An-Najah National University

Faculty of Engineering and Information Technology.

Department of Energy Engineering and Environment.

2020-2021

Graduation project

Feasibility Analysis for Establishing WtE Plant in Zahrat Al-Finjan landfill - Jenin.

Submitted by: Eng. Dana Hassiba

Supervisor: Dr. Mohammed Alsayed

December 20 – June 1

In partial fulfillment of the requirements for a Bachelor's degree in Energy and Environmental Engineering

Acknowledgment

First of all, thank you God for enabling me to achieve what I have reached to this day. I would like to thank my supervisor, Mohammed Alsayed, who provided me with help and support every time I feel lost, who encouraged me in many stages during my preparation for this research, and the person who I have learned from a lot!

Abstract

The utilization of Municipal Solid Waste (MSW) for energy production has been implemented globally for many decades. Palestine, however, is still dependent on landfills for only disposing of the generated MSW. Furthermore, the growing threat of energy insecurity and the inability to control the disposing of generated MSW properly can be reduced through the renewable and continuous provision of energy, where generated electrical energy from MSW will strongly achieve this purpose. Among the different alternatives for securing national energy sources, energy waste seems to be beneficial in providing energy and helps in reducing generated MSW quantities and their corresponding negative environmental consequences at the same time. In this research, the feasibility analysis was conducted for establishing WtE incineration and landfilling plant as a supposed MSW treatment method in the West Bank-Jenin government. Changes in waste generation quantities and waste composition as a result of the recycling process were also taken into account. Each method looked at the potential of producing electricity from a specific MSW capacity and consequently the related calculation of profitability factors. The first scenario involves treating 1200 daily tons of MSW, whereas the second and third scenarios involve treating 974 and 1148 daily tons of MSW, respectively, as a result of including the sorting process for extracting valuable waste composition such as plastic, metals, and glass in the second scenario and extracting valuable metals and glass only in the third scenario, before being incinerated. The results revealed that there is a distinction between the two suggested technologies in terms of initial investment cost, the potential of produced electrical energy, and resulting profitability factors. However, the amount of total produced electrical energy that could be obtained from the two WtE technologies is as follows: 1 GWh from the LFGtE plant, 10 GWh from the first scenario of incineration, and 6, and 10 GWh from the second and third scenarios of incineration, respectively. Furthermore, economic profitability factors NPV, LCOE, and IRR are 26 million dollars, 0.1065 USD/kWh, and 54%, respectively, for the LFGtE plant. That is 95 million dollars, 0.0883 USD/kWh, and 35% for the first incineration scenario. Whereas 40 million dollars, 0.1044 USD/kWh, and 25% and 132 million dollars, 0.0723 USD/kWh, and 51%, respectively, for the second and third incineration scenarios.

Contents

List of Figures

List of Tables

Nomenclature

Symbol	Description	Unit
A	Debt annual payment	$
d	Debt interest rate	%
Ep incineration	Potential electrical energy could be obtained from landfilling technology	kWh
EpLFGtE	Potential electrical energy could be obtained from incineration technology	kWh
Eele	Daily available of produced electrical energy	kWh
EeleConv	The unit conversion factor from MJ to kWh	-
En	The energy content of MSW composition	MJ/kg
QMSW	Daily quantities of disposing of municipal solid waste	tons
ηele	Electrical efficiency of WtE incineration plant	-
n	Number year	year
N	WtE plant estimated	years
In	WtE plant initial investment at year n	$
Fn	WtE plant fuel cost at year n	$
OMn	WtE plant operational and maintenance estimated cost	$
i	Economic discount rate	%
Rt	Total income revenues of plant	$
Cn	Plant cash flow at year n	$
r	Internal rate of return.	%
CNCFn-1	Cumulative net cash flow at year n-1	$
NCFn	Net cash flow at year n	$
A	Debt annual payment	$
P	Funded capital cost	$
Nd	Debt payback period	years
Revele	Daily revenues from selling electricity	$
Revfee	Daily revenues from getting gate fee payments	$

List of abbreviations

Aw	Annual worth
DOC	Degradable Organic Carbon
DOCf	Degradable Organic Carbon Fraction
EQA	Environment Quality Authority
GWh	Gega Watt-hour
HHV	High Heating Value
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
JSCs	Joint Service Commissions
kWh	kilo Watt-hour
LCOE	Levelized Cost Of Electricity
LFG	Landfill Gas
LFGtE	Landfill Gas to Energy
MARR	Minimum Attractive Rate of Return
MCF	Methane Correction Factor
Mg	Megagram
MJ	Mega Joule
MoLG	Ministry of Local Governance
MSW	Municipal Solid Waste

Chapter 1: Introduction

1.1 Problem statement

Energy in all its forms is considered to be the fundamental essence of our existence as human beings. In this accelerating world of technology and development, the energy demand is continuously increasing and is expected to increase even more in the future. We as human beings depend mostly on fossil fuels as our main source of energy, such as oil and gas, which are providing almost 80% of the global energy demands, which are used almost in everything from a water heater to mechanical engines. While other sources of energy such as solar energy and nuclear are considered to be more eco-friendly, only contributing 13.5% and 6.5% of the total energy needs. However, they are less used because they can barely satisfy the enormous current global needs. Because of this uncontrolled consummation of energy, the world has been suffering from several serious problems, starting from climate change, and ending with contaminations that are responsible for diseases like Malaria, in addition to other disasters like droughts and floods. According to the World Health Organization (WHO), almost 160,000 people die cause of gas emissions and other effects of climate change.[1] Because of these many terrible effects, the environment has been facing, a search for better energy alternatives has begun. One of the many suggested alternatives is the use of municipal waste as a source of energy[2]. Nowadays, the world's economies are driven by consumer-based lifestyles, it is only normal that this mad rate of consumption is followed by some sort of by-product. That unfavorable by-product is waste. Municipal solid waste (MSW), is classified into two groups, organic and inorganic[3]. The most common examples of inorganic are paper, plastic, metal, and others Interestingly, the complexion or composition of MSW depends on many factors, such as economic, development, climate, culture, and energy resources. And since these factors are variable from one country to another, the MSW is consequently different depending on the country. In industrial high-income countries, the waste tends to be mostly inorganic, whereas, in less-developed countries, the waste is at its highest proportions, organic[4]. The World Bank has stated in a report, that the amount of estimated waste produced every year is about 1.3 billion tons. The report also predicts that by the year 2025, the summation will rise to be up to 2.2 billion per year [5]. These previous statistics show that the disposal of MSW is a serious problem, in developing countries. collection, transport, and disposal of waste are current issues [6]. Even in developed countries that make use of waste to produce heat, energy, and fuel [7]. The incompetence to manage waste conveniently can usually stand in the way of providing other services properly, such as education, health, and electricity.

The continuous demand for energy and MSW generation are two related problems. A suggested solution for both is to use waste as a way to produce electrical energy. This suggestion came to life with the help of modern technology. Technologies such as WtE, which is adopted by governments, are proven to be the most efficient when it comes to waste management. There are three main technologies for WtE [8]: the first is Thermal conversion methods, which are known as (incineration, pyrolysis, and gasification). Second, we have a biochemical conversion. And lastly, landfilling. “Incineration “can be defined as is the method that is mainly used when conducting a thermal conversion. This method relies on using controlled high temperatures of furnaces to destruct waste. Using this method 90% of the total volume is reduced, and that is consequent to the 70% reduction of the total waste mass [9]. Incineration, energy recovery, and air pollution, are the three stages of the completion of the process of Incineration. The result of this process, which is performed at a temperature between 750 and 1000 °C, is the emission of three air pollutants, which are damaging to human health. These are SOx, COx, and NOx [10]. In Palestinian Territories (PT), the problem of energy production and waste disposal is also present. 100% of fossil fuels and 89%, are the imported energy sources that Palestine relies on. Whereas due to the non-efficient methods of waste disposal, Palestinians are suffering from several environmental problems caused by the increasing amount of MSW. In 2019, the production of accumulated waste reached 2600 tons per day that equals 0.91 kg per capita per day. And the summation has been increasing by 4% every year since then. Three dumping sites can be located actively operating in Palestine. The first is serving the middle and northern area of the west bank, is Zahrat Al-Finjan, with a utilization rate of 88%. The second, with a very lower utilization rate of 9%, is located to operate for the southern part of the country, which is the Al-Menia dumpster. And the last is placed in the city of Jericho and is overloaded. To offer a solution for the accumulated MSW, and reduce the dependency on imported energy in addition to the reduction of the emission of CO2eq, the Palestinian government came up with the plan known as the plan of (2017-2022). To accomplish these objectives, the adaption of WtE technology is considered to be the most guaranteed and promising answer to the problem [11].

1.2 Landfill site

The study area, Zahrat AL finjan landfill; the selected landfill is located in the northern part of Palestine at a latitude of 32.3629 degrees and a longitude of 35.2228 degrees. Jenin's overall climate is temperate, with an average precipitation of 468.2mm/year and accumulative precipitation of 508.5 mm for 2021. Furthermore, about 20.8 degrees c. is the annual average temperature. The landfill began filling in 2007 and is still operational today, with a total area of 250 donnom, whereas only about 140 donnom was used. Furthermore, the landfill has four cells that are used to landfill the received MSW, with each cell having a lifespan of 13 years on average. Approximately 1200 daily tons of MSW which are collected go to Zahrat Al Finjan landfill, which is under the responsibility of Jenin JSC, while the landfill operates at more than 88% of its utilization rate since 2019. Currently, the used approach for running the landfill is landfilling without any gas recovery. However, it is worth noting that the leachate produced is collected and treated in special ponds after two methods for using the produced leachate and recirculating it to enter the landfill again have failed: the first method is by spraying the leachate, and the second method is by distributing the leachate by trucks. This research seeks better solutions for properly disposing of MSW, where any solution will be influenced by the compositions and quantities of MSW. **Error! Reference source not found.** illustrates the fractions of MSW in West Bank[12].

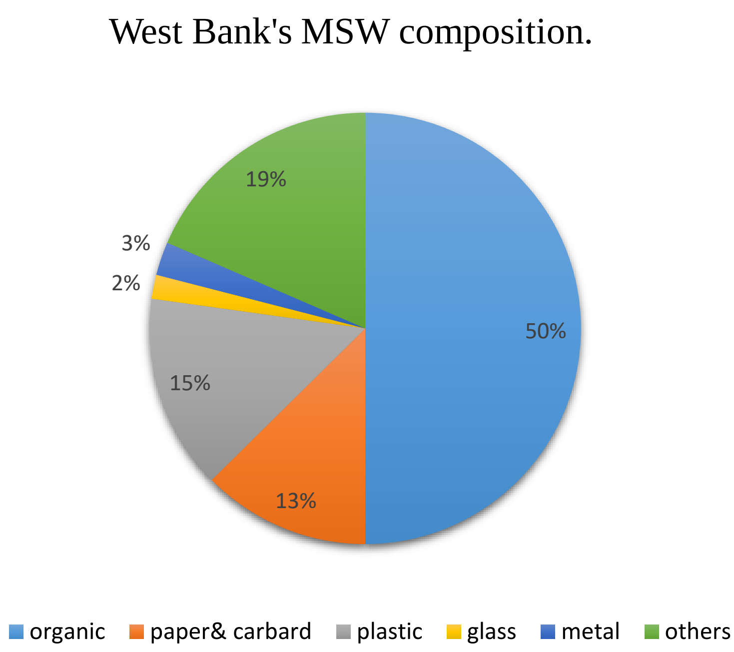

Figure 1: MSW fractions in the West Bank.

