An-Najah National University

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Municipal Solid Waste to Energy Alternatives in the Northern West Bank:

A Comparative Study

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Dedication

This thesis is dedicated for the sake of Allah's pleasure, my Creator and Master. To my dearest mother, who guided me through the valley of darkness with the light of hope and support. To all my family and friends, who encouraged and supported me. To my supervisor Dr. Mohammed Alsayed, who supported me.

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First and foremost, all praise and thanks are due to Allah (the Creator), Who helped and guided me through the challenges I faced in my study. Glory is to Allah Who gave me the strength, patience, and knowledge to continue and finish this journey successfully.

This thesis would never have seen the sun without the guidance of my committee members, and without the full support and help from friends and family. So, first of all, I would like to express my deepest gratitude and sincere thanks to my supervisor, Dr. Mohammed Alsayed for his excellent guidance, support, caring, patience, encouragement, motivation, valuable advice, and assistance throughout this research that have resulted in the completion of this thesis. I owe his heartfelt thanks for his time and effort that assisted me throughout my study.

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Finally, thanks to all study participants who provided me with valuable information and enrich this research with their experience, particularly; EQA, PENRA, MoLG.

الإقرار

أنا الموقعة أدناه، مقدّمة الرسالة التي تحمل العنوان:

Municipal Solid Waste to Energy Alternatives in the Northern West Bank: a Comparative Study

أقر بأن ما اشتملت عليه هذه الأطروحة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الاشارة إليه حيثما ورد. وأن هذه الرسالة كآملة أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work and has not been submitted elsewhere for any other degree or qualification.

Student's Name: Sabreen Fraij	**اسم الطالبة:**
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Date: 26/09/2021	**التاريخ:**

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List of Abbreviations

AD	Anaerobic Digestion
AP	Acidification Potential
A_t	Annual Cash Flows
ATCF	After Tax Cash Flow
AW	Annual Worth
CH_4	Methane
CHP	Combined Heat Power
CO	Carbon Monoxides
CO_2	Carbon Dioxide
C_t	Costs Negative Cash Flows
CV	Calorific Value
DISCO’s	Distribution Companies
DPBP	Discounted Payback Period
EPA	Environmental Protection Agency
EQA	Environmental Quality Authority
GCC	Global Climate Change
GDP	Gross Domestic Product
GEDCO	Gaza Electricity Distribution Cooperation
GF	Gate Fees
GHG	Green House Gas
GW	Global Warming
GWh	Giga Watt Hour
HC	Hydrocarbon
HEPCO	Hebron Electricity Power Company
ICE	Internal Combustion Engine
IE	Imported Electricity
IEC	Israeli Electric Company
IPCC	Intergovernmental Panel on Climate Change
ISWA	International Solid Waste Association
JDECO	Jerusalem District Electricity Company
JICA	Japan International Cooperation Agency
JSC	Joint Service Council
KWh	Kilo Watt Hour
LCA	Life Cycle Assessment
LCoE	Levelized Cost of Electricity
LFG	Landfilling Gas
LFGRS	Landfill Gas Recovery System
LFGtE	Landfilling Gas to Energy

LGU	Local Government Unit
LMOP	Landfill Methane Outreach Program
MARR	Minimum Attractive Rate of Return
MoLG	Ministry of Local Government
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MSWI	MSW Incineration
NAW	Net Annual Worth
NCF	Net Cash Flow
NDC	National Determined Contributions
NEDCO	Northern Electricity Distribution Company
NO_x	Nitrogen Oxides
NPV	Net Present Value
O_2	Oxygen
O_3	Ozone
$\eta_{\text{ov. all}}$	Overall Efficiency
PA	Palestinian Authority
PAG	Plasma Arc Gasification
PCBS	Palestinian Central Bureau of Statistics
PEERC	Palestinian Energy and Environment Research Center
PENRA	Palestinian Energy and National Resources Authority
PERC	Palestinian Electricity Regulation Council
PETL	Palestinian Electricity Transmission Ltd.
PM	Particular Matter
PPP	Public Private partnership
PT	Palestinian Territories
PW	Present Worth
$Q_{(CH4)}$	Quantity of methane $m^{\wedge 3}$ per year
RDF	Refuse Derived Fuel
RE	Renewable Energy
ROR	Rate Of Return
R_t	Revenue Positive Cash Flows
SELCO	Southern Electricity Company
SIR	Saving to Investment Ratio
SO_x	Sulfur Dioxide
SPP	Simple Payback Period
SS	Sewage Sludge
TEDCO	Tubas Electricity Distribution Company
TS	Transfer Station
TVoM	Time Value of Money

UNRWA	United Nation Relief and Works Agency
VAT	Value Added Tax
VOC	Volatile Organic Compound
WB	West Bank
WTE	Waste To Energy

List of Equations

No.	Equations
5.1	$\mathrm{PW} = \sum_{t=n}^{n} A_t(P\|F,i,t) = \sum_{t=0}^{n} \frac{A_t}{(1+i)^t}$
5.2	$AW = PW\ (A\|P,i,n) = PW\frac{i(1+i)^n}{(1+i)^n-1}$
5.3	$PW = \sum_{t=0}^{n} \frac{A_t}{(1+ROR)^t} = 0$
5.4	$SIR = \frac{\sum_{\mathrm{t=0}}^{\mathrm{n}} \mathrm{R}_t(\mathrm{P}\|\mathrm{F},\mathrm{i},\mathrm{t})}{\sum_{\mathrm{t=0}}^{\mathrm{n}} \mathrm{C}_t(\mathrm{P}\|\mathrm{F},\mathrm{i},\mathrm{t})} = \frac{\sum_{t=0}^{n} \frac{R_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}$
5.5	$SPP = \frac{Investment}{Savings}$
5.6	$LCoE = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$
7.1	$Electricity\ output\ \left[\frac{kwh}{year}\right] = Q\ (CH4)\ \times)\ \times \eta ov.all$

Municipal Solid Waste to Energy Alternatives in the Northern West Bank: a Comparative Study

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Abstract

The research aimed to determine the most economically feasible solutions among incineration and LFG (Landfilling gas) methods through detailed financial equations. Moreover, the possible challenges which faced each alternative have been defined and an environmental comparison was conducted between the current wastes disposal procedure at Zahrat Al-Finjan in Jenin (as a case study) and the proposed methods. In this comparison, the $CO_{2\text{-eq}}$ has been considered as the main indicator, the methodology with sequent steps was taken into account, the all governmental national reports were reviewed in addition to the data collected related to the energy and waste sectors.

Although the Palestinian Authorities have made efforts and collaborated together, such as Palestinian Energy and National Resources Authority, Environmental Quality Authority, and Ministry of Local Governmental, through implementing strategic plans to manage the current municipal solid wastes landfill, they still need to investigative studies related to the economic and environmental performances to establish new legislations and incentive programs. This study will help the stakeholders to take a decision to find potential sustainability waste to energy methods.

The resultants have been identified in chapter seven tables and figures, and both financial model scenarios were estimated through calculating the economic indicators such as PW, AW, ROR, SIR, SPP, and LCoE. Moreover, the investigation has been conducted through the sensitive analysis with a variation of some parameters. The energy recovery from the incineration proposed plant will reach up to 1,411.33 GWh per year, whereas the LFG will produce 118.87 GWh yearly. Furthermore, the energy recovery will contribute to supplying a share of the West Bank's energy demand. In the LFG scenario, the economical parameters are estimated more profitable than the incineration plant, but the environmental indicators will be more profitable than the LFG scenario. The incineration plant contributes in avoiding the CO_{2-eq} with an amount of 1,082,492.7 tons per year. Whereas; LFG plant, in the second scenario, it was observed to avoid CO_{2-eq} emissions in direct or indirect manner, which will prevent totally 92,320.96 tons CO_{2-eq} yearly including 1,144.4 tons CO_{2-eq} yearly with respect to Methane emissions. The recommendation for choosing of implementing incineration plant is as preferable solution when taking the environmental indicators in consideration and also from more energy recovery side. The LFG WTE alternative will be the most economically project. This study encourages the authorities to invest with incineration as preferable solution, and integrate it in the Palestinian market with a horizontal boiler design due to the landfill extended on a slope.

Chapter One

Introduction

1.1 Overview

Chapter one provides a general overview of our study report. It includes a general background, the organization of the report, problem statement, objectives, the scope of work, and finally the significance and importance of work.

1.2 General Background

Growing worldwide demand for energy production and scarcity problem (the depletion and the price fluctuation of the natural resources), and environmental impacts (Global Climate Change (GCC), Green House Gas (GHG) emissions, acid rain, ozone depletion) associated with conventional sources are at the base of probable energy crisis [1].

The huge demand occurred on energy resources for energy production to meet the growing global demand due to the rapid population growth, higher living standards, and economic development. Although energy is a fundamental input to economic activities; achieving sustainable energy source and securing reliable energy production is the most increasingly significant energy challenges globally [2]. Unfortunately, consuming high energy demand accelerates the depletion of natural resources particularly the non-renewable primary energy resources; specifically, fossil fuels; including coal, oil, and natural gas. These exhaustible energy sources are not distributed evenly on the earth and are facing probable depletion at some point in the future [3].

Moreover, the fluctuation of petroleum, crude oil, and hydrocarbons (HC's) prices, is a result of the supply and demand variation due to political events, and the presence of other competitive resources in the global market[4]. Also since energy is a basic need in human life; all sorts of processes require external energy in most sectors; such as industrial, agricultural, health, domestic, etc [1]. Furthermore, the severe energy demand for electricity generation represents more than 35 percent of primary energy consumed globally [5]. **Figure (1.1)** displays the global primary energy demand for electric generation projections [quadrillion BTU] until 2040 from several global sources. Also, it is worth mentioning that one-third which is nearly 20 percent of the global population of the world nations with large populations have no access to electricity [6, 7].

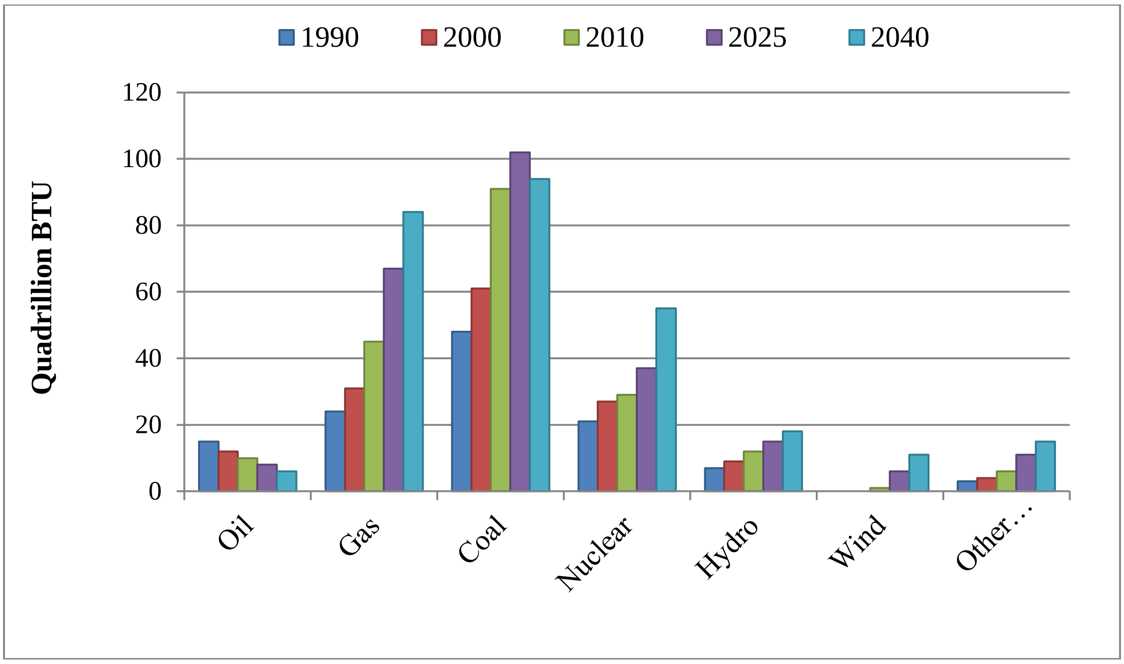


Figure (1.1): Estimates and Projection on Global Energy Sources for Electricity Generation [8].

The global population growth will certainly lead to greater energy consumption. On the other hand; the relationship between the economic, human developments, and the quality of life is growing from one side with the per capita Gross Domestic Product (GDP) growth rate. This presents an indicator of the total primary energy consumption per capita (t_{oe} per person)[9].

By 2040, the global population will reach 9.2 billion, up from 7.5 billion today, and economic expansion will drive the increasing energy demand; it is expected to rise 30 percent more in 2040 than it was in 2010. See **Figure (1.2)** for global primary energy demand [Quadrillion BTU] for many energy sources [8].

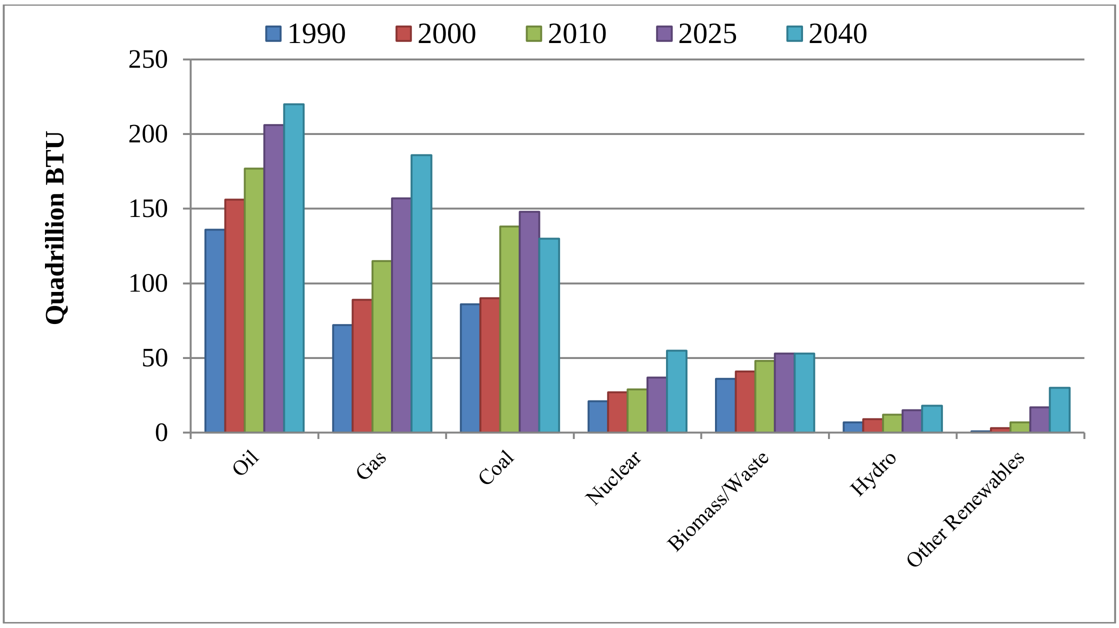


Figure (1.2): Global Primary Energy Demand[8].

Figure (1.3) shows the global primary energy consumption in percentages for 2010 [10]; oil, natural gas, and coal accounted for 35, 23, and 26 percent of global consumption; respectively. It is worth pointing out that the RE sources (Solar, wind, biomass, hydroelectric, geothermal) accounted for 10 percent of global primary energy consumption while taking into consideration the persistent efforts to increase RE share and reduce the world energy needs by one third in 2050 [9]. Also, the RE overall share is expected to be around 12, and 16 percent in 2012, and 2040; respectively [11]. While the share of modern RE in the final energy supply is expected to increase by about 17, and 25 percent by 2030, and 2050; respectively [12].

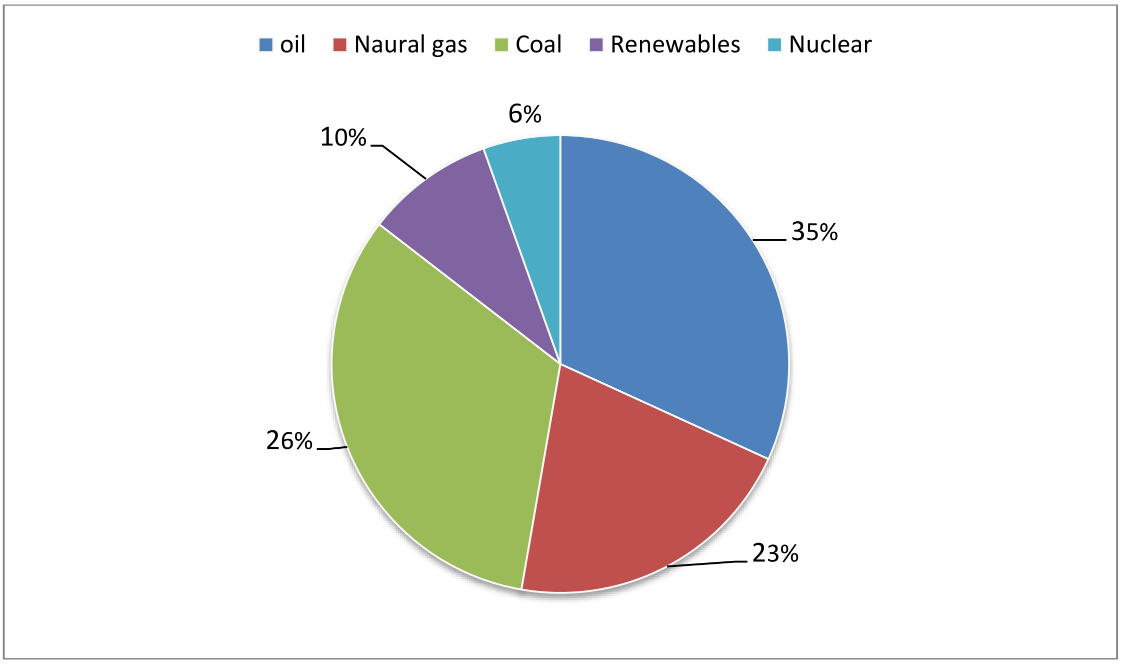


Figure (1.3): Global Primary Energy Consumption for 2010 [10].

Emissions projection from coal fossil fuels constitutes the largest share in global data and will reach about 80 percent in 2040 [7]. A significant proportion of world carbon dioxide (CO_2) emissions and air pollution are a result of fossil fuels combustion in order to satisfy energy demand [13]. Also, fossil fuels combustion accounted for 84 percent of global GHG emissions in 2009. In addition to that, the global emissions could be halved by 2050[14].

The technology improvements will help achieve more efficient fuel use and reduce emissions concentration produced from all sources of energy supply. The demand for natural gas is raising more than other sources to meet the increasing requirements for electricity and lower carbon heat. On the other hand, lower-carbon energy sources (wind, solar, biofuels, and nuclear) are increasing exponentially. The energy mix to meet the rising demand, while also indicating environmental impacts including the risks of GCC, will vary by sector type. Furthermore, the electricity demand will rise in all end-use sectors, while the mix of fuel supply for electricity generation is shifting to lower carbon sources [15]. **Figures (1.4) and (1.5)** show the type of fuel energy consumption [Quadrillion BTU] from 2017 to 2040 with annual growth rate, and global energy supplies [Quadrillion BTU] variation by sectors for 2017, 2025, and 2040; respectively[8].

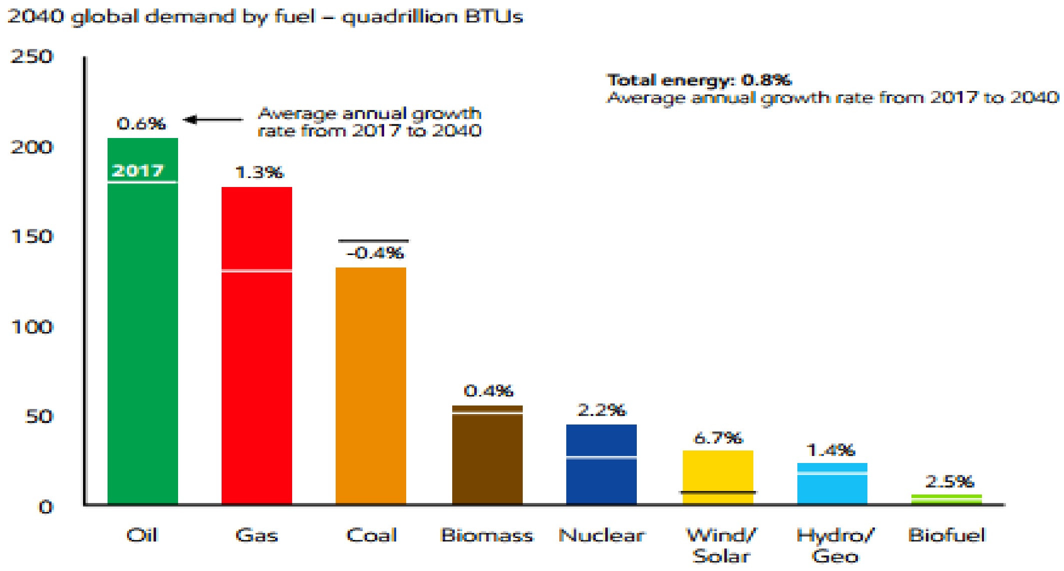


Figure (1.4): Energy supply evolves to meet demand projections [8].

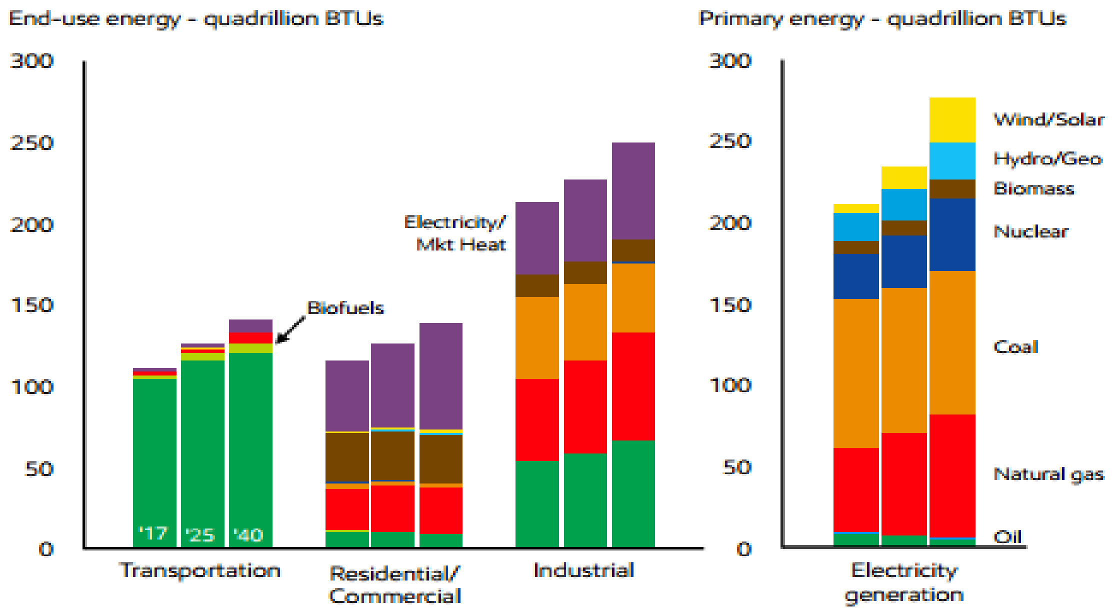


Figure (1.5): Global energy supplies vary by sector [8].

When it comes to fossil fuels' consumption environmental consequences; the pollutants emitted during the combustion are responsible for *smog*, ozone depletion, acid rain, GW (Global Warming), and GCC. It has reached high levels and seriously threatens vegetation, wildlife, and human health. Moreover, pollutants are classified as HC's including volatile organic compounds (VOC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxides (CO). And even though *Smog* is mostly made up of ground-level ozone (O_3), it also includes CO, particulate matter (PM) such as soot and dust, VOC's such as benzene, butane, and other HC's. The harmful ground-level O_3 should not be confused with the beneficial O_3 layer at the top of the stratosphere, which protects the earth from the sun's harmful ultraviolet rays. Therefore, they are called GHG with CO_2 being the primary component. Water vapor is usually taken out of this list since it falls as rain or snow as part of the water cycle and human activities in producing water. The GHG effect makes life on earth possible by keeping the earth warm at about 30°C warmer. However, excess amounts of air polluting gases disturb the balance by trapping a lot of energy causing the average temperature of the earth to rise and the climate to change. Furthermore, the GHG effect is referred to as undesirable consequences of GW or GCC [16].

The current global Municipal Solid Waste (MSW) generation is 1.3 billion tons per year and is expected to increase to approximately 2.2 billion tons per year in 2025. This amount may result in significant health, environmental, aesthetic, land-use resources, and economic concerns if not managed properly [17]. The 2013 world population was about 7.2 billion and is expected to increase by 1 billion in 2025 with an average growth rate of 1 percent per year [18]. Also the increase in urban population will be mainly in developing countries, and so the population growth, urbanization, and the increase in the standards of living will lead to an increase in MSW generation [19]. This resulted from population growth and the increase of per capita waste generation rates from 1.2 to 1.42 kg per person per day in the next fifteen years. Additionally, the international agreements, such as the Kyoto protocol, and the international financial institutional pressures will encourage developing countries to accelerate the development of new MSW policies. The results of MSW policy reform will be in substantial growth in WTE market annual investment from about 2.1 billion US dollars in 2010 to about 26.1 billion US dollars in 2025. Moreover, that will greatly stimulate the development of the WTE market and technologies globally [17]. Based on UN data [20]; the global average of the amounts of waste generated in urban and rural areas will increase significantly between 1950 and 2050. It's expected that the daily waste generation per capita in urban and rural areas will increase from 0.8 to 1.2 kg and from 0.4 to 0.6 kg; respectively. **Figure (1.6)** shows the projected annual global waste quantities in million tons for urban and rural areas up to 2050.

