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Solid Waste Management Strategies via Waste to Energy (WtE) Potential Assessment in Palestine

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DEDICATION

الإهداء

إلى أمّي، إيمان، من خلقت وجودي من جوفِ العدم

إليها ابتهاجُ الرّوحِ في جسدي وتباشير الصباحِ الغضّ

إلى أبي، عبد الناصر، من تبدأ الحياة من يديهِ وينزغ النّهار بطلّته

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إلى أرواح كلّ من سبقونا إلى الله:

إلى جدّي محمد علي: هديرُ الموجِ، صوتُ الجياع

ونبيّ الباحثين عن الحقيقة

إلى خالتي ومعلمّتي نهاية الزرعي

إلى شهيدة العلم دينا تايه، والصّديق أنس سلامه

وكل من سبقوهم،

يتسابقون

ويلتحمون بالرملِ القديم

يسافرون لعرسهم.

أخيراً،

إلى فلسطين، البلاد التي هي بحجم القلب،

لا شيءَ فيها بعيدٌ ولا شيء فيها قريبٌ.

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الإقرار

أنا الموقعة أدناه، مقدّمة الرسالة التي تحمل العنوان:

Solid Waste Management Strategies via Waste to Energy (WtE) Potential Assessment in Palestine.

استراتيجيات إدارة النفايات الصلبة وتقييم إمكانية تحويل النفايات إلى طاقة في فلسطين

أقرّ بأنّ ما اشتملت عليه هذه الأطروحة إنما هو نتاج جهدي الخاص، باستثناء ما تمّـت الاشارة إليه حيثما ورد. وأن هذه الرسالة كاملة، أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أيّ 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.

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List of Abbreviations

DISCO’s: Distribution Companies

EPA: Environmental Protection Agency

EQA: Environment Quality Authority

GEDCO: Gaza Electricity Distribution Corporation

Gg: Giga gram

GHG’s: Green House Gases

GWP: Global Warming Potential

HA: Hazardous Waste

HEPCO: Hebron electricity Power Company

HP: High Price

IEC: Israeli Electric Company

IPCC: Intergovernmental Panel on Climate Change

ISWA: International Solid Waste Association

JDECO: Jerusalem District Electricity Company

JICA: Japan International Corporation Agency

JSC: Joint Service Council

kWh: Kilo Watt Hour

LCA: Life Cycle Assessment

LFG: Landfill gas

LGU: Local Governmental Unit

LP: Low Price

MARR: Minimum Attractive Rate of Return

MJ: Mega Joule

MOLG: Ministry of Local Governance

MSW: Municipal Solid Waste

MW: Mega Watt

Mwh: Mega Watt Hour

NDC: National Determined Contributions

NEDCO: Northern Electricity Distribution Company

NIS: New Israeli Shekel

NPV: Net Present Value

OECD: Organization for Economic Co-operation and Development

OX: oxidation factor

PA: Palestinian Authority

PCBS: Palestinian Central Bureau of Statistics

PENRA: Palestinian Energy and Natural Resources Authority

PERC: Palestinian Electricity Regulation Council

PETL: Palestinian Electricity Transmission Ltd.

RES: Renewable Energy Sources

SELCO: Southern Electricity Company

SPP: Simple Payback Period

SWM: Sustainable Waste Management

SW: Solid Waste

TEDCO: Tubas Electricity Distribution Company

UNRWA: United Nations Relief and Works Agency

USD: United States Dollar

WtE: Waste to Energy

List of Nomenclature

A: share of carbon content in paper and textiles in waste

B: share of carbon content in garden and park waste

C: share of carbon content in food waste

D: share of carbon content in wood and straw waste

C: number of composition material of MSW

CF_i: fraction of carbon in the dry matter of component i of MSW

CT_{cost}: collection and transfer weighted costs in $/ton

$CT_{governorate}$: collection and transfer cost of MSW for specific governorate in $/ton

CO_2e: carbon dioxide equivalent

CPU_{ele}: produced electricity unit cost in $/kWh

CPU_{therm}: produced thermal energy unit cost in $/L diesel equivalent

dm_i: dry matter content in the component i of the MSW

DOC: degradable organic carbon in waste under aerobic conditions

DOC_f: fraction of DOC decomposing under anaerobic conditions

E_{ele}: daily available electric energy in kWh

EF_j: aggregate methane (or Nitrous Oxides) emission factor

E_{therm}: daily available thermal energy in L diesel equivalent

En: MSW composition and its energy content in MJ/kg

Ext_{rate}: energy content in MSW extraction rate in %

F: fraction of CH_4 in the landfill gas

FCF_i: fraction of fossil carbon in the total carbon of component i of MSW

G: total number of governorates delivering its MSW to the WtE plant

I: MSW composition type (organic, plastic…etc.)

IW_j: amount of solid waste of type j incinerated

J: category or type of waste incinerated (MSW, Hazardous Waste (HW), Industrial Waste, and Sewage Sludge).

$ktCO_2$: kilo ton carbon dioxide

MCF: methane Correction Factor

$MSW_{governorate}$: daily generated waste from each governorate in (ton/day)

OF_i: oxidation factor of component i of MSW

OM_{ratio}: WtE plant running administrative and maintenance costs including labor wages and equipment costs

P_{ele}: produced electricity unit selling price $/kWh

$percentage_{composition}$: percentage of each composition material

P_{therm}: produced thermal generated energy in $/L diesel equivalent

Q: methane generation (kg CH_4/kg waste/year)

Q_{MSW}: available quantities of MSW

Rev_{ele}: daily revenues in $ from selling electric energy

Rev_{therm}: daily revenues in $ from sellig thermal energy

$saving_{ele}$: daily savings from generating electricity for the WtE

S: stoichiometric factor to convert carbon into CH_4

W: waste amount deposited per year (kg/year)

WF_i: the fraction of waste type/material of component i in the MSW (as wet weight incinerated)

η_{ele}: electricity conversion efficiency

η_{therm}: thermal conversion efficiency

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Abstract

Global energy demand is increasing as population and living quality continue to grow. As a result, efforts were oriented toward utilizing renewable energy resources. Waste to energy is considered one of these options. Palestinian territories depend completely on imported energy (100% fossil fuel and 89% electricity are from Israel), and it suffers from municipal solid waste accumulation and environmental problems due to improper disposal methods. This research focuses on the West Bank area, in which three MSW dumping sites are currently used, which are; Zahrat Al-finjan in Jenin (88% utilization), Al-menia in Bethlehem (9% utilization), and Jericho (overloaded) dump site.

This study investigates three options to adopt incineration technology as waste to energy solution using spatial analysis: building large waste to electricity plant in Zahrat Al-finjan, small size plant near Tulkarm, or adopting waste to heat solution in Zahrat Al-finjan. Results show that Tulkarm small plant is the most rational compared to other options, it will cover electricity shortage in the governorate since it will be able to incinerate 527 ton of MSW / day, so, serve some of the northern governorates in this regard. In the same manner, using Tier 1 method which

is created by IPCC, the equivalent carbon dioxide emissions were calculated, the suggested plant in Tulkarm is expected to save 642,043 $ktCO_2e$ per year. Adding to all of these, many legislative and financial scenarios where considered in the analysis. Produced electricity selling price and MSW tipping fees are crucial for the plant feasibility, specifically; its SPP.

At last, a full economic study was performed to investigate the feasibility of the suggested plant in Tulkarm. The investment and maintenance and operational costs were calculated. Later, ten scenarios were generated with fixed values of capacity, investment and maintenance and operational costs. Each of the scenarios considers a varying value of the Minimum Attractive Rate of Return (MARR), MSW to plant tipping fees, and generated electricity selling price. Also, it calculates the value of levelized cost of energy ($/kWh), annual net value ($/year) and net present value ($). As a result, it is seen that such huge investment in both money and technology needs to be supported by the government. The ninth and tenth scenarios had the values of MAAR equal to 10% and 5%, these two scenarios were the best among the others. It is of importance to assert on the role of the Palestinian government in such projects to assure its profitability and also share responsibility with the stakeholders of the project. The ultimate cooperation of all parties will lead to success and sustainable operation of this plant.

