Economic and Environmental Benefits of Waste Incinerators Comparing to Conventional Electric Generators

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Abstract

Solid waste management is one of the main issues faced by national authorities, especially in the countries and the cities with high population density. One of the most used waste treatment technologies is the incineration, which is a thermal treatment that converts waste into ash, electricity and heat. The use of waste incineration is controversial due to several opinions regarding the economic and the environmental aspects. In this paper, the waste incineration technique is compared, in terms of economic saving and greenhouse gases (GHG) emissions, to the conventional electric generators.

The results show the reduction in carbon dioxide (CO_2) emissions and operating cost when replacing conventional power generators by waste incinerators. The case study is applied to Lebanon. Due to the integration of three waste incinerators of 1000 tons/day into the Lebanese electric grid, the reduced operating cost is then 23.03 million $ per year and the reduced CO_2 emissions are 286200 tons per year.

Keywords: *waste management, waste-to-energy, waste technologies, incineration, electricity*

Introduction

The problem of municipal solid waste (MSW) management has become a major social problem[1]. Waste disposal must reduce the harmful impact of the solid waste (SW) on the environment with a reasonable cost. MSW incineration (MSWI) plays a role in the MSW management and in energy recovery that can be used as power generator[2].

Many researchers were interested in the study of the environmental and economic aspects of the MSWI. Economopoulos et al. evaluated the construction and operating costs of various technological operating schemes[3]. Murphy et al. did a comparison between four MSW technologies: incineration, gasification, generation of biogas and utilization in a combined heat and power (CHP) plant, generation of biogas and conversion to transport fuel by evaluating the technical, economic and environmental aspects[4]. Tsai et al. calculated the mitigation of CO_2 emissions of the MSWI compared to fossil fuels, and the economic gain resulting from selling electricity from MSWI to the electric utility service[5]. Liamsanguan et al. assess the environmental performance of energy from MSW incineration and compare it to conventional power plants and suggest measures for improvement[6]. In[7], the combustion of coal and MSW in terms of fuel characteristics, combustion technology, emissions, and ash utilization/disposal are compared. Chen et al. compared the thermodynamic and the economic performances of a novel waste incineration power and a coal power plant[8]; the economic performance is considered as the payback period of the system. Mayer et al. compared the environmental benefits and the techno-economic aspects between the different waste-to-energy systems[9]. In[10], the authors studied the case of the Lebanese waste if it is completely incinerated and compared the incinerators emissions with respect to the international standards.

This work provides a novelty based on the comparison between the waste incinerators and the conventional power generators in terms of economic and environmental aspects. The comparison is made by a novel decision-making algorithm when substituting the conventional generators by waste incinerators. The simulation of this latter compares the emissions of CO_2, which is the main greenhouse gas (GHG), and the operating costs of both systems on hourly basis. In section II, the incineration as a waste-to-energy treatment technique is discussed. In section III, the proposed comparative analysis algorithm is developed. Section IV corresponds to a case study. In section V, the results will be discussed.

Waste-to-Energy Treatment Technique: Incineration

MSW results from daily residential and commercial activity. If the waste is not properly handled and treated, it will have a negative impact on the environment like air pollution and surface and ground water pollution, as well as the soil and crops[11].

Figure 1 represents the solid waste treatment hierarchy components. MSW incineration technology is mostly used at an advanced level of the waste treatment after the recycling technologies.

Waste incineration is based on the burning of waste in the presence of oxygen at temperatures of 850°C and above, accompanied with heat and energy recovery and mechanisms to clean flue gas, and can receive different types of waste[12]. Figure 2 represents the flowchart of the waste-to-energy (WtE) incineration process. MSW incineration is characterized by the volume reduction up to 90% of the initial incinerated volume[13] in addition to the benefit of producing energy (electrical and thermal).

The waste is moved by a grate through the boiler where it will be combusted. The turbine is turned by the steam pressure that is produced by the water heating in the boiler[10].