1.3 Objectives of the work

This research aims to evaluate the economic feasibility of two well-known techniques of WtE technologies by calculating the amount of potential electrical energy that would be recovered based on the characteristics of the MSW in the West Bank. The first technology, Landfill Gas to Energy (LFGtE), considers the installation of a gas collection system to collect generated methane CH4 and then uses it to generate electricity after prepping the existing landfill.

The Incineration plant, on the other hand, is the second WtE technology that considers the construction of an incineration WtE plant, which comprises three proposed scenarios related to the incineration plant. The first scenario involves all of the MSW compositions arriving at the site and being used to generate electrical power. While the second scenario entails an external recycling process before the MSW arrives at the site, this recycling process will extract all of the metals, glass, and plastic from the collected MSW. The recycling process, like the third scenario, will extract only metals and glass from the collected MSW. Furthermore, an economic analysis will be performed by using the parameters of NPV, LCOE, IRR, SPP, SIR and Aw for each technique to know where the power is and weaker viewpoint, also to help the decision-maker to take the right decision.

1.4 Scope of the work

JSCs and landfills both play critical roles in disposing of MSW generated in the West Bank, where waste collection is handled by the Joint Service Commissions (JSCs) in cities and/or villages that have already contracted with municipalities for MSW collection services. Besides, transferring MSW to transfer stations, and then the separation process, as would be done in the second and third scenarios by using the incineration WtE plant technology, are also under the responsibility of JSCs. In the end, the waste collection, transportation, and separation processes are all handled by the same commission for the two proposed WtE technologies.

After that, gate fees are paid when the MSW arrives at the site. Currently, the landfill's primary function is to receive transferred MSW from six governorates (Nablus, Jenin, Ramallah, Tubas, Qalqelia, and Tulkarem) and safely treat it by landfilling it as Zahrat Al-Finjan currently does without methane recovery.

1.5 Significance of the work

Because of the increasing amount of waste generated each year and the approaching capacity of the existing sanitary landfills, as well as the presence of many restrictions and factors that limit and prevent the work of expanding the current landfills or constructing new ones as a result of what the occupation imposes. It is necessary to find an effective solution that includes many matters that must be resolved according to the risks involved. Establishing a WtE station eliminates all current obstacles, beginning with the arrival of the Zahrat Al-Finjan landfill at full capacity, as well as the inability to expand into the A lands, getting rid of leachate's bad odors due to their presence in areas close to the surrounded population, reducing reliance on imported energy, and the possibility of obtaining large amounts of water.

1.6 Organization of the report

This research consists of six chapters including an introduction that shows the general state of the globally increasing demand for energy and generation MWS in the time. In the second chapter, the constraints, standards, and codes are related to the research. Chapter three shows a quick background of studies related to energy and MSW generation combined with WtE technologies as an effective solution. Then chapter four shows the methodology and experimental methods were used. In the end, chapter five shows the results and discussion of this research as well as the research's conclusion in chapter six.

Chapter 2: Constraints, Standards and Earlier course work

2.1 Constraints

The accuracy of utilized-based input data, which are obtained from the JSCs data book of solid waste management and a feasibility study for the WtE plant in West Bank - Palestine.

2.2 Standards

Standards of Intergovernmental Panel on Climate Change (IPCC)

2.3 Earlier course work

There is some earlier course that helped in constructing the base-knowledge of this study, such as a course of Energy and Environment, Thermodynamics, Bio-energy, Cogeneration, and Life Cycle Assessment (LCA).

Chapter 3: Literature Review

The search for alternative energy sources and increasing concerns over the generation of municipal solid waste are two widely discussed themes in contemporary academic literature.

Even in developed and developing countries, the disposal of MSW remains a contentious issue. This conflict is escalating in impoverished areas with inadequate infrastructure, limited financial resources, and improper waste disposal behavior of people who live there. For so, existing open dumpsites provide ample evidence of a lack of potential for sanitary solid waste management [13]. Open dumpsites and unhealthy landfills that do not follow sanitary landfill safety standards and regulations are vulnerable to a variety of problems, including leachate leakage and the presence of birds, rodents, and insects, all of which contribute to the spread of diseases near the landfill. Furthermore, explosions and combustion pose a public health risk, as do asphyxiation, vegetation damage, and greenhouse gas (GHG) emissions [14]. Whereas landfill gas (LFG) can significantly contribute to increasing Greenhouse Gases (GHG), which primarily consist of methane (CH_4) and carbon dioxide (CO_2), but also include ammonia (NH_3), carbon monoxide (CO), hydrogen (H_2), oxygen (O_2), and non-methane organic compounds (NMOCs) [15]. This produced biogas is the result of the physical, chemical, and microbial processes that occur in the waste. Due to the organic nature of most waste, microbial processes govern the process of biogas generation [16]. To be more specific, methane is regarded as one of the most important GHGs because its global warming potential has been estimated to be more than 25 times that of carbon dioxide and is an explosive gas with concentrations of between 5 and 15% in the air [17]. In addition, it can stay in the atmosphere for as long as 12 years [18]. Landfills and waste produce 55 million tons of methane annually [19]. As a result of growing concerns about global warming and environmental protection awareness, Landfill Gas Recovery (LFGR) technology was used and is still used to collect the produced biogas and use it to generate electrical power, as well as to minimize its contaminant effects that would release to the environment. LFGtE technology is envisioned as an integrated solution capable of meeting the needs for renewable energy and sustainable solid waste management at the same time. The lack of access to energy resources in developing countries, and the abundance of trash create other issues.

Current global municipal solid waste (MSW) generation levels are approximately 1.3 billion tons per year and are expected to increase to approximately 2.2 billion tons per year by 2025 [20].

For this, global articles were conducted to study the potential of generating power from MSW by using WtE technologies. Recently, a study analyzed energy and economically different technology types (biogas from sanitary landfills; mechanization of the organic fraction in anaerobic digesters; and combustion in incinerators) for treatment and energy recovery from Urban Solid Waste (USW) in Brazil [2]. Result assured that incineration is the most effective technology of energy generating among the other studied technologies, which equals 48.9% of the total population's consumption of the city. Also, economic viability was only confirmed for landfill gas energy recovery. Lastly, the study ensured the importance of the Government's support for providing the assist for other waste treatment technologies to be confirmed. In this context, in Malaysia, an existed landfill was performed as a case study to investigate the advanced of new WtE technologies including incineration, gasification, anaerobic digestion (AD), and Landfill Gas Recovery System (LFGRS) by evaluating the energy, economic, and environmental impacts [21]. The results showed that incineration technology provides the best MWS management in terms of environmental and economic impacts. It has the highest potential for electrical and heat production. So, it is considered to have the most net profit of selling generated electrical power, followed by AD, gasification, and LFGRS. The study also compared incineration and AD technologies, they have high electrical energy potential. But, incineration was proved to be better than AD, especially in heat production. Another study supports incineration waste treatment, in China [22], and an economic analysis study of a business case for WtE plant incineration MSW was made with an incinerator capacity of 1000 tons/day. The results confirmed that the plant has good profitability with an IRR of 12% and a simple payback period (SPP) of 11.3 years. This analysis is based on the Chinese feed-in tariff of .106 $/KWh and tipping fee of 13.04 $/ton, which are the main factors that can be controlled by the Government to make establishing a WtE plant is financial viability to the market. Another important issue was discussed, a combination of industrial and economic analysis, where it was obvious when China-made equipment is replaced by imported equipment, investment cost was reduced to about (30-35) % of the original cost. Besides, the economic analysis shows how this replacement is impacting other economic keys such as IRR is increased from 12% to 18%, and SPP is reduced from 12 to 8 years.

Whereas in European United, the EU's waste hierarchy is considered recycling as a waste treatment option is preferred over WtE recovery because of the Circular Economic (CE) expression, which focuses on the maintaining of the value of products, materials, and resources in the economy as long as possible, and including minimization of waste generation, with disregarding economic, environmental, social and health aspects of sustainability. [23] Sie Ting Tan acknowledges that following the CE waste disposal style is risky if it focuses merely on materials cycles and displays the significant role of WtE. The study demonstrated that applying the WtE plant to combust the non-recyclable waste, and recyclable waste gets to the recycling industry to fulfill the CE's target, has more benefits rather than using only recycling for waste disposal. Where founded that recycled products contain a toxic substance which affects in a bad way of environmental, social, health aspects, and economical due to other existed waste. Whereas these toxic substances reduce the quality of recycled materials, to solve this problem, the study showed that it's essential to use WtE technology besides the recycling process. Indeed, WtE technology allows the recovery of both energy and residue materials from non-recyclable waste and hence contributes to keeping materials in circulation. Other studies confirm the importance of a combination between the WtE technologies and recycling valuable waste. A case study was performed in three Swedish municipalities to show the different combinations of incineration, materials recycling of separated plastic and cardboard containers and compared with landfilling [24]. The study confirmed that recycling plastic and incinerating the rest of the waste is the most expensive recycling option but results in the lowest environmental impacts and reduced landfilling in favor of increased recycling of energy and materials leads to lower environmental impact, lower consumption of energy resources, and lower economic costs, where landfilling of energy-rich waste should be avoided as far as possible, partly because of the negative environmental impacts from landfilling, but mainly because of the low recovery of resources when landfilling. Besides, in Iran, an applicable project has mixed both WtE and the recycling process. In 2005, a study of techno-economic assessment of MSW plants was published [25]. The study discussed incineration waste treatment with three different suggested scenarios. First, consider all fractions of MSW was introduced as plant's fuel. The second scenario, which includes the extraction of the valuable fraction of MSW such as plastic, metals, and glass. The last scenario, which includes the extraction of valuable fractions of MSW with an advanced controlling level of released emissions.

Through calculating plant cost analysis, the study showed that each scenario has a different LCOE, the highest value is for the third scenario due to having the lowest heating values of waste composition, and owning additional cost of advanced environmental controlling, followed by the second scenario, then the first, respectively. This arrangement is due to the converse relationship that connects both MSW calorific value and the LCOE as was obvious in the results of the study.