Chapter One

Introduction

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1.1 Background

Energy is considered one of the main continuous drivers for economic development of governments, social advancement and improving quality of life. It plays a vital role in infrastructure expansion, manufacturing processes, and so, the industrial and economic growth of nations, which caused exponential power generation growth rate (Chaar and Lamont, 2010). However, energy generation contributes to environmental and air pollution issues, it brings many environmental problems such as resources depletion, global warming, and acid rain (Juaidi et al. , 2016). The traditional ways for energy generation are mainly focused on burning different types of fussil fuels like coal, gas and oil. These processes are the essential emittors of pollutant gases like CO_2, CO, SO_2, NOX, and HC. These gases in return lead to many consequences; Ozone depletion, acid rain, ocean acidification and changes to the plant and nutruin levels. Since the industrial revolution back in 1970’s, greenhouse gases have been increasing. It is estimated that the increase percentage is about 80%, equivelent to 473 ppm CO_2e in the atmoshphere concentration (International Energy Agency, 2017; Butler and Montzka, 2011). This phenomena have increased the suface temperature of earth by 0.75 °C over the past 10 years (IPCC,2008). Further discussion about global warming is perferable to understand its contribution to our daily life; ocean acidification have increased by 30% since 1970's (Quéré et al., 2013). The plant and nutrition levels have changed also; the plants needs carbon dioxide but within controllable values, the rise in carbon dioxide levels enturrept the benefits from other nutrition like nitrogen and phosphorus (Taub et al., 2008). Other effects like changing the ozone levels have been made, the ozon depltion has doubled as a result of methane and NOx presence in air (West et al., 2006), which in return forms smog that affects humans and plants; between 362,000-700,000 deaths in the world occur every year due to pollution in the air we breathe (Anenberg et al., 2010). For these reasons, the world is searching for energy generation alternatives that can replace the old technologies and are better in terms of environmental aspects (Mezher, Dawelbait and Abbas, 2012).

Renewable energy resources utilization is robustly related to sustainable development. Hepbasli (2008), have discussed their opportunities as reliable, cost effective and safe to the environment. That is why they occupy the most sensitive role in setting the strategies for reducing greenhouse gases, emissions and mitigating global warming effects. Also, they are of service for countries that targets to achieve secure and reliable energy alternatives (Casanova-Peláez, 2015).

Global population and technological demand increase rapidly; it is expected to move from 7.6 billion inhabitants in 2018 to 9.7 billion in 2050 as noted in the report of Department of Social and Economic Affairs of United Nations (2017). As a result, energy resources depletion and solid waste generation rate became issues of with critical consideration. The generation of solid waste has been increasing rapidly because of the rise of world population, technological innovations and changes in life style over the past decades (Lino and Ismail, 2018). According to the World Bank report (2015), the income level and lifestyle are positively correlated with the amount of solid waste generation. The daily generated solid waste is about 1.3 Giga tons with perspective increase to about 2.2 Giga tons until 2025 (Ham and Lee, 2017).

Municipal solid waste (MSW) was defined by Al-Khatib and Arafat (2010) as “the solid wastes from homes, streets and public places, shops, offices, and hospitals, which are very often the responsibility of municipal or other governmental authorities for collection, transport and final disposal”. The Palestinian Central Bureau of Statistics (PCBS) also defines Solid Waste (SW) as "useless materials with low liquid content that can sometimes be hazardous". These materials can include waste and garbage resulted from all sectors and activities (PCBS, 2013c). Former researchers like Medina (2006), Vesilind et al., (2202) have mentioned that MSW can be divided into several types; residential, commercial, institutional and service, construction-and-demolition waste, industrial waste, and agricultural and animal husbandry waste.

A growing concern in the recent times has been focused on handling and disposal of solid waste. The truth is developed countries has come a long way in waste management as they already have established specialized programs regarding citizen’s awareness towards the importance of proper treatment and disposal of solid waste. They also improved their used technologies and updated other ones for sufficient solid waste treatment. However, the developing countries are still facing many problems that impede their development process, most commonly because of the lack of awareness and interest in such topics. Previous researchers have found that most of the third world cities account 30-50% of their budgets for waste management issues; collecting, transporting and treatment. They mention that the reason could be that the policy makers and private sectors pays less attention to this field when compared to other urban issues (Supriyadi & Kriwoken 2000, WHO 2002, Mbuligwe 2004, Zurbrugg et al. 2004, Abu Qdais 2007). Leading to unsophisticated and rudimentary solutions are mostly practiced such as open dumps for waste landfilling (Berkun et al., 2005).

There are many risks associated with the disposal of solid waste in dumps. These risks are related to public health and mainly caused by toxic emissions, soil pollution, and underground water pollution (UNICEF, 2013; Iakovou et al., 2010). Besides these consequences, it is believed that inconvenient treatment of waste generates emissions that contribute to the global warming since organic wastes release Methane (CH_4) and Carbon dioxide (CO_2) denominated as greenhouse gases (GHG's) the danger lies in the fact that the warming power of CH_4 is 28 times more than CO_2 (Myhre et al. , 2013). Previous researchers and policy makers have been analyzing ways to a more sustainable waste management for the sake of protection of people and environment and conservation of resources (Brunner and Rechberger, 2015; Stanisavljevic and Brunner, 2014; Stanisavljevic et al., 2015). In the same way, according to Soltani et al. (2016), Sustainable Waste Management (SWM) can be defined as the assessment of the impacts of treatment of municipal waste with three main aspects; environmental, economic and social. As indicated in past contributions, SWM appears to be more tangible when minimizing the generation of harmful materials and maximizing the reused, recycled and recovered materials (International solid waste association, 2013; Tot et al., 2016; Singh and Ordo, 2016).

MSW containes different types and fractions such as food waste, paper, wood, cotton and leather. Also, other materials like plastics, rubber, and fabrics, this makes it a vital source of biomass (Cheng and Hu, 2010). The United States Environmental Protection Agency (EPA) classifies MSW as a renewable energy resource (U.S. Environmental Protection Agency, 2006a). In addition, the U.S. Department of Energy includes MSW in renewable energy (Energy Information Administration, 2007). However, the remaining proportion (non-renewable) of MSW must be separated or treated in other ways (Themelis and Millrath, 2004). In the traditional sense, Renewable Energy Sources (RES) are those replaced readily by a natural process like hydropower, wind power, solar power, and biomass (Cheng and Hu, 2010). The scarcity of traditional energy resources and demand growth has been a major motivation for researchers to develop and utilize RES. RES are used to generate energy in a convenient manner, while causing less harm to the environment. They began to receive attention since governments are trying to reduce their carbon footprint and

Greenhouse Gases (GHG's) in order to minimize their impact on global warming and take a step forward the sustainable development. The use of RES for energy and power generation has been growing over the past decades due to increasing of public awareness regarding air pollution and climate changes issues (Kaplan et al., 2009). Under good designs and conscious decisions, investing in RES seems to be cost-effective, environmental friendly and suitable for local conditions (Hepbasli, 2008). Moreover, RES can provide energy services for remote areas and rural regions; this gives advantage to social, economic and environmental enhancement (Thiam,2011).

Since the last century, the concept of Waste to Energy (WtE) plant has been practiced in Europe as convenient, non-harmful way to generate energy. Most of the developed countries, for example: U.S.A., China and Japan generate electricity from their solid wastes. WtE refers to the generation and utilization of energy from solid wastes. The general concerns for the quality of the groundwater and scarcity of lands used for landfilling have encouraged European countries to establish WtE plants in 1960's. Generally, the operational concept behind WtE plants is rather simple; it produces heat, steam and electricity from utilizing solid wastes (Ham and Lee, 2017).