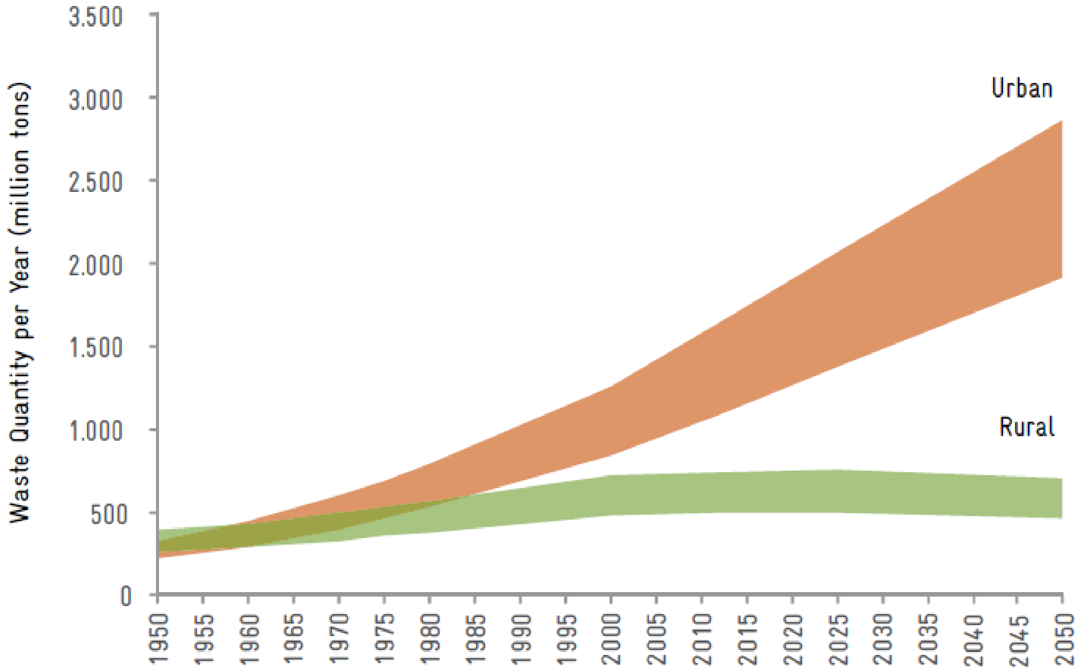


Figure (1.6): Rural and urban global waste generation up to 2050 [17].

Choosing sustainable solutions and suitable WTE methods for MSW proper treatment helps achieve MSW management. Globally, the implementation of WTE facilities will play a significant role in minimizing MSW challenges, contribute to the growing RE market, and provide economic and environmental benefits [17]. Choosing the proper method for a certain area depends on the MSW management level, waste characteristics, land space availability, available capital, technological complexity coupled with business skills requirements, geographic locations of the plants, and technology's efficiency. Moreover, there are a number of well-developed techniques across the globe; such as incineration, gasification, plasma arc gasification (PAG), pyrolysis, biomethanol, and refuse-derived fuel (RDF). To date, about 70 percent of MSW are disposed into landfills or uncontrolled dumpsites, and this seriously affects surface water, groundwater, or soil and emits GHG's. Eventually, proper disposal of waste is a significant challenge for municipalities [21].

The MSW management system must follow the waste hierarchy includes source reduction, reuse, recycling combustion with or without energy recovery, and finally landfilling. The WTE is a technology for treating the remaining non-recyclable MSW fractions. On the other hand, energy recovery from MSW has a role in the circular economy when it is used for non-recyclable and hazardous waste fractions, considering the environmental and social aspects [20].

The MSW incineration (MSWI) technology has remained to be the most integral part of MSW management in many countries; this technology has the advantage of reducing waste by 80 percent. Moreover, it can handle all types of waste including organic materials requiring a low level of technology and human resource skills, though it has a major drawback by generating high levels of pollutants which contribute to negative environmental impacts. In this technology, MSWI directly burns waste with excess oxygen at temperatures over 800˚C. As the waste is incinerated, it releases heat and heats water in a boiler system to drive a steam cycle and steam turbine. The by-product of MSWI is bottom ash consisting of recovered mineral materials such as silicon, iron, calcium, aluminum, sodium, and potassium in their oxide state. These materials are present within a range of 80 to 87 percent by mass in the bottom ash, also these materials are integrated with industries [22].

MSWI is suitable for both urban and rural areas based on the mentioned advantages in comparison with PAG, pyrolysis, and RDF technologies, and also MSWI has good efficiency of about 27 percent. In terms of the environmental impacts, pyrolysis produces fewer pollutants compared to the other technologies except for PAG. This makes pyrolysis technology preferable to developed countries with high public awareness levels. As for the economical side; the advanced PAG is the most expensive technology, it has low land area requirements, has the highest efficiency, and is best for highly developed countries with limited land resources. On the other hand; RDF technology does not deal with organic waste or high protein contents, since it has relatively low costs and good efficiency. Moreover, the results make it the best technology for industrial waste treatment. Finally; the biomethanation is characterized by low capital requirements, unsophisticated technology, simplicity of operation, very high efficiency with organic waste, highest land area requirement, and can be developed in all sizes. These conditions make the biomethanation an optimal technology for rural and agricultural areas in both developed and developing countries[17].

At the local energy level in Palestinian territories (PT), electricity consumption reached approximately 4,865 GWh with a peak demand of 930 MW. Electricity accession is almost 24 hours without shortcuts in the West Bank (WB); nearly all Palestinians have access to electricity as follows: 93 percent of the rural population, and 99 percent of the urban population.

Moreover, its annual average consumption growth is about 3.5 percent annually which equates to an additional demand of about 150 GWh annually[23, 24].

Regarding the local MSW sector, waste disposal is managed by 15 Joint Service Councils (JSC) (13 JSC's in WB). They collect and transfer generated waste and controls landfill sites. The MSW is mostly collected from houses and commercial facilities, but the medical waste is the responsibility of the Ministry of Health, and construction and demolition wastes are under the responsibility of who generates them. In MoLG 2019 data book, the waste generation in the PT reached about 3,950 tons per day, and 1,441,750 tons annually, of which the WB produces 2,600 tons per day or 949,000 tons annually. Moreover, the per capita waste generation reached 0.91 kg per day, and also more than 2,000 tons of MSW are collected daily by the JSC's (83 percent of the generated wastes). The collection of the remaining quantities is under the responsibility of both Local Governmental Units (LGU's) and the United Nations Relief and Works Agency (UNRWA). The MSW annual growth equals 4 percent, which is correlated with local population growth rate, and living standards [25].

Organic waste constitutes 50 percent of the MSW composition, and according to the International Solid Waste Association (ISWA) guidelines, the calorific value (CV) of MSW differs based on its content [26]. **Table (1.1)** summarizes the CVs in addition to the Palestinian MSW composition as claimed in the MoLG data book [25, 26].

Table (1.1): The Palestinian MSW composition and CV's [25, 26]

Fraction	**CV [MJ/kg]** [25]	**Palestinian MSW [%]**[26]
Paper	16	12.6
Organic	4	50
Plastic	35	14.6
Glass	0	1.8
Metals	0	2.5
Textiles	19	18.5
Others	11	

The Palestinian Authority (PA) aims to prepare for the transition from an authority to a free state; its efforts forward extensively towards future energy independence through reaching a political solution with the Israeli side by developing its ministries capacity to be able to control its own natural resources. In this context; three government ministries, which are the Palestinian Energy and National Resources Authority (PENRA), Palestinian Environment Quality Authority (EQA), and Ministry of Local Government (MoLG) are directly in these efforts. Each ministry works to solve the challenges at the national level. Moreover, the PENRA dedicates its efforts to solving electric supply shortage problems and developing national energy resources independence. And while both the EQA and the MoLG are cooperating to manage the current MSW landfills and find future sustainable and environmentally friendly solutions for the MSW disposal [25, 26].

The PA periodically manages the ministries to prepare five-year time strategic plans. Based on that, all ministries prepared their strategic plans in 2017 to form the general governmental roadmap until 2022. Each of the ministries mentioned before had 2017 - 2020 plans that included direct and/or indirect objectives and implementation of related strategies for managing the energy, environment, and/or MSW sectors [27–29]. The key points in these strategies are abbreviated as follows:

1. In PENRA strategic plan, the first objective is stated for increasing national capacity to fulfill and secure energy demands. To this end, PENRA has adopted diversifying resources and implementing national strategic energy storage.

2. MoLG's third strategic objective is to develop an efficient and environmentally safe MSW management. Two strategies are adopted to encourage policies and methods to reduce the MSW-generated quantities, recycle, reuse, and produce energy before final disposal in an environmentally friendly manner, and to prevent the use of random dumpsites by closing or reconditioning them to reduce negative environmental and health impacts.

3. The EQA has collaborated with the National Determined Contributions (NDC) to the United Nations framework convention on the GCC. Two scenarios have been implemented; the first one is the independence scenario, which assumes a political agreement between PA and the Israeli side. If so, a saving of 290 and 3 kt $CO_{2\text{-eq}}$ should be achieved by 2040 through reducing landfill CH_4 and recovering electricity from waste, respectively. The same targets become 290, and 0.5 kt $CO_{2\text{-eq}}$ assuming the second scenario of the current political situation.

1.3 Organization of the report

The report consists of eight chapters; the first chapter provides an overview and general background, problem statement, the objectives of our study, and the scope and the importance of work. The second chapter presents a literature review and overview, while the third chapter provides the theoretical background and overview. The fourth chapter offers explanations for understanding the WTE technology alternatives process, especially incineration and LFG. The fifth chapter presents the economic criteria and definitions for parameters such as PW, AW, ROR, SIR, SPP, and finally LCoE. The sixth chapter displays the methodology applied in our study. The seventh chapter presents results and discussion for economic performance models incineration and LFG, and finally the sensitive analysis of both scenarios. Whereas the eighth chapter provides a conclusion and recommendations, followed by the references.

1.4 Problem Statement

Palestine suffers from many political issues, on top of which is the division of lands according to the Oslo Accords, where the lands classified as A are under the full administrative and security control of PA, but the lands classified as B and C are under partial and complete control of Israel; respectively. This has limited the PA’s ability to build new sanitary landfills, especially when taking into account that suitable lands are located only in C areas. On the other hand, Palestine suffers from full dependence on about 90 percent of imported electricity (IE). That is why there is a need to find a sustainable solution for the MSW disposal, in the meantime, reducing the national dependency on IE and also the energy shortage problem. In this context, the PA is making efforts to build national strategic plans to contribute in solving these mentioned challenges.

Although PA is going forward to invest/implement/build an incineration WTE plant; until now, there is a lack of studies to investigate potential sustainability. PENRA, MoLG, and EQA need investigative studies related to the economic performance and environmental potential of establishing a WTE plant. Moreover, decision-makers need studies that take into account detailed financial models and comparative analysis to understand the benefits of WTE plants.

1.5 Objectives

This research aims to fulfill the following objectives:

1. Determine the most feasible solution for incineration and LFG facilities' investment from an economic point of view excluding the detailed technical design. Also, define possible challenges that will face each alternative that needs new legislations, actions, and/or incentive programs.

2. Performing environmental comparison between the current MSW disposal procedure and the proposed WTE plants. The comparison will consider $CO_{2\text{-eq}}$ to be the main indicator due to its international importance in determining GW Potential.

1.6 Scope of Work

This research will investigate the economic and environmental performance of establishing a WTE plant in Palestine, specifically in Zahrat Al-Finjan landfill, with the exception of the detailed technical design. The study will consider the current MSW situation as a baseline scenario, and then compare it with incineration and LFG technologies plants. Also, the study will consider at least NPV, ROR, SPP, breakeven analysis, and LCoE as main economic performance indicators, and for environmental issues, $CO_{2\text{-eq}}$ as a performance indicator.

1.7 Significance/Importance of Work

The study will provide the PA’s decision-makers with a detailed insight regarding the actual feasibility of building a WTE plant, comparing it to another practical application utilizing the current landfill, and generating electricity through recovering and utilizing the already generated CH_4.

Chapter Two

Literature Review

2.1 Overview

Chapter two presents a literature review regarding various globally comparative studies considering the potential of all WTE methods.

2.2 Literature Review

(A. Ramos & A. Roubo, 2020) studied the potential of generating electricity from the waste to meet the electrical demand in various world regions. The study considered three WTE technologies; incineration, gasification, and two-stage plasma gasification. The life cycle assessment (LCA) method was used for the comparison, and the results showed that incineration is preferable when considering GW and terrestrial ecotoxicity potentials. However, gasification is preferable when considering eutrophication, acidification, marine aquatic ecotoxicity, and potentials for human toxicity. Finally, the two-stage plasma gasification analysis results showed negative values for all impact categories [30]. (S. Tan, 2015) took the existing landfill in Malaysia as a case study; it has shown that incineration and anaerobic digestion (AD) WTE technologies have good potential in Malaysia. The 3E (economic, environment, and energy) assessment proved that incineration is the best option for MSW management from an electricity and heat production point of view. In addition, AD was found to be more sustainable when only electricity production was considered[31]. (W. Foster, 2021) reviewed the comparative analysis of different WTE technologies in the UK; the study examined incineration, gasification, pyrolysis, AD, and hydrothermal, and the results indicated that AD implementation is the most viable since it provides biogas for electricity generation which is about 1.165 TWh from 90 million tons of manure and slurry. On the other hand, the economic analysis, specifically the capital costs, were found insufficiently high. Although the environmental benefits of manure treatment included reducing the pollution potential with CH_4, and NO_x emissions reduction up to 90 and 50 percent; respectively, compared to no treatment [32].

(I. Khan & Z. Kabir, 2020) compared incineration, gasification, pyrolysis, and AD as alternatives for electricity generation to achieve MSW management in Bangladesh. The comparison is based on a three-dimensional sustainability framework including 34 indicators covering economic, environmental, and social aspects. The results showed that AD was the most sustainable option and incineration was the least, whereas it was found that gasification, pyrolysis, and AD were 33, 65, and 111 percent; respectively, more sustainable WTE technologies than incineration [33]. (M. Elmnifi, 2019) completed a quantitative analysis of potential WTE electricity production up to 2030 in Libya, and two scenarios for WTE development for six cities by MSW mass-burn and mass burn recycling were considered. The results showed that the mass-burn with recycling scenario projected a potential production of about 57 MW of electricity from MSW by 2030. The value forms 0.24 percent of the 24.1 GW peak electricity demand in 2030.

While this value forms 0.82 percent of the peak electricity demand projected for the final mass burn scenario of 2030, through which potential production of WTE electricity will reach about 197 MW. Also, the potential WTE electricity produced by mass burn scenario is five times greater than that of with recycling [34]. On the other hand, (S. Tan & H. Hashim, 2014) compared incineration, landfilling, and AD from different perspectives, and the results showed that incineration is the most economical profitable and climate-friendly alternative when compared to conventional landfilling; it produces 1,430 MW per day of heat and 480 MW per day of electricity from 1,000 tons per day of MSW. Moreover, the Landfill Gas Recovery System (LFGRS) showed the lowest potential of energy production compared to incineration, and AD, where AD generated less energy product compared to waste incineration compensated by high production of fertilizer of AD equals to 1,070 ton per day. Also, for an environmental perspective, landfilling produced 2,775 ton CO_2 per day, while incineration could avoid 2,250 tons of CO_2 per day due to fossil fuel replacement compared to the baseline. The LFGRS showed the highest total emission of 2,143 tons CO_2 per day compared to incineration of 524.2 tons CO_2 per day, and AD 287.2 tons CO_2 per day. On the other hand, AD was found to provide a potential carbon avoidance of 2,487.8 tons CO_2 per day compared to the baseline scenario, due to its lower total emissions [35].

(T. R. Ayodele, 2017) performed an LCA study of WTE technologies in some cities of Nigeria. The study aimed to evaluate their electricity generation potential, GW potential, acidification potential (AP), and dioxin or furan emission potential, according to ISO 14040/43. The considered WTE plants were landfilling gas to energy (LFGtE), a hybrid of incineration and AD, and a hybrid of incineration and LFGtE. The results indicated that the hybrid of incineration and AD were potentially viable compared to other technologies in terms of GW potential, and ecosystem potential measured by AP. The hybrid of incineration and AD has the potential of reducing GW in the range between 75.7 and 93.3 percent compared to landfilling without energy recovery. Similarly, a hybrid of incineration and LFGTE provided a reduction in the range between 75.3 and 84.8 percent, while LFGTE could reduce the GW potential by 75 percent. However, the LFGTE technology is the best in terms of carcinogenic reduction potential measured by dioxin or furan emissions [36].

(D. Moya & D. Jaramillo, 2017) chose Quito, Ecuador as a case study and estimate power generation potential, energy recovery, and biogas generation from MSW. The estimation was based on general models of thermo-chemical and bio-chemical processes considering the chemical composition of wastes. The achieved results indicated that the MSW composition of the study area included 69.3 percent of biodegradable waste and 30.7 percent of non-biodegradable waste with moldy waste accounting for 81.4 percent of biodegradable waste. On the other hand, the energy potentials using thermo-chemical and bio-chemical processes were 5,970 and 62 kWh per ton MSW; respectively. Finally, the power production potentials for thermo-chemical and bio-chemical processes were 0.07 and 0.78 MW per ton MSW; respectively [37]. (S. Sharma & S. Basu, 2020) compared different waste treatment technologies including thermal methods; which are pyrolysis, incineration, and gasification; or bio-chemical methods, such as AD, aerobic composting, bio-ethanol production, and fermentative bio-hydrogen production along with pre-treatment technologies. The results revealed that there is a preference for AD over other methods based on the environmental and techno-economic sustainability views. On the other hand, incineration is the least preferable from an environmental perspective, due to its releasing of toxic gases and heavy metals at threatening levels [38]. (L. C. Malav, 2020) conducted a WTE comparative study between pyrolysis, gasification, incineration, and bio-methanation as appropriate RE sustainable sources, and the study took India as a case study regarding waste handling, collection, separation, and proper disposal solutions. The results showed that incineration is the best option since it handles any type of wastes. Moreover, the development of the WTE sector will also provide significant business potential with high income to companies and people involved directly or indirectly in the WTE processes [39]. (J. J. Cabello Eras, 2020) performed an evaluation of the bioenergy potential of biomass wastes in Colombia. The study dealt with wastes that included agriculture, livestock, and processed industry slaughterhouses. It also examined different WTE technologies, particularly incineration and AD instead of unsustainable energy sources fossil fuels or cooking wood in end-use energy mix plants. The results showed that the bioenergy potential produced by incineration is about

120,000 GWh, in comparison; a higher energy potential than produced through AD is about 60,000 GWh. Also, the potential biogas accounts for 90 percent of the country's end-use of natural gas and LPG. Moreover, about half of the solid biomass available in incinerators can be used potentially instead of solid fuels, such as wood and coal. Finally, the combined use of the two technologies can support about 50 to 97 percent of the use of gaseous and solid fuels. Whereas using combined heat and power systems to produce heat and electricity can increase biomass sharing up to 15-28 percent of the country's end-use energy mix plant [40].

(H. Chen, 2020) estimated the potential of building a hybrid power system from WTE and coal-fired power generation unit. In the proposed system, it is assumed that energy loss from MSWI is fed to the steam cycle of the coal-fired power plant. More clearly, superheated steam generated by the boiler is used to partially heat coal power plant feed in the water, but bioenergy from MSW produces electricity. Moreover, the proposed system enabled raising the overall system efficiency [41]. (C. B. Agaton, 2020) compared landfilling with WTE technologies from a sustainability point of view, taking the Philippines as a case study. The study conducted an economic feasibility analysis under uncertainty by applying an investment model. The results showed that incineration LCOE equals 0.03 $ per kWh, followed by gasification and pyrolysis at 0.07 and 0.12 $ per kWh; respectively. Furthermore, after comparing these results to the current electric generation cost of 0.11 $ per kWh, it showed that the pyrolysis alternative needs governmental support to become feasible [42]. (P. E. Escamilla-García, 2020) performed a techno-economic feasibility study of energy production from MSWI in Mexico compared to RE's (hydroelectric and wind power). This emphasized that there is technical feasibility to increase the energy production capacity through MSWI. The MSWI could reach up to 58.9 MW for 3 million inhabitants. Moreover, sensitivity analysis result showed that the project will become economically viable by reducing capital costs by 10 percent [43].

(R. M. Barros, 2019) conducted an economic analysis for incineration of MSW disposal in Brazil; the analysis considered randomly poor quality dumps and landfills. The results showed that the average power produced through incineration was about 15 percent of the waste generation rate from the study area population. Moreover, the economic feasibility has demonstrated that higher feed-in tariff is needed; so government incentives required making it feasible [44]. (L. A. Hadidi & M. M. Omer, 2016) developed a financial model for comparing gasification, and AD as viable WTE solutions in Saudi Arabia. The results of the beneficial financial model analysis investigated significant factors for gasification plants investment including facility generation capacity, generated electricity revenue, and capacity. Similarly, the same factors were applied for AD plants to make an economical comparison between the two alternatives. The claimed results enable decision-makers to determine how to achieve integrated MSW management systems [45]. (H. Cheng & S. Tao, 2018) focused on environmental consequences by applying incineration WTE technology in

China, specifically mercury emissions. Through the study, it was found that the total mercury emissions from MSWI were about 6.1 tons in 2016 and projected to reach 10.6 tons by 2020. Also, MSWI is estimated to have an average current mercury emission factor of 0.083 g per ton with 95% between 0.056 and 0.116 g per ton [46]. (C. Yaman, 2020) conducted a study for analyzing GHG reductions, energy recovery potentials, as well as the environmental impacts from MSW in Dammam, Kingdom of Saudi Arabia. The study examined three scenarios for MSW management, including composting with material recovery facility (MRF), landfilling, and incineration. According to the Intergovernmental Panel on Climate Change (IPCC); LFG emission and Individual waste reduction models of EPA were used to build a strategy that helps stakeholders control GHG emissions by mitigation policy and energy recovery from MSW. The study excluded the waste transportation and disposal phases, and the results of the study showed that the least amount of GHG's from MRF and composting could be 2,142,618 tons of $CO_{2\text{-eq}}$ per year. While the amount of GHG's from incineration was 287,873 tons of $CO_{2\text{-eq}}$ per year. Moreover; the GW potentials for three scenarios revealed that the highest GHG reduction per ton of MSW was 1.091 tons of $CO_{2\text{-eq}}$ per ton of MSW from MRF, and composting followed by incineration which equals 0.147 tons $CO_{2\text{-eq}}$ per ton MSW. Whereas that through landfilling of generated additional GHG's with 0.265 tons $CO_{2\text{-eq}}$ per ton MSW. Furthermore, the incineration option would generate a power of about $1.91\times10^{\wedge 9}$ kWh per year and also it could reduce usage by $1.12\times10^{\wedge 6}$ barrels per year [47].

(G. Chen, 2019) studied incinerating sewage sludge (SS) in China, which showed that over 50 billion tons are discharged annually. Moreover, the results revealed that incineration is a good option to use in MSW treatment. Although SS is difficult to treat due to the huge amount of heat required to remove the large moisture content [48]. (M. C. Samolada, 2014) applied a SWOT analysis for evaluating WTE solutions from GHG emissions decrease, technology precocity, and legislation in Greece. The results indicated that sludge pyrolysis can convert both raw and digested sludge into useful bioenergy in the form of oil and gas, and form biochar as a byproduct as an environmentally resistant that holds potential for carbon confinement, soil conditioning, as well as absorbent production [49]. (L. Lombardi, 2017) conducted an impact assessment for different potential SS treatment methods in Italy, which included land spreading, composting, incineration, landfill, and wet oxidation. The results showed that SS treatment by applying sludge incineration significantly reduced human and ecosystem toxicity indicators, acidification, and eutrophication; but with the undesired result of increasing the resource depletion indicators and GW using combined treatment of SS, and other types of waste were recommended. Moreover, it was found that there is a future potential in incinerating 100% of sludge with energy recovery, which will allow reducing the values of all the considered environmental indicators by a range between 48 and 92%. Finally, other studies were dedicated to find potentials of applying WTE technology [50].

(M. Azam, 2020) took Lahore, the second-largest city in Pakistan as a case study. In the study, it was found that proper disposal ways have been limited due to the lack of pre-planning, infrastructure, political will, and public awareness. Moreover, the MSW generation and characteristics of physical or chemical composition were also important for effective waste treatment. Also even though the average high heating value of MSW was measured as 14,490 kJ per kg, still the energy recovery potential of 48 MW was assessed further from 2000 tons of MSW per day. These results promoted policy-makers to establish an MSW management strategy for potential RE alternatives [51].

(I. A. Al-Khatib, 2019) studied the current situation of the MSW sector in the West Bank of Palestine under the perspective of potential private sector involvement. Whilst the current 12 JSC's were investigated for MSW management or operation the TS and sanitary landfill, only Two JSC's have had Public Private Partnership (PPP) contract. The research analyzed the appropriate actions could encourage the JSC's or ease the implementation of the PPP in the local MSW field. In order to achieve the financial and environmental sustainability in all contracted PPP's, many parameters are believed to support them such as developing the investment promotion laws or legislations [52].

Chapter Three

Theoretical Background

3.1 Overview

Chapter three presents theoretical background regarding the current situation of PT, especially in the WB. It also indicates the current situation in both MSW and the energy sectors.