Chapter 4: Methodology

4.1 MSW composition and energy content

The first step for calculating the obtainable electrical energy from waste is by evaluating the energy content En (MJ/kg) of waste as being the plant fuel. Depending on data of solid waste management of JSCs in the West Bank and Gaza [12], nearly 1200 daily tons are disposed of in Zahrat Al-Finjan landfill from different TSs in the middle and northern part of the West Bank. But, in general, all produced MWS that come from different cities and are disposed of in the landfill, have the same waste fractions as Figure 1 showed, and different energy content of each fraction. As Table 1 illustrates.

Table 1: MSW properties in West Bank.

Fraction	MWS%	En
Paper	12.6	16
Organic	50	4
Plastic	14.6	3
Glass	1.8	0
Metals	2.5	0
Textiles	18.5	19

4.2 Estimation of electrical energy potential from WtE technologies:

4.2.1 Electrical energy generation using landfill gas to energy technology

The energy potential of Landfill Gas to Energy (LFGtE) technology that can be obtained from waste anaerobic degrading is determined by the methane content of the landfill gas generated, which is determined by the methane generation potential of the waste disposed of in landfill as a primary factor. In addition, there are other factors on which methane generation depends, such as the humidity, temperature, oxygen presence, and refuse degradability[26]. As a result, it should employ a model for calculating the generated methane to assess the potential of electrical power.

4.2.1.1 LFG model

LFG models were initially developed to estimate landfill air emissions and to obtain information about future generated potential methane, especially if there is no collection system at the landfill site. In this study, a widely used model, LandGEM-v302, was chosen to estimate the predicted methane during the project's lifespan. It applies a first-order decay equation to calculate methane generation rates in units of flow (cubic meters [m3]/year or average cubic feet [ft3]/minute) or mass (Megagrams [Mg]/year). LandGEM was designed for U.S. regulatory applications, but has been used for modeling LFG collection in the U.S., in general, and also worldwide. It applies the following first-order exponential equation to estimate methane generation [26]:

$$Q_{CH4} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} K\,L0\,\frac{Mi}{10}\,(e^{-ktij}) \qquad (1)$$

Where:

- Q_{CH4} = maximum expected methane generation flow rate (m3 /yr)
- i = 1 year time increment
- n = (year of the calculation) – (initial year of waste acceptance)
- j = 0.1 year time increment
- k = methane generation rate (1/yr)
- L_0 = potential methane generation capacity (m3 /Mg)
- Mi = mass of solid waste disposed of in the ith year (Mg)
- t_{ij} = age of the jth section of waste mass Mi disposed of in the ith year (decimal years)

The LandGEM equation is used to estimate methane generation for a given year from cumulative waste disposed of up through that year.

4.2.1.2 Determining the in site constants that related to biogas generation

Even though the disposed of MSW quantities have a large impact on the potential of producing methane, both k and L_0, constant factors, have an ample effect on the output generated methane in the first-order decay equation. For this, to be more precise, interviews were conducted with the general landfill manager while the landfill site was visited to get more details about the site characterization and the following MSW management.

- The methane generation rate constant (k)

Describes the rate at which refuse decays and produces methane. At low k values, methane generation is limited because a relatively small fraction of the deposited waste decays each year and produces LFG. At higher k values, a greater percentage of waste decays and produces LFG each year, resulting in higher methane generation rates. While several factors influence the k value, it is primarily controlled by waste type (organic waste degradability) and moisture content (estimated based on average annual precipitation)[27]. As equation (2) shows:

$$K = (3.2 \times 10^{-5} \times annual\ precipitation\ (mm)) + 0.01 \qquad (2)$$

- The potential methane generation capacity (L_0)

Describes the total amount of methane gas potentially produced by a metric tonne (Mg) of waste as it decays. It depends almost exclusively on the waste composition. The higher cellulose content in refuse results in a higher value of L_0. Although the potential methane generation capacity may never be reached at sites in very dry climates, the L_0 is viewed as being independent of moisture above a certain minimum threshold. Furthermore, because calculating L_0 is dependent on variable parameters as a result of waste composition changes, the annual landfill gas emissions are also altered through L_0, which is obtained from[28]:

$$\mathrm{L0} = \frac{\mathrm{MCF} \times \mathrm{DOC} \times \mathrm{DOCf} \times \mathrm{F} \times \frac{16}{12} \times 1000}{0.714} \qquad (3)$$

Where L_0 is the generation potential, MCF is the correction factor for methane, DOC is the degradable organic carbon (fraction), DOC_f is the fraction of degradable organic carbon assimilated, F is the fraction of CH4 in the biogas, and 16/12 is the CH_4/C mass ratio; 1000 is the conversion from Mg to kg, and 0.714 is the density of methane at STP (kg/m3).

The following section described the selected equations that are used to calculate the parameters described above:

- Correction Factor for Methane (MCF)

This factor is an adjustment to the estimated biogas generation in the model which takes into consideration the degree of anaerobic degradation of waste, where there is some degradable organic carbon that does not degrade or degrades very slowly, under anaerobic conditions in the SWDS. It varies by the variation of SWD site because it depends on the depth of the waste and landfill type (management, un-management deep, un-management shallow, and unspecified site) as defined by following management practices. The following table illustrates how to choose the MCF factor[29].

Table 2: Default MCF values for site conditions factor.

Landfill type	MCF value
Managed sites	1
Unmanaged, deep sites (≥ 5m)	0.8
Unmanaged, shallow sites (<5m)	0.4
Unspecified SWDS – default value	0.6

➢ Degradable Organic Carbon (DOC)

The DOC content is expressed in equation (4) and is essential in the calculation of the methane generation, which depends on the composition of the waste and varies from city to city [30].

$$DOC = 0.40\ (A) + 0.17\ (B) + \ 0.15\ (C) + \ 0.30\ (D) \qquad (4)$$

Where default values for DOC related to A, B, C and D are as presented in Table 3:

Table 3: Default DOC values for major waste streams.

Waste Stream	DOC (by weight) in wet SW
Paper and textiles [A]	40%
Garden and park waste, and other non-food waste [B]	17%
Food waste [C]	15%
Wood and straw waste [D]	30%

➢ Fraction of Degradable Organic Carbon assimilated (DOC_f)

DOCF (fraction of degradable organic carbon that assimilated). This parameter is the portion of the DOC that is converted into biogas. The default value used by the IPCC 2006 Guidelines is 0.50 [29]. However, this factor can range from 0.42 to 0.98 at 10 C or 50 C, respectively.

➢ Fraction of CH4 in the biogas (F)

The fraction of methane in the SWDS gas is the volume fraction of produced methane. LFG from SWDS zones in the main anaerobic phase contains a composition of mainly CH4, CO2, and a large number of trace components, which pose less than 1% of volume. Usually, the fraction of methane is assumed to be 50% from the produced biogas with 50% of the CO2 fraction [29].

After introducing the model's input data that includes information about the landfill site such as annual disposal of municipal solid waste (MSW). In addition, in this study, an opening and closing year were assumed for the new landfill site's management that is going to be achieved by using new technology for generating electrical energy from the covered biogas. For thus, calculating the potential electrical energy $E_{p(LFRE)}$ that can be obtained from landfill gas using the FOD equation, equation (1), which calculates the generated biogas at the projected year due to the waste cumulatively disposed of through it. If we need to predict the total generated biogas during the waste disposed at the site, we will use the project's life span by replacing the given projection year by the year that the landfill is still receiving MSW. To begin, the amount of recovered methane (Q_R) can be calculated by multiplying the generated biogas by the collection system efficiency ($\eta_{collection\ system}$), as well as illustrated in the following equation.

$$Q_R = Q_{CH_4} \times \eta_{collection\ system} \tag{5}$$

Secondly, determining the engine efficiency (η_{engine}) that would be used to flare the recovered biogas and then generate electricity by the turbine ($\eta_{turbine}$) should be specified. Lastly, the estimated electrical energy from biogas can be obtained by the following equation (6).

$$Ep_{LFGtE} = Q_R \times 10 \times \eta_{overall\ (LFGtE)} \tag{6}$$

Where 10 is the conversion factor from 1 m3 of CH4 to 1 kWh and $\eta_{overall\ (LFGtE)}$ is the total efficiencies that would be used in the LFGtE plat regardless of whether it is turbines or engines.

4.2.2 Electrical energy generation using incineration technology

There are three options for energy harvesting from WtE plant incineration MSW. The only option considered here is electrical energy (Eele) kWh/day as aforementioned. For estimating the daily availability of Eele, two steps should be done. First, calculating the obtainable energy content (En) of a specific MSW as equation (7) illustrates. The second step is calculating potential electrical energy (Ep) generated from the incineration plant with 22% overall electric plant efficiency (η_{overall}), and 1200 tons of disposed of MSW. Using equation (8) gives potential electrical energy in kWh that could be obtained.

By using equation **Error! Reference source not found.**1), we can obtain the energy content of MSW composition in (MJ/kg).

$$E_n = \sum_{fraction=1}^{f} E_{n_{fraction}} \times MSW_{percentage} \qquad (7)$$

$$E_{p(incineration)} = \frac{Q_{MSW} \times \frac{1000kg}{ton} \times E_n \times \eta_{overall}(\text{incineration})}{EleConv} \qquad (8)$$

Where EleConv is the conversion factor from MJ to kWh and $\eta_{\text{overall (incineration)}}$ is the total efficiencies that would be used in the incineration plat regardless of whether it is turbines or engines.

4.3 Estimation of plant cost

This section of the research defines the total cost of establishing a WtE plant that will be spent, including both construction and required equipment costs for the initial investment cost. Also, operational cost, which includes staff salaries, raw materials, and other costs associated with environmental treatment and control. Lastly, maintenance costs include the periodic maintenance check for existing equipment.

4.3.1 Project costs for LFGR technology

This section investigates the cost of establishing a Landfill Gas to Energy (LFGtE) plant according to a study was done in 2010, where the landfill is already present but needs to be prepared before it can be used to generate electrical energy. However, certain conditions must be met for the project to be successful, one of which is finding an effective solution for reusing the produced leachate to reintroduce the cell. In addition, good design for the landfill should be considered before the installation of the wells. Furthermore, there will be a cost for building and installing the required wells. [Based on a feasibility study performed by international consultants at Zahrat Alfinjan landfill.]

Another study, a feasibility study, was done in the West Bank, which involved different types of WtE technologies that could be applied in Palestine[31]. The section titled "enhanced landfill gas extraction from landfills followed by electricity production" illustrates the plant's required cost, which includes landfill capping and the gas collection system with other equipment as an initial investment cost. Operating cost, on the other hand, is composed of the required annual operating cost.