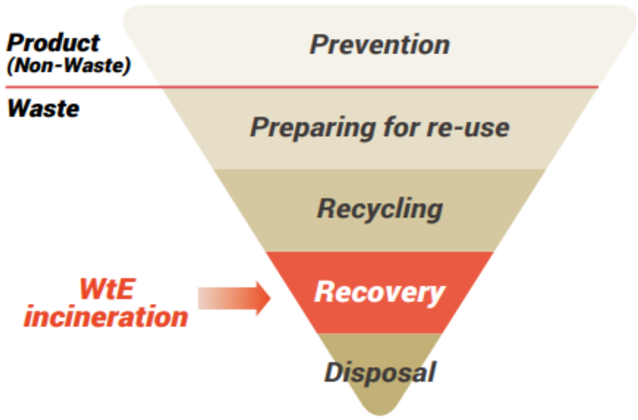

Figure 3. Waste hierarchy for sustainable waste management[12]

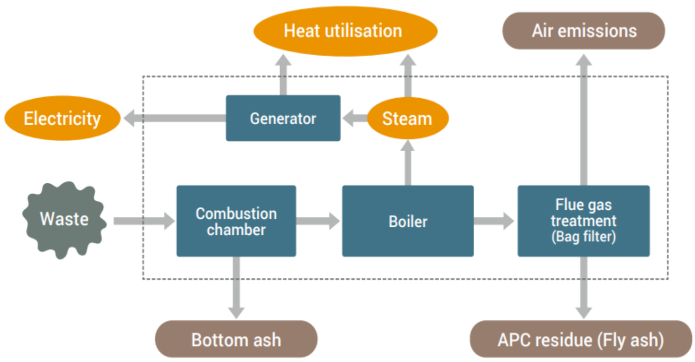

Figure 4. Flowchart of the waste incinerator[12]

The waste incineration facilities must be monitored and controlled to avoid pollution issues such as dust and dioxins, knowing that the latest technologies meet the strict environmental standards especially for the dioxins[12]. In fact, the incinerators air pollution control device (APCD) are able to remove two categories of pollutants: particulate matter and acid gases. The particulate (dioxin, furan and mercury) removal is done with fabric filters (baghouses) and electrostatic precipitators with dry powdered activated carbon injection systems. Acid gases such as hydrochloric acid (HCl), sulfur dioxide (SO_2) and nitrogen oxides (NOx) removal is done with spray dryer absorbers with alkaline-reagent injection, dry-lime injection systems and selective non-catalytic reduction[14].

Knowing that the main GHG, the CO_2, corresponds to approximately 96.5% of the gases emitted by the waste incineration[15,16], we will compare the CO_2 emissions of an MSWI to the conventional power generators.

The operating cost of the MSWI is considered expensive[13], for this reason we will compare it to the operating cost of the conventional generators.

Comparative Analysis Algorithm

To find the economic and environmental benefits of the incinerators comparing to the conventional generators, it is better to use an algorithm that can calculate the emissions reduction and the economic gain simultaneously.

The proposed algorithm is similar to that used in[17], but with some modifications related to the integration of incinerators into the electric grid.

a) General description:

The developed algorithm is used to control the power output of conventional generators and incinerators. It takes into account the electrical demand and the operation of the incinerators integrated in the grid. Its period of operation is a default time and it can be changed by the operator. At the end of each period, the algorithm calculates the operating cost and emissions and their reductions due to the integration of incinerators in the power grid.

This algorithm, which is developed with MATLAB programming language, compares the hybrid case (conventional generators + incinerators) with the conventional case (i.e. without incinerators) in order to satisfy the electrical demand.

b) Inputs and outputs:

The input parameters to this algorithm are:
Hourly based electricity demand; Matrix representing conventional generators in ascending order of importance with their operating cost ($/hour) and CO_2 emissions (kg/hour); Matrix representing incinerators in ascending order of importance with their operating cost ($/hour) and CO_2 emissions (kg/hour).