3.2 Theoretical Background

The current PT situation is way more different than any of the other entire regions in the Middle East. Based on the partition of Palestine by United Nations resolution 181 in 1947, the Palestinian land was divided to, as known now, WB and the Gaza Strip. Later in 1993, Oslo divided the land into three administrative categories that were labeled as A, B, and C. A areas are under full administrative and security control of the PA, B areas are under the administrative control of PA, whereas C areas are under administrative and security control of Israel that forms 61% of WB. And although, Oslo Accord was designed to finish in five years, but still until now, the agreement did not reach its end and further negotiations are still necessary. This situation limited the PA's abilities to implement development plans [53]. Moreover, the published data by PCBS shows that the population of PT is 4,976,684 inhabitants in the mid of 2019 distributed as 2,986,714 and 1,989,970 in WB and Gaza Strip; respectively [54]. Whereas, the total GDP in 2014 was 4.4

$ per capita and the average salaries range between 25 and 30 $ per day according to the World Bank report in 2018 [55].

3.2.1 The PT current situation for the MSW sector

The JSC's work in the WB through covering 83% of the MSW management service sector in 2019. **Figure (3.1)** describes the waste flow of the collected quantities [ton/day] in the WB. Also, it is worth nothing that recycling is still minimal.

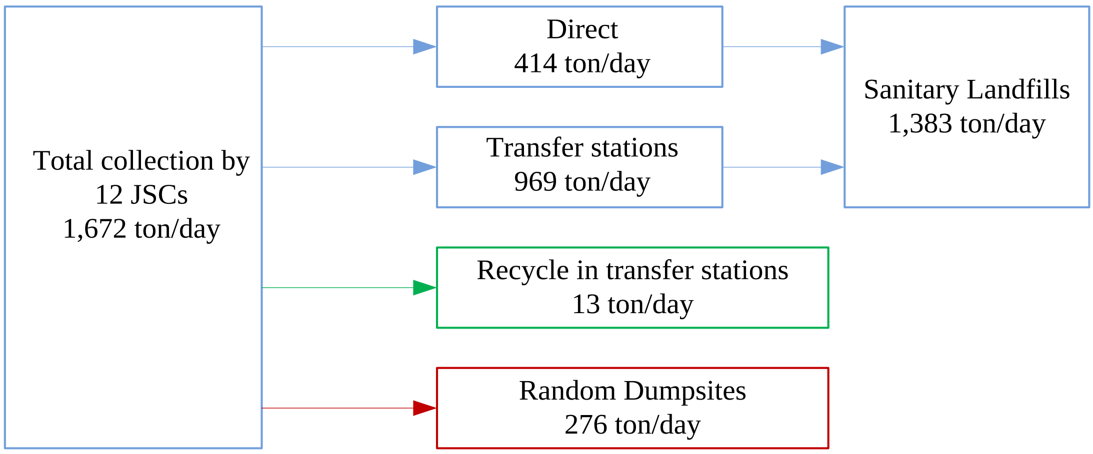


Figure (3.1): JSC collected quantities of waste flow [25].

Japan International Cooperation Agency (JICA) helped PA and funded 11 Transfer Stations (TS), the main purpose is to shorten the long-distance of waste transportation and to reduce costs. These stations serve the municipalities through discharging MSW collection trucks within a short distance of the collection channels. Then in the station, the waste is weighed, packed, and transferred into massive load trucks. Furthermore, the TS's have significant importance in lowering the costs and managing waste streams because the transportation roads are comparatively long and the WB road infrastructure are unsuitable. See the current (2019) MSW generation with transfer quantities [ton/day] and distance traveled [km] to the final destination in **Figure (3.2)** [25]. The figure illustrates the current situation of each governorate from the collected and transferred quantities, and then the traveled distances from TS or municipality centers to the final destination disposal dumping sites. Furthermore, the MSW-generated quantities are much more than that transferred and disposed in the dumping sites, for example, the transfer rate in Nablus and Hebron is higher than the collection rate because its villages and LGU's do not record their collected quantities in the MoLG database correctly. And so, their real disposed MSW appears in the dumping sites records only, which is represented by the transferred quantities for these two governorates particularly [55].

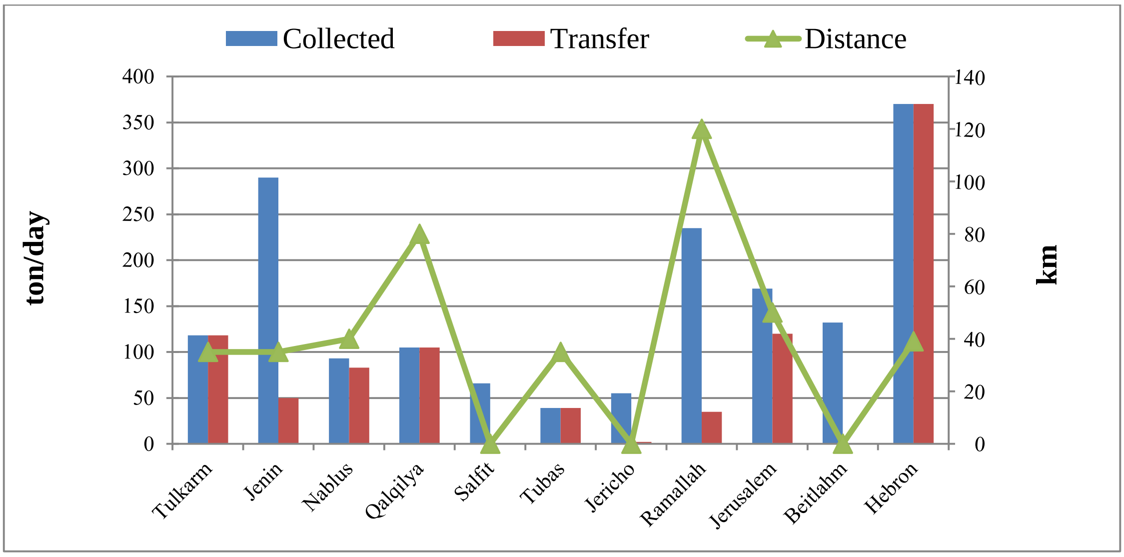


Figure (3.2): The current (2019) MSW generation with transfer quantities [ton/day] and distance travelled [km] to final destination [25].

Undoubtedly, the WB deals with three landfills located in the governorates of Jericho, Jenin, and Hebron. However, the most important ones are Zahrat

Al-Finjan in Jenin and Al-menia between Hebron and Bethlehem. Unfortunately, Zahrat Al-Finjan is upon reaching its maximum capacity within the next few years (before 2025) without the possibility of expansion. Moreover, the landfill in Jericho has already reached its maximum capacity without the possibility of expansion. Accordingly, there have been some efforts towards implementing a new landfill in Ramallah governorate; but due to problems concerning the lands and the lack of proper communication with the Israeli government, the project didn't see the light and does not appear to do so in the next years [56]. As a result of that, the situation can be identified as critical due to the lack of capacity. Another problem is regarding the odors and their impact on public opposition, this is because there is a poor management of leachate and uncontrolled GHG's in the current dumpsites endangering the health of local citizens and ground water. For all the previous reasons, efforts must be made to ensure sustainable management of MSW [55].

The MSW management cost is estimated in terms of the main costs items, collection, transfer, and landfilling. Moreover, the collection process is the responsibility of municipalities in the main cities, the UNRWA in refugee camps, and LGU in rural areas and villages. After that, the collected MSW quantities are transferred to TS or directly to the dumping site; while shifted to dumping sites, gate fees should be paid per ton of MSW, which ranges from 8 to 18 $ per ton, with a weighted average of 9 $ per ton. **Figure (3.3)** displays the MSW management system cost analysis [$/ton MSW] for each governorate in the WB [25].

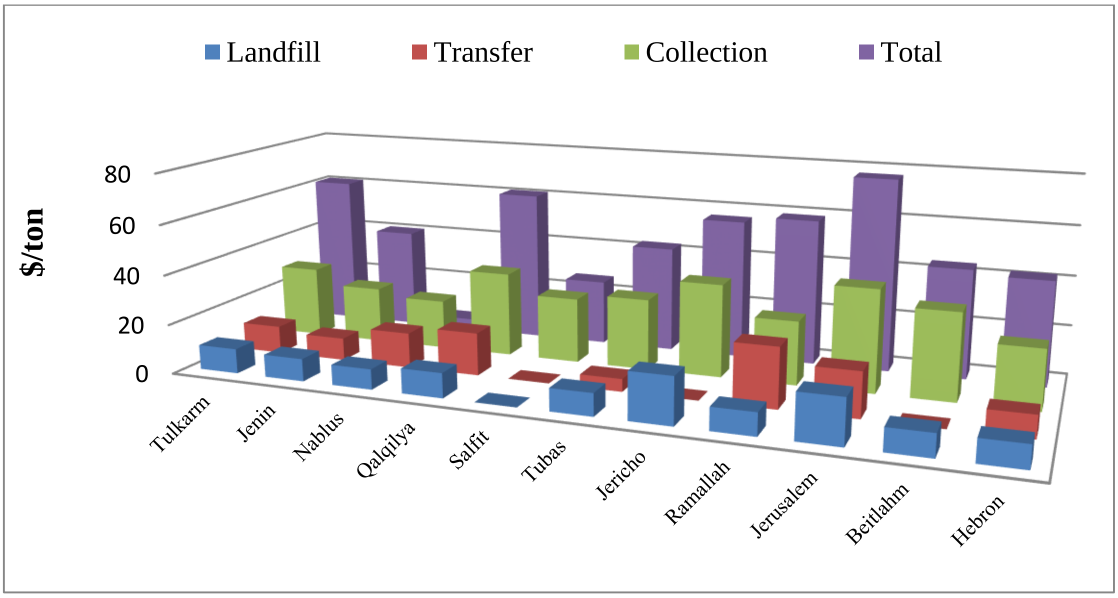


Figure (3.3): WB MSW management system cost [$/ton] [25].

3.2.2 The PT current situation for the energy sector

Energy sources differ from other countries in the WB, since 100% of the fossil fuels and almost 89% of all electricity is supplied by the Israeli Electric Company (IEC) [57]. Moreover, the IEC has a high voltage grid of 161 kV and connects to the 11, 22, 33 kV Palestinian low and medium voltage grids. Also, the connection between the two grids is carried out with hundreds of small link points; it is strengthened by adding new substations.

Although there are efforts to develop the energy sector, the complicated political situation between both sides limits most of the programs and plans that PENRA prepared as a decision-maker. **Figure (3.4)** illustrates the relationship between Palestinian energy institutions and the Palestinian energy supply chain. Also, since the main controller or regulator is the

Palestinian Electricity Regulation Council (PERC) that sets the prices and regulations, the Palestinian Electricity Transmission Ltd. (PETL) owns all transmission points, purchase, wholesale and operates grid, while distribution to energy consumers is implanted by several Distribution Companies (DISCO’s), namely; Jerusalem District Electricity Company (JDECO), Tubas Electricity Distribution Company (TEDCO), Southern Electricity Company (SELCO), Northern Electricity Distribution Company (NEDCO), Hebron Electricity Power Company (HEPCO), and Gaza Electricity Distribution Cooperation (GEDCO).

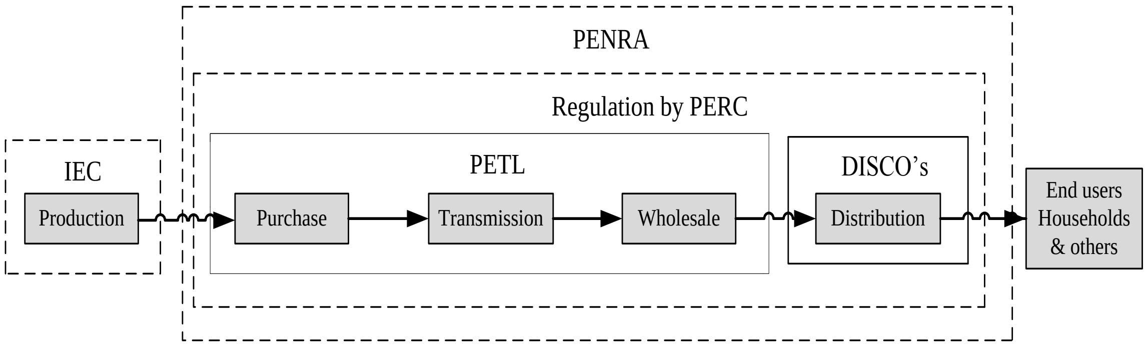


Figure (3.4): **PT energy sector supply chain [58]**.

According to the annual report of PERC, an upgrading for PT electric grid is necessary, since the technical and non-technical loss is about 26% equivalent to 688.4 GWh as shown the WB DISCO's market share based on the number of customers. **Figure (3.5)** shows the percentages for distribution of consumers in the WB based on service-providing company [58].

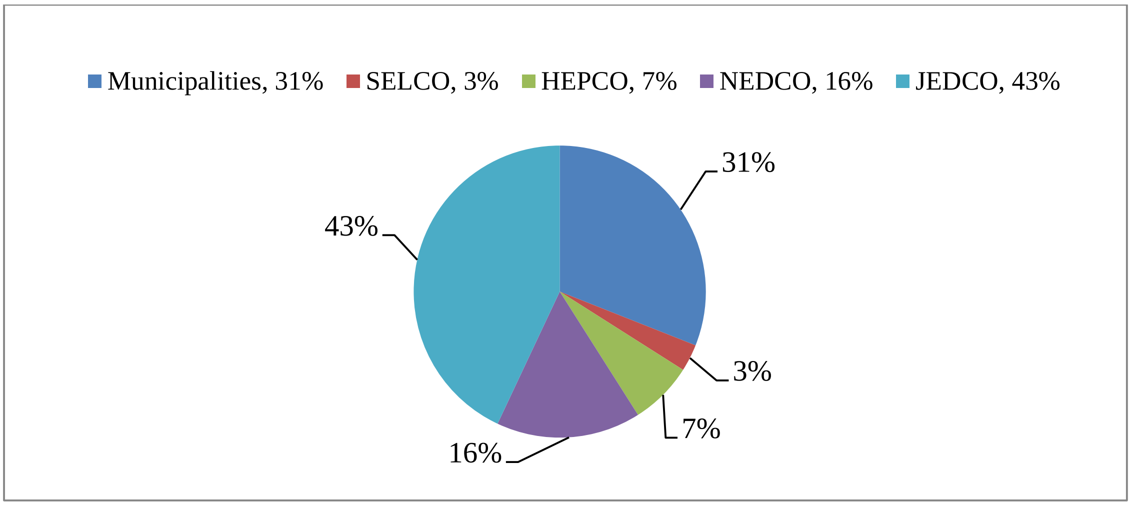


Figure (3.5): WB DISCO's market share based on the number of customers [58].

Despite the large numbers of consumers connected to one of the DISCO's companies, there are 305 town and village council municipalities that directly serve 31% of citizens. Based on the PENRA national energy efficiency action plan, the PA's sustainable goal in 2020 is to produce 130 MW from RES and about 500 MW in 2030. Photovoltaic power generators' contribution is intended to be 80%, 10% from wind energy, and the remaining 10% from biogas and biomass energy sources. However, PERC regulates the process of purchasing electricity from IEC and selling it to end-users through DISCO's, municipalities, and villages councils. Moreover, the electric tariff values differ with classified sectors as shown in **Table (3.1):**

Table (3.1): Palestinian end-users electricity tariff [$/kwh] by sectors[58].

Sector	Price [$/kwh]
Residential	0.1470-0.1541
Commercial	0.1628-0.1657
Industrial	0.1281-0.1392
Water Pumping	0.151
Agriculture	0.1334
Street Lighting	0.133
Temporary Services	0.2193

The difficult political situation between the PA and the Israeli side has limited the development of infrastructure, regulations, and policies [59]. In addition to that, the costs of electricity and other sources of energy, like fossil fuels costs, are higher in PT than in any other country according to the Paris agreement between both sides.

Chapter Four

WTE Technology Alternatives

4.1 Overview

Chapter four indicates the MSW disposed of by modern ways achieved through typical processes including WTE technology options, such as incineration and LFG plants.

4.2 Incineration WTE Technology

Incineration deals with MSW without the need for chemical pre-treatment or mechanical sorting. In this section, the incineration facility's parts and process concepts will be demonstrated. **Figure (4.1)** shows a cross-section of a WTE facility with a semi-dry flue gas treatment system.

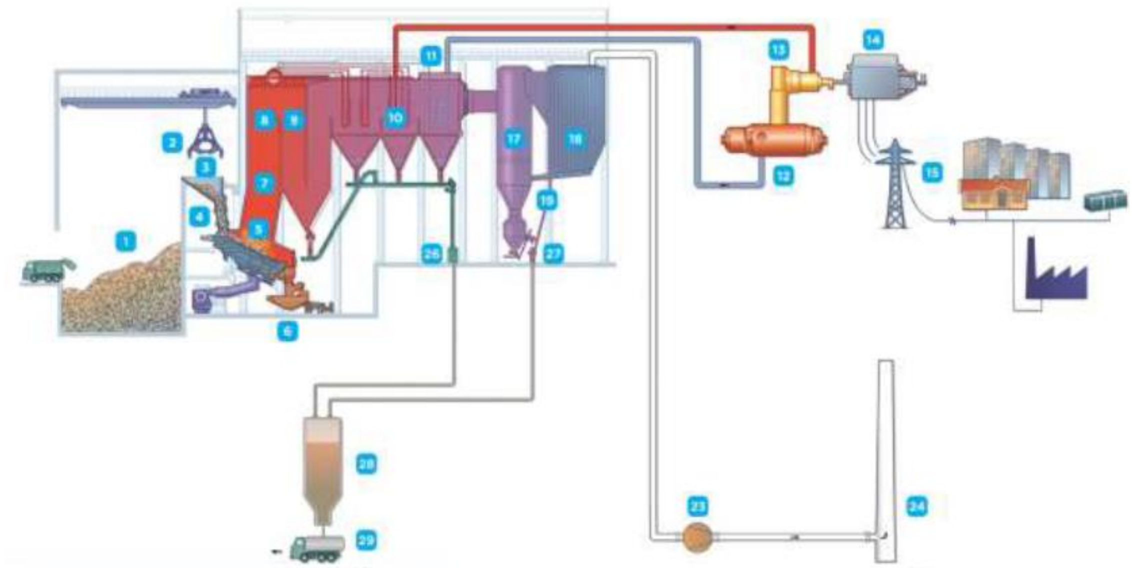


Figure (4.1): A cross-section of a WTE facility with a semi-dry flue gas treatment system [26].

The major sections are furnace or boiler, energy recovery, flue gas treatment, and ash or residue handling units. As numbered in **Figure (4.1)**, Furnace or Boiler includes the following parts; 1. Bunker 2. Waste Crane 3. Hopper/Feed Chute 4. Feeder Ram 5. Grate 6. Bottom Ash Discharger 7. Furnace 8. After Burning Chamber 9. Radiation Part 10. Convection Part 11. Economizer. Also, the Energy Recovery Section includes; 12. Condenser 13. Turbine 14. Generator 15. Electrical Output. In addition to the Flue Gas Treatment Unit which includes; 17. Reactor for Acid Gas Absorption 18. Bag House Filter 19. Residue Recirculation 23. ID Fan 24. Stack. Also, the Ash/Residue Handling Unit includes; 26. Boiler Ash Conveying System 27. Flue Gas Cleaning Residue Transport System 28. Ash/Residue Silo 29. Ash/Residue Discharge [26].

The amount of MSW is determined in the installed weighing station, and the MSW is loaded from the trucks to the tipping halls. In order to avoid unpleasant odors, the tipping hall building should be kept at pressure slightly atmospheric conditions. Moreover, the size of the waste bunker depends on WTE plant capacity, and through the waste feeding process, the waste crane can pick up wastes directly from the feeder, then it mixes and feeds the incoming waste uniformly into the combustion unit in the highest energy efficiency way, and then it distributes the waste hopper through a chute. In the combustion zone, the chute functions as an air seal to avoid uncontrolled air leakage into the combustion chamber. Furthermore, the grate is designed according to the respective principles of movement including inclined or horizontal with forward and background movements. Also, the grate contributes to transportation, agitation, stirring, mixing, distribution and leveling of the waste, and distribution of primary combustion air to the waste layer.

The primary combustion occurs in a furnace, where it is cooled by water walls with steam which is later used for energy recovery. The steam passes through the gas tube walls to form the walls and ceiling of the furnace. This part of the furnace must be highly resistant to corrosion as the very high temperature of the flue gas makes the acidic and alkaline components extremely aggressive. Moreover, secondary air is supplied to complete the combustion through an arrangement of nozzles above the waste, and an additional function of supplying secondary air is to mix the combustion gasses and ensure a uniform temperature of the flue gas. Typically, 40% of the total combustion air is supplied as secondary air and 60% as primary air. Besides, the furnace should be equipped with at least two auxiliary burners to be used during starting up and shutting down of the plant and thus to maintain the temperature in the event of sudden temperature drop. Undoubtedly, the combination of high temperature and alkaline in the flue gas makes the flue gas aggressive, thus the tube walls of the furnace and the boiler tubes must be coated with the corrosive and temperature resistant alloy Inconel, or with a refractory lining to avoid direct contact between the flue gas and the boiler tubes. Typically corrosion protection should be applied until the flue gas temperature is approximately between 850 and 900 C° in the boiler.

Moreover, the temperature and the pressure of the steam affect on boiler's overall efficiency. However, the optimum steam parameters depend on design criteria, both of which increase maintenance costs. Furthermore, the higher temperature and pressure will produce more electricity or lead to a higher risk of corrosion. It also should be mentioned that most the incineration facilities operate with a steam pressure range between 40 and 60 bars, and a steam temperature range between 400 and 425 C°.

Basically, there are two basic boiler designs; vertical and horizontal design as shown in **Figures (4.2)** and **(4.3)**; respectively. The vertical boiler design has vertical passes in both the radiation and the convection part. Whereas the horizontal boiler design has vertical radiation passes followed by a horizontal convection pass with pre-evaporator, superheater, evaporator, and economizer sections.

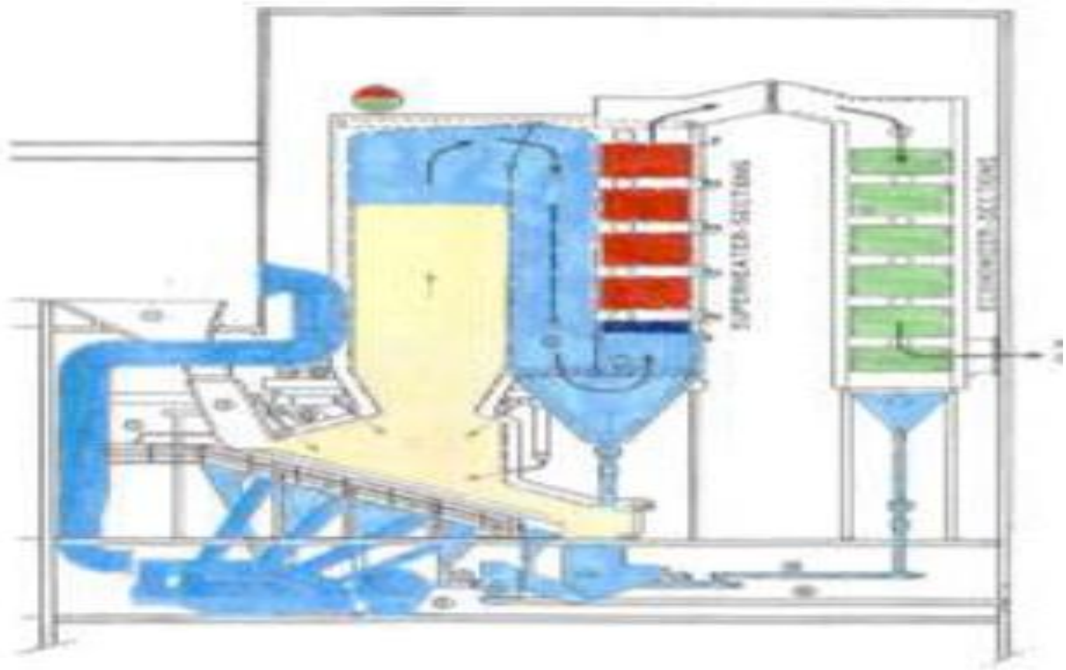


Figure (4.2): The vertical boiler set up [26].

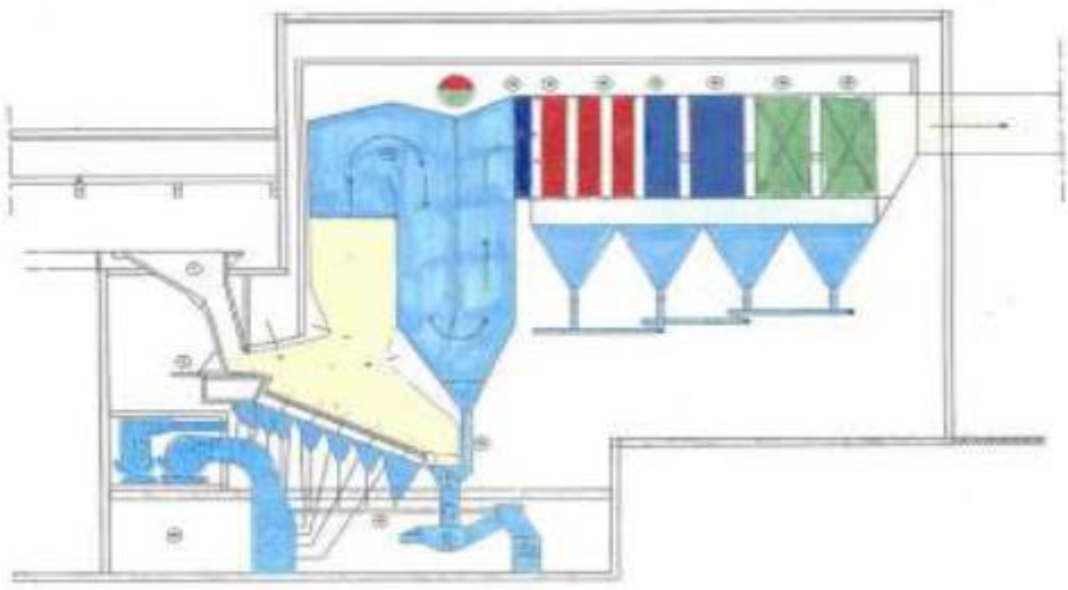


Figure (4.3): The horizontal boiler set up [26].

