage of CO found in them and the percentage of the excess air according to the amount of the required air for the complete combustion. For the power generation, a Rankine cycle is used.

The gasification performance model is based on the recycling fluidized bed gasifier. The additional variables for this model are the percentage of the air required for complete combustion that enters the gasifier, the extent by weight of the complete combustion and the percentage by volume of the methane contained in the resulting gas. Also, the chemical composition of the organic portion of the solid residue is required. For the power generation, a combined Brayton-Rankine cycle is implemented

For the anaerobic digestion model, the mesophilic process is selected. The variables concerning the process are the percentage of the volatile part of the feedstock, the percentage of the total solid biomass that is converted and the average annual ambient temperature. For the power generation, a Diesel engine which is fueled with the produced biogas is employed.

2.3. Financial Model

For the estimation of the installation cost, empirical equations based on data from various sources, are used (Papazoglou, 2011; Whyte & Pery, 2001; Ferber & Rutz, 2011; Dounavi, 2011; Mallon & Weersink, 2007). The installation cost for combustion is estimated to be:

IC=4029-643lnC (€/kW$_e$), for gasification: IC=7675-1235lnC (€/kW$_e$) and for anaerobic digestion:

$$IC=\begin{cases} (15.35-2.256\cdot \ln 1000C)\cdot 10^6\cdot C & , C<0.5MW \\ 1.25\cdot 10^6\cdot 2C & ,C>0.5MW \end{cases} \quad (€),$$

where C is the installed capacity of electrical power in MW. The number of created jobs are roughly estimated to be 3 employees/MW$_e$ and the cost of maintenance, management, security, utilities, etc. is estimated to be equal to 2/3 of the total cost of labor. The cost of accumulation and transportation of the feedstock (MSW) is not taken under consideration.

The level of depreciation is different for the three technologies, and it is: 4 % for the combustion facility, 5 % for the gasification facility and 8 % for the anaerobic digestion facility (Official Government Gazette (OGG), A96/5.5.1998). The feed in tariff is 131 €/MWh for anaerobic digestion and 90 €/MWh for combustion and gasification (Official Government Gazette (OGG), Law n.4524, A85/7.4.2014) and the level of taxation is set to 35 % for all technologies. The capacity factor is set to be 0.85 for all technologies (Knoke *et al,* 2010; Caputo *et al,*2005). The discount rate (cost of capital) is calculated from WACC formula and is equal to 12.35 %.

3. Results

According to Table 1, which summarizes the main results of the investigation, gasification is the most efficient route and for the same feedstock has the highest electricity installed capacity. However, combustion has the highest thermal capacity. The finance indicators illustrate clearly that the only alternative that adds positive value in financing terms is anaerobic digestion. In environmental terms combustion has the higher CO_2 emissions. Although gasification presents the highest installed capacity and the lowest amount of CO_2 emissions per MWh of produced electrical energy, it doesn't contribute to any positive value in financial terms.

Figure 2 shows the percentage of electrical energy production that the anaerobic digestion facility could cover in Kos. WtE technologies usually operate in steady state conditions and can significantly reduce the amounts of electrical energy produced from fossil fuels.

Figure 3 illustrates that anaerobic digestion starts to be financially sustainable even with a feed in tariff much lower than the authorized at the time being around 65 €/MWh. It is mentioned previously that combustion and gasification do not add value in the case of Kos with a feed in tariff of 90 €/MWh, but they do add value with a feed in tariff around 105 €/MWh for combustion and a feed in tariff around 170 €/MWh for gasification. Moreover, according to Figure 3 combustion could be economically viable with a percentage of subsidy around 27. Gasification needs much higher subsidy up to 55%.

Table 1: Technology comparison, Kos.