Palestine is recognized with a highly different energy situation compared to other countries in the Middle-East. Palestine is divided into two main areas: West Bank (which includes East Jerusalem) and Gaza strip. According to Palestinian Central Bureau of Statistics (2018), the population of Palestine at the end of 2017 was 4,781,248 inhabitants, distributed as follows: 2,881,957 inhabitants in West Bank and 1,899,291 in Gaza Strip. While Palestine is one of the countries in the Middle East, it’s way more different than any of the countries in the entire region. First, Israeli occupation affects the potential development of the energy sector infrastructure and regulations and policies, also prohibits development actions (Abu, Flamm and Azraq, 2012). Furthermore, Israel controls the main energy resources and systems in the West Bank, which is the area of the land that the Palestinians want for a state with East Jerusalem as its capital. For example, Palestine’s main source of electricity and energy comes from other countries, 100% of the fossil fuels and 89% of electricity supply are imported through Israel (Juaidi et al. , 2016).

This makes it complicated for Palestine to process and to produce any sort of electricity or energy and to have it imported from other countries in the region. In the same regard, Israel restricts the flexibility and diversity of energy resources. Third, the costs of electricity and other sources of energy like fossil fuels are higher than any country in the region (Abu Hamed et al., 2012); table (1.1) shows the energy prices for the year of for 2017, when it is compared to local average income it shows how expensive these ranges are, it is worth to mention here that Paris Protocol asserts that the difference in the final price of gasoline to consumers in Palestine and in Israel must not exceed 15% of the official final consumer price in Israel, while the Israeli average income is three to four times higher than the Palestinian average income (Paris Protocol, 1994). Finally, there are many other factors that adversely add up to this situation. For example, Palestine lacks a clear energy policy and properly functioning energy institutions. Moreover, the political situation creates an uncertain future for investments, which all in all makes Palestine a country that is more difficult than the rest of the countries in the Middle East when it comes to energy planning.

Table (1.1): Energy Prices in West Bank (Source: PCBS, 2017).

	LPG ($/12 kg)	Kerosene ($/L)	Coal ($/kg)	Gasoline ($/L)	Diesel ($/L)
West Bank	17.98	1.56	1.91	1.70	1.59

Despite all of that, Palestine is rich in RES that can play an essential role in converting the situation to a more developed one from sustainability point of view, since it has high potential of solar, wind and biomass sources (IRENA,2014). Developing energy alternatives can help clean energy generation in the future and allow Palestinians to cope with their increasing energy demand as a result of the rapid population growth.

The Palestinian lands are characterized by being rich in natural resources especially the solar radiation, the sun provides almost 3,400 hours of sunshine throughout the year. These rays have an intensity of 2.63 kWh/ m^2.day in winter while in summer it provides 8.4 kWh/ m^2.day (WAFA, 2019). The average monthly temperature ranges between 8ºC as minimum and 30 ºC as maximum. In winter, rainfall yearly average is around 500 mm according to the published data of Palestinian News and Info Agency WAFA in 2019.

This study is focused mainly on the west bank which is bordered by Jordanian river, the Dead Sea and Jordan in the East side. In 2017, the total population reached 2,881,687 Palestinians that live in different governorates; this number is expected to grow by 2% (World Bank, 2018). Each house has an average of 4.8 persons per household, while the statistics of 2014 shows a total GDP of4.4$ per capita while the average salaries range between 25$ to 30 $ per day (World Bank, 2018).

1.2 Problem Statement

In 2018, Palestine produced 1.44 million tons of MSW (MOLG, 2018). According to the national strategy for solid waste management (2010), solid waste management is facing many challenges at the legislative, organizational, technical, environmental, and financial levels. There is also a general lack of accurate national statistics regarding solid waste generation, source, and composition.

Adding to these obstacles, the energy sector in Palestine is characterized by high restrictions of energy flexibility and diversity for the reason of dependence on imported energy sources. Palestine imports 100% of fossil fuels and approximately 89% of electricity through Israel (Juaidi et al., 2016). While Israel controls most of energy sources in Palestine, it sets too many barriers on the aspirations of Palestinians towards development and evolution of energy infrastructure and regulations. In return, it influences energy growth in Palestine (Abu Hamed et al., 2012).

All in all increases the need for new orientations for energy generation and utilization in order to fulfill the increasing energy demand in Palestine among with the raising population that results in rapid municipal waste generation.

There's a necessary need to solve the problems of energy shortage and increasing waste generation rates. The traditional ways of waste disposal are not convenient and have many consequences on human health and environment. Besides, the scarcity of lands in the West Bank among with the concerns on the quality of water that is affected by inconvenient disposal of municipal waste shows the exigency to have a solution that can solve both problems.

Adopting WtE in Palestine seems to be the suitable solution in the light of its success during the past decades in different countries around the world. The experiment of WtE technologies proved its ability to generate proper amount of energy while having fewer negative impacts on environment. As a matter of fact, it actually decreases the GHG's emissions and so contributes to the reduction of GW impact. This study will investigate the potential of a WtE plant in the West Bank by conducting spatial analysis of waste generation and energy demand. Also, it will carry out a full assessment of the suggested plant; the assessment includes environmental analysis and economic analysis to come up with a recommendation and decision whether this plant is a feasible solution to be adapted in Palestine or not.

1.3 Significance of this Research

In the light of the previous introduction, it can be concluded that no studies addressed waste to energy option in Palestine. This research will be the first of its kind to investigate the sustainability of building a WtE plant in the West Bank, Palestine through the study and analysis of different indicators, such as: NPV, SPP and CO_2e. In addition to that, this research will determine the capacity of the proposed plant and define the most suitable location considering waste generation rate, water availability and electric grid feed in capacity.

What's more in its value is this research's correlation with PENRA vision in the upcoming five years regarding waste to energy potentials in Palestine. This research will investigate the sustainability of building a WtE plant to study the crises of high waste generation and energy shortage in Palestine. It will discuss WtE as an option for safe and controlled waste disposal and energy generation in the light of sustainability. This will require the cooperation of all responsible entities regarding waste and energy.

1.4 Research Questions and Objectives

Following the preceding sections, this section states the questions that the researcher aspires to answer and the objectives to be achieved.

- *This research aims at answering the following questions:*

1. What is the Palestinian profile regarding waste generation, disposal and control?
2. What are the possibilities to enhance the electricity grid in the West Bank using WtE technologies?
3. What are the environmental and economic sequences of investing in a WtE plant?
4. What ae the challenges and the needed legislatives to ease performance of such investments?

- *This research aims to achieve the following objectives:*

1. To study the Palestinian waste and energy profiles using spatial analysis.
2. To determine the proposed WtE plant's capacity and location.
3. To investigate the plant sustainability by determining different economic and environmental indicators.
4. To conduct a scenario based analysis that includes ten scenarios for the Palestinian Authority (PA) to support such an investment.

1.5 Thesis Structure

There are six chapters in this thesis categorized as follows: first chapter initiates for the research by providing background and stating the objectives of this research. The second chapter proceeds with the literature review and includes a summary of all the studies that address this issue. Chapter three presents the data acquired and used to conduct the analysis, it has data regarding waste and energy sectors in Palestine. Chapter four complements the thesis and presents the research methodology. The Fifth chapter reveals the results of the analysis and the discussion made on it. Finally, chapter six includes the conclusions of the analysis, and gives some recommendations with a set of limitations and future work.