4.3.2 Project costs for incineration technology

A feasibility study for establishing a WtE plant in West Bank-Palestine assumed and separated the cost of the incineration plant, which considers incinerating 1000 tons of MSW daily would cost 110 million €as a capital cost, around 20 €/ton for the plant's operating cost, and 1 million €for annual required maintenance. This estimation of the plant's cost is based on some preconditions that contribute to the construction of a typical applicable plant [31]. These estimations are taken into consideration in this research to incinerate 1200 tons/day for three proposed scenarios.

4.4 Economic performance calculations

Using alternative economic analysis to investigate the viability of a project, which is the basis for determining whether an investment in a project with a high budget will be feasible or not by using economic factors such as LCOE, which is used for calculating the cost in $/kWh of produced electric energy Eele (kWh/day), and NPV, which is used for analyzing the profitability of the project, which is dependent on the difference between the two of the present value of cash inflows (revenues) and the present value of cash outflows (total cost) over a specific period of the time. Furthermore, IRR is used to estimate the maximum profitability percentage of a potential investment. In addition, the saving to Investment Ratio (SIR) tells whether a project that will save money in the future is worthwhile or not, determining whether the potential savings outweigh the initial investment. These economic factors were used in equations (9) - (13).

$$LCOE = \frac{\sum_{n=1}^{N} \frac{In + Fn + OMn}{(1+i)^n}}{\sum_{n=1}^{N} \frac{\text{Eele}}{(1+i)^n}} \tag{9}$$

$$NPV = \sum_{n=1}^{N} \frac{Rt - (In + Fn + OMn)}{(1+i)^n} \tag{10}$$

$$NPV = 0 = \sum_{n=1}^{N} \frac{Cn}{(1+r)^n} \tag{11}$$

$$SIR = \frac{\sum_{n=1}^{N} \frac{Rt}{(1+i)^n}}{\sum_{n=1}^{N} \frac{(In + Fn + OMn\ )}{(1+i)^n}} \tag{12}$$

$$Spp = n - 1 + \frac{CNCF\ n - 1}{NCF\ n} \tag{13}$$

4.5 Fund structure

It was assumed that a debt ratio of 70% of the original capital cost would be obtained from an investor or company willing to invest in this project, with a debt payback period of 10 years and a debt discount rate of 5%, to build a WtE station for treating MSW.

When the station begins selling electrical energy, the debt will be repaid through annual payments from the station's total revenues. Equation (14) illustrates how to calculate the annual payment.

$$AW = P \times \frac{i \times (1 + d)^{Nd}}{(1+d)^{Nd} - 1} \tag{14}$$

4.6 Revenues

The designed plant has two income sources -total revenues (Revt)-. The first source is Rev_{ele}, which is revenue generated from the sale of daily produced electrical energy E_{ele} kWh/day. As shown in equation (15), annual electricity revenues in $could be obtained from annual electrical energy per year by converting daily production to annual and using the feed-in tariff factor ($/kWh), which equals 0.4 Nis/kWh and 0.117 $/kWh. The other source, Rev_{fee}, is revenues that come from gate fee payments, where municipalities pay for each ton disposed of their MSW to be treated in a landfill ($/ton). Annual revenues from MSW gate fees could be calculated using equation (16), where QMWSn is the number of tons of MSW disposed of each year.

$$Rev_{ele} = \sum_{n=1}^{N} E_{ele} \times feed\ in\ tariff \times 365 \qquad (15)$$

$$Rev_{fee} = \sum_{n=1}^{N} Q_{MSW} \times gate\ fee \qquad (16)$$

$$Rev_{total} = Rev_{ele} + Rev_{fee} \qquad (17)$$

Chapter 5: Results and Analysis

5.1 Rapid increase in MSW generation

The sheer amount of waste generated is a problem if it is not treated or disposed of improperly. If that is done, the environment will be harmfully affected. The number of the population is yearly increasing. Consequently, the amount of generated waste will be increasing. The rate of production could reach 1,012,429 tons annually in 2043. As shown in Figure 2, it has become necessary to find a method that works on treating waste to achieve our main goal of reducing the amount of waste generated. Motivating factors such as a lack of energy resources and the absence of projects that could support the West Bank's internal economy could be incentives for establishing the WtE plant and generating electricity through it, reducing reliance on Israeli energy imports.

Indeed, waste compositions could be an indication of how industrialized a country is. In developed countries, the non-organic fractions are more the organic fractions, which indicates a high ratio of industrial generated waste. In contrast, developing countries usually have a high ratio of organically generated MSW due to lower industrial production. Nevertheless, the waste compositions are influenced by other factors such as climate, the progress of development, energy resources, and the prevalent lifestyle of society. Accordingly, energy content and the potential of producing electrical energy are dependent on varying both waste compositions and net waste calorific value. Figure 3 can illustrate West Bank MSW fractions and their energy compositions.

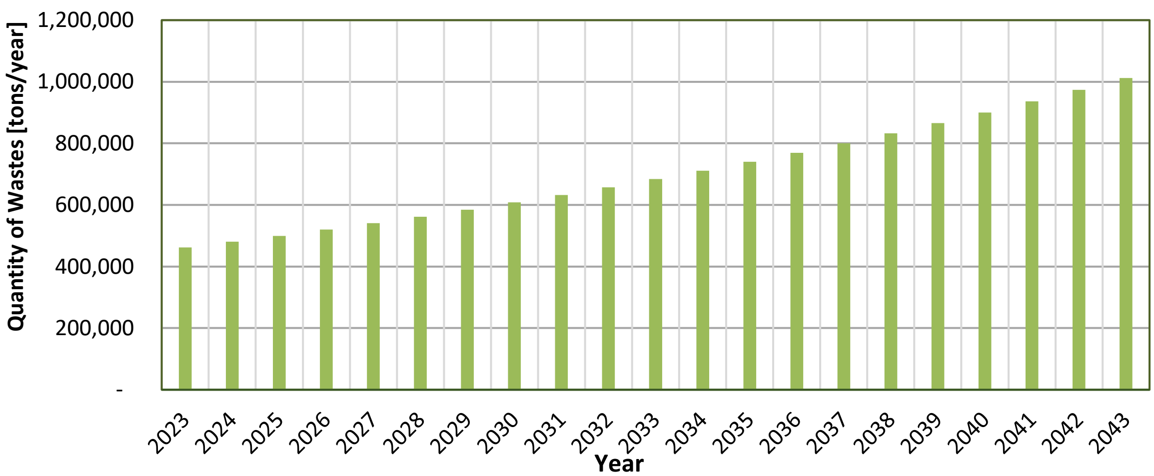

Figure 2: Increasing of MSW generation.

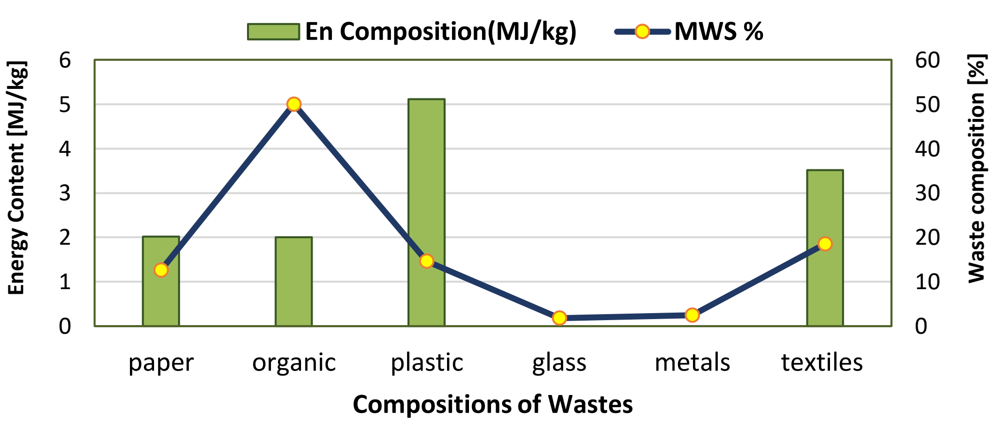

Figure 3: MSW fractions and their energy content in the West Bank area.

5.2 Potential energy and economic analysis for WtE technologies

In this section, the main research goal is illustrated by assessing the economic analysis of the proposed WtE technologies to select one of them and use it to manage the generated MSW in the West Bank, specifically at Zahrat Alfinjan landfill. Each WtE technology demonstrates the capacity that is dependent on and how the MSW composition plays a primary role in the used WtE technology, whether it is in the form of methane generated as in the LFGtE technology or the amount of energy contained as in the incineration plant.

Table 4: Constants were considered in assessing the proposed WtE technologies.

Common assumptions in all WtE technologies	
Feed-in tariff [$/kWh]	0.1171
Gate fees [$/ton]	8
Hurdle Rate (MARR)	12%
n [year]	30

As Table 4 illustrates, the desired feed-in tariff is 0.1171 $/kWh, which sets the price of produced electrical energy that the plant would use to sell the electricity as a plant income source. Furthermore, as is already happening in the landfill understudy, gate fees are the obvious second revenue source that a plant would gain by receiving MWS from JSCs. Besides, a minimum attractive rate of return is taken into consideration while performing the economic analysis to be a revenue percent who has participated in the project's initial investment during the lifespan of the plant.

5.2.1 Potential energy and economic analysis for LFGtE technology

This research zone is for using the generated methane gas CH_4, which is produced as a result of the biodegradation of organic waste during the anaerobic digestion process that occurs inside the landfill, to generate electrical energy and to detect what the long-term potential of electrical energy could be obtained by installing the landfill gas collection system on the site. Furthermore, some assumptions were used in the analysis, which should be mentioned.

Table 5: Assumptions were considered in LFGtE technology's financial analysis.

Parameter	Assumption
Dept ratio	50%
Dept discount	5%
Dept payment time	5
1 m^3 CH4 to kWh	10
Gas collection system η	80%
Overall plant η	33%

About the annual generated LFG from landfill, after entering the required inputs data to the program, the LandGEM model provided a predicted value of methane generation for (2022-2052) as the plant's lifespan is assumed. Table 6 shows the results of predicted CH_4 gas.

Methane recovery estimation

As above mentioned, the LandGEM model was used for predicting the produced methane CH_4 from the site. Although the program provides default values for k and L_0, which can be dependent on whether the site's input data is not enough to be used, both k and L_0 were calculated in this research according to the site characterizations including the waste type, moisture content (estimated based on average annual precipitation), and the climate to give a more accurate analysis were equals 0.016/year, and 93 m^3 /Mg, respectively.

Table 6: Predicted methane by using the LandGEM model.

Predicted year	Accumulated Methane m^3/year
2023	647,075.13
2037	11,747,036.14
2051	29,871,305.20
2052	29,965,341.27

The results of the methane estimated amount revealed that in 2022, which is the first year of operation of the plant, the program assumed that methane gas could not be obtained through that year. After a year, the plant generated methane gas at a rate estimated to be 647,075.13 m^3 in the second year, which is the first year it could generate electrical power.