The output parameters of this algorithm are:
Generators matrix; Incinerators matrix; Electricity generated by the incinerators; Electric energy produced by conventional generators; Total electric power supplied to the network; Total operating cost ($/hour); Reduced operating cost due to the integration of incinerators ($/hour); Total CO_2 emissions (kg/hour);

Reduced CO_2 emissions due to the integration of incinerators (kg/hour).

c) Operating steps:

The operating steps of the algorithm are as follows:

- Data acquisition
- Selection of incinerators
- Selection of conventional generators
- Calculation of the total operating cost and emissions
- Calculation of the total operating costs and emissions in the conventional case (without incinerators)
- Calculation of the reduced operating cost and reduced emissions due to the integration of incinerators
- Display of the outputs

Figure 3 represents the flowchart of the operating steps of the proposed algorithm.

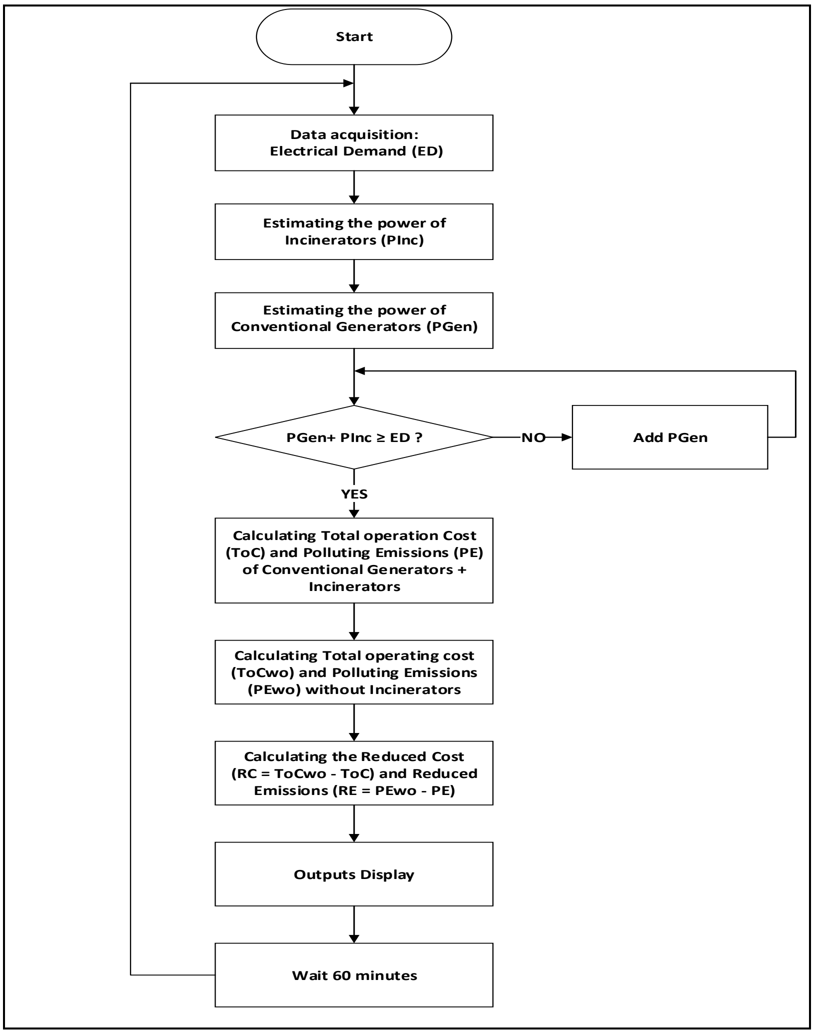

Figure 5. Flowchart representing the operating steps of the algorithm

Case Study: The Lebanese Case

In order to apply this research, we chose the case of Lebanon which has a mismanagement of the SW sector. Lebanon produced 2040000 tons of MSW in 2014 with a generation growth equal to 1.65% per year, this means that in 2020 the waste production is around 6166 tons per day[18]. Based on the Lebanese Council of Ministers decision number 3 of August 27, 2019, three thermal disintegration facilities (incinerators) must be constructed. Each incinerator must treat around 1000 tons per day of MSW.