On the other hand, the horizontal boiler requires more space than the vertical one and is slightly more expensive than the vertical boiler solution. Moreover, the horizontal boiler design contains mechanical cleaning, where the super heater tubes are cleaned by a rapping device to remove the ash deposit, but the vertical boiler design uses soot blowing for cleaning.

In the energy recovery section, the energy can be recovered to produce power and/or steam, and the choice of energy recovery system depends on the local energy infrastructure, the end-use consumption of the region, and energy alternatives' prices. For combined heat and power plants; one ton of waste with a lower CV of 10 MJ per kg can be converted to approximately 2 MWh heat and 2/3 MWh electricity. If only electricity is produced, the energy output can be expected to rise to approximately between 0.70 and 0.75 MWh per ton of waste with a lower CV of 10 MJ per kg. In general, the energy production per ton of waste varies proportionally with the CV. Furthermore, electricity has a higher market value than heat, also the CVs of wastes depend on the income level of the country [26]. In Palestine, the weighted average lower CV is about 11.6 MJ per kg MSW [25].

The pollutant of flue gas from waste requires treatment before being emitted into the atmosphere. Different treatment methods exist from the dry solutions to the more complicated wet solutions. Principally, all processes are based on a reaction between lime injected in a reactor and the acidic components in the flue gas and their transformation into solid compounds. These compounds are removed along with the dust as fly ash in a downstream baghouse filter by adding activated carbon between the reactor and the bag-house filter to remove dioxins and mercury.

Finally, the ash/residue handling unit is considered an important part of the incineration facility since the volume of the MSW after combustion is reduced to about 10% of its original volume, and about 20% based on weight. This combination consists of bottom ash, fly ash, and residues after the flue gas treatment process. Moreover, the bottom ash quality, such as remaining organic content, is measured to evaluate the combustion process. For example, if it is lower than 3%, it may be used for construction purposes instead of stones after sorting the metals for recycling. As for the other components such as the fly ash and flue gas residues they should be treated since they are considered hazardous waste [26].

4.3 LFG WTE Technology

The LFG facilities firstly came in mid to late 1970's and increased during 1990's particularly track for efficiency. The landfilling WTE facility as shown in **Figure (4.4)**, includes LFG collection, treatment system, and energy recovery system producing electricity and heat, which is called CHP. Using the LFG as an alternative RE fuel, biodiesel, or ethanol to meet the fuel demand of the end-users is cost-effective compared to natural gas. Also, it's important to know that LFG can be used directly as feedstock for alternative fuel, such as compressed natural gas, liquefied natural gas, or methanol.

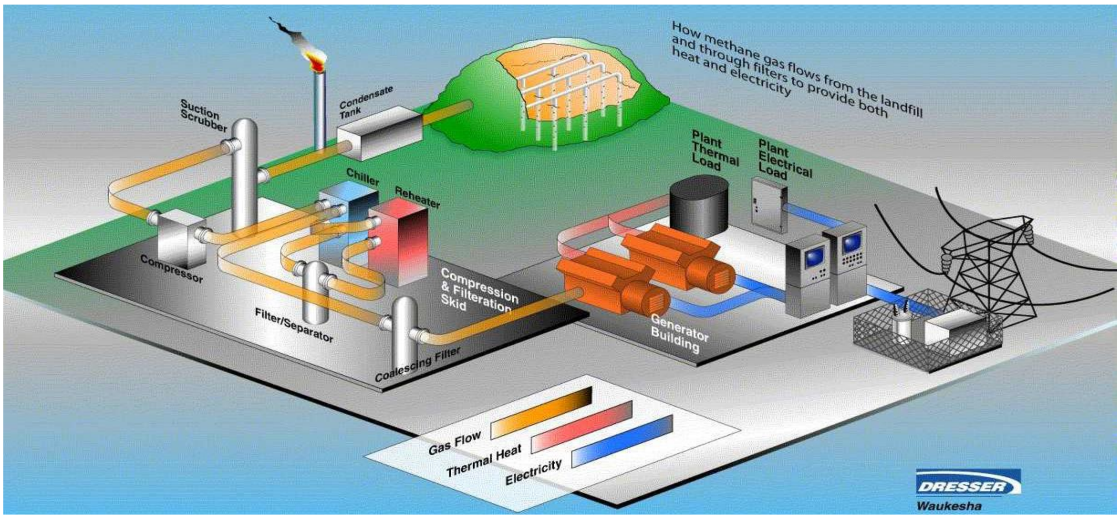


Figure (4.4): **A diagram of the LFG energy facility [60]**.

There are many types of applications for LFG direct use, for example, Boilers can be easily converted to use LFG alone or in combination with fossil fuels. Direct thermal applications include kilns; such as cement, pottery, or brick; sludge dryers, infrared heaters, paint shop oven burners, etc. The combustion device uses LFG to leachate evaporation, which disposes the waste leachate and reduces the treatment cost. End-use options for LFG energy facilities illustrated example in **Figure (4.5)**, such as producing electricity, medium-Btu gas for heating or other purposes, or upgrading the LFG to near pipeline quality for transportation fuel or other uses.

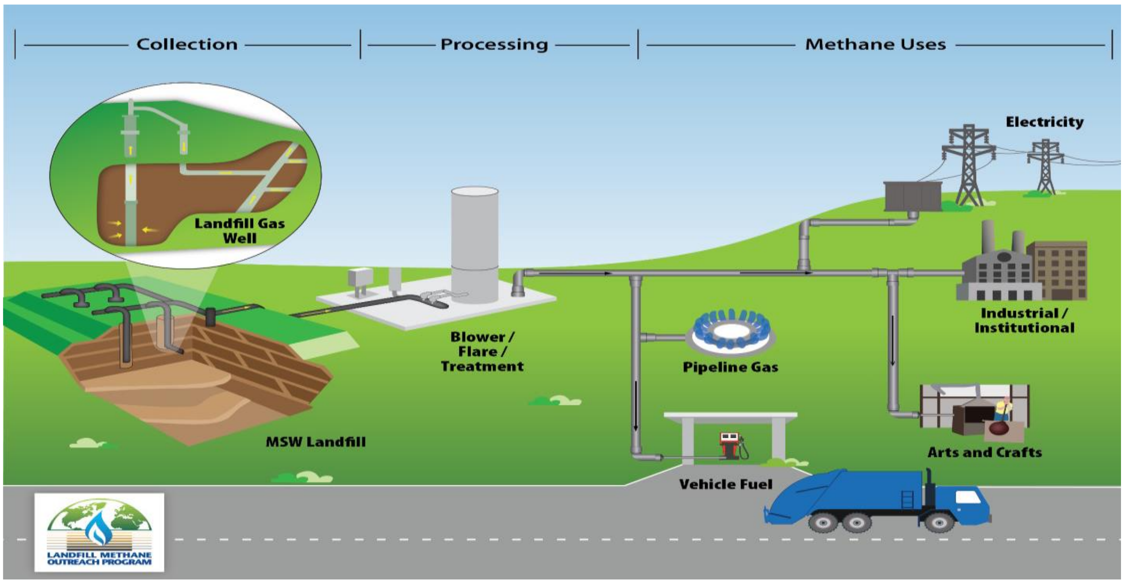


Figure (4.5): **Example LFG End-Use Options [60]**.

While the MSW is first deposited in a landfill, it undergoes an aerobic "with oxygen" decomposition stage when little CH_4 is generated. And then, typically within less than one year, anaerobic conditions are established and methane-producing bacteria begin to decompose the waste and generate CH_4. The changes in typical LFG composition [percentages by volume] over time are indicated in **Figure (4.6)** [60]. Furthermore, the LFG is considered a natural byproduct of the decomposition of organic material in anaerobic "without oxygen" conditions. It contains CH_4 which almost ranges between 50 and 55 percent, and between 45 and 50 percent of CO_2 with less than 1% of non-methane organic compounds (NMOCs), and trace amounts of inorganic compounds. Moreover, CH_4 is effectively GHG 28 to 36 times more than CO_2 at trapping heat in the atmosphere over 100 years [61].

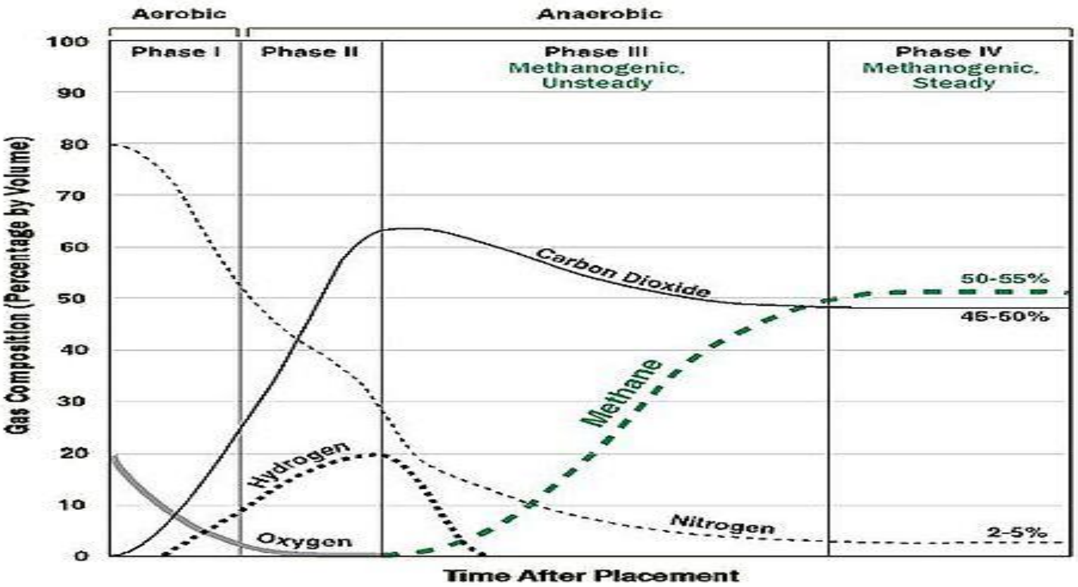


Figure (4.6): Changes in Typical LFG Composition after Waste Placement [60].

Notice that bacteria decompose landfill waste in four phases; the gas composition changes with each phase and waste in a landfill may be undergoing several phases of decomposition at once. Eventually, the time after placement scale, which is the total time and phase duration, varies with landfill conditions. Whereas *phase I;* the aerobic bacteria lives only in the presence of oxygen, and it consumes oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is CO_2. This stage will continue until the available oxygen is depleted. In the next *phase II;* through the anaerobic process, the bacterium doesn't require oxygen, it converts compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols, such as methanol and ethanol. While the acids mix with the moisture existing in the landfill and nitrogen is consumed, CO_2 and hydrogen are produced. Furthermore, in *phase III*; the anaerobic bacteria consumes the organic acids produced in phase II and form acetate, which is an organic acid. This causes the landfill to become a more neutral environment in which methane-producing bacteria are established by consuming CO_2 and acetate. In the final stage, i.e. *phase IV;* the composition and production rates of LFG remain relatively constant, Moreover, LFG usually contains approximately between 50 and 55 percent CH_4 by volume, between 45 and 50 percent CO2, and between 2 and 5 percent other gases, such as sulfides. The LFG is produced in stability during *Phase IV*, typically for a range between 20 and 30 years [59, 61].

Many landfills collect and use LFG as a RE resource while reducing GHG emissions, and the gas collection systems are installed as vertical walls or horizontal trenches. Some types of LFG collection system uses drilling vertical wells in the waste and connecting wellheads to lateral piping that transports the gas to a collection header using a blower or vacuum induction system. Whereas, another type of LFG collection system uses horizontal piping laid in trenches the waste; the horizontal trench systems are considered useful in deeper landfills, and areas of active filling. In this context, the design chosen on-site depends on specific conditions and the timing of LFG collection system installation. And so, some collection systems involve a combination of vertical wells and horizontal collectors. Furthermore, the well-designed systems of either type are effective in collecting LFG. **Figure (4.7)** illustrates the design of a typical vertical LFG extraction well, and **Figure (4.8)** indicates a typical horizontal extraction well.

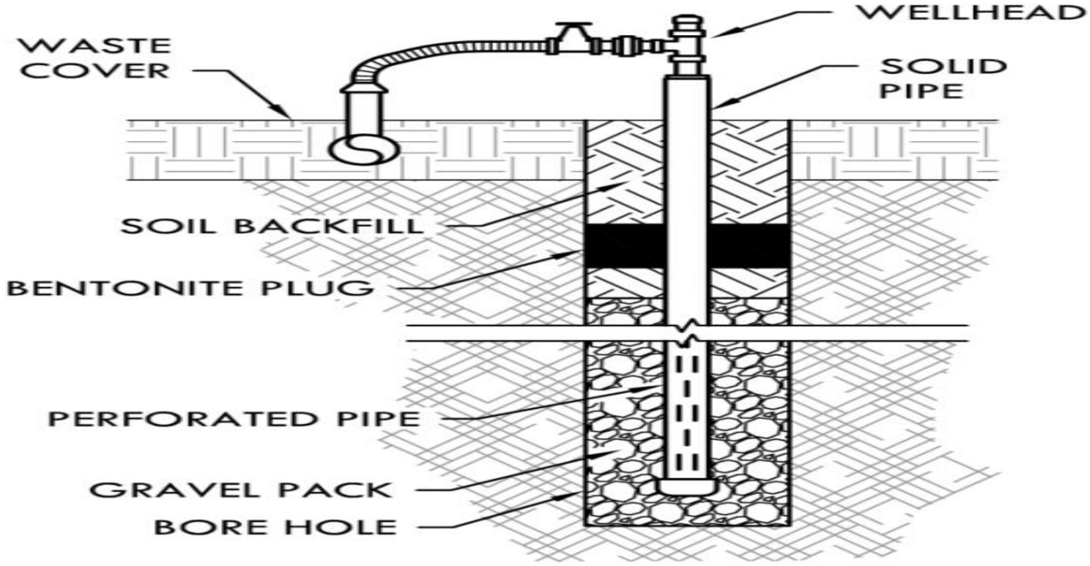


Figure (4.7): Vertical Extraction Well [60].

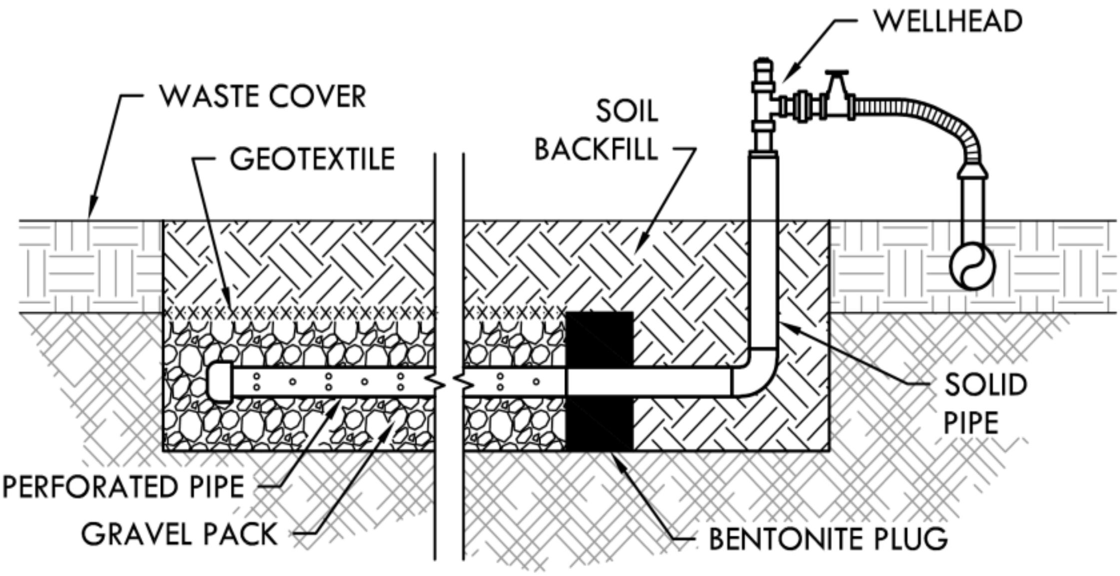


Figure (4.8): Horizontal Extraction Well [60].

The energy recovery systems include a flare for the combustion of excess gas and for use. It's important to know that LFG collection typically begins after a portion of the landfill, known as "cell", which is closed to additional waste placement. Through the condensate collection process, the warm gas from the landfill cools, and condensate "water" forms. If the water is not removed, that will block the collection system and disrupt the energy recovery process. On the other side, the blower is necessary to pull the gas from collection wells into the collection header and convey the gas to downstream treatment and energy recovery systems. Furthermore, the size, type, and the number of blowers needed depend on the gas flow rate and distance to downstream processes. Also to ignite and burn the LFG, the flare is a needed device to control LFG emissions during startup and downtime of the energy recovery system and to control gas that exceeds the capacity of the energy conversion equipment. Additionally, the flare is a cost-effectively way to gradually increase the size of the energy generation system at an active landfill. Also while more waste is placed in the landfill, and the gas collection system is expanded, the flare is used to control excess gas between energy conversion system upgrades to prevent CH_4 from being released into the atmosphere. It is worth noting that the flare designs are either open or enclosed; the enclosed flare is more expensive, but it provides more control on combustion conditions, reduces noise, and reduces light nuisances.

On the other hand, the LFG requires treatment to remove excess moisture, particulates, and other impurities. The type of treatment depends on the site on the specific LFG characteristics, and thus the type of energy recovery system employed. In addition, the boiled or internal combustion engine

(ICE) requires minimal treatment, such as dehumidification, filtration, and compression. Many gas turbines, ICE's, and micro turbine applications require siloxane and hydrogen sulfide removal using adsorption beds, scrubbers, or other technologies after the dehumidification step [60].

The development of MSW landfilling facilities contributes to reducing GHG emissions, improving local air quality, and controlling odors. The decomposition of the wastes process produces LFG, and GHG's especially CH_4 which has a potential of 21 times that of CO_2 for 100 years. And so, it has a short atmospheric life of about 12 years. Also, the annual potential from landfills depends on waste composition and biodegradation [63].

For these reasons, the CH_4 reduction from MSW landfilling is the best option to minimize the human impacts on GCC. Noting that the reduction of CH_4 emissions can occur in direct or indirect ways. Moreover, the CH_4 produced ranges between 60 and 90 by the landfilling process, and it depends surely on the effectiveness of system design. After that, the captured CH_4 will convert to H_2O and CO_2 while it is being burned to produce electricity and/or heat [64]. However, the alternative LFG fuel displaces the use of limited non-renewable resources in combustion to produce the same required amount of energy for the end-user facility or power plants. On the other hand, the NMOC's are considered as pollutants that are low concentrated in LFG, these are destroyed during the combustion in order to reduce health risks. Eventually, the overall environmental benefits were significantly achieved from landfilling application due to the direct CH_4 reductions, the indirect

CO_2 reductions, and both direct and indirect reductions of other air pollutants emissions excluding NO_x, which is generated from burning to produce electricity. On the other hand, collecting and combusting from the LFG process improves air quality surrounding the community by landfill odors reduction, which is usually caused by sulfates, thus the collecting prevents the gas from expanding to the structures of the facility, and it provides safety from explosion hazards [60].

Chapter Five

Economic analysis criteria

5.1 Overview

Chapter five identifies the economical parameters definitions used to estimate and investigate the feasibility of the WTE alternatives. Parameters conducted with respect to being presented are present worth (PW), annual worth (AW), simple payback period (SPP), rate of return (ROR), and saving to investment ratio (SIR). All but one of these measures of worth requires an i [%] which is the Minimum Attractive Rate of Return (MARR).

5.2 Economic Analysis Criteria

The measures of worth for investment projects are used to evaluate the attractiveness of a single investment opportunity to assess the feasibility of study, such as PW, AW, SPP, ROR, and SIR. All measures of worth require an interest rate which is the MARR to calculate the performance indicator, also the value of the MARR depends on the investor opinion and no specific value is proper for all applications.

For defining all of these measures of worth on cash flows, the following conventions are used; at any given point in time (t = 0, 1, 2,..., n), there may exist both revenue (positive) cash flows (R_t), and costs (C_t) represent negative cash flows and the net cash flow at t (A_t) which is defined as this relation ($A_t = R_t - C_t$).

5.2.1 PW

The PW value is an equivalent value of all cash flows at t = 0, and while representing cash flows values, it's necessary to draw cash outflows (downward) and some represent cash inflows (upward) based on the signs and directions of the cash flows. The concept of PW as a measure of investment can be generalized as follows: *Description:* All cash flows are converted to a single sum equivalent at time t = 0 using i=MARR. *Calculation Approach* in equation (5.1):

$$\text{PW} = \sum_{t=n}^{n} A_t(P|F,i,t) = \sum_{t=0}^{n} \frac{A_t}{(1+i)^t} \tag{5.1}$$

Decision Rule: If PW≥0, then the investment is attractive or feasible.

5.2.2 AW

The AW measure is an alternative measure, it converts all cash flows to an equivalent uniform annual series of cash flows over the investment life using i=MARR. The AW measure is generally calculated through firstly calculating the present worth measure and then multiplying this by the appropriate (A|P, i,n) factor.

If PW≥0, then for sure AW≥0, Feasible;

Furthermore, the alternative is considered to be not feasible.

The concept of AW as a measure of investment can be generalized as follows: *Description:* All cash flows are converted to an equivalent uniform annual series of cash flows over the planning horizon using i=MARR. Calculation Approach in equation (5.2):

$$AW = PW\ (A|P, i, n) = PW \frac{i(1+i)^n}{(1+i)^n - 1} \tag{5.2}$$

Decision Rule: If AW≥0, then the investment is attractive or feasible.

5.2.3 ROR

Moreover, if a cash flow series consists of an initial investment (negative cash flow at t=0) followed by a series of future returns (positive or zero cash flows for all t>0), then a unique ROR will exist. If these conditions are not met, a unique ROR will not be guaranteed and caution should be exercised in making decisions based on the ROR. The concept of ROR as a measure of investment can be generalized as follows: Description: an i, ROR, is determined which yields a PW equals to zero. The ROR implicitly assumes the reinvestment of recovered funds at ROR. Calculation Approach: find ROR such that in equation (5.3):

$$PW = \sum_{t=0}^{n} \frac{A_t}{(1+ROR)^t} = 0 \tag{5.3}$$

Important Note: Depending on the cash flow series multiple ROR's may exist, and if the cash flow series consists of an initial investment (net negative cash flow) followed by a series of future returns (net non-negative cash flows) then a unique ROR will exist. Decision Rule: If ROR ≥MARR, then the investment is attractive.

5.2.4 SIR

However, SIR calculation starts by considering the R_t and $C_t$mcan be calculated through the equation (5.4):

$$SIR = \frac{\sum_{t=0}^{n} R_t(\ P|F,i,t)}{\sum_{t=0}^{n} C_t(\ P|F,i,t)} = \frac{\sum_{t=0}^{n} \frac{R_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \quad (5.4)$$

Decision Rule: If SIR >1, then the alternative is feasible.

5.2.5 SPP

The SPP is a measure of economic performance calculated by ignoring the principle of TVM. The concept of SPP is generally shown as the following equation(5.5):

$$SPP = \frac{Investment}{Savings} \quad (5.5)$$

Description of SPP: The number of years required to recover the initial investment by accumulating net project returns. *Decision Rule:* If SPP is relatively short and acceptable by the investor, then the project is feasible. *Important Note:* This form of payback period ignores the time value of money and ignores returns beyond the predetermined limit.

5.2.6 LCoE

Levelized Cost of Electricity (LCoE) is an economic measure to calculate the lifetime costs and expenditures of a plant and to levelize the kWh of electricity production across various generation technologies. Moreover, it is a metric for electricity cost and incorporates TVoM as variable profits and costs in the equation (5.6).

$$LCoE = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}} \qquad (5.6)$$

Description: LCoE is an indicator of the real cost of generated electricity per kWh. *Decision Rule*: If LCoE ≤ predetermined threshold (normally local utility electricity cost) then the project will be feasible [64–68].

Chapter Six

Methodology

As this research aims to investigate the economic performance of building WTE plants in Palestine, the implementation methodology consists of sequential steps which are data collection, mathematical modeling, potential energy calculation, economic performance investigations, and finally discussion, conclusion and recommendations.

In the first phase; through *data collection* from the PA governmental bodies of energy, environment, and MSW management sectors including PENRA, JSC's, EQA, MoLG, and PETL all available governmental national reports, surveys, policies, and strategies regarding waste generation and disposal, and electricity demand and capacity were reviewed. Several meetings were organized with the engineer Basil Yaseen, the officer of Palestinian Energy and Environment Research Center (PEERC) in Ramallah. Moreover, the collected data resources included also the Palestinian Central Bureau of Statistics (PCBS), and non-governmental organizations (such as JICA) reports. In addition to that, state-of-the-art previous scientific contributions and related reports were also reviewed to investigate the most common approaches in estimating WTE plants' economic and environmental performance and to establish a baseline understanding from previous international cases. The next step, through *mathematical modeling* by determining and developing (if necessary) all mathematical formulations required to estimate output energy from incineration and landfilling gasification methods. Moreover, developing all economic formulation and defining all critical parameters to be used in performing sensitivity analysis, followed by future projection waste generation and electric demand growth.

In the potential energy calculation phase, determining the potential energy to be generated from each scenario is necessary. At this stage, both scenarios will be considered for economic investigation and detailed comparisons between the baseline scenario and the proposed ones will be conducted. At the final stage; all proposed scenarios will be analyzed from an economic point of view. Moreover a detailed discussion will be proposed, and appropriate conclusions will be highlighted, and based on that, applicable recommendations will be defined to help Palestinian decision-makers in making more clear decision regarding the implementation of WTE technology in PT as a solution for MSW disposal and energy shortage challenges.