Chapter Two

Literature Review

Chapter Two
Literature Review

2.1 Background

Municipal solid waste (MSW) was defined by Al-Khatib and Arafat (2010) as the solid wastes from homes, streets and public places, shops, offices and hospitals, which are very often the responsibility of municipals or any other governmental authorities for collection, transport and final disposal. MSW can be divided into several types; residential, commercial, institutional and service, construction and demolition waste, industrial waste and agricultural and animal husbandry waste (Medina 2006; Vesilind et al. 2002). The disposal of MSW is attracting a significant amount of attention since inadequate treatment of waste has several negative impacts on the environment. These impacts include leachate and dust production, GHG's emissions, impacts on the quality of ground water (Palmiotto et al., 2014). However, due to the energetic content and continuous production of MSW, it can be seen as an available source of energy (Lombardi et al., 2015). According to the ISWA guidelines (2013). Table (2.1) shows how each fraction of MSW has a different amount of energy (MJ/kg). This is worthy to consider when deciding how to handle and dispose of MSW.

Table (2.1): Calorific Values for different MSW Composition (Source: ISWA, 2013).

Fraction	Calorific value (MJ/kg)
Paper	16
Organic	14
Plastic	35
Glass	0
Metals	0
Textiles	19
Others	11

Different treatment technologies can efficiently generate energy from waste. The adoption of energy generation from waste technologies can lead to economic and environmental benefits as proved by previous researches which in return pushes the cycle of sustainable development (Baggio et al., 2009; Poulsen and Hansen, 2009; Ionescu et al., 2011b). Sustainability is a multidisciplinary issue that researchers and policy makers are analyzing. As considered by previous literature, Sustainable Waste Management (SWM) has the goals of people and environment protection and resources conservation (Brunner, 2010; Stanisavljevic *et* al., 2015; Stanisavljevic and Brunner, 2014). In this manner, the sustainability was defined as the assessment of current waste treatment in terms of economic, social and environmental aspects. SWM plays a major role in sustainable development.

The waste management hierarchy Directive 2008/98/EC in figure (2.1) is developed by the European Union (EU). Most of the studies mentioned later in this section were made in the light of this framework. Waste management hierarchy defines the priorities in waste management: waste prevention and minimization is the main priority, reducing waste can be achieved by strict avoidance of waste generation and reduction of waste, and this is where most preference is given. Then, reuse and recycling; these involve refined usage of components, while recycling involves waste sorting and reprocessing. Next is energy recovery, which is a treatment process to recover energy from waste most known as Waste to Energy (WtE) treatment, and finally disposal (landfill), it is the disposal of waste in landfills.

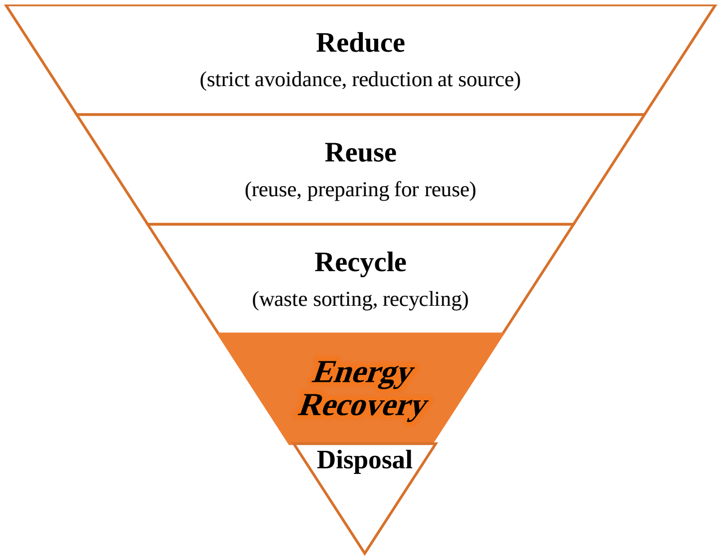

Figure (2.1): Solid Waste Management Hierarchy (Lèbre and Corder, 2015)

Producing energy from MSW gives significant economic (unit cost) and technical (unit efficiency) benefits when compared to other renewable energy sources (Xydis and Koroneos, 2012). Table (2.2) illustrates the main differences. Despite the wide spread of photovoltaic (PV) applications around the world, it is approved that the unit efficiency of PV application is the lowest among other renewable resources, the unit's efficiency of PV can reach a maximum of 15% (Xydis and Koroneos, 2012). Half of that in energy recovery from waste. On the other hand, it costs 0.14 euro per kWh per unit (Xydis and Koroneos, 2012). Still, has the highest cost among other resources and when compared to the cost of energy recovery, results are outstanding. These values are worth to study and analyze, in order to choose which application fits more in the country needs and can drive out the maximum benefits.

Table (2.2): Comparison between different energy sources (Source: Xydis and Koroneos, 2012).

Energy Sources	Unit Cost (€/kWh)	Unit's efficiency (%)
Photovoltaic	0.14	10 – 15 *
Concentrated Solar Power	0.09	25 - 30
Wind	0.04	20 - 38
Biomass	0.08	25 - 60
Geothermal	0.11	70 - 85
Hydro	0.05	35 - 45
Energy Recovery from MSW	*0.04*	*25 - 30*

- *New photovoltaic modules that are manufactured in 2019 reached higher efficiencies, approximately 17-18% but table (2.2) were the summarized comparisons made in 2015.*

Waste to energy is the recovery of energy from waste into electricity, heat and steam (Tan et al., 2015). As shown in waste management hierarchy in figure (2.1), WtE is ranked before disposal. This indicates the economic and environmental benefits of WtE option (Bjorklund et al., 2005). In addition, it is considered a promising waste management approach that can overcome waste generation problems and be a potential RES (Tan et al., 2015).

The general concerns for the quality of the groundwater and scarcity of lands used for landfilling have encouraged European countries to establish WtE plants in 1960s. Generally, the operational concept behind WtE plants is rather simple. It produces heat, steam, bio gas or electricity from utilizing solid wastes (Ham and Lee, 2017).

2.2 Waste to Energy Technologies

Over the past decades, WtE technologies have found their way as sustainable approaches for waste management and energy generation. Many countries have realized the potential in WtE techniques, notable examples are Japan, Germany and USA (Rogoff and Screve, 2011). In 1990, a general energy consumption of 394 trillion BTUs was mainly produced from MSW in USA. There have been 102 incineration plants to produce electricity in Japan, according to the Japanese Ministry of Health and Welfare. While Germany has many WtE operating plants through 1990's (Bajić et al., 2015). As shown in figure (2.2), WtE technologies can be classified into three main types: thermal treatment, biological treatment and landfill (Ting et al., 2014). Thermal treatment options like waste incineration and gasification produce electricity and heat. Biological treatment of WtE includes anaerobic digestion which produces biogas and fertilizers while landfill generates gas that can be treated in combined plants to produce electricity and steam.

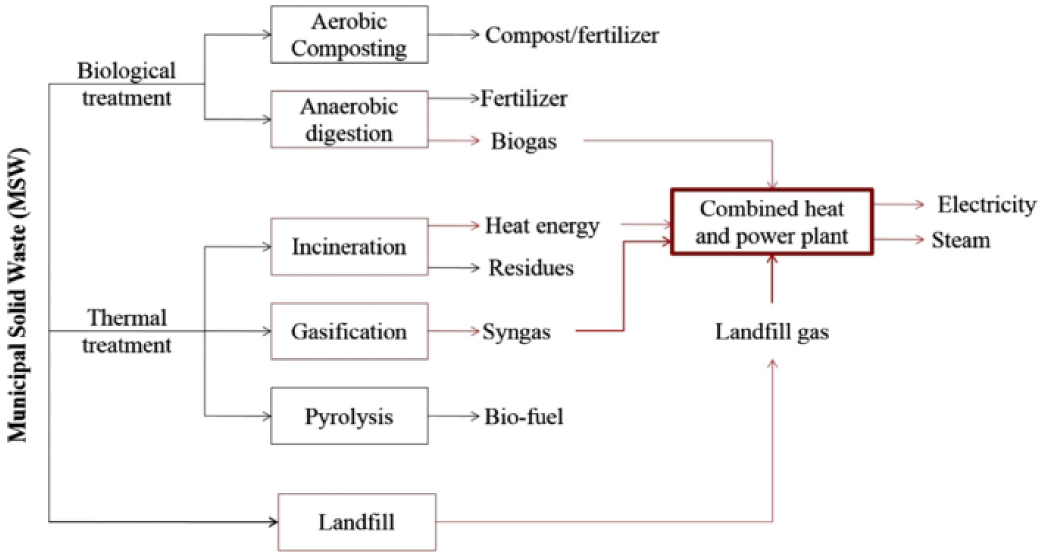

Figure (2.2): Waste treatment options and their final products (Ting et al., 2014).