The Lebanese MSW composition has a moisture content of 60%, an average chemical composition of $C_6H_{9.393}O_{3.249}N_{0.184}S_{0.013}$ and a calorific value ranging between 7.4 MJ/kg and 9.7MJ/kg [10]. We will consider that the average calorific value is 8.55 MJ/kg. The incinerator is considered with 3 boilers as in[10] and operating 300 days per year. The boiler's capacity must be equal to:

(Number of tons/day)*(365/300)/(3Boilers) =(1000tons/day)*(365/300)/3 = 405.56 tons/day.

Each boiler produces a power equal to:

(Boiler capacity in kg/day)*(Calorific value)/(1day/24hours)*(1hour/3600seconds)*(efficiency of the boiler) = (405.56*1000kg) *(8.55MJ/kg)*(1/24) *(1/3600)*(80%) = 32.11 MW.

Thus each incinerator produces a power equal to (3*32.11 MW)= 96.3 MW.

A back-pressure turbine has around 26% of waste to electrical efficiency[10]. Therefore, the electric power produced by each incinerator is 25.04 MW. The thermal power will not be considered due to lack of infrastructure in Lebanon, though it can increase the benefits of the incinerators.

The operating cost of an incinerator is equal to 35.7 $/ton[19]. Each boiler's capacity is 405.56 tons; thus, it is equal to 14480 $/day or 603 $/hour. Hence the operating cost of an incinerator is 1809 $/hour.

According to[20], we assumed that the emissions value of CO_2 is the highest value, which is equal to 130 g/kWh or 130 kg/MWh. Hence, the CO_2 emissions value per incinerator is 3250 kg/hour. The matrix of the incinerators is given in Table1.

Table 1: Incinerators matrix

Electric Power (MW)	Operating cost ($/hour)	CO_2 emissions (kg/hour)
25	1809	3250
25	1809	3250
25	1809	3250

Table 2: Conventional generators matrix (source: Electricité du Liban - EdL)

Plant name	**Power (MW)**	**Operating cost ($/hour)**	**CO_2 emissions (kg/hour)**
Zahrani I CCPP	469	53935	309540
Deir Ammar I CCPP	464	53360	306240
Zouk 1 Thermal Power Plant	607	80428	400620
Jieh 1 Thermal Power Plant	343	45448	226380
Zouk 2 ICE Power Plant	198	26235	130680
Jieh 2 ICE Power Plant	78	10335	51480
Additional power plant	75	8625	49500

The electric conventional generators are represented in Table2 with the corresponding operating cost in $/hour and CO_2 emissions in kg/hour. The data of the generators is provided by the main electricity producer in Lebanon, Electricité du Liban (EdL). The operating cost is calculated after calculating the data provided with the fuel costs of each power plant from[21]. We considered the average values: 0.1325 $/kWh for Jiyeh and Zouk power plants and 0.115 $/kWh for Zahrani and Deir Ammar power plants[21]. The additional power plant was added, in order to compare the conventional power production with the power production including the integration of the incinerators. Its power is considered equal to 75 MW which is equal to the total power of the incinerators. The operating cost of the additional power plant is considered as the lowest (0.115 $/kWh). The CO_2 emissions are equal to 660 kg/MWh.