Chapter Seven

Results and Discussion

7.1 Overview

In this section of the study, the comparison investigated the two WTE alternative scenarios, incineration and LFG proposed plant with the baseline landfill regarding the economic criteria and environmental consequences. Chapter seven indicates the results and discussions concerning the general economic input data for scenarios, the economic performance models and analysis, and the sensitive analysis for both proposed scenarios.

7.2 Results and Discussion

The economic performance was investigated in the established WTE plant in Palestine obtained at Zahrat Al-Finjan landfill based on the collected data from the governmental national resources [according to a feasibility study performed by international consultants at Zahrat Al-Finjan landfill, confidently reference] [70]. The economic analysis results were estimated through implementing mathematical modeling for two proposed WTE technology scenarios and applied comparably on the current landfill baseline. The first WTE technology scenario is the incineration model, and the LFG model is the second projected scenario. Based on the current MSW situation in Zahrat Al-Finjan in Jenin, the dumpsite operates on approximately 88 percent utilization of maximum capacity, it receives 1,000 tons per day with an MSW growth rate of 4 percent yearly, and it will reach its maximum capacity with 1,200 tons per day in the few coming years after the start of operating the proposed scenario. Additionally, there is no possibility to expand its capacity nor even a possibility to build a new sanitary landfill due to the scarcity of A lands which are under full administrative and security control of the PA and the other political reasons, thus the suitable lands situated are only in C areas. Moreover, local citizens' resistant and suffering from both odors and poor management of leachate, since the uncontrolled GHG emissions, in the current situation, significantly influence the health of citizens and the ground water.

These challenges promote MoLG and EPA to decide on implementing a sustainable solution to dispose of the continuously generated MSW quantities in healthy manners instead of almost utilized landfill. Moreover, this encourages governments to reform the MSW management system, in order to reduce the environmental effects of MSW, and help decision-makers reform $CO_{2\text{-eq}}$ offset programs to achieve CO_2 limitations and control emissions.

Zahrat Al-Finjan landfill is receiving 53 percent of the total generated MSW in the WB. Based on the current situation for the energy sector in PT, the energy consumed and demand is about 4,865 GWh and 930 MW, respectively; with respect to the annual demand growth rate which is about 3.5 in the WB choosing the preferred option solution, i.e. either incineration or LFG WTE technology and build the plant on the current baseline landfill will contribute in achieving direct or indirect targets of PA national strategic plans. On the other hand, producing and recovering energy especially electricity from more profitable proposed MSW plant will contribute in achieving PENRA national plans' targets to solve electricity supply problems and help the stakeholders to reform policy programs.

7.2.1 The General Economic Data

The general economic data is adopted on the plant for cost analysis in both scenarios as shown in the following **Table (7.1)** the general economic data is considered for the two scenarios.

Table (7.1): The general economic data is considered for the two scenarios.

General Economic Data	
Interest rate [i %][64]	10.00
Inflation rate [%][53]	2.40
Combined interest rate [%]	12.64
Life time [years]	30
Electricity feed in tariff [$/kwh][58]	0.117
MSW gate fees [$/tonne] [25]	12
Value Added Tax [VAT %][71]	16.50

The normal values of interest and inflation rates adopted in Palestine [%] are 10 and 2.4; respectively [54, 65]. The MoLG and JSCs pay the GF for the MSW disposed from each governorate to the current Zahrat Al-Finjan landfill [25]. The value of GF in **Table (7.1)** is adopted as a weighted average. The normal value-added tax [VAT %] is 16.5% in Palestine, and the investors may pay it of their net revenues as income tax based on the Palestinian laws [71].

7.2.2 Economic Performance Modeling

The implementation of the projected WTE plant and economic performance investigation for cost analysis has been adopted for both scenarios. The amount and characteristics of the MSW properly disposed to the proposed WTE plant used as general input data in the calculations including the weighted average CV which is about 11.6 MJ per kg of MSW based on the data provided in **Table (1.2)**. Moreover, in the first years, the MSW will be disposed to the plant in tons with an amount of about 1,000. And although the plant capacity is about 1,200 tons of MSW per day, it will reach up to 4% with MSW generation's annual growth rate. The MSW growth rate is adopted in Palestine based on the increase of the quality of life but it doesn't depend on the proportional rise of population. Moreover; the most important data for plant establishment includes operating and maintenance growth rate which will be about 2 percent per year, also the salvage value will be about 10 percent of the initial investment of the plant at the end of last year of NCF. In the following **Table (7.2)** it is shown that the general input data used in mathematical modeling in both scenarios. The incineration's ηov.all equals 20 percent in the first scenario but 33 percent in the second scenario.

Table (7.2): The general input data used for mathematical modeling in both scenarios.

	Incineration	LFG
CV [MJ/kg MSW] [25]	11.6	
First year MSW input [tonne/day] [25]	1,000	
Plant capacity [tonne of MSW/day] [25, 54]	1,200	
MSW generation annual growth rate [%][70]	4	
Plant overall efficiency [η ov. all %][54]	20	33
O&M costs growth rate [%][54]	2	
Salvage value [% of initial investment] [$]	10	

7.2.2.1 Incineration Modeling

The incineration plant $\eta_{\text{ov.all}}$ will be about nearly 20 percent; **Table (7.3)** indicates the important specific economic data for the incineration scenario calculations assuming that the incineration WTE plant will require an investment cost of about 96,000 $ per daily ton of MSW transferred to the plant. Furthermore, the operating and maintenance costs are estimated to be 16.5 $ per daily ton of MSW in each year. Depending on data in **Table (7.2),** estimation of energy produced from incineration plant may reach about 1,411.33 GWh yearly. Notice that the amount is calculated based on the CV of MSW and the daily amount of MSW plant capacity.

Table (7.3): The specific economic data used to mathematical modeling in the first scenario

Incineration scenario	
Investment [$/ daily tonne] [70]	96,000
year] [70]	16.5
Energy output [GWh/year]	1,411.33

The establishment of the incineration WTE plant is expected to be in 2025 with an operation lifecycle of 30 years. The landfill capacity (1,200 tons MSW per day) will receive the disposed of the quantity of MSW incrementally based on MSW yearly growth rate of 4 percent. The disposed MSW will be about 1,000 tons per day, and then the amount of electricity produced will be between the range of 235 to 275 GWh yearly until the 6th year through the plant lifespan to reach about 282 GWh per year with receiving 1,200 tons of MSW per day until the end of lifetime due to the plant capacity that will reach the max in few coming years.

While the investor pays the investment and O&M costs, they have approximately calculated -115 million $ in the first year, -19,800 $ at the end of the first year (2025); respectively. The O&M cost will increase with an annual growth rate of about 2%. Also, It was calculated to be 35,165 $ in 2055 (end of lifespan). The MoLG and JSC's pay gate fees (GF) in $ per ton of MSW to the investor. The weighted average GF is calculated to be 12 $ per ton. The GF is estimated as a part of revenues +4,380,000 $ in 2026, then it will be 5,256,000 $ at end of its lifetime. The electricity production is estimated from the incineration plant in the first year at about 235 GWh to reach 282 GWh at the end of lifetime based on the quantity of the disposed MSW yearly. Whereas the electricity feed-in tariff is 0.117 $ per kWh and it is estimated to be 27,521,000 $ at the end of the first year (2025), it will also increase to be about 33,025,200 $ in 2055.

The depreciation value, based on the investment, the salvage values, and the lifecycle of the plant are calculated to be about -3,456,000 $ per year in a linear manner. The taxable NCF is estimated in dollars after discounted linear depreciation from revenues on the NCF, and the investor pays a value to the government as a tax value percentage of the profit. The After-tax cash flow (ATCF) is estimated in dollars with taking the value-added tax (VAT) of 16.50 percent into consideration. See **Table (7.4)** which shows the NCF & ATCF results in dollars through incineration plant lifespan, and **Figure (7. 1)** which indicates the ATCF in million dollars versus each year. The SPP will be after 5 years.

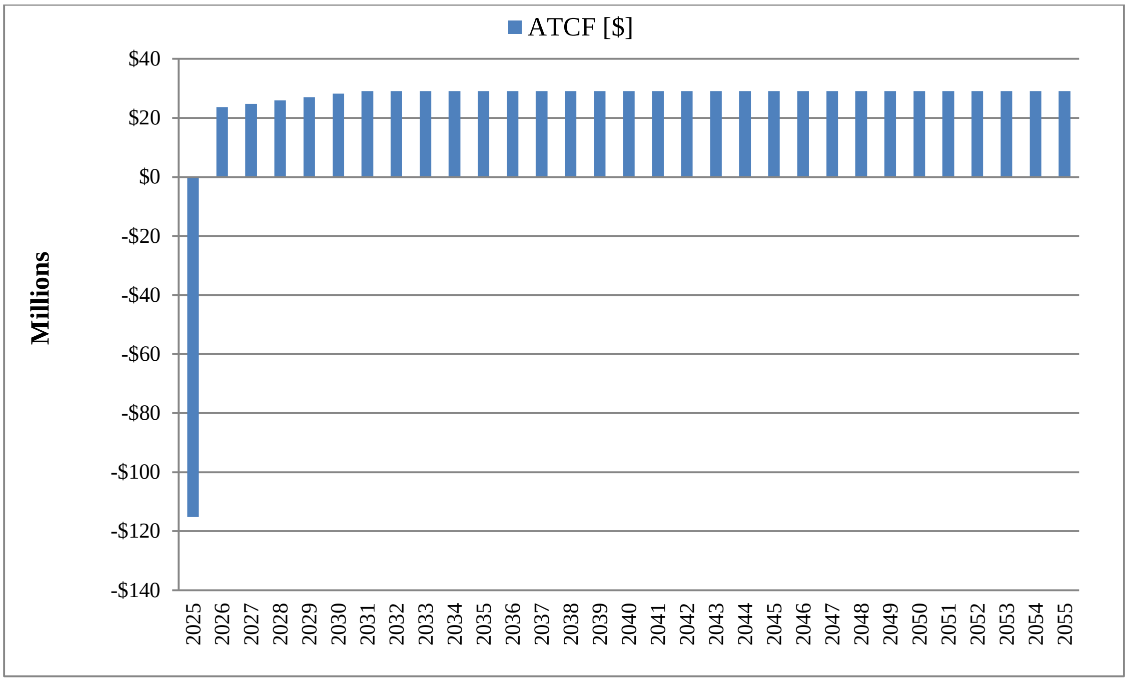


Figure (7.1): **The ATCF [million dollars] first scenario**.

Table (7.4): The NCF & ATCF results in dollars through incineration plant lifespan.

Year number	Year	NCF [$]	ATCF [$]
0	2025	-$115,200,000	-$115,200,000
1	2026	$ 31,881,200	$26,620,802
2	2027	$ 33,156,844	$27,685,965
3	2028	$34,483,522	$28,793,741
4	2029	$35,863,275	$29,945,834
5	2030	$37,298,226	$31,144,019
6	2031	$38,259,339	$31,946,548
7	2032	$38,258,902	$31,946,183
8	2033	$38,258,456	$31,945,811
9	2034	$38,258,001	$31,945,431
10	2035	$38,257,537	$31,945,044
11	2036	$38,257,064	$31,944,648
12	2037	$38,256,581	$31,944,245
13	2038	$38,256,089	$31,943,834
14	2039	$38,255,587	$31,943,415
15	2040	$38,255,074	$31,942,987
16	2041	$38,254,552	$31,942,551
17	2042	$38,254,019	$31,942,106
18	2043	$38,253,475	$31,941,652
19	2044	$38,252,921	$31,941,189
20	2045	$38,252,355	$31,940,717
21	2046	$38,251,778	$31,940,235
22	2047	$38,251,190	$31,939,743
23	2048	$38,250,590	$31,939,242
24	2049	$38,249,977	$31,938,731
25	2050	$38,249,353	$31,938,210
26	2051	$38,248,716	$31,937,678
27	2052	$38,248,066	$31,937,135
28	2053	$38,247,404	$31,936,582
29	2054	$38,246,728	$31,936,018
30	2055	$38,246,038	$31,935,442

Eventually, the economic performance will be determined depending upon default input parameters by using the incineration analysis model. The default economic output is calculated to be as indicated in the following **Table (7.5)**. The determination of the economic output data through both

NCF and ATCF for incineration WTE plant (i = 10% & n = 30 years) based on the economic input data. **Table (7.5)** displays the results in the first scenario, the SPP determined through applying equation (5.5) on the NCF, and ATCF to be 4 and 5 years; respectively, along the lifetime of the project.

Table (7.5): **The economic output data for the first scenario**.

	[NCF]	**[ATCF]**
SPP [year]	4	5
Discounted PBP [year]	5	7
PW [$]	+ 164,611,345.63	+ 96,254,388
AW [$]	+ 21,409,185.21	+ 12,518,748
IRR [%]	30	23
SIR	+ 2.7	+ 2.0
LCoE [$]	0.050	0.061

The discounted PBP will be in 5 and 7 years of the established project and is calculated from cumulative PV of both NCF and ATCF; respectively. Whereas the NPV for both NCF and ATCF has been estimated to be approximately +165 million $, and +96 million $; respectively. This is determined by using the calculations on PV in the incineration analysis model by equation (5.1). The NAV is determined through applying equation (5.2) on both NCF and ATCF, and it will be approximately +21, and +13 million dollars; respectively. The result of this analysis; the PW and AW values are greater than zero and so the project will be feasible.

The IRR will be greater than MARR. As the default economic input data, the i[%] is with a percentage of 10, inflation rate equals 2.40 percent, and so the compound interest rate is 12.64 percent. The IRR is estimated through equation (5.3) by using the incineration economic analysis model, it is calculated to be 30 and 23 percent for both NCF and ATCF; respectively. The SIR will be estimated through equation (5.4) which depends on the NPV for both incomes cash flows [net revenues] and the outcomes cash flows [the net costs]. The value of SIR is calculated approximately at about +2.7, and +2.0 for the NCF and the ATCF; respectively. The results will be greater than 1 and even the project will be feasible. On the other hand, the LCoE estimated 0.050, and 0.061 dollars per kWh for both NCF and ATCF; respectively. The calculation for LCoE is estimated through equation (5.6), and the resultant values of LCoE are less than the normal local electricity tariff. Clearly; the project will be feasible because the LCoE values will be less than the current price (0.117 $ per kWh) of IE from the Israeli side, and that better choice for the government will be to buy the electricity from the plant investor with the new electric tariff costs.

7.2.2.2 LFG Modeling

The proposed LFG plant $\eta_{\text{ov.all}}$ is 33 percent, additionally, **Table (7.6)** indicates the important specific economic data for the second scenario (LFG WTE technology plant) calculations. The economical calculations for the LFG WTE plant require investment cost which is about 11,667 $ per daily ton of MSW transferred to the plant. Furthermore, the operating and maintenance costs are calculated to be 9 $ per daily ton of MSW in each year. Depending on data in the previous **Table (7.2)** the energy will be produced from the LFG plant may reach yearly about 118.87 GWh. Notice that the amount has been calculated based on the CV of MSW and CH_4 with an energy content of 11.6, and 12.3 MJ/kg [72]; respectively, and the daily quantity of MSW plant capacity. The electricity output calculated from the LFG plant also dependent on the quantity of CH_4 will be produced in cubic meters [$m^{\wedge 3}$] for each year along with the lifespan of the plant, based on the following equation (7.1):

$$Electricity\ output\ \left[\frac{kwh}{year}\right] = Q\ (CH4)\ \times 10 \times \eta ov.all \tag{7.1}$$

Where the $Q_{(CH4)}$ is in $m^{\wedge 3}$, η ov. all = 33 percent, and 10 kWh electricity average amount will be produced each year for 1 $m^{\wedge 3}$ of CH_4. Based on the LandGEM-v302 model, the expected amount of CH_4 is adopted for MSW disposed to the LFG plant. The model is designed through Landfill Methane Outreach Program (LMOP) for U.S regulatory applications in general and also worldwide [60, 73, 74]. See **Figure (7.2)** and **Figure (7.3)** which indicate the quantity of CH_4 produced in million $m^{\wedge 3}$ each year from the LFG and the electricity generated in GWh for each year in the second scenario; respectively.

Table (7.6): The specific economic data used to mathematical modeling in the second scenario.

LFG scenario	
Investment [$/ daily tonne] [70]	11,667
O&M costs [$/daily tonne. O&M costs [$/daily tonne . year] [70]	9
Energy output [GWh/year]	118.87

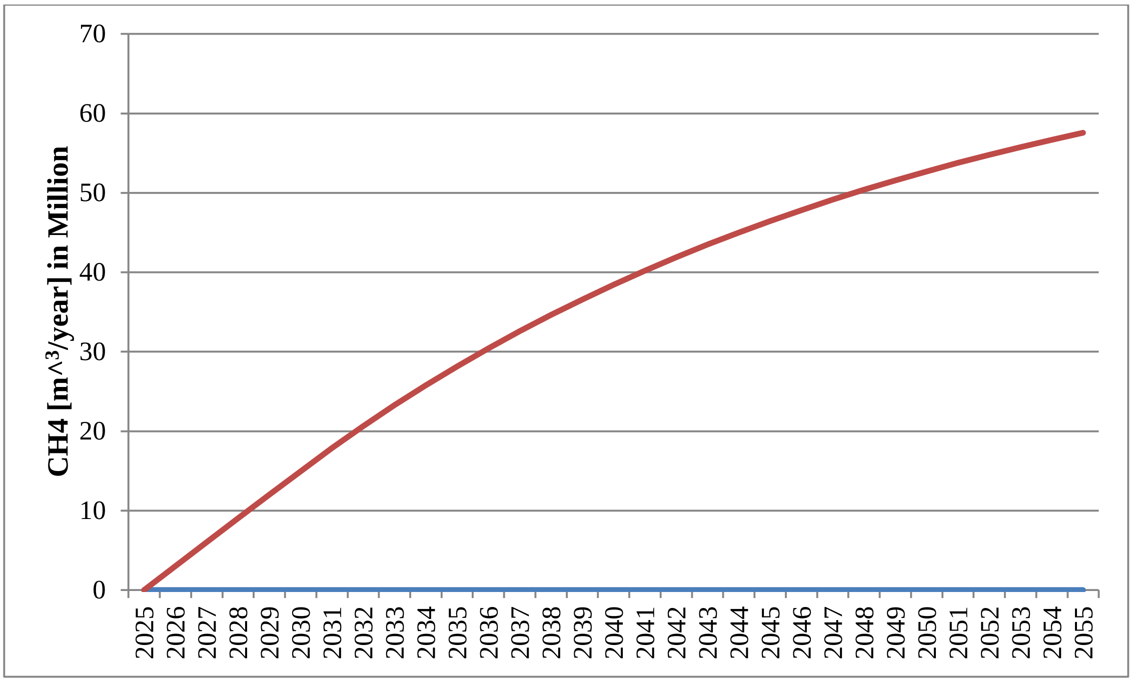


Figure (7.2): Quantity of CH_4 [million m^3] produced each year from LFG in the second scenario.

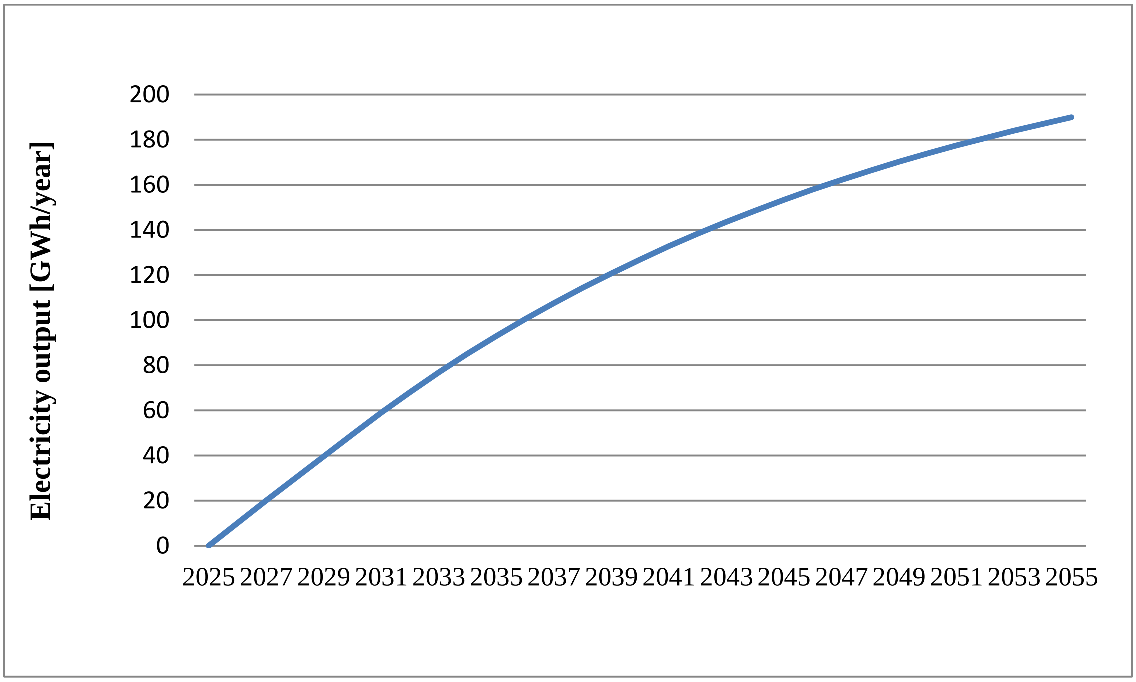


Figure (7.3): Electricity output produced [GWh] each year from LFG in the second scenario.

The establishment of the projected LFG WTE plant is supposed to be in 2025 with a lifecycle of 30 years. The landfill capacity (1,200 tons MSW per day) will receive the disposed quantities of MSW incrementally based on MSW's yearly growth rate of 4 percent. The disposed MSW will be about 1,000 tons per day from the first year of 2025 to 2029 and then the landfill will receive the max MSW capacity to the end of the lifespan of the plant. Moreover, the amount of electricity will be produced between a range of 10 to 190 GWh yearly through the plant life cycle, and the plant will not produce energy or CH_4 in the first year. Notice that, the amount of energy is not constant due to the accumulative parts of CH_4 amount and still collective in the landfill without decomposition for next year.

The total investment cost will be approximately about -14 million $, and also the O&M costs approximately will reach -10,800 $ at the end of the first year, and then it will increase every year with an O&M cost growth rate of 2 percent. It will be approximately reached -19,179 $ in 2055 at end of its lifetime. The gate fees with a value of 12 $ per ton will reach +4,555,200 $ in 2026 and then it will be +5,256,000 $ at end of its lifetime. The electricity will be produced from the LFG plant estimated at the beginning of 2026, which is about 10 GWh to nearly about 19 GWh at the end of its lifetime based on the amount of the disposed MSW yearly. The electricity feed-in tariff is 0.117 dollars per kWh, and it was calculated to be about +1,171,344 dollars in 2026, it will also increase to be estimated at an amount of +22,218,895 dollars in 2055.

The depreciation value [$/year], based on the investment and the salvage values of the LFG plant life cycle, was calculated to be about -420,000 in a linear manner. The taxable NCF is estimated in dollars after the discounted linear depreciation from revenues on the NCF. The investor will pay a value to the government as a tax value percentage of the profit. Moreover, the After-tax cash flow (ATCF) is estimated in dollars with taking the value-added tax (VAT) of 16.50 percent into consideration. **Figure (7.4)** indicates the ATCF in million dollars for each year in the second scenario; the SPP will be 3 years. Furthermore, **Table (7.7)** shows the results of NCF and ATCF in dollars through LFG plant lifespan.

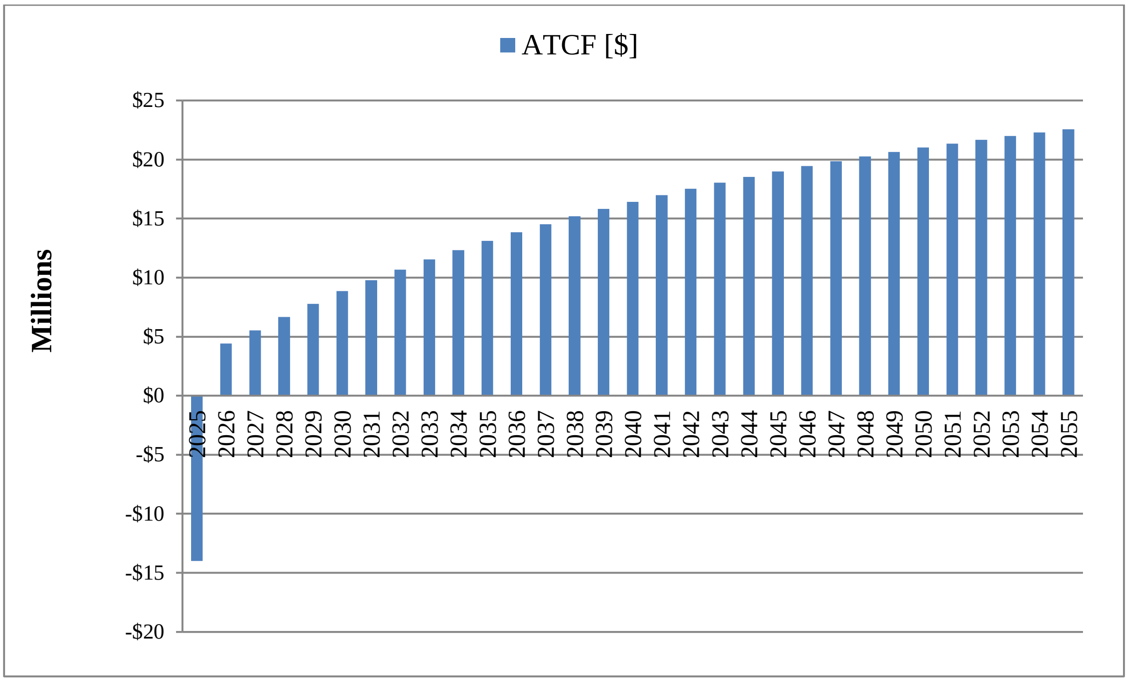


Figure (7.4): The ATCF [million dollars] in the second scenario.