WtE technologies discussed in this section include anaerobic digestion or biomethanation, gasification, landfilling and incineration (Moya *et al.*, 2017). All technologies have different outputs and characteristics, they also use different waste fractions (Münster and Lund, 2010). All technologies will be briefly discussed but incineration will be explained in details in this section since it will be considered the most favorable technology that will be adapted in this research for many reasons that will be explained later.

2.2.1 Anaerobic Digestion (Biomethanation)

Anaerobic digestion (AD) or biomethanation is a biological process that involves the degradation of organic biodegradable waste in the absence of air (Lastella et al., 2002). This process produces biogas which is generally composed of 50– 75% CH_4, 25–50% CO_2 and 1–15% of other gases such as, water vapor, NH_3, H_2S. And a highly viscous semi solid remains that are normally called digestate. The biogas can be utilized by combusting in order to generate heat and power especially in combined heat and power (CHP) engines, or can be used in internal combustion engines, in boilers or kitchens. The final usage of biogas determines the level of purification and removal of impurities mainly CO_2, H_2S or water (Kumar et al., 2016; Mustafi et al., 2008; Rajaeifar et al., 2017).

Generally, AD can be broken down into different stages illustrated in figure (2.3). The first one is called the Hydrolysis, in which the complex and organic components of the MSW are converted into organic soluble materials, for example, carbohydrates and fats are converted to sugars and fatty acids. Next, there is Fermentation, at this stage the organics are broken down into acetic acid, H_2 and CO_2. Finally, the Methanogens, in this stage the methane (CH_4) formation starts.

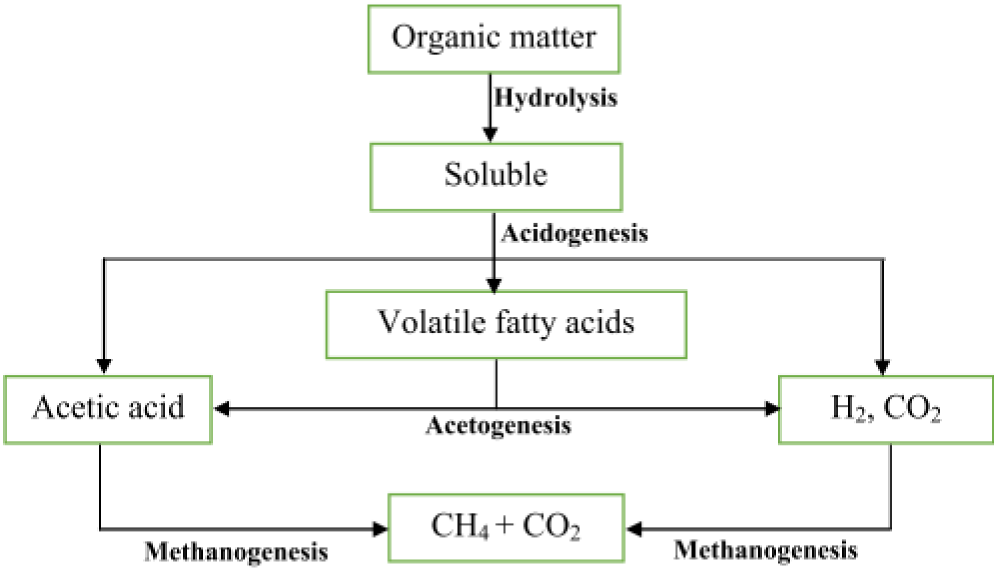

Figure (2.3): Stages of anaerobic digestion process (Kumar and Samadder, 2017).

There are two types of AD processes: wet and dry. The main difference between them is the percentage of dry and wet contents. The wet one contains 1-15% of dry matter and produces more liquid waste while the dry one contains about 24-40% of dry content (Luning et al., 2003). Moreover, the reactor of the wet process is generally smaller and requires less volume than that used for dry process. This is due to the difference mentioned above. However, the choice of the reactor, type of the process, and the gas yield from AD are usually dependent on the region in which it operates, the required quality and the final products (Kumar and Samadder, 2017).

From environmental point of view, AD has many advantages that enhances it as a sustainable form of waste disposal. Several previous studies have found that AD boosts the generation of biogas, decreases the waste amounts through the digestion process that empowers the waste adminsitration. Moreover, as mentioned by Arafat et al., (2015) and Saxena et al., (2009), the electricity generation using AD in 3 weeks is estimated to be 2 to 4 times more than landfilling in 6-7 years. Other study asserted that one cubic meter of biogas generated from AD can generate a total of 2 kWh electricity at 35% conversion effeciency (Murphy et al. ,2004). According to Scarlat et al. (2015), 1 tonne of MSW can produce 150 kg of methane, taking into accont that the MSW consists from 60% organic matter and 40% moisture. There is a wide technique used to improve the quality of the biogas generated by the AD, this method is improved by the removal of carbon dioxide and other gases that can be used in transportation fuel (called biomethane), it can replace natural gas in a wide range of domestic and industrial applications (Kasturirangan, 2014; Appels et al., 2008). Though that previously AD was mainly used for domestic sewage and agricultural treatment, right now it is widley used for energy recovery from MSW, it is mostly used in developing countries since the MSW generated there has a hight content of moisture, according to Yap and Nixon (2015). Studies by Abbas et al. ,(2017) and Ali et al. ,(2013a,b) preformed earlier has evaluated the feasbaility of biogas recovery using AD, and it was found that it gurantees an economically and environmentaly sustainability.

2.2.2 Gasification

Gasification is the process of coverting MSW to syngas (combustable gas) sometimes a mixture of H_2, CO, CH_4 and CO_2. The process is done as a series of reactions to from gas forming and sometimes referred as indirect combustion. It is performed within the presence of oxygen (partial oxidation). However, the amount of oxidant is lower than that required for combustion (Arena, 2012). When gasification is done with the absence of oxygen, it is called pyrolysis. The process is performed in high temperature usually between 550–1000°C, but it mostly depends on the reactor type and compostion of feedstock (Klinghoffer and Castaldi, 2013). The final products depend on the type of materials (raw) being used but they are mostly carbon, hydrogen ash and other gases such as nitorgen, CH_4, sulphur and oxygen (Lombardi et al., 2015).