	Combustion	Gasification	Anaerobic Digestion	
Installed electrical capacity	1,115	2,136	996	kW
Electrical energy generation	8,306	15,905	7,417	MWh/year
Electrical efficiency	23.7	45.3	21.5	%
Installed thermal capacity	2,762	2,353	994	kW
Thermal energy generation	20,565	17,523	7,399	Mwh/year
Thermal efficiency	58,63	50	21.4	%
Financing (Project Valuation)				
Installation cost	4,415,820	14,392,203	2,490,401	€
Energy cost	531,66	904,9	335.8	€/Mwh
NPV	-649,199	- 6,174,759	2,465,203	€
Payback period	9.1	14.75	4.25	years
Profitability index	-14.7	-42.9	99	%
IRR	10.1	5.3	26.3	%
MIRR	11.6	9.9	15.5	%
CO_2 Emissions	14,987	14,395	7,542	tons
	1,804	905	1,017	kg/Mwh

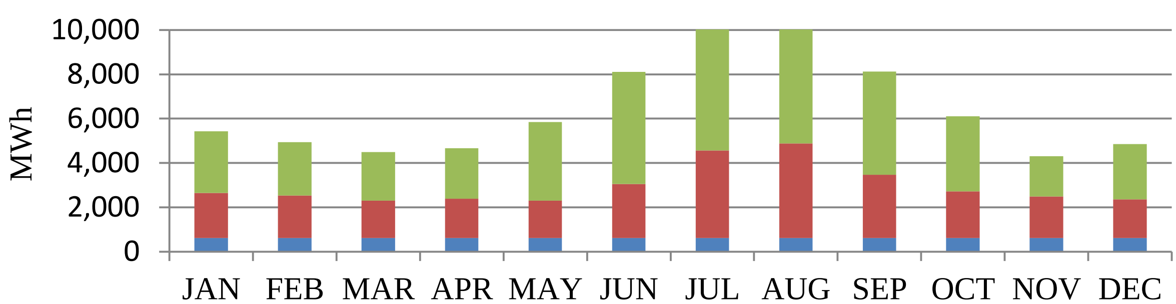

Figure 2: Electricity production from oil (red), PV & Wind (green) and anaerobic digestion (blue).

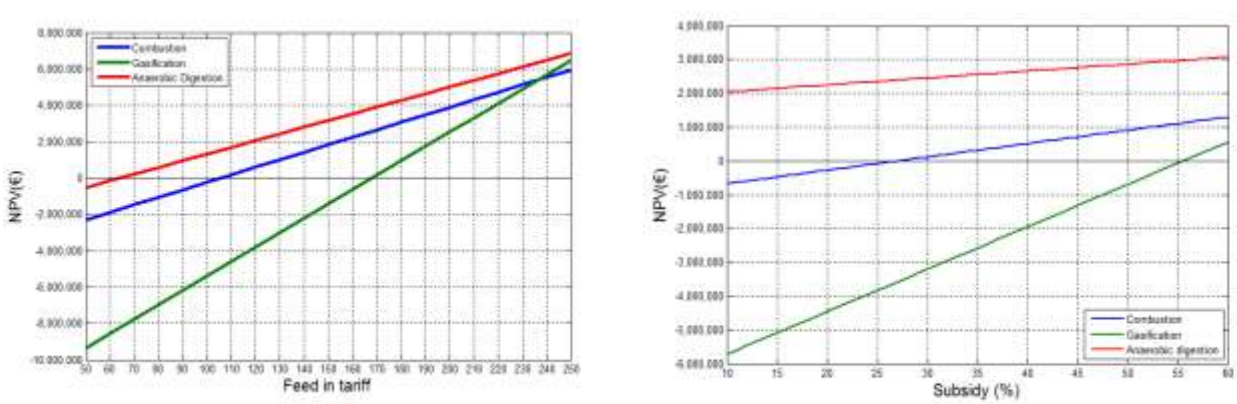

Figure 3: Parametric analysis regarding feed in tariff (left) and percentage of subsidy (right).

4. Conclusions

The investigation regarding the optimum WtE technology that could be implemented in the island of Kos, concludes that anaerobic digestion is the only financially feasible technology. However, adjustments on several parameters, such as an increase of the feed-in tariff, could lead to the financial viability of combustion and gasification. The program that has been developed for the purposes of this thesis could be used for different regions, enabling decision makers to valuate projects related to biomass or WtE technologies.

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