Table (7.7): The NCF & ATCF results in dollars through LFG plant lifespan.

Year number	Year	NCF [$]	ATCF [$]
0	2025	$ -14,000,000	$ -14,000,000
1	2026	$ 5,715,745	$ 4,772,647
2	2027	$ 7,058,808	$ 5,894,105
3	2028	$ 8,401,257	$ 7,015,050
4	2029	$ 9,745,718	$ 8,137,675
5	2030	$ 11,021,853	$ 9,203,247
6	2031	$ 12,145,458	$ 10,141,458
7	2032	$ 13,214,249	$ 11,033,898
8	2033	$ 14,230,898	$ 11,882,800
9	2034	$ 15,197,948	$ 12,690,286
10	2035	$ 16,117,817	$ 13,458,377
11	2036	$ 16,992,806	$ 14,188,993
12	2037	$ 17,825,104	$ 14,883,961
13	2038	$ 18,616,791	$ 15,545,021
14	2039	$ 19,369,850	$ 16,173,825
15	2040	$ 20,086,162	$ 16,771,945
16	2041	$ 20,767,520	$ 17,340,879
17	2042	$ 21,415,629	$ 17,882,050
18	2043	$ 22,032,108	$ 18,396,811
19	2044	$ 22,618,502	$ 18,886,449
20	2045	$ 23,176,276	$ 19,352,190
21	2046	$ 23,706,825	$ 19,795,199
22	2047	$ 24,211,478	$ 20,216,584
23	2048	$ 24,691,496	$ 20,617,399
24	2049	$ 25,148,081	$ 20,998,648
25	2050	$ 25,582,376	$ 21,361,284
26	2051	$ 25,995,466	$ 21,706,214
27	2052	$ 26,388,385	$ 22,034,302
28	2053	$ 26,762,118	$ 22,346,368
29	2054	$ 27,117,598	$ 22,643,194
30	2055	$ 27,455,716	$ 22,925,523

Eventually, the economic performance will be determined depending upon default input parameters by using the LFG analysis model. The default economic output adopted is as indicated in the following **Table (7.8).** The determination of the economic output data through both NCF and ATCF for the LFG WTE plant (i = 10% & n = 30 years) is based on the economic input data in **Table (7.2).** The results in the second scenario, the SPP determined through applying equation (5.5) on the NCF, and ATCF along the lifetime of the project.

Table (7.8): The economic output data for the second scenario.

	[NCF]	[ATCF]
SPP [year]	3	3
Discounted PBP [year]	3	4
PW [$]	+87,686,073.97	+68,211,403
AW [$]	+11,404,362.14	+8,871,506
IRR [%]	57	48
SIR	+7.2	+5.9
LCoE [$/kwh]	0.026	0.032

The discounted PBP will be in 3 and 4 years of the established project and will be calculated from the cumulative PV of both NCF and ATCF; respectively. Whereas the NPV for both NCF and ATCF has been calculated to be approximately +87 million dollars and +68 million dollars; respectively, it is determined by using the calculations of PV in the LFG analysis model by equation (5.1). Furthermore, the NAV is determined through applying equation (5.2) on both NCF and ATCF will be approximately +11, and +9 million dollars; respectively. The result of this analysis; the PW and AW values are greater than zero and so the project will be feasible.

The IRR will be greater than MARR, and as the default economic input data, the i is with a percentage of 10, inflation rate equals 2.40 percent, and so the compound interest rate is 12.64 percent. The IRR is estimated through equation (5.3) by using LFG economic analysis model, it will be calculated to be 57 and 48 percent for both NCF and ATCF; respectively. The SIR will be estimated through equation (5.4), which depends on the NPV for both incomes cash flows [net revenues] and the outcomes cash flows [the net costs]. The value of SIR has been estimated approximately about +7.2 and +5.9 for the NCF and the ATCF; respectively. Furthermore, the results of SIR will be greater than 1 and so the project will be feasible.

On the other hand, the LCoE is estimated at 0.026 and 0.032 dollars per kWh for both NCF and ATCF; respectively. The calculation for LCoE is through equation (5.6), and the resultant values of LCoE are less than the normal local electricity tariff. Clearly; the project will be feasible because the LCoE values will be less than 0.117 dollars per kWh of IE from the Israeli side and that better choice for the government will be to buy the electricity from the plant investor with the new electric tariff costs.

7.2.2.3 Sensitivity Analysis

The economical parameters for the both proposed scenarios indicate the project feasibility by using equations and model analysis. In this research, it will be necessary to determine SPP, discounted PBP, PW and AW, IRR, and LCoE to investigate what parameters matter the most. Usually, one factor or parameter at a time is varied and independence with other factors is adopted. The effect of variation may be determined using sensitive analysis and some of the parameters evaluated for sensitivity are i [%], CV of MSW, the overall efficiency of the plant [$\eta_{ov.\ all}$], and the gate fees. The determination of the economic parameters will help the decision-maker to decide to build the proposed plant when the investigation of project feasibility is achieved. Whereas the PW and AW should be greater than zero, the SIR should be greater than 1, and the IRR should be equal or greater than MARR. When the SPP has the least years and the LCoE may be equal to or less than the national local selling price, then the project is feasible.

7.2.2.3.1 Incineration Sensitivity Analysis

To determine the sensitivity measure of PW or AW on both NCF and ATCF the incineration economic analysis model in the first scenario will be used, which will be estimated in four cases. In the first case, the i value will vary, and while the value of i varies in range from 10 to 20 percent with an increment of 5 percent in each step, the other parameters will be influenced. Whereas the economic input data remains constant as a default value. The results are shown in **Table (7.9) and Table (7.10);** the incineration economic performance NCF and the incineration economic performance ATCF; respectively.

Table (7.9): NCF economic performance first scenario.

Incineration [NCF]			
	i = 10%	i = 15%	i = 20%
SPP [year]	4	4	4
Discounted PBP [year]	5	6	7
PW [$]	+164,611,345.63	+85,542,637.92	+39,669,671.71
AW [$]	+20,986,443.84	+15,214,368.41	+9,078,813.00
IRR [%]	30	30	30
SIR	+2.43	+1.74	+1.34
LCoE [$/kwh]	0.05	0.07	0.08

Table (7.10): ATCF economic performance first scenario.

Incineration [ATCF]			
	i = 10%	i = 15%	i = 20%
SPP [year]	5	5	5
Discounted PBP [year]	7	9	16
PW [$]	+101,801,409.31	+40,323,969.60	+ 4,676,298.05
AW [$]	+12,978,750.35	+7,171,905.66	+ 1,070,218.98
IRR [%]	24	24	24
SIR	+2.07	+1.55	+1.22
LCoE [$/kwh]	0.06	0.07	0.09

To better interpret the results, graphically display the parameter versus the measure of worth. The NPV-NCF & the NPV-ATCF, and DPBP-NCF & DPBP-ATCF curves in million dollars will be indicated in **Figure (7.5)** with i [%] variation. The discounted PBP will vary and increase, but PW will decrease with increasing i values. On the other hand, the AW will decrease with increasing i values. **Figure (7.6)** indicates the sensitivity of AW in million dollars with the i [%] variation values. Notice that the risk will be more through increasing the i value, and with all of i values, the estimation of ATCF indicators will make the proposed plant feasible. Whereas, the IRR will be 24 percent greater than the MARR of the projects, and so the proposed plant will have a return and profit on the investment costs; the SPP will be after 5 years.

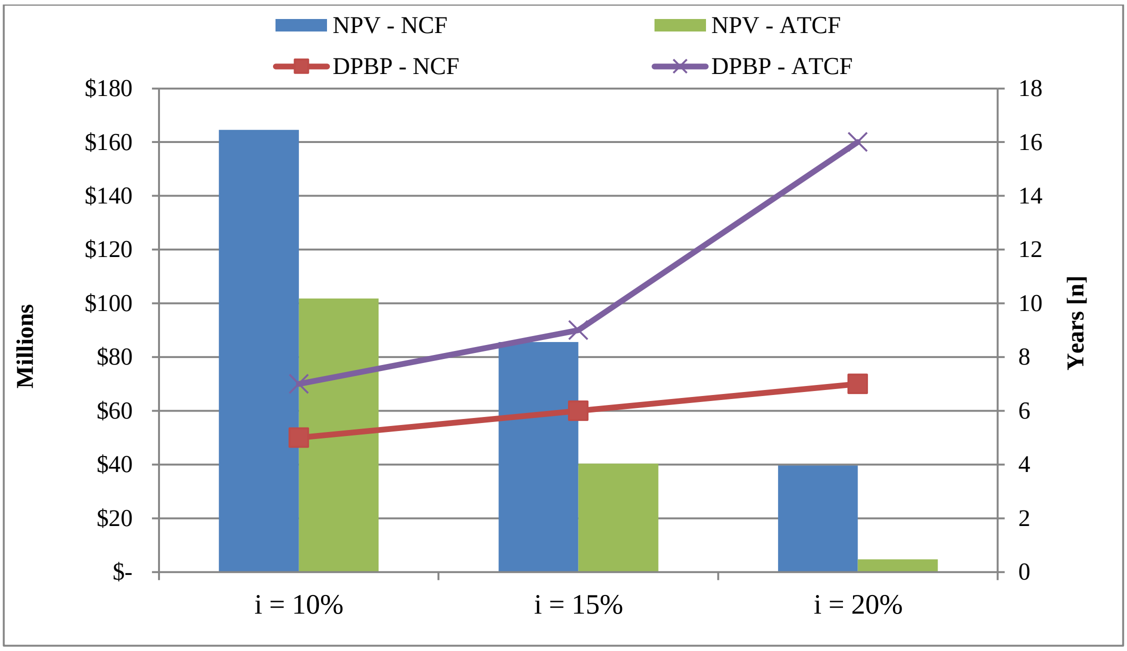


Figure (7.5): The NPV-NCF & NPV-ATCF, and DPBP-NCF & DPBP-ATCF [million dollars] with variation of i [%] values in the first scenario.

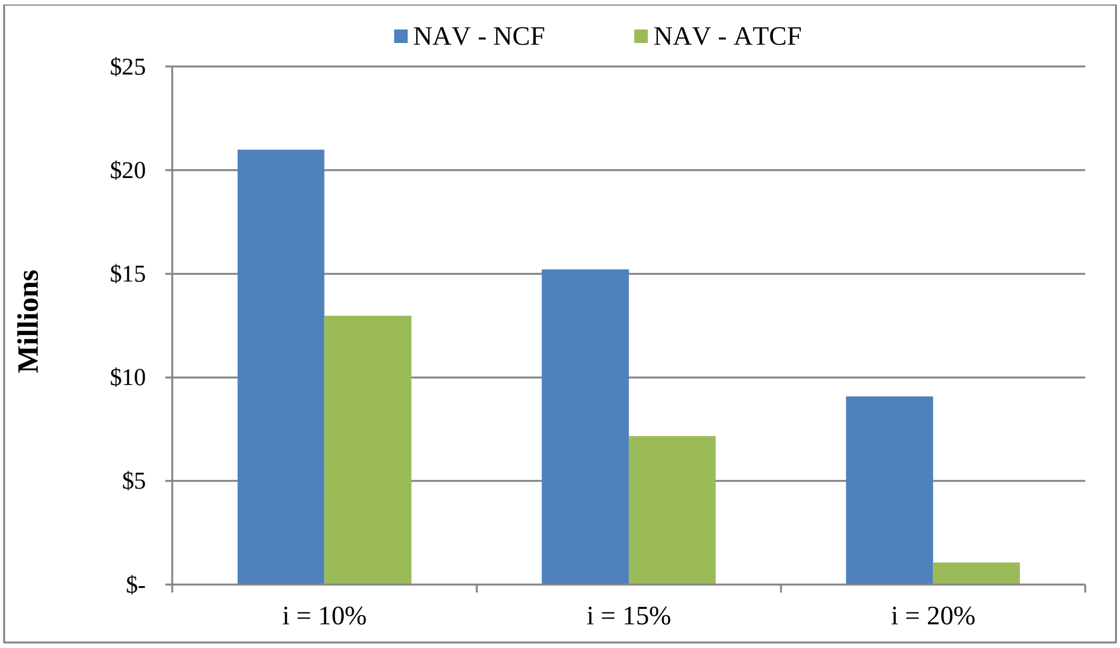


Figure (7.6): The sensitivity of AW [million dollars] with i [%] value variations in the first scenario.

In the second case; **Table (7.11)** shows the sensitivity measure of worth through variation of CV range from 8 to 11.6 MJ per kg of MSW with a constant default value of i equals 10 percent. See **Figures (7.7) and (7.8)**. In this case, the projected plant will be profitable.

Table (7.11): The sensitivity analysis through CV [MJ/kg] variations with constant i=10% for both NCF & ATCF in the first scenario.

Incineration [NCF] @ i= 10%			
	CV = 11.6	CV = 10	CV = 8
SPP [year]	4	4	5
Discounted PBP [year]	5	6	8
PW [$]	+164,611,345.63	+131,294,701.36	+89,648,896.03
AW [$]	+20,986,443.84	+16,738,875.84	+11,429,415.84
IRR [%]	30	27	23
SIR	+2.43	+2.14	+1.78
LCoE [$/kwh]	0.05	0.06	0.07
Incineration [ATCF] @ i= 10%			
	CV = 11.6	CV = 10	CV = 8
SPP [year]	5	5	6
Discounted PBP [year]	7	8	12
PW [$]	+101,801,409.31	+73,982,011.35	+39,207,763.89
AW [$]	+12,978,750.35	+9,432,031.07	+4,998,631.97
IRR [%]	24	21	17
SIR	+2.07	+1.82	+1.52
LCoE [$/kwh]	0.06	0.07	0.08

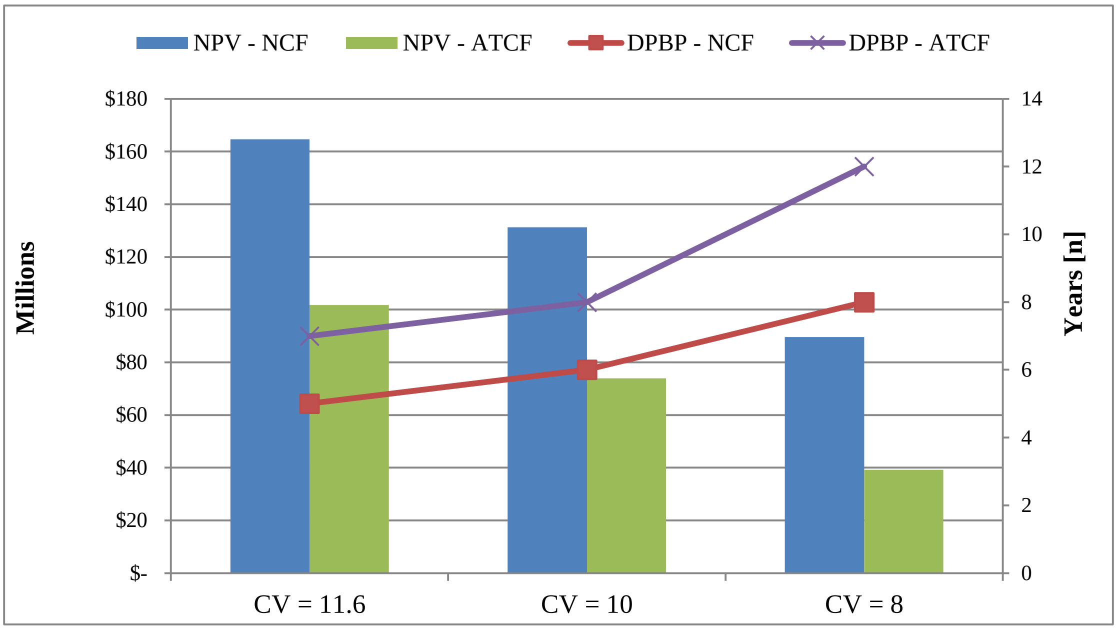


Figure (7.7): The NPV - NCF, the NPV - ATCF, DPBP - NCF, and DPBP - ATCF [million dollars] with variations of CV [MJ/kg] @ i=10% in the first scenario.

The measures indicated in **Figure (7.8)** NAV for both NCF and ATCF in million dollars are increasing economically with rising the CV's upon to 11.6 MJ per kg at i = 10 percent in the first scenario.

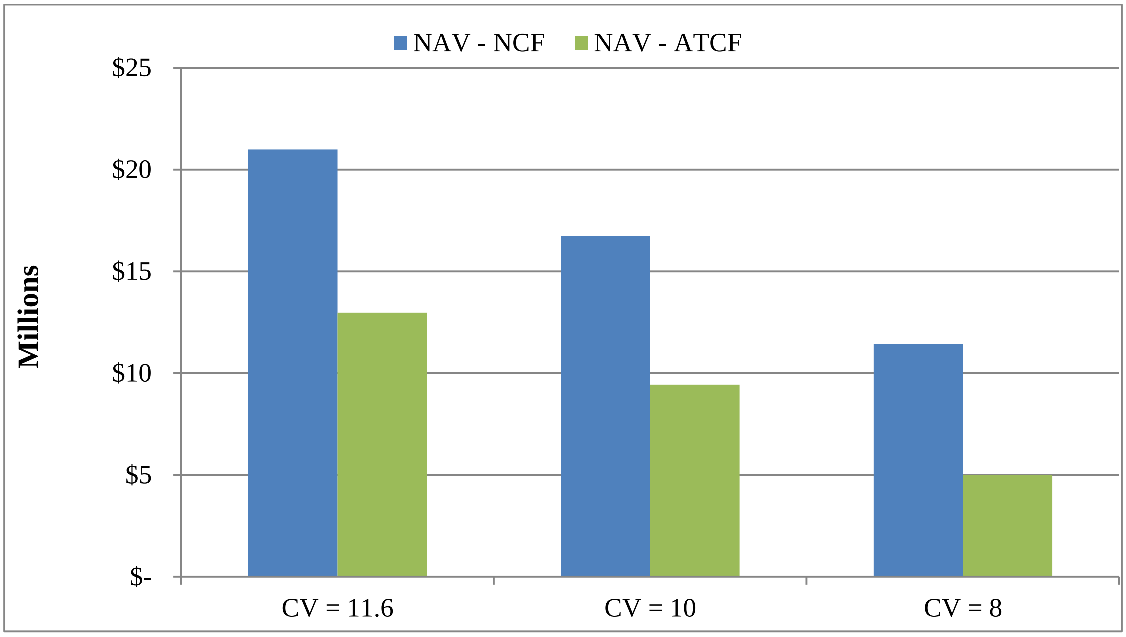


Figure (7.8): The sensitivity of AW [million dollars] with the CV [MJ/kg] variations @ i=10% in the first scenario.

On the other side, the sensitivity of measure worth determined through $\eta_{ov\,all}$ variation range from 20 to 23 percent for the incineration plant. The SIR is estimated with constant default values i equal 10 percent and CV of 11.6 MJ per kg MSW. As shown in **Table (7.12) and Figure (7.9).** Furthermore, the suggested plant will be projected in the third case.

Table (7.12): The sensitivity analysis through $\eta_{ov.all}$ [%] variations with constant i=10% & CV= 11.6 [MJ/kg] for both NCF & ATCF in the first scenario.

Incineration [NCF] @ i= 10% and CV= 11.6 [MJ/kg MSW]				
	$\eta_{ov.\ all}$ = 20%	$\eta_{ov.\ all}$ = 21%	$\eta_{ov.\ all}$ = 22%	$\eta_{ov.\ all}$ = 23%
SPP [year]	4	4	4	4
Discounted PBP [year]	5	5	5	5
PW [$]	164,611,345.63	176,688,629.17	188,765,912.72	200,843,196.27
AW [$]	20,986,443.84	22,526,187.24	24,065,930.64	25,605,674.04
IRR [%]	30	32	33	34
SIR	2.43	2.53	2.64	2.74
LCoE [$/kwh]	0.05	0.05	0.05	0.04
Incineration [ATCF] @ i= 10% and CV= 11.6 [MJ/kg MSW]				
	$\eta_{ov.\ all}$ = 20%	$\eta_{ov.\ all}$ = 21%	$\eta_{ov.\ all}$ = 22%	$\eta_{ov.\ all}$ = 23%
SPP [year]	5	5	5	4
Discounted PBP [year]	7	7	6	6
PW [$]	101,801,409.31	111,885,941.07	121,970,472.83	132,055,004.59
AW [$]	12,978,750.35	14,264,436.09	15,550,121.82	16,835,807.56
IRR [%]	24	25	26	27
SIR	2.07	2.16	2.25	2.34
LCoE [$/kwh]	0.06	0.06	0.05	0.05

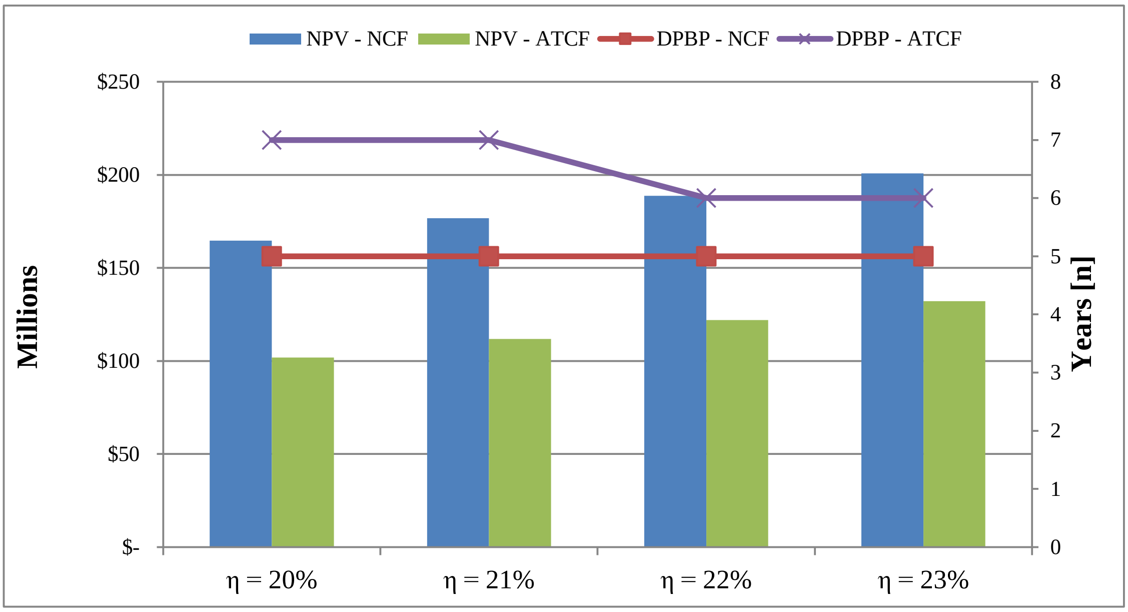


Figure (7.9): The NPV- NCF, the NPV- ATCF, DPBP - NCF, and DPBP - ATCF [million dollars] with variations of $\eta_{ov.\ all}$ [%] @ i=10% & CV= 11.6 [MJ/kg] in the first scenario.

The measures indicated in **Figure (7.10)** NAV for both NCF and ATCF in million dollars are increasing economically with rising the $\eta_{ov.\ all}$ [%] values in the first scenario.

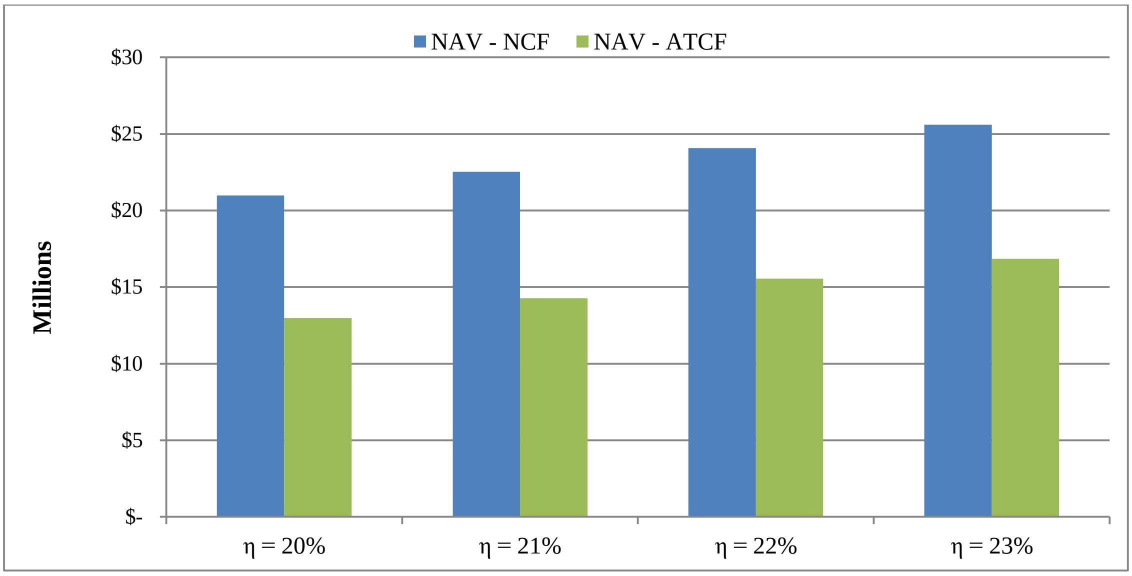


Figure (7.10): The sensitivity of AW [million dollars] with the $\eta_{ov.\ all}$ [%] variations @ i=10% & CV= 11.6 [MJ/kg] in the first scenario.