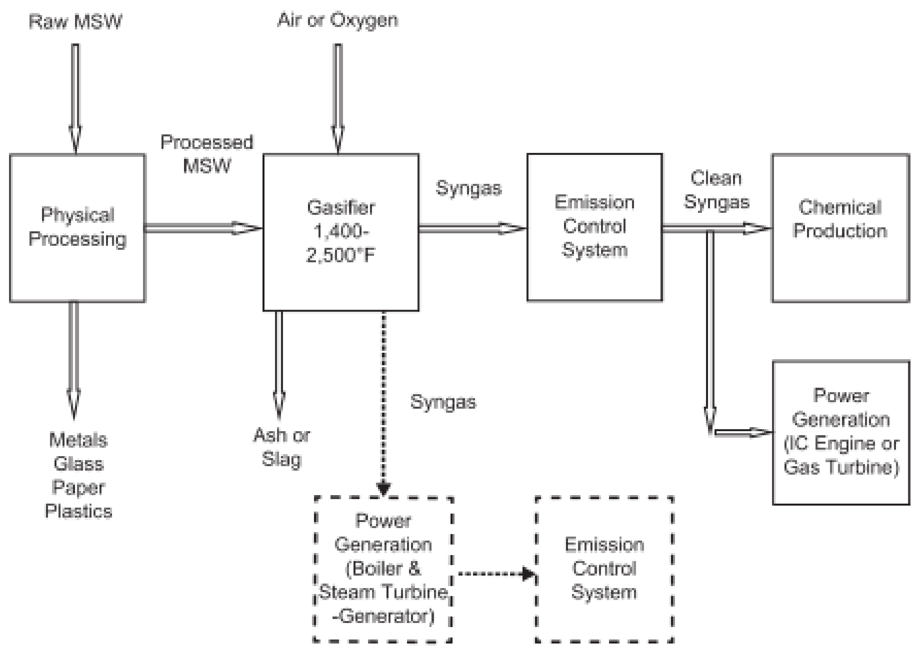

Figure (2.4): Common Gasification system (Source: SCS Engineers).

As illustrated in figure (2.4), At the first stage of gasification process, waste is burned with oxygen known as dehydration, the amount of oxygen is usually controlled in order to supply a suffecient amount to produce the gas, the temperature at this stage starts from 780 °C. Next, the syngas is directed to the produce electrcity or heat in the power generation plant. The other products of the gasification process are referred to as chaar, and is mainly composed of carbn and ash. The second gasification process is done to the by products (usually solids) using steam and oxygen, they can be used to provide heat (energy) for earlier processes. According to Tan et al. (2015), the gasification of biomass needs only a single pass due to its high reactivity. That’s why it is very common to dispose of the residuals using landfilling.

The wild advantages of gasification are that it can be applied to small or medium scales. The emissions reductions of some NOx and dioxines and the ability to utilize syngas in thermal devices with high effeciences (Luz et al., 2015). However, gasification technology is not a wide practice of MSW treatment, it is is still in the development stages and there are only limited number of plant commercially available aroung the world (Arena, 2012).

2.2.3 Landfilling

Landfilling is the disposal of MSW on land in a controlled way to minimize the negative impacts through the energy recovery (biogas recovery) and management of leachate (Kumar and Samadder, 2017). The main product from this process is biogas, which is formed of of CH_4 (50–

75%), NH_3 (0.1–1%), N_2 (3.9–4.1%), O_2 (0.9–1.1%), non-methane volatile organic compounds 0.01–0.60%, CO_2 (25–50%), and water vapor 6–6.5% (Zuberi and Ali, 2015). Figure (2.5) describes how landfills operate while figure (2.6) illustrates the stages of landfilling that ends up with the final products.

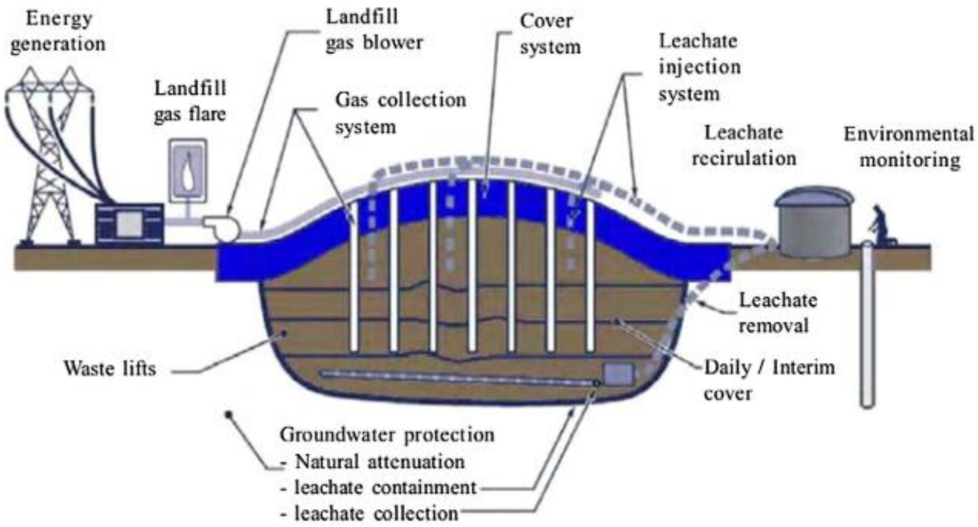

Figure (2.5): Controlled landfill with energy recovery (Zaman, 2010).

Landfillig accounts for methane release in the atmosphere, that's why some countries like Sweden eliminated landfilling and replaced it with gasification or pyrolysis. Also, in the SWM hirearchy, landfilling takes the final proiority due to its environmental concerns, it is the least ranked option for MSW disposal. Landfilling is most commonly practiced in developing countries. Although it is considered the simplest ways for MSW disposal, it has a lot of environmental concerns among other restrictions regarding lands and water quality . It created fears of soil, water and land pollution. However, some countries still practice landfilling, e.g in the U.S.A, landfilling accounts for 50% of MSW disposal. In addition, it is the widest applied solution for MSW management despite its environmental impacts according to the World Energy Council report in 2016.

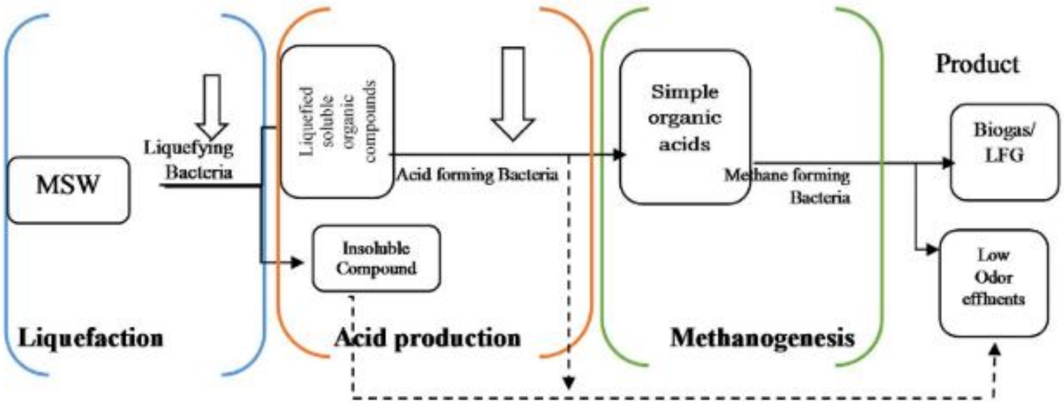

Figure (2.6): Main Stages of Landfilling (Beyene, Werkneh and Ambaye, 2018).

In Palestine, the final disposal destinations of MSW are landfills, there are three sanitaory landfills in the WestBank, which receive MSW either by direct transportation or by transfer stations, althought these landfills have served the Palestinian community a lot and have been some how of a healthy and managed way for MSW disposal, still, these landfills do not utilize MSW to generate any form of energy, in the same manner, they have many other technical problems that will be discussed later.

2.2.4 Incineration

Incineration is defined as the energy recovery from waste through combustion, this process is done in high tempratures which sometimes exceeds 800 ºC (Ouda et al., 2015). Incineration can actually reduce the volume of waste up to 80% and 70% for mass since it can handle all type of different waste composition (Cheng and Hu, 2010; Rogoff and Screve, 2011).

Generally, the operational concept behind WtE incineration plants is rather simple; it is done by producing heat through burning of MSW in the incinerator. Next is the transfer of heat to water in order to produce steam, then high pressure and temperature steam transfers its energy to mechanical work through a steam turbine, and finally to electricity by using a generator (Ham and Lee, 2017; Tan et al., 2015). This power generation process is called Rankine power generation cycle (Çengel and Boles, 2008). The whole process is illustrated in figure (2.7). Before releasing the resulted combustion gas to the atmosphere, an air control system is used to remove pollutants from combustion gas. The remaining ash from the burning process is then collected from the boiler and control systems.