After fifteen years of operation, the generated methane gas equals 11,747,036.14 m^3, indicating that output is widely increasing. At the end of 2051, when the plant has completed its life cycle at a rate estimated to be 29,871,305.20 m^3. One year after, in 2052, the peak of methane generation would be obtained at a rate estimated to be 29,965,341.27 m^3, and then the generation would decrease exponentially after the site closure caused by the decreasing of the amount of decomposable waste in the landfill.

The collection system efficiency was considered to be 80%, whereas the typical efficiency ranges from 50 to 95 percent according to EPA for LandGEM modeling [32]. Furthermore, the overall plant efficiency is considered to be 33%[33]. Figure 4 shows the annual m^3 of methane production.

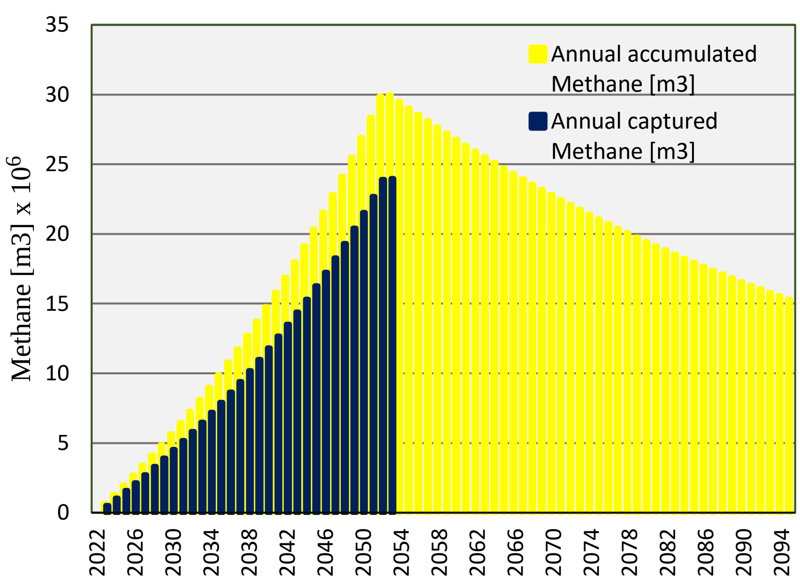

Figure 4: Annual accumulated and captured methane in Zahrat Alfinjan landfill.

Electrical energy recovery estimation

The amount of potential electrical energy that can be generated from the plant is reliant on the amount of MSW tons and consequently on the amount of captured methane (which depends on the collection system effectiveness) as a result. Also, the amount of kWh from 1

m^3 of CH4 could be obtained. Furthermore, the overall efficiency of the total equipment used to generate energy on the site, whether it is engines or turbines, influences the final amount of potential electrical energy. Figure 5 illustrates the amount of potential electrical energy that could be recovered.

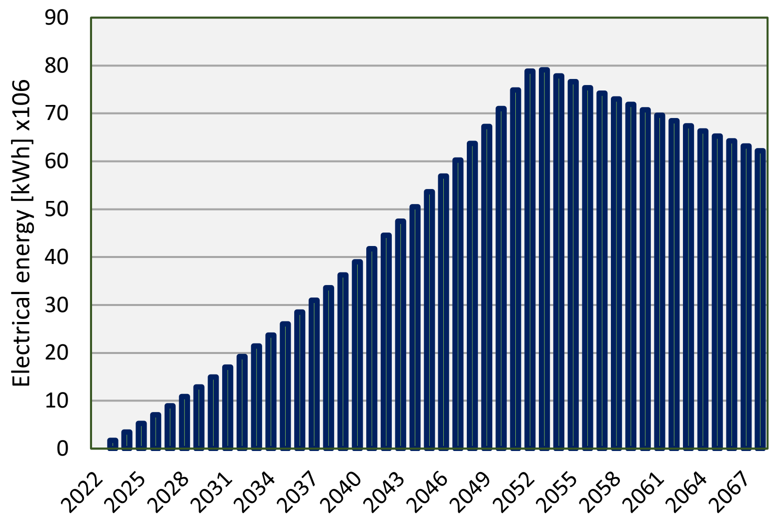

Figure 5: Annual electrical energy potential [GWh] in Zahrat Alfinjan landfill.

From Figure 5, it is obvious that electrical energy increases with increasing the amount of produced methane gas up to the end of landfilling the generated MSW. For this, in 2052, the methane generation rate arrives at its peak level of LFG generation, where the potential electrical energy is estimated to be 79 GWh. Otherwise, the amount of potential electrical energy will decrease to 68 GWh at the end of 2062 when the landfill stops disposing of the MSW and waste biodegradation is halted as a result. On the other hand, 68 GWh, which is the amount of produced electrical energy during the period (2053-2068), is considered as a lost massive amount of energy when the generation is only dependent on the plant's life span (2022-2052) to generate electricity. However, exploiting this huge amount of energy will increase the costs involving the additional cost of the new equipment which would be used.

5.2.2 Potential energy and economic analysis for incineration technology

In this section, this research has chosen Zahrat Alfinjan landfill to establish the WtE combustion plant as a case study for doing and investigating economic analysis. As mentioned before, the recycling process would not be done inside the plant and the generated waste would be sorted before entering the plant. Because of that, the economic analysis would only include electricity sales and tipping fees as the plant's two incoming profit sources, with no recycling profit. Furthermore, the following assumptions were also used in conducting the financial analysis for three WtE combustion plant's suggested scenarios.

Table 7: Assumptions were considered in incineration WtE financial analysis.

Common constants in all scenarios			
Debt ratio	70%		
Debt discount rate	5%		
Debt period [years]	10		
Plant overall efficiency η	22%		
Different values related to each scenario			
Plant capacity [tons]	1200	974.4	1148.4
En [MJ/kg]	12.6	9.2	13.2
Total potential Eele [GWh/day]	337	201	338

Electrical energy recovery estimation

Based on these assumptions, economic analysis was performed for three scenarios with three different tons of capacity. It was obvious that plant capacity is an independent input factor, which other output factors are dependent on it, where any differentiation of plant capacity would cause a variation of some sensitive factors including the initial investment, waste energy content, and consequently, the produced electrical energy, as the above table illustrated.

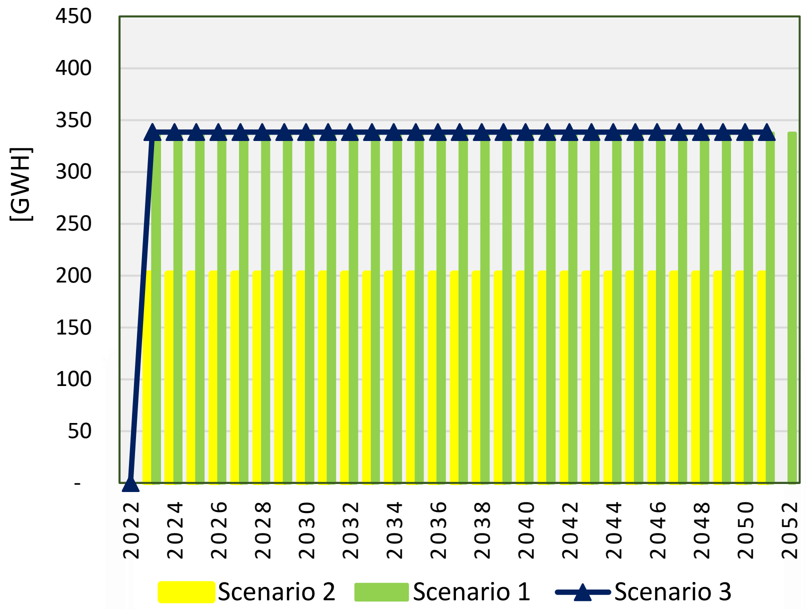

Figure 6: Annual produced electrical energy from the incineration WtE's scenarios.

Receiving a specific amount of generated MSW in each scenario is caused by having a constant amount of produced electrical energy annually, which could be confirmed by Figure 6. For that, scenario 1, which has a capacity of 1200 tons, would produce 337 GWh annually. In contrast, scenario 2, which has a capacity of 974 tons due to the extraction of plastic, metals, and glass, would produce 201 GWh annually. While the production in scenario 3 would be 338 GWh annually with a capacity of 1184 tons caused by the extraction of merely metals and glass.

5.3 The economic comparison of LFGtE and incineration WtE technologies for MSW treatment plant

Utilization of the generated MSW to actively recover value from waste in the form of materials and energy has been encouraged worldwide. For that, many kinds of research have been conducted to evaluate the impact of WtE technologies from an economic and environmental point of view and subsequently assess the potential of each technology for energy uses and carbon reduction. In this research, two WtE technologies for establishing an MSW treatment plant, LFGtE and incineration plant, have been studied to investigate the potential of producing electrical energy while MSW is being managed. However, each WtE technology has conditions that make it economically viable; for example, while the use of incineration plant WtE technology is financially feasible in some parts of the world, it may not be in others, and so on for other WtE technologies. Furthermore, the country's policies and regulations, which are dependent on the government regarding MSW management methods of disposal, in the same time are considered one of the most sensitive factors that influence the feasibility of WtE technologies, play a critical role in selecting the appropriate technology that will be used and in preparing the market to deal with various types of waste treatment.

In this section, the financial results for each proposed WtE plant technology at Zahrat Al-Finjan landfill have been obtained. Table 8 below depicts three different fundamentals on which the scenarios rely: capacity and capital cost, amount of produced electricity, and profitability factors.

Table 8: Financial results for proposed WtE plant technologies.

	LFGtE	INC/Scenario 1	INC/Scenario 2	INC/Scenario 3
Capacity and capital cost				
Plant capacity [tons]	1200	1200	974.4	1148.4
Initial investment [$]	9,730,000	157,990,800	128,288,530	151,197,196
Produced electricity				
Total potential Eele [GWh]	1,052.13	10,455.06	6,256.63	10,489.89
Profitability factors				
NPV [$]	26,528,619.79	95,443,014.54	40,317,185.13	132,607,947.22
LCOE [$/kWh]	0.1065	0.0883	0.1044	0.0723
IRR [%]	53.89%	35.85%	25.46%	51.12%
SPP [year]	2.08	2.79	4.5	1.5
SIR [%]	3.04%	1.44%	1.29%	1.71%
Aw [$]	3,293,359.89	11,848,644.91	5,005,122.82	16,462,435.59

This table provides an obvious differentiation through the expected economic performance of the studied WtE Technologies that combine the potential of electricity and the profitability factors as main parameters that will contribute to choosing the suitable scenario. Thus, based on the assumptions previously discussed, all scenarios are expected to enter with specified capacities of 1200 tons, except for the second and third incineration plant scenarios, which include external recycling processes, reducing the capacities to 974 and 1184 tons, respectively. From this point, it is discovered that LFGtE and INC/scenario1 have the same capacity, this putting them closer to being compared, whereas INC/scenario2 and INC/scneraio3 rely on the recycling process to reduce the incomed MSW to the site, putting them as far away from being compared to other treatment plants with 1200 capacities.