On the other hand, the variation of the GF range will be helpful to determine the sensitivity of the measure worth for both NCF and ATCF. In this case, the GF range is estimated to be from zero to 12 dollars per ton of MSW. Also, it's important to know that the GF default value is 12 dollars per ton MSW. The resultants economic data calculated through the incineration analysis model, as shown in **Table (7.13) and Figure (7.11). Figure (7.12)** indicates the sensitivity of AW with the GF variations range. The results in the fourth case; the proposed project will be profitable.

Table (7.13): The sensitivity analysis through GF [$/ton] variations with constant i=10%, CV= 11.6 [MJ/kg] & $\eta_{ov.all}$ = 20% for both NCF & ATCF in the first scenario.

Incineration [NCF] @ i= 10%, CV= 11.6 [MJ/kg MSW] & $\eta_{ov.\ all}$ = 20%				
	GF = 0	GF = 4	GF = 8	GF = 12
SPP [year]	4	4	4	4
Discounted PBP [year]	6	6	5	5
PW [$]	+126,169,063.78	+138,983,157.73	+151,797,251.68	+164,611,345.63
AW [$]	+16,085,403.84	+17,719,083.84	+19,352,763.84	+20,986,443.84
IRR [%]	26	28	29	30
SIR	+2.09	+2.20	+2.32	+2.43
LCoE [$/kwh]	0.05	0.05	0.05	0.05
Incineration [ATCF] @ i= 10%, CV= 11.6 [MJ/kg MSW] & $\eta_{ov.\ all}$ = 20%				
	GF = 0	GF = 4	GF = 8	GF = 12
SPP [year]	6	5	5	5
Discounted PBP [year]	9	8	7	7
PW [$]	+69,702,103.97	+80,401,872.41	+91,101,640.86	+101,801,409.31
AW [$]	+8,886,381.95	+10,250,504.75	+11,614,627.55	+12,978,750.35
IRR [%]	20	22	23	24
SIR	+1.79	+1.88	+1.97	+2.07
LCoE [$/kwh]	0.06	0.06	0.06	0.06

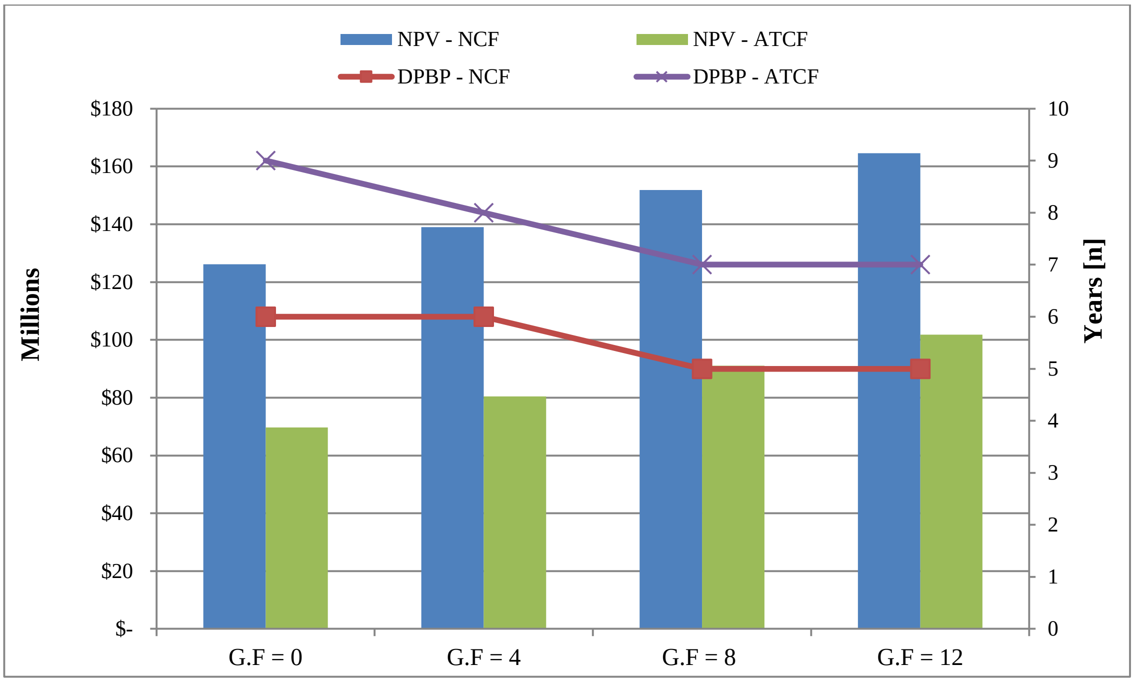


Figure (7.11): The NPV-NCF, the NPV-ATCF, DPBP-NCF, and DPBP-ATCF [million dollars] with variations of GF [$/ton] @ i=10%, CV= 11.6 [MJ/kg] & $\eta_{ov.\ all}$ = 20% in the first scenario.

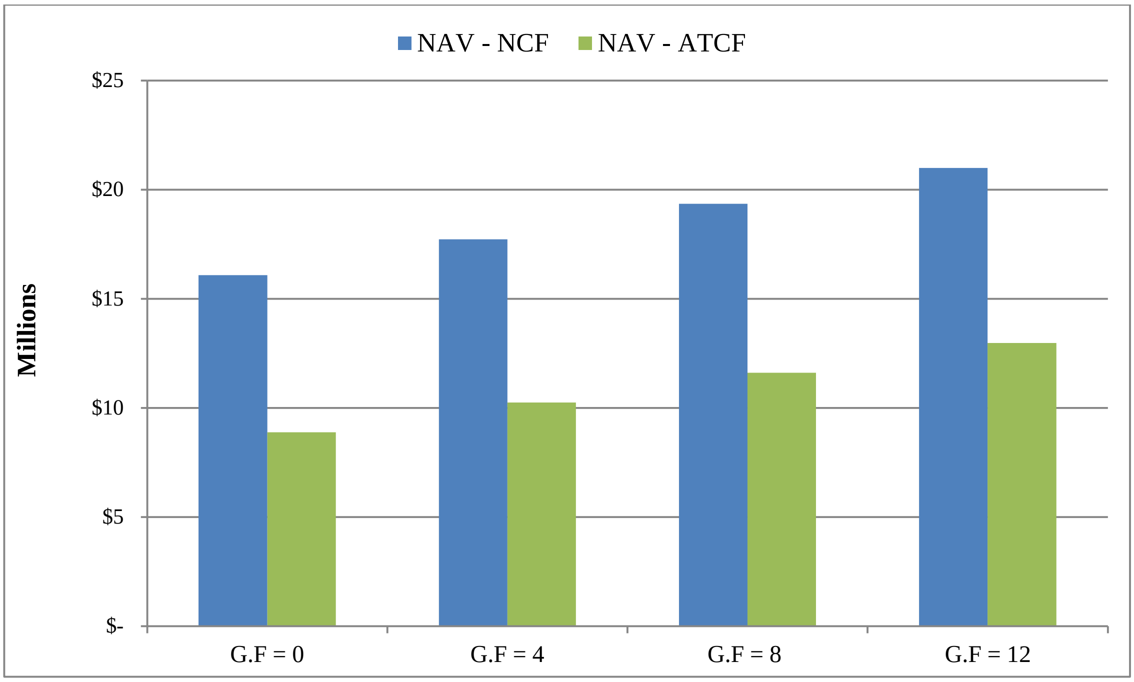


Figure (7.12): The sensitivity of AW with the GF [$/ton] variations @ i= 10%, CV= 11.6 [MJ/kg] & $\eta_{ov.\ all}$= 20% in the first scenario.

7.2.2.3.2 LFG Sensitivity Analysis

To determine sensitivity measures of PW or AW for the NCF and ATCF by using the LFG economic analysis models. In the same way, by using the LFG model the investigation of the economic parameters has been estimated in four cases.

In the first case, the i value will be varied, and while the value of i varies in a range from 10 to 20 percent with an increment of 5 percent in each step, the other parameters will be influenced. On the other side, the economic input data remains constant as default values. The results are shown in **Table (7.14)** for the LFG economic performance for both NCF and ATCF.

Table (7.14): Economical performance second scenario.

LFG [NCF]			
	i = 10%	i = 15%	i = 20%
SPP [year]	3	3	3
Discounted PBP [year]	3	3	4
PW [$]	87,686,073.97	51,743,799.69	32,755,978.00
AW [$]	11,404,362.14	9,258,342.31	7,510,099.13
IRR [%]	57	57	57
SIR	7.22	4.68	3.33
LCoE [kwh/year]	0.026	0.044	0.066
LFG [ATCF]			
	i = 10%	i = 15%	i = 20%
SPP [year]	3	3	3
Discounted PBP [year]	4	4	4
PW [$]	68,211,403.02	38,936,051.18	23,511,631.79
AW [$]	8,871,506.12	6,966,695.38	5,390,609.48
IRR [%]	48	48	48
SIR	5.87	4.01	2.95
LCoE [kwh/year]	0.032	0.051	0.074

To better interpret the results, graphically display the parameter versus the measure of worth. The NPV-NCF & the NPV-ATCF, and DPBP - NCF & DPBP - ATCF will be indicated in **Figure (7.13)** through i variation whereas **Figure (7.14)** indicates the sensitivity of AW with the i variations.

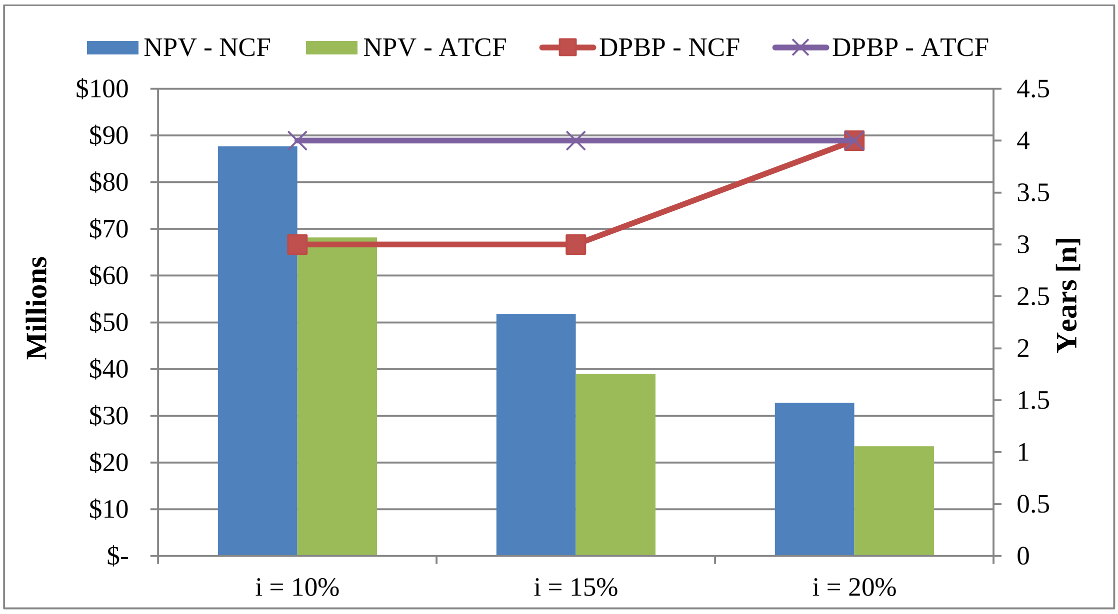


Figure (7.13): The NPV-NCF & NPV-ATCF, and DPBP-NCF & DPBP-ATCF [million dollars] with variations of i [%] values in the second scenario.

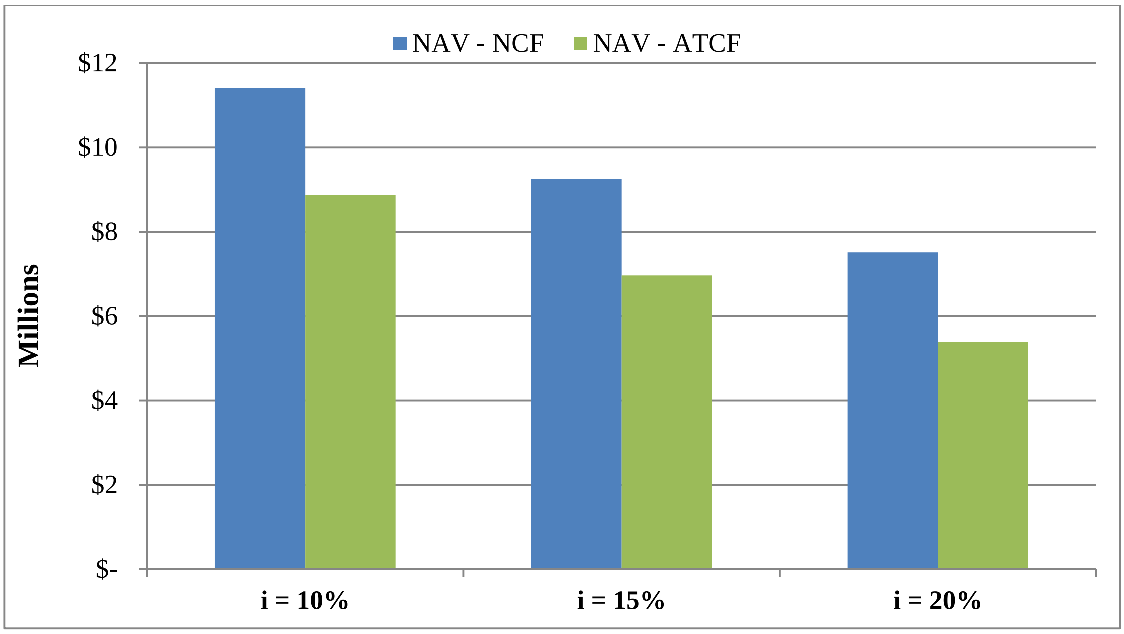
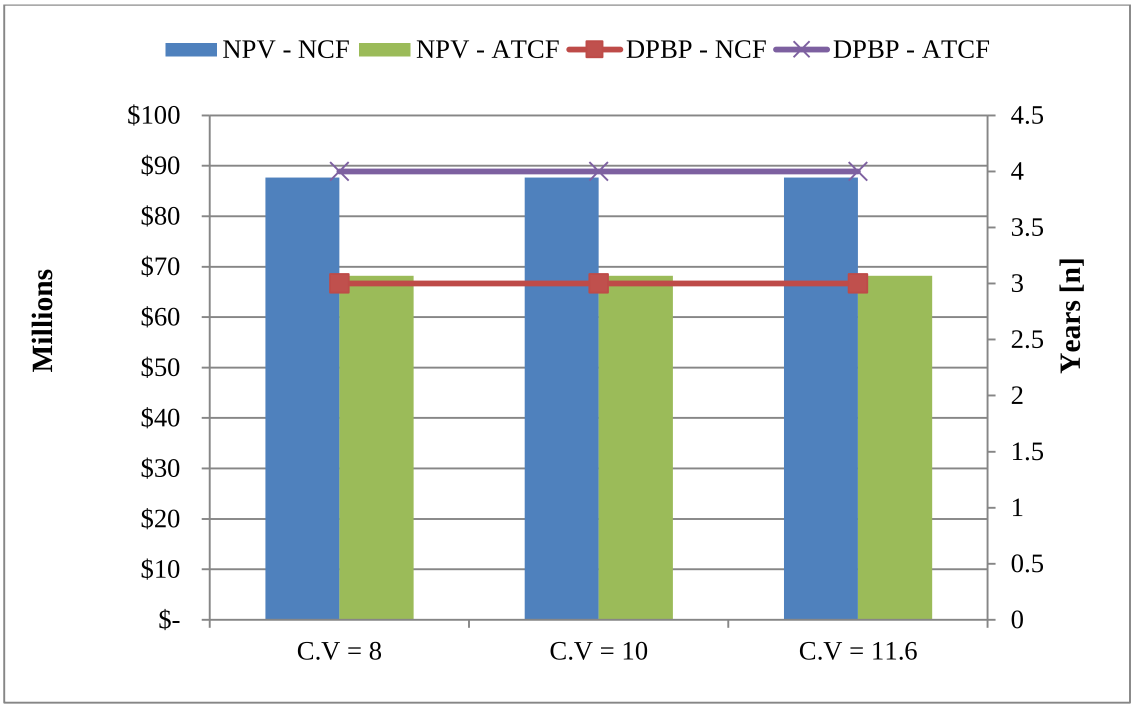


Figure (7.14): The sensitivity of AW [million dollars] with i [%] value variations in the second scenario.

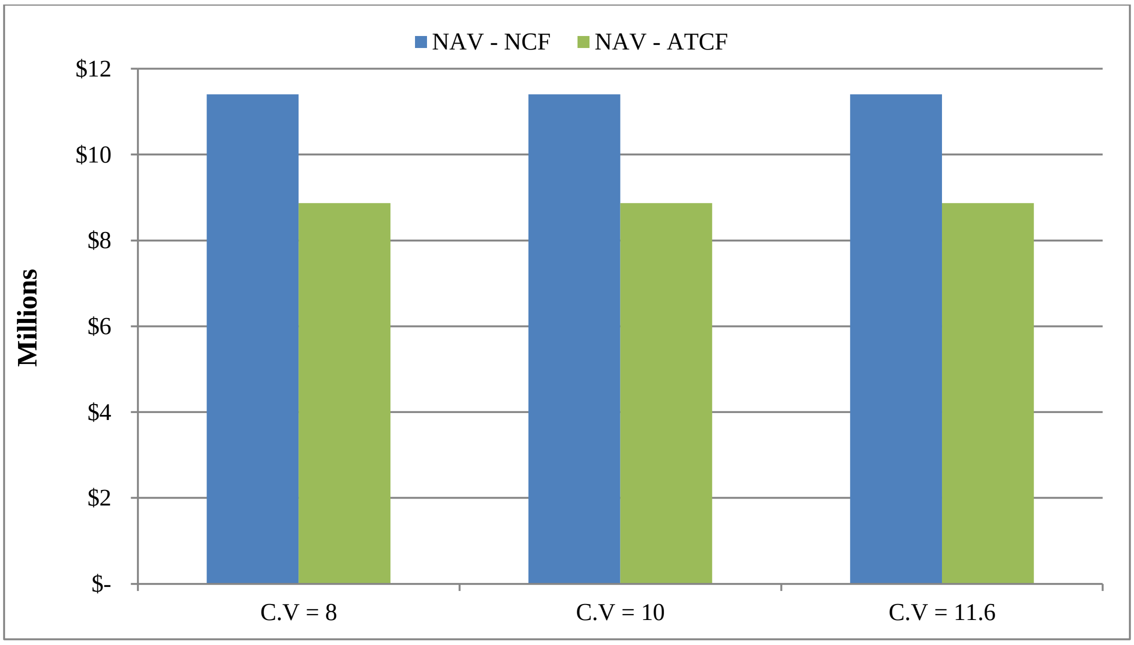
In the second case, **Table (7.15)** shows the sensitivity measure of worth through variation of CV range from 8 to 11.6 MJ per kg of MSW with a constant default value of i equals 10 percent. See **Figures (7.15) and (7.16).**

Table (7.15): The sensitivity analysis through CV [MJ/kg] variations with constant i=10% for both NCF & ATCF in the second scenario.

LFG [NCF] @ i = 10%			
	C.V = 8	C.V = 10	C.V = 11.6
SPP [year]	3	3	3
Discounted PBP [year]	3	3	3
PW [$]	+87,686,073.97	+87,686,073.97	+87,686,073.97
AW [$]	+11,404,362.14	+11,404,362.14	+11,404,362.14
IRR [%]	57	57	57
SIR	+7.22	+7.22	+7.22
LCoE [$/kwh]	0.026	0.026	0.026
LFG [ATCF] @ i = 10%			
	C.V = 8	C.V = 10	C.V = 11.6
SPP [year]	3	3	3
Discounted PBP [year]	4	4	4
PW [$]	+68,211,403.02	+68,211,403.02	+68,211,403.02
AW [$]	+8,871,506.12	+8,871,506.12	+8,871,506.12
IRR [%]	48%	48%	48%
SIR	+5.87	+5.87	+5.87
LCoE [$/kwh]	0.032	0.032	0.032



Figures (7.15): The NPV- NCF & NPV- ATCF, and DPBP - NCF & DPBP- ATCF [million dollars] with variations of CV [MJ/kg] @ i=10% in the second scenario.



Figures (7.16): The sensitivity of AW [million dollars] with the CV [MJ/kg] variations @ i=10% in the second scenario.

The sensitivity of measure worth determined through $\eta_{ov.all}$ variations range from 20 to 23 percent for the incineration plant in the third case. The SIR is estimated with constant default values i equal 10 percent and CV of 11.6 MJ per kg MSW. As shown in **Table (7.16), Figures (7.17),** and **(7.18).**

Table (7.16): The sensitivity analysis through $\eta_{ov.all}$ [%] variations with constant i=10% & CV= 11.6 [MJ/kg] for both NCF & ATCF in the second scenario.

LFG [NCF] @ i= 10%, C.V= 11.6 [MJ/kg MSW]				
	$\eta_{ov.\ all}$ = 20%	$\eta_{ov.\ all}$ = 21%	$\eta_{ov.\ all}$ = 22%	$\eta_{ov.\ all}$ = 23%
SPP [year]	3	3	3	3
Discounted PBP [year]	3	3	3	3
Present worth	+62,980,893.58	+64,881,292.07	+66,781,690.57	+68,682,089.06
Annual worth	+8,191,231.35	+8,438,395.26	+8,685,559.17	+8,932,723.07
IRR [%]	49	50	51	51
SIR	+5.47	+5.60	+5.74	+5.87
LCoE [kwh/year]	0.043	0.041	0.039	0.038
LFG [ATCF] @ i= 10%, C.V= 11.6 [MJ/kg MSW]				
	$\eta_{ov.\ all}$ = 20%	$\eta_{ov.\ all}$ = 21%	$\eta_{ov.\ all}$ = 22%	$\eta_{ov.\ all}$ = 23%
SPP [year]	3	3	3	3
Discounted PBP [year]	4	4	4	4
PW [$]	+47,582,577.39	+49,169,410.13	+50,756,242.87	+52,343,075.61
AW [$]	+6,188,541.92	+6,394,923.78	+6,601,305.64	+6,807,687.50
IRR [%]	41	41	42	42
SIR	+4.45	+4.56	+4.67	+4.78
LCoE [kwh /year]	0.053	0.051	0.048	0.046

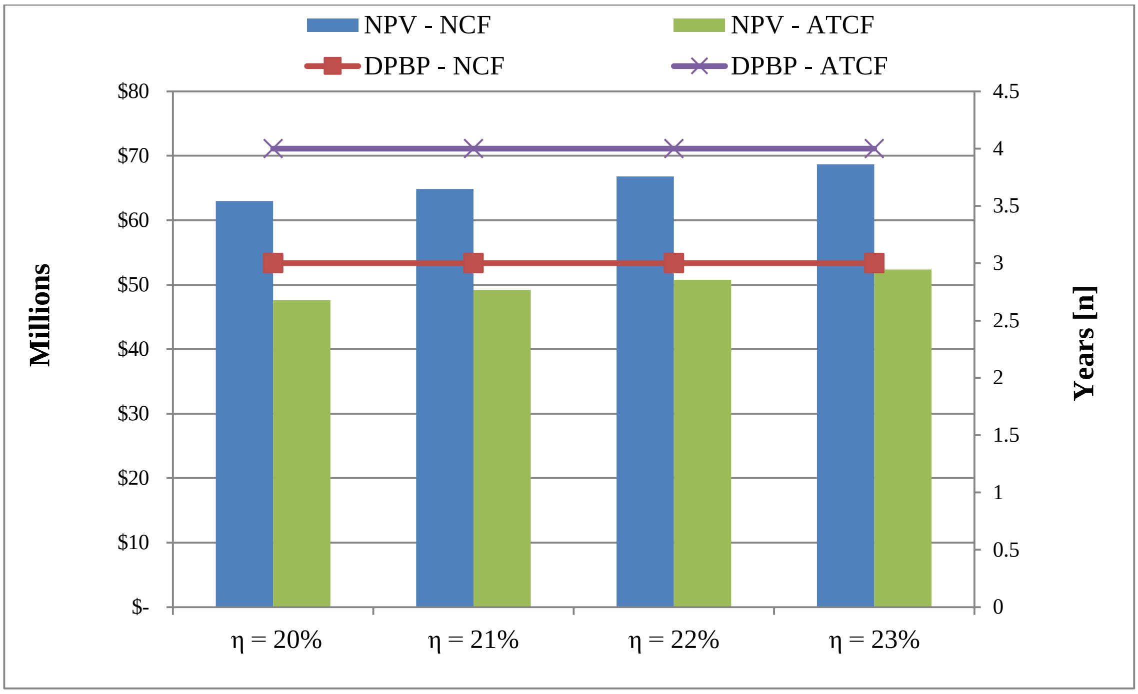


Figure (7.17): The NPV- NCF & NPV- ATCF, and DPBP - NCF & DPBP - ATCF [million dollars] with variations of $\eta_{ov.\ all}$ [%] @ i=10% & CV= 11.6 [MJ/kg] in the second scenario.