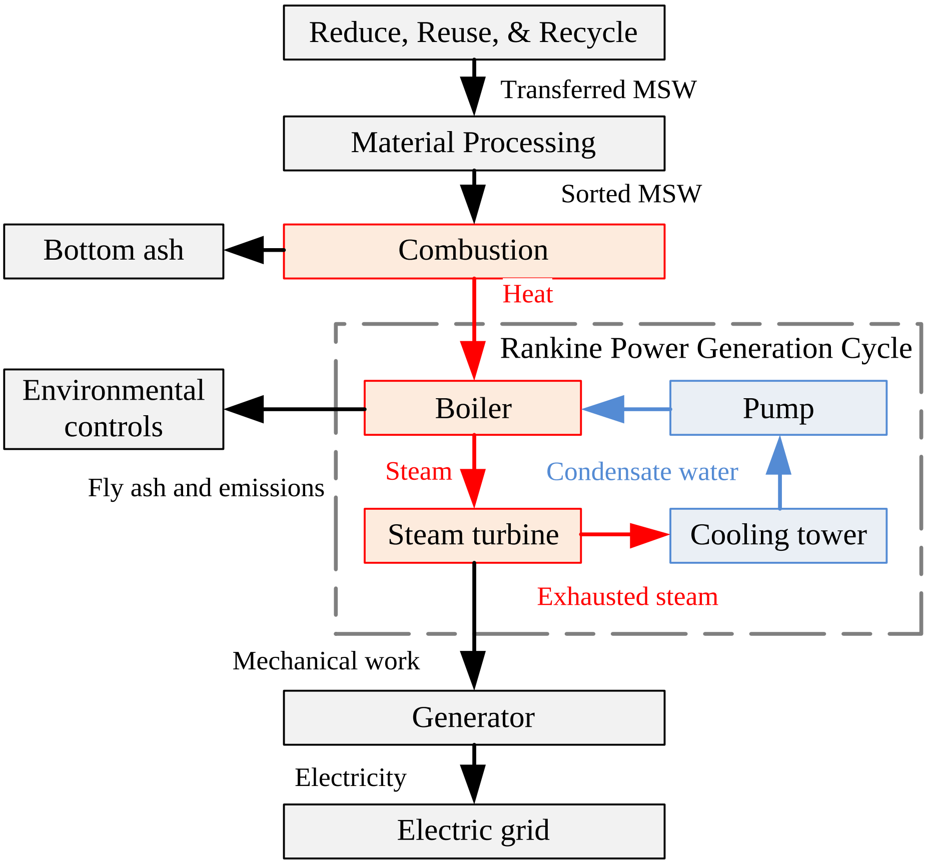

Fig (2.7): WtE incineration plant working concept

Richardson, (2013) describes how incineration plants work, as seen in figure (2.8). First, the waste is collected and transferred by vechiles then dumped from the trucks into a large hole which is quite large enough to allow for storage or stockbiling waste for two to three days which guratess the plant operation during (Rogoff and Screve, 2011). Hence, trash is viewed as a replinshed fuel source that will be renewed as life goes and people produce waste. The waste is then thrown in the combustion room or chamber, here the combustion process occurs. The incineration process, as explained earlier will produce heat that is later used to supply stam into the boiler. One quality of steam is that it holds high pressures that is then used to transfer mechanical energy to electrical energy through the turbine which realeses heat from steam to mechnical energy, next the generator produces electricity from it. One final remark about incineration plants is that they have high quality air control system. The importance of these systems lies in the fact that they remove quite large amount of pollutants from combustion gases before releasing them in the smoke stack. In addition, the final product that stays in the bottom of the incineration room is the bottom ash, this is collected and utilized in different ways, it can be landfilled or sold to manufacturing and construction markets.

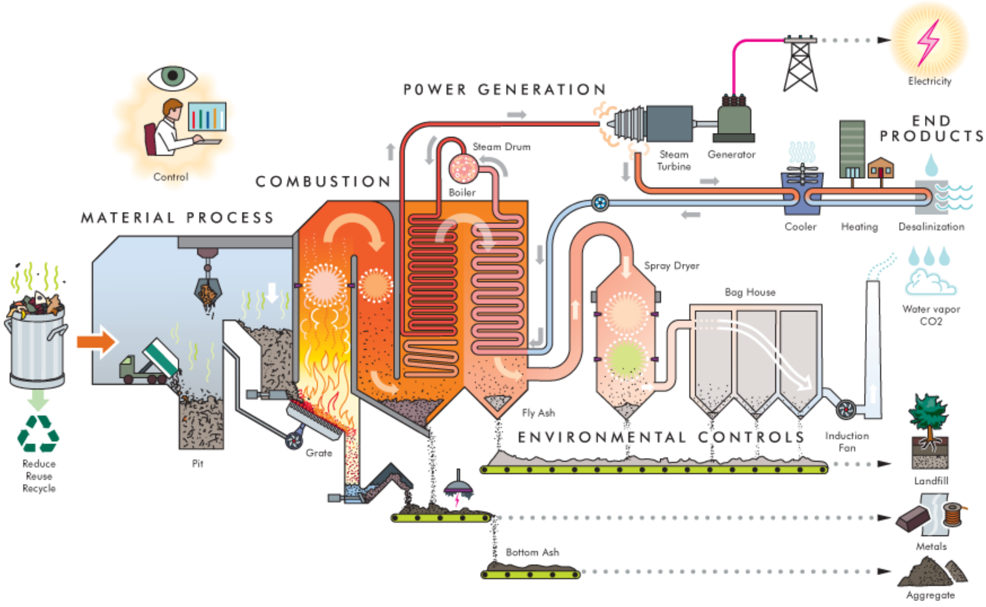

Fig (2.8): How waste to energy plant works (Source: U.S Energy Information Administration, 2018).

To better understand how incineration gives a share in the environment, we should understand what it produces. Rendek, (2006) mentioned that the main products of incineration are solid residues, bottom ash, fly ash and gaseous products that include almost 12% CO_2. The final products of incineration are listed in the table (2.3) along with their approximated percentage resulted form 1 ton of MSW.

Table (2.3): Solid Products from Incineration (O.Hjelmar, 1996).

Final Product	Percentage (%)
Flying Ash	1-3
Settled Ash	25-42
Dry Acid Gas	2-5
Semi Dry Acid Gas	1.5-4

The remaining's of the incineration process are the nitrogen and water vapor that their percentages are not included in table (2.3). Without intervention, MSW incineration is a large source of air pollution, but in fact, incinerators are equipped with heat recovery equipment and air control systems that perform with high efficiencies and can remove large percentage of emissions before their release into the atmosphere. A previous contribution by Sundqvist, (1999) indicates that 1 ton of MSW can generate up to 1.1 ton of CO_2, 393 g of SO_2, 1,790 g CO, and 852 g of NOx. In addition, it can generate approximately 0.98 Mwh of electricity if it operates at the optimum conditions. Azapagic, (2007) has summarized the mass percentage in the gases resulted from incineration, his findings are summarized in table (2.4).

Table (2.4): Gaseous Emissions from Incineration of MSW.

WtE process	Gaseous effluent	Mass percentage
Incineration	CO_2 (Tang et al., 2013)	7.31 wt%
	NOx	0.134 wt%
	SO_2	0.0335 wt%
	HCl	0.00672 wt%
	CO	0.0336 wt%
	Dioxins and furans	0.0672 wt%

Looking back to the old times, the formal management of MSW was first initiated by the rise of problems associated with population growth in cities especially after the industrial revolution. As Roberts, (2017) asserted with the advancement of science, it was proved that common diseases were directly connected to bacteria, which was called germs back in that time, and other micro particles that were found in soil, air or water, sure thing it was all because of the open dumping practices in lands and rivers in that era.