Many differences can be observed when using the LFGtE or incineration WtE plant as MSW treatment process from procedures and outputs aspects, such as complexity, resource stability, volume waste reduction, plant initial investment, potential electrical energy, and the plant revenues.

- **Complexity**

The installation of a waste incineration plant helps to reduce the amount of waste that is landfilled in an existing Zahrat Alfinjan landfill waste management system, which currently lacks a method for energy recovery from waste. However, the incineration plant is considered more complex than the LFGtE recovery plant where it needs more complex types of equipment in addition to entire control systems for monitoring the whole process, especially the flue gasses and residual ash as process's resultants. Besides, depending on the incineration plant as treatment MSW process in the West Bank requires new policies and regulations to govern the disposal of incineration resultants including the ash as well as flue gas emissions to be at the desired threshold safety levels. Otherwise, using the LFGtE recovery plant is simpler to implement because of the landfill and the regulations that already exist. Also, the produced leachate is already being treated. Thus, establishing the LFGtE plant merely needs to be updated to comprise the collection systems to recover the energy.

- **Resource stability**

The possibility of relying on the plant as a constant resource of supply, the amount of produced kWh per day, is considered a sensitive factor in investing in WtE plants for MSW treatment. However, the incineration plant provides a stable resource of electrical energy in contrast to the LFGtE plant which produces an unstable amount of daily electrical energy due to the continuous waste decomposition processes that occur at different periods depending on the methane generation rate coefficient for each waste composition type.

- **Volume waste reduction**

The potential of volumetric reduction of the MSW is highest by using an incineration plant where the reduction can reach 90% of total waste volume. On the other hand, the LFGtE recovery plant would depend on pressuring the generated MSW for volumetric reduction, which is reduced to approximately 20% of total volume waste.

- **Plant initial investment**

The LFGtE plant has the least initial investment cost for treating the MSW. This is related to less required complicated pieces of equipment, fewer construction costs, less needed procedures, installation, and financing, and consequently lower labor wages unlike the requirements of the incineration plant.

- **Potential electrical energy**

The total amount of produced electrical energy clearly distinguishes LFGtE and the incineration plant for treating the generated MSW, whereas the total amount of electrical energy produced by the incineration is ten times greater than that produced by the LFGtE recovery plant, as illustrated in INC/scenario 1 versus LFGtE plant. This occurs due to the high capacity of energy contents that MSW compositions have in the combustion process, unlike the methane generation rate and the potential of generation methane rate during the MSW decaying in the LFGtE plant.

- **Plant revenues**

Economic performance for each WtE plant shows the potential revenues of the plant in form of profitability factors. However, as a result of differentiated required initial and O & M costs for each LFGtE and incineration WtE plant, the revenues will also be differentiated. The profitability factors comprise the NPV, LCOE, IRR, SPP, SIR, and Aw.

- Net present value (NPV)

Which is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project. For establishing a WtE plant for treating the generated MSW, the net plant's revenues are more than three times greater than the LFGtE plant by the incineration plant. However, this significant difference is influenced by parameters such as total costs and revenue generated by each WtE technology.

- Levelized cost of electricity (LCOE)

Using the LCOE for investment planning and comparing the different methods of electricity generation measures the net plant costs and the amount of generated kWh that can be obtained from different resources. Because of this, LCOE produced by the incineration plant is less than that produced by the LFGtE plant, which means that the potential electrical energy revenues in the incineration plant are higher than revenues by the LFGtE plant. However, when considering the desired level of LCOE, 0.1171 USD/kWh, it becomes obvious that both WtE technologies are economically feasible and viable whereas the produced LCOE is under the desired level.

- Internal rate of return (IRR)

An annual return indicator, which forms the actual profitability potential of the investment. Thus, the higher the IRR, the higher the potential for returned revenues. The IRR in the incineration plant indicated that investing in the incineration WtE technology can yield approximately 35% of the potential annual return, as illustrated in INC/scenario 1. While the investment yields at the LFGtE plant give an IRR of approximately 54% of the potential annual return.

- Simple payback period (SPP)

The payback period refers to the amount of time it takes to recover the cost of a specific investment. Therefore, the desirability of an investment is directly related to its payback period. Whereas the shorter payback periods mean more attractive investments. Thus, investing in LFGtE technology may be more attractive rather than investing in incineration WtE technology which can need more time to return its initial cost.

- Saving to investment ratio (SIR)

SIR, benefits to cost ratio, which is an indicator that tells all stakeholders whether a project will be cash-flow-positive or is not. Thus, the higher SIR, the higher the total revenues that the plant achieves over its whole lifespan. However, the net revenues of investing in LFGtE technology are three times greater than its original cost. On the other hand, the net revenues of investing in incineration technology are only 44% of its original cost.

- Annual worth (Aw)

Aw proves the calculated annual revenues from that plant would be dollars per year, which is a uniform annual worth of all estimated receipts (income) and disbursements (costs) during the life cycle of a project. As a result, when the NPV of a project is high, the Aw is also high.

In contrast, there is also a significant differentiation between the proposed scenarios for establishing an incineration WtE plant. Although INC/Scenario 3 is similar to INC/Scenario 1 in terms of incinerator volume and the total amount of produced electrical energy, the profitability factors are vastly different. On the other hand, the incinerator volume for INC/Scenario 2 would be smaller, resulting in a lower total amount of produced electrical energy. Because of this, choosing the perfect scenario for using incineration technology for MSW treatment becomes as easy as possible to be accurately selected by depending on the profitability factors. In the end, two profitability factors can be dependent on determining the suitable incineration scenario, IRR and LCOE, which have been calculated in each case. As previously mentioned, all alleged incineration scenarios have an IRR greater than the assumed rate, making them financially viable with a different ratio of annual return revenues. Furthermore, all of them have a level of LCOE that is lower than the desired level of LCOE, implying the possibility of receiving resources over the life cycle plant by selling electricity at different ratios for three scenarios. Finally, INC/Scenario 3 demonstrated it is worthy, which is considered the most economically viable compared to INC/Scenario 1 and INC/Scenario 2. As a result, it has the lowest LOCE while also having the highest IRR.

5.4 Sensitivity analysis

While calculating the profitable factors, it was obvious that there are uncertainty factors that could change these factors, consequently changing the decision indexes. For that, it is necessary to know how the uncertainty factors influence the economic analysis to be well controlled. Whereas any variation of profitable factors can transfer an economically viable project to an unviable, in contrast. Examples of the considered uncertainty factors:

5.3.1 Feed-in tariff and tipping fees

In the three proposed scenarios, the income of the WtE plant comes from electricity sales and the tipping fee of MSW. Both feed-in tariff and tipping fees are dominated by the Government, which could directly affect the income and cash flow, which leads to a variation of profitability factors specially IRR. For example, when the feed-in tariff increases to 0.123 $/kWh, IRR increases to 21.9%. In contrast, when the feed-in tariff decreases to 0.111 $/kWh, IRR decreases to 20%. Similarly, when the tipping fee increases to 9 $/ton, IRR increases to 20.7%, and when the tipping fee decreases to 7 $/ton, IRR decreases to 20% as shown in figures 7 and 8 When the profitability is stronger, IRR is higher.

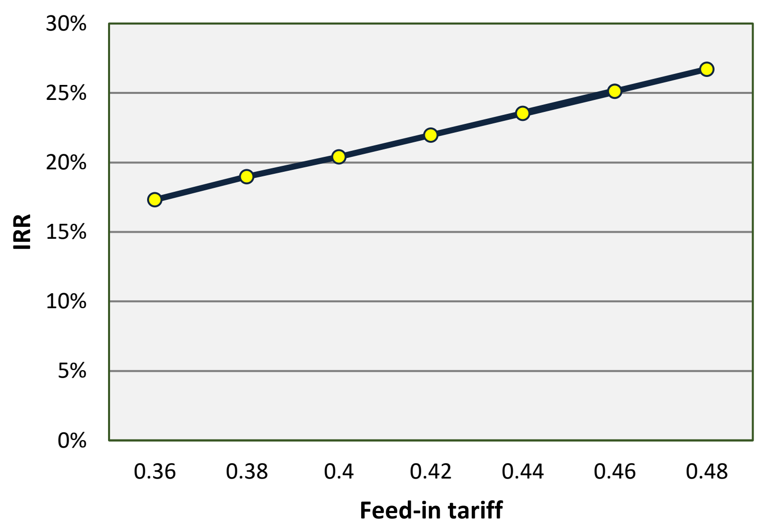

Figure 7: The influence of feed-in tariff on IRR.

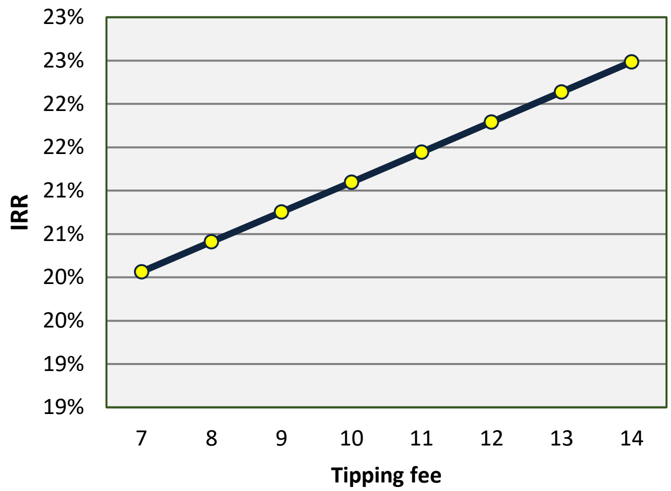

Figure 8: The influence of tipping fee on IRR.

5.3.2. Debt discount rate

The debt discount rate can influence the financial expenditure and expenses, and consequently influences the LCOE and IRR of the WTE plant. Where it is found, the higher of debt discount rate, the higher LCOE, and the lower IRR. For example, when the debt discount rate increases to 7%, LCOE increases to 0.106 $/kWh, in the same ratio, IRR decreases to 29%.

Figure 9 shows how the debt discount rate affects LCOE and IRR. Nevertheless, the occurred influence of increasing is a little variation. Where changing in IRR through debt discount rate is less compared with feed-in tariff and tipping fees.