Results and Discussions

The simulation of the algorithm is done when the electrical demand (load) is given. In order to have a significant comparison, the demand must be chosen in a way to replace the additional power plant by the three incinerators. It must be slightly less than the total power which is 2234 MW so that the algorithm does not choose the additional power plant. For this reason, the electrical demand is considered equal to 2233 MW.

```
Load =
       2233

Waste-to-Energy =
    75

Conventional Generation =
       2159

Total Production =
       2234

Generators =
         469          1        53935        53935   3.0954e+05   3.0954e+05          NaN          1        53935   3.0954e+05
         464          1        53360        53360   3.0624e+05   3.0624e+05          NaN          1        53360   3.0624e+05
         607          1        80428        80428   4.0062e+05   4.0062e+05          NaN          1        80428   4.0062e+05
         343          1        45448        45448   2.2638e+05   2.2638e+05          NaN          1        45448   2.2638e+05
         198          1        26235        26235   1.3068e+05   1.3068e+05          NaN          1        26235   1.3068e+05
          78          1        10335        10335        51480        51480          NaN          1        10335        51480
          75          0         8625            0        49500            0          NaN          1         8625        49500

Incinerators =
         25          1         1809         1809         3250         3250
         25          1         1809         1809         3250         3250
         25          1         1809         1809         3250         3250

Fuel cost ($/hour)=
      269740

Reduced cost ($/hour)=
       3198

CO2 emissions (kg/hour) =
     1424940

Reduced CO2 emissions (kg/hour)=
      39750
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Figure 4: Simulation's results

Figure 4 represents the results of the simulation. Knowing that the values 1 or 0 in the second columns of each matrix represent the state of the generator (1=On, 0=Off). The eighth column of the generators matrix represents the state of the generators in the conventional case (i.e. without incinerators). It is remarkable that the last value of the second column of the generators matrix is 0, and that of the eighth column is 1. This means that the three incinerators have replaced the additional power plant of capacity 75 MW.

The obtained reduced operating cost is 3198 $ per hour, and the reduced CO_2 emissions are 39750 kg (39.750 tons) per hour. In one day, the reduced operating cost is 76752 $ and the reduced CO_2 emissions are 954 tons. We consider that the yearly operating hours are equal to 7200 hours (300 days) due to the regular maintenance of the incinerators, thus the reduced operating cost is 23.026 million $ per year and the reduced CO_2 emissions are 286200 tons per year.

Conclusion

Waste incinerators, when used as power plants, have shown benefits in terms of operating cost and GHG emissions comparing to the conventional power plants. They are considered as one of the most efficient waste disposal technique due to their efficiency. However, the optimal mix of waste components and their calorific values must be found in order to get the optimal economic and environmental performances of the incinerator. In addition, many studies can be driven to find the benefits of all the other WtE technologies.

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Ekonomické a ekologické přínosy spaloven odpadu ve srovnání s konvenčními elektrickými generátory

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Abstrakt

Nakládání s pevným odpadem je jedním z hlavních problémů, kterým čelí vnitrostátní orgány, zejména v zemích a městech s vysokou hustotou obyvatelstva. Jednou z nejpoužívanějších technologií zpracování odpadu je spalování, což je tepelné zpracování, při kterém se odpad přeměňuje na popel, elektřinu a teplo. Využití spalování odpadů je kontroverzní kvůli některým názorům na ekonomické a ekologické aspekty.

V tomto článku je technika spalování odpadu z hlediska ekonomických úspor a emisí skleníkových plynů (GHG) porovnávána s konvenčními elektrickými generátory. Výsledky ukazují snížení emisí oxidu uhličitého (CO_2) a provozních nákladů při záměně konvenčních generátorů energie za spalovny odpadu. Případová studie je aplikována na Libanon. Díky integraci tří spaloven odpadu o výkonu 1000 tun/den do libanonské elektrické sítě jsou pak snížené provozní náklady 23,03 milionů $ ročně a snížené emise CO_2 jsou 286 200 tun ročně.

Klíčová slova: *odpadové hospodářství, energetické využití odpadu, emise oxidu uhličitého, spalování, elektřina*