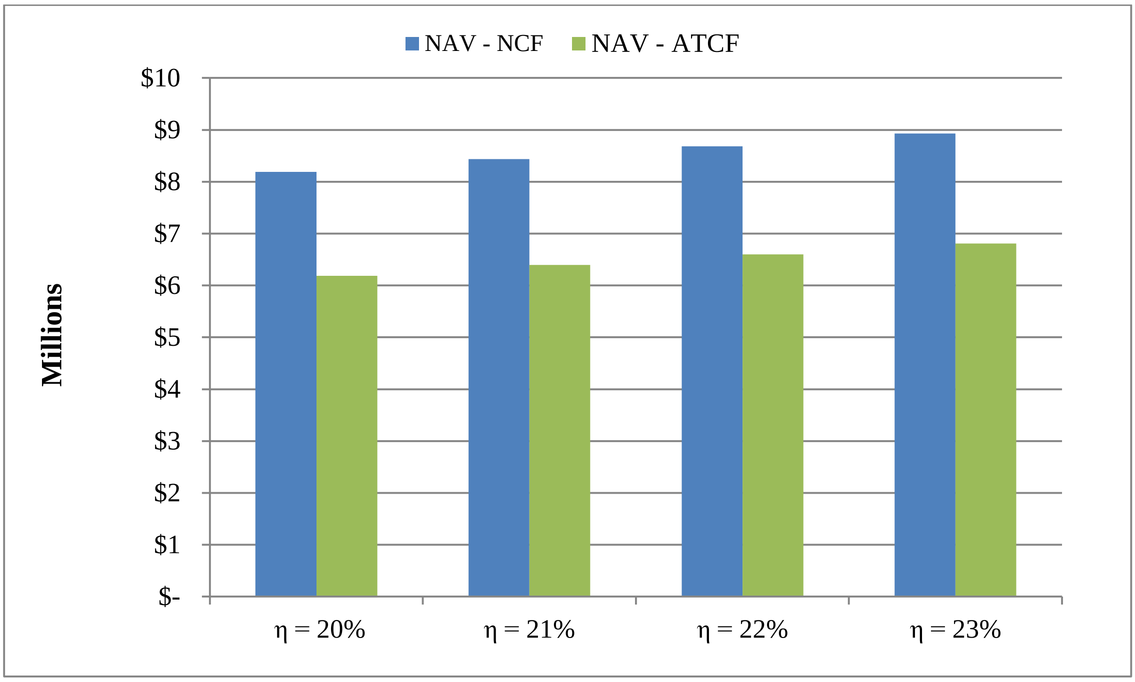


Figure (7.18): The sensitivity of AW [million dollars] with the $\eta_{ov.all}$ [%] variations @ i=10% & CV= 11.6 [MJ/kg] in the second scenario.

The variation of the GF range will be helpful to determine the sensitivity of the measure worth for both NCF and ATCF in the fourth case. The GF range is estimated to be from zero to 12 dollars per ton of MSW. It's important to know that the GF default value is 12 dollars per ton MSW. The resultants economic data calculated through the LFG analysis model as shown in **Table (7.17),** and **Figure (7.19). Figure (7.20)** indicates the sensitivity of AW [million dollars] with the GF [$/ton] variation range in the second scenario.

Table (7.17): The sensitivity analysis through GF [$/ton] variations with constant i=10%, CV= 11.6 [MJ/kg] & $\eta_{ov\ all}$ = 33% for both NCF & ATCF in the second scenario.

LFG [NCF] @ i= 10%, CV= 11.6 [MJ/kg MSW] and η.= 33%				
	GF = 0	GF = 4	GF = 8	GF = 12
SPP [year]	5	4	3	3
Discounted PBP [year]	6	5	4	3
PW [$]	+48,616,819.06	+61,639,904.03	+74,662,989.00	+87,686,073.97
AW [$]	+6,323,054.34	8,016,823.61	+9,710,592.88	+11,404,362.14
IRR [%]	32	40	48	57
SIR	+4.45	+5.37	+6.30	+7.22
LCoE [$/kwh]	0.026	0.026	0.026	0.026
LFG [ATCF] @ i= 10%, CV= 11.6 [MJ/kg MSW] and η = 33%				
	GF = 0	GF = 4	GF = 8	GF = 12
SPP [year]	6	5	4	3
Discounted PBP [year]	8	6	5	4
PW [$]	+35,588,575.16	+46,462,851.11	+57,337,127.07	+68,211,403.02
AW [$]	+,628,614.11	+6,042,911.45	+7,457,208.79	+8,871,506.12
IRR [%]	28	34	40	48
SIR	+3.62	+4.37	+5.12	+5.87
LCoE [$/kwh]	0.032	0.032	0.032	0.032

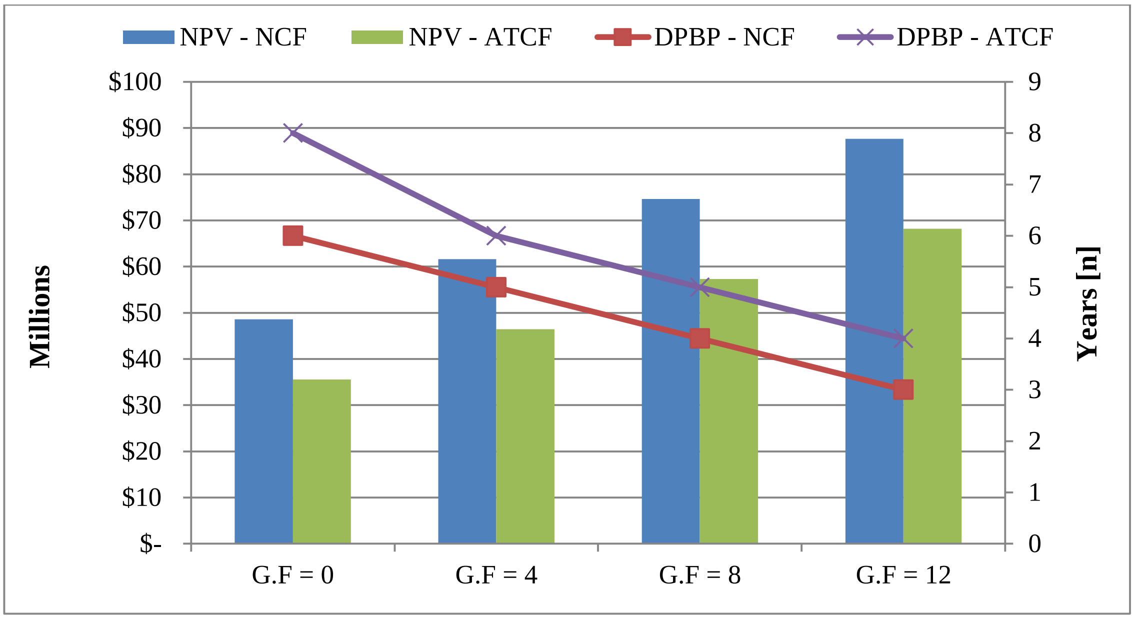


Figure (7.19): The NPV-NCF & NPV-ATCF, and DPBP-NCF & DPBP-ATCF [million dollars] with GF [$/ton] variations @ i=10%, CV= 11.6 [MJ/kg] & $\eta_{ov.all}$ = 33% in the second scenario.

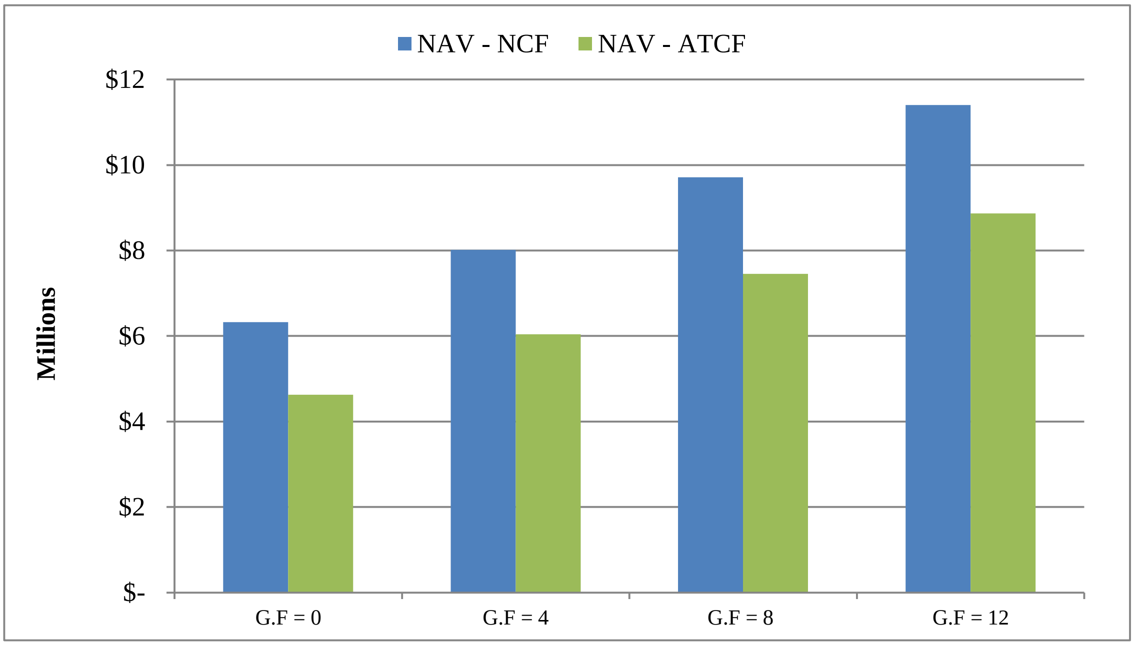


Figure (7.20): The sensitivity of AW [million dollars] with the GF [$/ton] variations @ i=10%, CV= 11.6 [MJ/kg] & $\eta_{ov.all}$ = 33% in the second scenario.

Finally, all resultant indicators investigated that the projected LFG plant will be feasible economically.

Chapter Eight

Conclusion and Recommendations

Based on the financial model designed, the economic analysis and default data were investigated in two scenarios. In the incineration first scenario, the average energy recovery amount from the incineration WTE plant has been estimated to be about 1,411.33 GWh yearly. The project will be feasible and return the investment cost after 5 years (SPP = 5). Furthermore, the NPV and NAV are calculated to be +96 and +13 million dollars; respectively, the IRR is estimated to be 23 percent, the SIR is estimated to be +2, and the LCoE is 0.061 [$/kWh] which is less than the national local tariff (0.117 [$/kWh]). On the other hand; in the second scenario for the LFG plant, the average energy recovery amount from the proposed plant has been estimated to be about 118.87 GWh yearly, thus the project will be feasible and return the investment cost after 3 years (SPP = 3). The NPV and NAV are estimated to be +68 and +9 million dollars; respectively, the IRR is calculated to be 48 percent, the SIR is about +5.9, whereas the LCoE is 0.032 [$/kWh] which is less than the national local tariff. In this situation, the recommendation for the stakeholders is to make the decision-makers implement incentives programs for the consumers.

The resultants values from sensitive analysis for both scenarios were estimated in four cases for each scenario on NCT and ATCF. Based on data in **Tables (7.10)** and **(7.14)** from incineration model analysis; the analysis for sensitivity in the first case, through variation of i [%] between 10 and 20 percent as input data. The significant output results for sensitive analysis on ATCF are revealed in DPBP, PW, and AW with respect to increasingly (7, 9, and 16), decreasingly million dollars (101, 40, and 4), and decreasingly million dollars (12, 7, and 1); respectively, which shows that the recommendation for i = 10 percent is of a preferable value economically. Moreover, using more i option in calculations will be riskier; from the side of using any value of i in range will be not sensitive for SPP and IRR regarding values to 5 and 24 percent; respectively. Whereas, the SIR and LCoE are estimated to be decreasingly (2.07, 1.55, and 1.22) and increasingly (0.06, 0.7, and 0.09); respectively, with little sensitivity on the project feasibility studies. Furthermore, in comparison with the resultants in the LFG scenario from LFG model analysis, the analysis for sensitive analysis in the first case, through variation of i [%] between 10, and 20 percent as input data. The significant output results for sensitive analysis on ATCF revealed in SIR, PW, and AW with respect to decreasingly values for all (5.87, 4.01, and 2.95), million dollars (68, 38, and 23), and million dollars (9, 7, and 5); respectively. This shows that the recommendation for i = 10 percent is a preferable value economically but has fewer revenues and profits on the investment i [%] than in the first scenario except for SIR with more saving on average. Also, using more i option in calculations will be less risky than this in the first scenario; from the side of using any value of i in range will be not sensitive for SPP, DPBP, and IRR regarding values to 3, 4, and 48 percent; respectively, but these values investigated that the LFG scenario is more economically. Furthermore, the LCoE is estimated to be increasingly

(0.032, 0.051, and 0.074) with little sensitivity on the project feasibility study, although the LCoE results in the LFG plant investigated to be more than in the first scenario. So the recommendation for this a good opportunity regarding for PA to take a decision to choose either the highest energy selling price $ per kWh, or the energy recovery price from LFG, which is less than local national price, or the least purchasing price for customers by implementing incentives program for energy recovery from incineration plant.

On the Other hand, in the second case; the i reset to the default value equals 10 percent, and the sensitivity is estimated based on the CV of varied values at 8, 10, and 11.6 MJ per kg MSW. As resultants are indicated in **Tables (7.11),** and **(7.15)** for both scenarios. From LFG modeling; the sensitivity of measures, such as (PW, AW), (SPP, DPBP), IRR, SIR, and LCoE with respect to (68, 9) million dollars, (3, 4) years, 48 percent, 5.87, and 0.032[$/kWh]; respectively, remain the same with calorific variation values. Whereas, the resultants from the incineration model investigated are not constant values. Where the SPP is 5 years, the minimum period to return investment at 11.6 MJ per kg, SIR reaches 2.7 the maximum, the LCoE is upon 0.06 $ per kWh, IRR reaches 24 percent, and both worth measures of present an annual reach to 101, and 12 million dollars, respectively. That means, the preferable option will be the incineration alternative when the CV of MSW is at 11.6 MJ per kg.

The third case for estimating the sensitivity measures, where the i, CV remains default values regarding 10 percent, and 11.6 MJ per kg; respectively with regarding the input $\eta_{ov.all}$ values varied at (20, 21, 22, and 23) percent based on values shown in **Tables (7.12),** and **(7.16)** for both scenarios. On one hand, in the incineration plant analysis, the output parameters are more sensitive assessment with increasing the $\eta_{ov.\ all}$ values. On the other hand, the LFG sensitivity measures are a preferable option due to less SPP, most IRR, and more savings. Whereas its LCoE is less than both local prices in the first scenario, but the first option conducted with respect results for both PW and AW with most values.

The fourth case resultants are estimated for both scenarios in **Tables (7.13),** and **(7.17).** Reset the default data to estimate sensitivity measures for both scenarios. Where the CV, and i are stetted to be 11.6 MJ per kg, and 10 percent, respectively; whereas the $\eta_{ov.all}$ as default data will be special for each WTE plant. The $\eta_{ov.all}$ for incineration and LFG set to 20, and 33 percent; respectively. In this case, the variable values are estimated to be for the GF (0, 4, 8, and 12) which will the government pay to the plant investor in $ per disposed MSW ton to the landfill. In the incineration, the sensitivity measures for that variation will not affect LCoE which resulted in constant (0.06 $ per kWh), but it is more than in LFG prices (0.032 $ per kWh). The PW, and AW in the incineration scenario will be increasingly affected by rising GF values, but it's more than in LFG analysis. The LFG SPP will be after 3 years, but it will be after 5 years in the incineration scenario. The SIR and IRR will be the most and preferable analyses for the LFG.

Additionally, the WTE solution and energy recovery will contribute to a circular economy, it will reduce environmental effects and support social aspects. In the incineration scenario; the environmental assessment has been considered. The proposed plant will prevent import the of electricity from the Israeli side. The IE is about 90 percent. The energy recovery quantity with 1,411.33 GWh yearly has been considered to reduce the effect of CO_{2-eq} emissions that contribute to GW potential. According to OECD data, Israel produces 0.767 kg of CO_{2-eq} per kWh electricity generated from burning fossil fuels [32]. The incineration plant contributes to avoiding the CO_{2-eq} regarding with amount of 1,082,492.7 tons per year. Whereas the LFG plant, in the second scenario, has been adopted to avoid CO_{2-eq} emissions directly or indirectly. It will prevent a total of 92,320.96 tons CO_{2-eq} yearly. Whereas the LFG recovering energy amount has been estimated at 118.87 GWh electricity per year. The avoided annual ton CO_{2-eq} emissions directly have been estimated to be 91,176.6 based on the energy recovery from the LFG second scenario. Whereas, the indirectly avoided amount CO_{2-eq} is an equivalent amount of produced CH_4 from energy recovering by LFG WTE technology. Based on LandGEM-v302 model data, the emissions were calculated with an annual amount of 24,032.4 ton CH_4. Taking into consideration that the effect of CH_4 is 21 times of CO_2 effects, that clears the releasing of CH_4 emissions to the atmosphere is worse than MSW landfilling environmental effects; especially there is some of the CH_4 quantity remains without decomposition after the end of the LFG plant (after 30 years) operation lifetime, and recommendation for recovering the energy from released amount or free into the atmosphere. Finally, that obviously the recovering amount of the energy from incineration is more than from the LFG plant, and so the avoided $CO_{2\text{-}eq}$ is larger as an environmental performance indicator.

The PA has efforts to build national strategic plans to contribute in solving the mentioned challenges in previous sections. The study for both two proposed WTE plant scenarios, especially in Zahrat Al-Finjan in Palestine, will help PA decision-makers to investigate establishing the more profitable alternative with respect to the environmental and economical potentials. And so, the detailed financial models and comparative analysis for both alternative scenarios, and apply it to the current baseline will support PENRA, EPA, and MoLG's national strategic plans. It helps for developing and upgrading the legislations and laws with understanding the benefits of the proposed scenarios excluding the detailed technical design.

The comparison from an economic point of view, the most feasible solution is LFG with respect to the least period to cover investment cost after 3 years, but in the incineration option that will cover it after 5 years through operation the plant. Surely, these measures are estimated by default input data. The potential NPV and NAV for the LFG scenario are estimated with respect to +68, and +9 million dollars; respectively. The values are less than in the incineration scenario which is calculated +96, and +13 million dollars; respectively. The results indicate the first scenario is more profitable. The savings and profits on the investment in LFG analysis (SIR = +5.9) are more than in the incineration scenario (SIR = +2). From the side of the electricity, tariff costs both scenarios less than the local selling price (0.117 [$/kWh]), the LCoE for the incineration, and LFG calculated as 0.061, and 0.032 [$/kWh]; respectively. The resultant default data shows that a recommendation for PA to develop incentives programs and to take new legislation and actions. Based on the sensitivity measures calculated from variation values for both scenarios, in the first case: the incineration sensitivity results were investigated that more economically feasible at i = 10 percent and more projected than in LFG plant, but the Least LCoE whereas SPP for LFG is the least. On the other hand; at i = 10 percent, and variation of CV, the LFG sensitivity measures are not affected by CV's, whereas the incineration sensitivity measures investigated to be more economically at CV = 11.6 MJ per kg, but LFG analysis is more profitable at that CV. The sensitivity analysis calculated also at default data of CV = 11.6 MJ per kg, and i = 10 percent. Then the resultant measures such as the IRR, and SIR investigated the most for LFG with SPP = 3 years which is reached to 4 years in an incineration plant. Finally, whilst the default data as CV, i, and (incineration $\eta_{ov.\ all}$ = 23 %, LFG $\eta_{ov.\ all}$ = 33 %) with GF variations; the IRR and SIR for LFG estimated profitably than incineration plant. The LFG energy recovery price is the least at GF = 12 $ per ton MSW.

The comparison from the environmental performance point of view; The $CO_{2\text{-}eq}$ has been considered as a performance indicator. The incineration plant contributes to avoiding $CO_{2\text{-}eq}$ total amount of 1,082,492.7 tons per year.

The avoided total annual ton of $CO_{2\text{-eq}}$ emissions, directly and indirectly, have been estimated to be 92,320.96 based on the energy recovery from the LFG plant. As that mentioned before, the effect of CH_4 is 21 times the CO_2 effects, which clear the release of CH_4 to the atmosphere is worse than MSW landfilling environmental effects. Then, the $CO_{2\text{-eq}}$ emissions are the least quantities produced from the LFG WTE scenario. By using the economic analysis for both incineration and LFG scenarios; the annual MSW quantity investigated to be in a range between 430,000 and 445,000 tons yearly; respectively. The energy recovery quantity from both incineration and LFG facilities is approximately estimated to be 1,411.33, and 118.87 GWh per year. The results revealed that the incineration will produce 3282.2 kWh per ton MSW, whereas the LFG will produce 265.9 kWh per ton MSW. This result indicates that the energy recovery from incineration is greater than from the LFG scenario. The proposed plants will contribute to a share reduction of GHG's due to the reduction of fossil fuels usages for producing electricity with a quantity of 830,484 and 69,948 barrels of oil for incineration and LFG plants; respectively. Whereas the total GHG's reduction results revealed as a fraction for both incineration, and LFG plants to 2.5, and 2.1 ton $CO_{2\text{-eq}}$ per ton MSW; respectively. The conclusion of these resultants, the proposed WTE incineration plant is more profitable than the LFG facility.

The recommendation for choosing of implementing incineration WTE alternative is a preferable solution in taking the environmental indicators into consideration and also from more energy recovery side. The LFG WTE alternative is the most economical project. This study will be useful not just for helping the stakeholders in decision making but also has benefits for the coming study. The recommendation for the coming study about the LFG WTE technology, the facility will continue to produce CH_4 gas until after the lifespan (after 30 years of operation). Many scenarios could be suggested where the electricity may be produced by implementing plant including steam turbines and generators while the composition and decaying of the CH_4 after the waste placement time. The study may include the problem of choosing the generators' size and loading factors.

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جامعة النجاح الوطنية

كلية الدراسات العليا

خيارات توليد الطاقة من النفايات الصلبة في شمال الضفة الغربية

دراسة مقارنة

إعداد

صابرين فريج

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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وترشيد الاستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية، نابلس، فلسطين.

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الملخص

هدف البحث إلى إيجاد الطريقة الأفضل فاعلية وتأثيرًا من بين طريقة ترميد النفايات أو طريقة غاز الطمر عند التخلص من النفايات الصلبة وذلك بالنظر إلى المؤشرات من الناحية الاقتصادية من خلال معادلات مالية مفصّلة. بالإضافة إلى ذلك، تم تحديد المعيقات المحتمل تواجدها في كل طريقة، وكما أجريت أيضًا مقارنة بيئية بين الطرق الحالية المستخدمة في التخلص من النفايات الصلبة في مكب زهرة الفنجان في جنين (كدراسة حالة) والطرق المستقبلية المقترحة. وقد تم اعتبار انبعاث مكافئ ثاني أكسيد الكربون كمؤشر رئيسي في هذه المقارنة، وتم النظر في المنهجية المتبعة بخطواتها المتتالية، كما تمت مراجعة ومقارنة جميع التقارير الوطنية الحكومية بالإضافة إلى البيانات التي تم جمعها والمتعلقة بقطاعي الطاقة والنفايات.

وعلى الرغم من أن السلطات الفلسطينية بذلت جهودًا جمة وتعاونت مع مؤسساتها في القطاع مثل سلطة الطاقة والموارد الوطنية الفلسطينية، وسلطة جودة البيئة، ووزارة الحكم المحلي لإيجاد حلول للمعيقات الحالية ولتنفيذ خطط استراتيجية فعّالة لإدارة مكب النفايات البلدية الحالي، إلا أنها لا تزال بحاجة إلى إجراء دراسات استقصائية تتعلق بالأداء الاقتصادي والبيئي لوضع تشريعات جديدة وطرق أفضل، لذا ستساعد هذه الدراسة المسؤولين في اتخاذ القرار المناسب للعثور على بدائل مناسبة ومحتملة عند التخلص من النفايات الصلبة وكيفية إنتاج الطاقة منها.

إضافة إلى ما سبق تم حساب وعرض النتائج المتعلقة بالسيناريوهين في جداول وأرقام الفصل السابع؛ حيث تم تقدير نتائج سيناريوهات النموذج المالي من خلال حساب المؤشرات الاقتصادية مثل PW و AW و ROR و SIR و SPP و LCoE. ومن ثم تم التحقق من القيم والمؤشرات وتحليل

الحساسية والخطورة مع تباين بعض المدخلات. أيضًا، تم حساب الطاقة المنتجة من محطة الحرق المقترحة في عملية ترميد النفايات وتبين أنها ستصل إلى 1411.33 جيجا لكل ساعة سنويا، بينما سوف تنتج طريقة غاز الطمر 118.87 جيجا لكل ساعة سنويًا. يجدر الإشارة أيضًا إلى أن توليد الطاقة من خلال هذه الطرق سوف تساهم في توفير **جزء** من الكهرباء اللازمة والمطلوبة في مناطق الضفة الغربية. علاوة على ذلك، تبين أنه في حال استخدام طريقة غاز الطمر فإن هذه الطريقة ستكون مربحة أكثر من طريقة ترميد النفايات عند قياس المؤشرات الاقتصادية، لكن من جهة أخرى سيكون لها آثار أكثر على البيئة حسب المؤشرات البيئية المقدّرة. ذلك يعني أن طريقة ترميد النفايات تؤثر بشكل أقل على البيئة، حيث أن الحرق تجنب انتاج مكافئ ثاني أكسيد الكربون بمقدار 1.082.492.7 طن سنويًا. بينما وجد أن مصانع غاز الطمر تجنب انتاج مكافئ ثاني أكسيد الكربون، سواء بشكل مباشر أو غير مباشر، بمقدار 92,320.96 طنًا سنويًا بما في ذلك 1,144.4 طن من مكافئ ثاني أكسيد الكربون سنويًا بالإضافة إلى انبعاثات الميثان.

توصي الدراسة باختيار تنفيذ طريقة ترميد النفايات، بما أنها وفق الدراسة، أكثر الحلول فعالية وربحًا من الناحية البيئية ومن ناحية كمية الطاقة المنتجة. أما من الناحية الاقتصادية فتعتبر طريقة غاز الطمر هي الأفضل ماديًا واقتصاديًا. وتشجع هذه الدراسة السلطات على الاستثمار في طريقة ترميد النفايات باعتباره الحل الأنسب، كما توصي بتصميم مرجل أفقي لاستخدامه في الحرق في المكبات وذلك بسبب تواجد المكبات على أرض منحدرة.