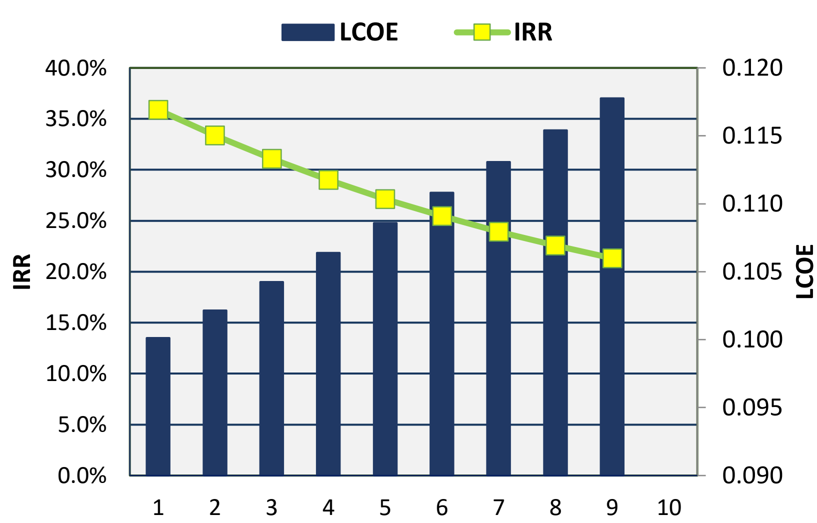

Figure 9: The influence of debt discount ratio on LCOE and IRR.

5.3.3 Debt repay period

As time goes on, the net profit of the plant increases yearly because of that, repay debt annual payments during a longer period makes it easier due to the difference between the out cash flow (debt payments and O&M costs) and in cash flow (net revenues), which increases annually and consequently affects both of LCOE and IRR. Where a longer debt period means higher IRR and lower LCOE. As Figure 10 shown. However, the ability to repay debt payments is strong for a WtE project, where the project can guarantee its capability to repay both principles and interests payment.

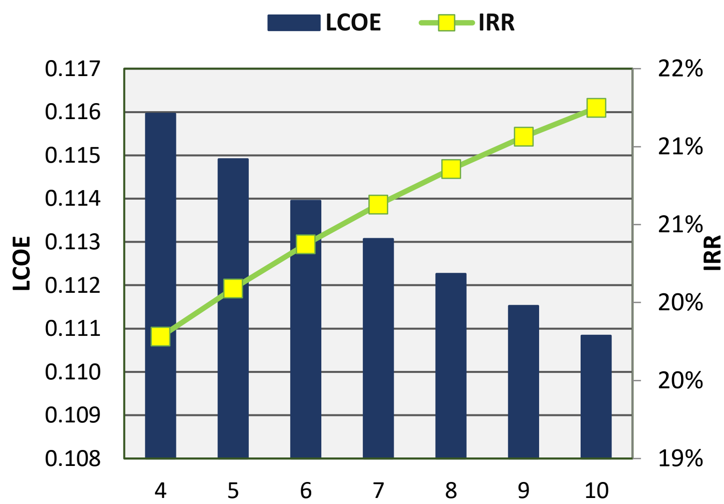

Figure 10: The influence of debt repay period on LCOE and IRR.5.3.4 Debt ratio

5.3.4 Debt ratio

The Debt ratio could influence the LCOE and IRR of the WtE project. When the debt ratio decreases to 30% of the total project, IRR decreases to 19%, and LCOE increases to 0.117 $/kWh. In contrast, when the debt ratio increases to 80% of the total project, IRR increases to become 27%, and LCOE decreases to 0.105 $/kWh. As Figure 11 shows. Thus, the Debt ratio can influence the LCOE and IRR of the WtE project. If the project has low finance due to fewer investors' participation, they may aim for a high debt ratio, even if it comes from a bank or a new investor/sponsored company. In this way, they could increase the IRR of the project.

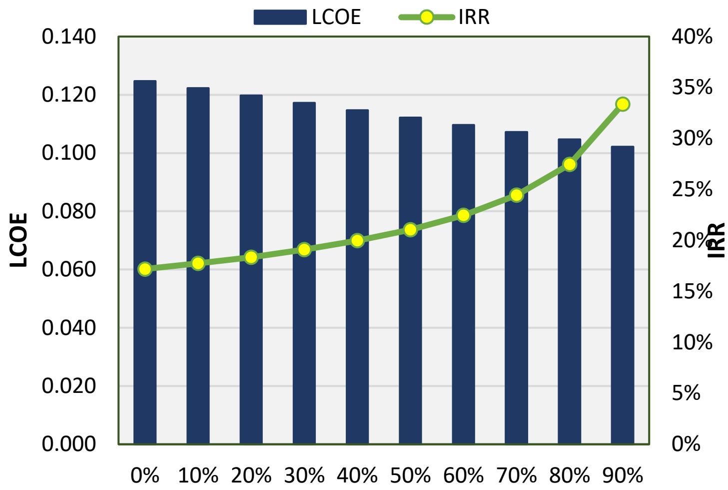

Figure 11: The influence of debt ratio on LCOE and IRR.

5.3.5 High heating value and Plant electrical efficiency

HHV or energy content and plant electrical efficiency are the main reasons that could affect the income from electricity sales, and consequently, directly influence the profit and economic effects such as LCOE and IRR. As Figure 12 and Figure 13 show, IRR increases to 23.1%, 21.8% when HHV and plant efficiency increases to 14,000 MJ/ton, and 23%, respectively. Similarly, LCOE decreases to 0.1037 $/kWh and 0.1068 $/kWh when HHV and plant efficiency increases to 14,000 MJ/ton and 23%, respectively. Both LCOE and IRR have a proportional relationship with HHV and plan electrical efficiency.

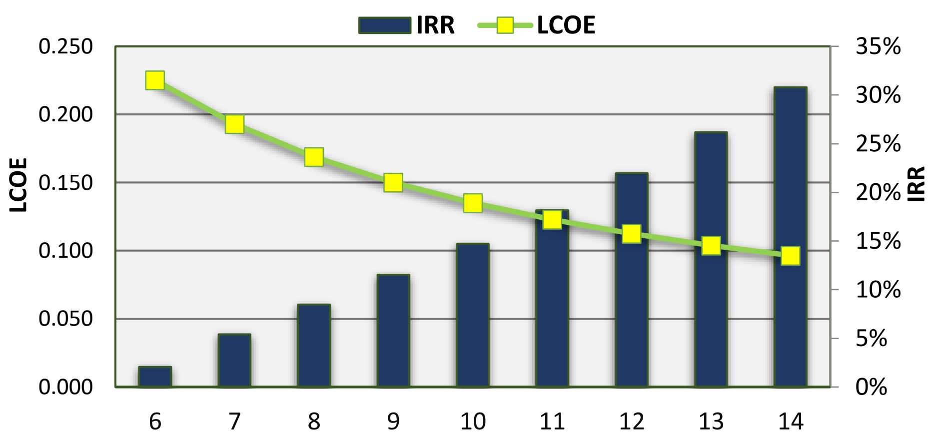

Figure 12: The influence of HHV on LCOE and IRR.

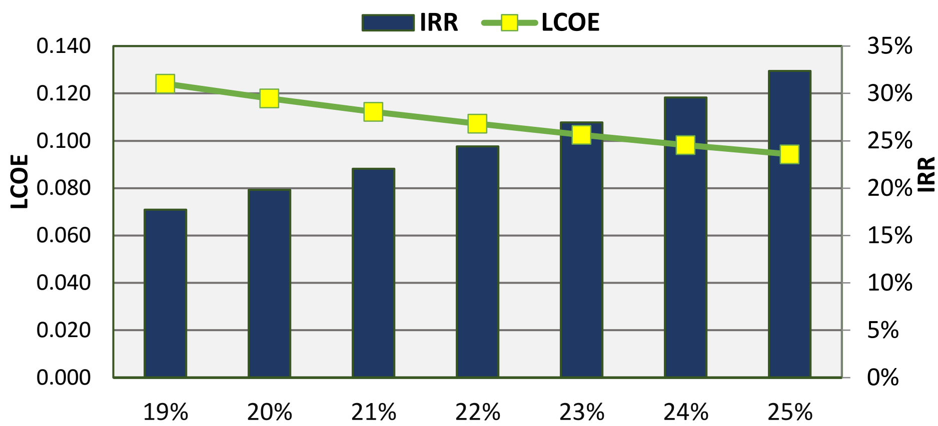

Figure 13: The influence of plant efficiency on LCOE and IRR.

5.3.6 MARR

The MARR or interest rate set as a revenue ratio by project investors may have an impact on the LCOE of the WtE project. When the MARR decreases to 10%, LCOE would be less than 0.11 $/kWh, but increasing MARR to 18%, LCOE would be more than 0.13 $/kWh. This means the higher MARR is, the higher LCOE is. As shown in Figure 14.

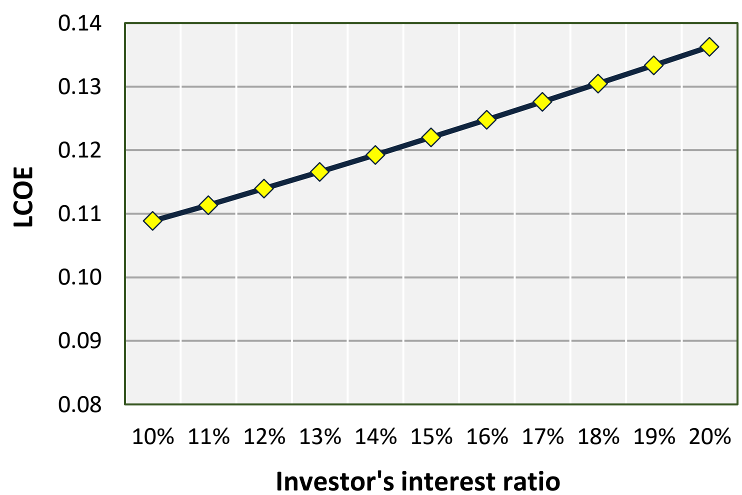

Figure 14: The proportional relationship between MARR and LCOE.

Chapter 6: Conclusion and Recommendations

The followed MSW management system in the West Bank faces challenges and obstacles, the most significant of which are the restrictions imposed on arrival to land A, which means that no proposed solutions for expanding an existing landfill or establishing a new sanitary landfill are applicable. Two of the West Bank's sanitary landfills are overloaded. Besides, the increasing growth rate of generated MSW, which increases 4% annually, has become necessary to provide sustainable solutions. Virtually, PA and interested authorities found that building a WtE plant is an effective solution for generated MSW management, where EQA put a strategic plan (2017-20201) that included policies and strategies that support establishing a WtE plant as being a promised solution, which is supposed to be in the Zahrat Al-Finjan landfill, which is overloaded.

This research included a feasibility analysis for establishing a WtE plant with two suggested technologies as a potential MSW treatment method in the West Bank, specifically at the Zahrat Alfinjan landfill, over a 30-year lifecycle. The first technology was the establishment of the LFGtE recovery plant to generate electrical energy by using the produced LFG. While the second technology was the establishment of an incineration WtE plant to generate electrical energy through three proposed scenarios which are: scenario 1 to incinerate 1200 tons of daily MSW with all contained fractions, scenario 2 to incinerate 974 tons of sorted MSW from valuable plastic, metals, and glass, and scenario 3 to incinerate 1148 tons of sorted MSW from only metals and glass. Thus, when considering the variation in MSW receipted capacity, the results revealed that the amount of total produced electrical energy that could be obtained from the two WtE technologies is as follows: 1 GWh from the LFGtE plant, 10 GWh from the first scenario of incineration, and 6, and 10 GWh from the second and third scenarios of incineration, respectively. Furthermore, economic profitability factors NPV, LCOE, IRR, SPP, SIR, and Aw have been calculated for both WtE plants. The results revealed that differentiation was obtained for each treatment method, with the NPV, LCOE, IRR, SPP, SIR, and Aw for the LFGtE plant being 26 million dollars, 0.1065 USD/kWh, and 54%, 2 years, 3%, and 3 million dollars, respectively. That is 95 million dollars, 0.0883 USD/kWh, 35%, 2.8 years, 1.44%, and 11 million dollars for the first incineration scenario. Whereas 40 million dollars, 0.1044 USD/kWh, 25%, 4.5 years, 1.29%, and 5 million dollars and 132 million dollars, 0.0723 USD/kWh, 51%, 1.5 years, 1.71%, and 16 million dollars, respectively, for the second and third incineration scenarios.

The findings showed that the three scenarios related to the establishment of an incineration WtE plant have a high response to changing uncertainty factors, particularly the debt ratio, HHV, and both feed-in tariff and tipping fees, where these factors have a direct impact on net profit and plant income. Thus, it could be possible to obtain a higher value of net profit by optimizing these uncertainty factors. Where it is found, having a high debt ratio means that the risk of the government will be less and the plant will obtain higher annual returned revenues, IRR. Another controllable factor is HHV, where increasing the energy content of MSW compositions could be accomplished through suggested considerations such as pre-drying organic fractions of MSW by exposing them to sunlight. Furthermore, the Palestinian Government plays a primary role by providing incentives to support these projects, such as buying the produced electricity and setting the level of desired feed-in tariff and tipping fees, which are the main factors that could highly affect the plant income. With these incentives, the government can control the market for establishing WtE projects efficiently.

References

[1] M. Asif and T. Muneer, “Energy supply, its demand and security issues for developed and emerging economies,” *Renew. Sustain. Energy Rev.*, vol. 11, no. 7, pp. 1388–1413, 2007, DOI: 10.1016/j.rser.2005.12.004.

[2] R. E. dos Santos, I. F. S. dos Santos, R. M. Barros, A. P. Bernal, G. L. Tiago Filho, and F. das G. B. da Silva, “Generating electrical energy through urban solid waste in Brazil: An economic and energy comparative analysis,” *J. Environ. Manage.*, vol. 231, no. September 2018, pp. 198–206, 2019, DOI: 10.1016/j.jenvman.2018.10.015.

[3] S. Ghanimeh, M. El Fadel, and P. Saikaly, “Mixing effect on thermophilic anaerobic digestion of source-sorted organic fraction of municipal solid waste,” *Bioresour. Technol.*, vol. 117, pp. 63–71, 2012, DOI: 10.1016/j.biortech.2012.02.125.

[4] P. T. T. Trang, H. Q. Dong, D. Q. Toan, N. T. X. Hanh, and N. T. Thu, "The Effects of Socioeconomic Factors on Household Solid Waste Generation and Composition: A Case Study in Thu Dau Mot, Vietnam," *Energy Procedia*, vol. 107, no. September 2016, pp. 253–258, 2017, DOI: 10.1016/j.egypro.2016.12.144.

[5] C. S. Burke, E. Salas, K. Smith-Jentsch, and M. A. Rosen, "Measuring macro-cognition in teams: Some insights for navigating the complexities," *Macrocognition Metrics Scenar. Des. Eval. Real-World Teams*, pp. 29–43, 2012, DOI: 10.1201/9781315593173-4.

[6] L. A. Guerrero, G. Maas, and W. Hogland, “Solid waste management challenges for cities in developing countries,” *Waste Manag.*, vol. 33, no. 1, pp. 220–232, 2013, DOI: 10.1016/j.wasman.2012.09.008.

[7] Z. Minghua *et al.*, “Municipal solid waste management in Pudong New Area, China,”

Waste Manag., vol. 29, no. 3, pp. 1227–1233, 2009, DOI: 10.1016/j.wasman.2008.07.016.

[8] K. A. Kalyani and K. K. Pandey, “Waste to energy status in India: A short review,” *Renew. Sustain. Energy Rev.*, vol. 31, pp. 113–120, 2014, DOI: 10.1016/j.rser.2013.11.020.

[9] S. Kumar, “Technology Options for Municipal Solid Waste-to-energy Project,” *TERI Inf. Monit. Environ. Sci.*, vol. 5, no. 1, pp. 1–11, 2000, [Online]. Available: http://www.pssurvival.com/ps/Gasifiers/Technology_For_Municipal_Solid_Waste-To-Energy_2000.pdf.

[10] A. Tozlu, E. Özahi, and A. Abuşoılu, “Waste to energy technologies for municipal solid waste management in Gaziantep,” *Renew. Sustain. Energy Rev.*, vol. 54, pp. 809–815, 2016, DOI: 10.1016/j.rser.2015.10.097.

[11] R. A. Tayeh, M. F. Alsayed, and Y. A. Saleh, “The potential of sustainable municipal solid waste-to-energy management in the Palestinian Territories,” *J. Clean. Prod.*, vol. 279, p. 123753, 2021, DOI: 10.1016/j.jclepro.2020.123753.

[12] S. Abu Muferreh, *Solid Management of Joint Services Councils West Bank and Gaza*. 2019.

[13] M. Salem, K. Raab, and R. Wagner, “Solid waste management: The disposal behavior of poor people living in Gaza Strip refugee camps,” *Resour. Conserv. Recycle.*, vol. 153, no. October 2019, p. 104550, 2020, DOI: 10.1016/j.resconrec.2019.104550.

[14] A. Aydi, “Energy Recovery from a Municipal Solid Waste (MSW) Landfill Gas: A Tunisian Case Study,” *J. Waste Water Treat. Anal.*, vol. 03, no. 04, pp. 3–5, 2012, DOI: 10.4172/2157-7587.1000137.

[15] V. S. George Tchobanoglous, Hilary Theisen, Samuel Vigil, Tchobanoglous George, *Integrated Solid Waste Management: Engineering Principles and Management Issues*. 1993.

[16] Q. Aguilar-Virgen, P. Taboada-González, and S. Ojeda-Benítez, “Analysis of the feasibility of the recovery of landfill gas: A case study of Mexico,” *J. Clean. Prod.*, vol. 79, pp. 53–60, 2014, doi: 10.1016/j.jclepro.2014.05.025.

[17] F. Joos *et al.*, "Global warming feedbacks on terrestrial carbon uptake under the Intergovernmental Panel on Climate Change (IPCC) emission scenarios," *Global Biogeochem. Cycles*, vol. 15, no. 4, pp. 891–907, 2001, DOI: 10.1029/2000GB001375.

[18] T. Oakes, *Climate Change 2007: Impacts, Adaptation and Vulnerability The*. 2009.

[19] A. Liquide, "Comments Received during the Public Review Period on the " Inventory of U . S . Greenhouse Gas Emissions and Sinks :" pp. 1990–2009, 2009.

[20] Global Facilitation Team United Nations, “Sustainable Energy for All 2014 Annual Report,” *Sustain. Energy All 2014 Annu. Rep.*, p. 58, 2014.

[21] S. T. Tan, W. S. Ho, H. Hashim, C. T. Lee, M. R. Taib, and C. S. Ho, “Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid

waste (MSW) management in Malaysia," *Energy Convers. Manag.*, vol. 102, pp. 111–120, 2015, DOI: 10.1016/j.enconman.2015.02.010.

[22] X. gang Zhao, G. Wu Jiang, A. Li, and L. Wang, "Economic analysis of the waste-to-energy industry in China," *Waste Manag.*, vol. 48, pp. 604–618, 2016, DOI: 10.1016/j.wasman.2015.10.014.

[23] J. Van Caneghem, K. Van Acker, J. De Greef, G. Wauters, and C. Vandecasteele, "Waste-to-energy is compatible and complementary with recycling in the circular economy," *Clean Technol. Environ. Policy*, no. 0123456789, 2019, DOI: 10.1007/s10098-019-01686-0.

[24] O. Eriksson *et al.*, "Municipal solid waste management from a systems perspective," *J. Clean. Prod.*, vol. 13, no. 3, pp. 241–252, 2005, DOI: 10.1016/j.jclepro.2004.02.018.

[25] E. Haghi and F. B. Tehrani, "Techno-economic assessment of municipal solid waste incineration plant-case study of Tehran, Iran," *First Sustain. Dev. Conf. Eng. Syst. Energy, Water Environ.*, no. September, p. 5, 2015, [Online]. Available: http://www.researchgate.net/publication/277708896.

[26] I. Best, P. Guide, and L. Projects, "LFG Generation, Emissions and Collection," pp. 63–76, 2012.

[27] J. K. Park, Y. G. Chong, K. Tamada, and N. H. Lee, "Methods for determining the methane generation potential and methane generation rate constant for the FOD model: a review," *Waste Manag. Res.*, vol. 36, no. 3, pp. 200–220, 2018, DOI: 10.1177/0734242X17753532.

[28] M. J. Krause, G. W. Chickering, and T. G. Townsend, "Translating landfill methane generation parameters among first-order decay models," *J. Air Waste Manag. Assoc.*, vol. 66, no. 11, pp. 1084–1097, 2016, DOI: 10.1080/10962247.2016.1200158.

[29] IPCC, "2006 IPCC Guidelines for National Greenhouse Gas Inventories: Vol 5 Chapter 3 Solid Waste Disposal," *2006 IPCC Guidel. Natl. Green. Gas Invent.*, vol. 4, pp. 6.1-6.49, 2006, [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/20604432.

[30] R. Piatti, C. Sharma, and M. Yamada, "Chapter 2: Waste generation and composition and management data," *IPCC Guidel. Natl. Green. Gas Invent.*, vol. 5, no. 2, p. 23, 2006.

[31] M. P. X. E. Sa, "Feasibility Study for the Waste to Energy Plant," pp. 703–875, 2013.

[32] "2.1 Introduction to LandGEM," pp. 1–6, 2005.

[33] E. Dace, D. Blumberg, G. Kuplais, L. Bozko, Z. Khabdullina, and A. Khabdullin, "Optimization of landfill Gas Use in Municipal Solid Waste Landfills in Latvia," *Energy Procedia*, vol. 72, pp. 293–299, 2015, DOI: 10.1016/j.egypro.2015.06.042.