Over the past decades, it was clear that there must be other ways to deal with the rapid increase in waste volume and responsible authorities have realized the pressure that the public can make in order to guarantee that they have clean natural resources for living and newer strategies to handle MSW. By the middle of the 19^{th} century, people had started to understand that incineration was the solution, to recover heat and some materials and that landfilling will no longer be suitable in the face of urbanization. Reviewing previous literature revealed that the first incinerator in the UK was built in 1870, while US had it first incinerator with no heat recovery in 1885. The initial WtE plants had simple water wall and lacked gas treatment mechanisms, also, most often they had technical problems that led to their shutdown and a lot of rundown hours. At the same time, there were recovery plants which were built to recover metallic and nonmetallic materials; iron, aluminum, glass and paper fiber (Makarichi et al., 2018; Lu et al., 2017). Public awareness continued to grow, and incinerators were located far from residence areas, moreover, governments developed new strategies and laws to regulate the framework of WtE plants. With the continuous improvements made to enhance the operation of WtE plants, the objectives of MSW treatment has shifted towards heat recovery. Also, the regulations of emissions and flue gases were familiarized, the adoption of MSW incineration required volume reduction of MSW, heat recovery from MSW and emissions control.

According to Stear (1971), the early incinerators had different types: continuous feed, batch-feed, ram-feed, metal conical and waste heat recovery incinerators. The continuous feed incinerators were categorized as; traveling grate, reciprocating, rotary kilns and barrel grate, contrast with the batch feed incinerators they did not have periodic fed of the refuse to allow complete combustion, thus, it allowed continuous fed incinerators the enough capacity to handle larger amounts of MSW compared to batch incinerators. The heat recovery incinerators were grouped into; low pressure boilers, high pressure boilers and water wall furnaces. Most literature shows that the low pressure boilers were developed first, and their combustion chambers had boilers which caused in lowering the combustion efficiency because of furnace cooling. Later, the high-pressure ones were developed to prevent the excessive cooling of the furnace, they also were capable of cooling the flue gases to 250-300°C. Regarding the water wall ones, they were applied in Europe at first and were superior to the previous ones because they had higher efficiencies. The heat recovered from these incinerators were used to heat water for industrial and domestic purposes and seawater desalinization as included in the reports of the Energy Information Service Office. The heat recovery for electricity did not begin until the middle of the 20^{th} century, it was initiated in France, through this century there have been major changes in incinerators designs and they were more complex, had improved greatly and had higher combustion efficiencies and more control on air emissions and efficient handling systems for materials and air. Nowadays, the incineration technology is divided into; moving grate, fluidized bed incinerators and rotary kiln (Kuras, 2017).

The moving grate incinerators uses mass burn, it performs better in combustion products removal, it has large capacity up to 1200 ton per day according to the Rand et al., (1999). It superiority is the fact that it needs no pretreatment or processing, however, it requires high capital and its maintenance is costly (Xin-gang et al., 2016). Unlike the grated incinerators which burn MSW layer by layer, the fluidized bed incinerators light and burn all of the MSW uniformly (Tang et al, 2009). The main advantages of them is that they are very adaptable for a large range of waste, high efficiency (up to 90%), and they have high tolerance to high moisture and low calorific value waste. Yet, they require preprocessing which can be very expensive and complex (Jian & Hai, 2004), and these incinerators are mostly used in small and mid-sized cities. The rotary kiln incinerators work differently; the MSW is incinerated through a furnace by the rotating of the inclined cylinder, this logic optimizes the mixing of different types of waste and delivers uniform burning, as well, they do not require pretreatment as they can mix different composition, fractions and heating values of waste (Xinmei Li et al., 2016; Rand et al., (1999). In addition, they can stand higher temperatures up to 1400°C. Even with all these advantages, they are recognized with small capacity, require high capital and maintenance costs (Rand et al., 1999).

To have a general comparison between incinerators mentioned above, previous literature have proved the superiority of moving grate incinerators to the rotary kiln and fluidized bed ones, their main advantage is their large capacity; their potential to process large volumes of MSW with no need to any sorting or pretreatment activities (Brown, 2011; Wissing et al., 2017). Also, they asserted on the fact that they can handle different compositions and types of waste (Kuras, 2017; Lombardi et al., 2015). Despite the wide spread of the fluidized bed and rotary kiln incinerators in the 20th century, only the moving grate incinerators have been under full development and tests in order to stand the requirements of large scale performance, they can be installed in large units that have the ability to burn 50 tons of MSW per hour. In contrast, as mentioned before, moving grate incinerators have high investments and operational costs compared to other incinerators, for example, the fluidized bed incinerator's capital and maintenance costs are 70% of moving grate's costs (Fitzgerald, 2013; Brown, 2011).

Regarding the WtE plant efficiency, generally it depends on the recovered energy or heat. The Rankine cycle is used deucedly, it uses either combined heat and power or combined steam and power arrangements, the efficiency can reach up to 60% (Maria et al., 2016; Islam, 2018; Lombardi et al., 2015). In most cases, the efficiency of WtE processes can be strengthened by burning MSW with coal, known as co-firing (Suksankraisorn et al, 2004). Co-firing is the partial presence of coal as the main fuel in boilers. It is one of the common ways to use renewable waste with the fossil fuels systems (Surroop et al., 2011). Fouad et al., (2010) have mentioned that the direct co-firing is used worldwide since it is the least expensive and most straightforward method. The co-firing is done by burning MSW with coal in the same furnace. This method lets the coal-operating machines to have a renewable energy source as a fuel without the need to burn coal alone and pollute the environment. It also saves the utilities a lot (Surroop et al., 2011).

2.3 Air Emissions Control Technologies

The main products from incineration process include and not limited to; Heavy Metals (HM), Particular Matter (PM), Incomplete Combustion Products (ICP) and acid gases. The particular matter can be defined as ant liquid or solid that can be windblown or suspended in air. The sizes of these matters in incinerators have a diameter between 0.01 to 300 microns (one millionth of a meter). The PM resulted from MSW incineration include carbon, water and other products. In addition to PM, heavy metals emission includes mercury, lead and calcium. They are toxic emissions and many regulations were set in the 1990's to keep control of them. Other products from combustion process are sulfur dioxide, hydrogen chloride and they are categorized as acid gases. The last category includes the incomplete combustion products as carbon monoxide and organic emissions (Henselder, 1986). The Environmental Protection Agency (EPA) has the authority to regulate emissions, it sets emission regulation from different sources including MSW. During the 1980's and 1990's, EPA issued emissions regulations for MSW combustors and set emissions types to be controlled and their limits as well. These regulations also specified the control technologies to be used. In the end of 2005, EPA declared the performance standards of MSW incinerators. The current emissions limits for very small, small and large MSW incinerators are shown in Appendix I.

The PM from MSW combustion is usually carbon, water, and ICP. There are two techniques to control PM in WtE plants; electrostatic precipitators (ESPs); and fabric filters. Figure (2.9) shows how the electrostatic precipitators work, they have high removal efficiency and can perform in a good way in high temperatures. As described by Rogoff and Screve, (2011) they use positive and negative charges to collect the particles, when the gas enters the system it goes through the electrical field that charges the particles, then these particles are collected on large plates with opposite charges called fields. There are several fields, and more fields gives higher efficiencies. The cleaning process of the fields should be done between time to time by banging, if plates are not cleaned the efficiency will go down. Anyway, with periodic cleaning and good maintenance the efficiency can reach to 99%.

ESP's have a lot of advantages. They have high removal efficiency, their energy consumption is low and they have minimal fire hazard potential. However, their efficiency might be affected by several factors which include but not limited to; the area of the collection plates, velocity of the gas between plates, the strength of the electrical field and particles size. On the other hand, the main drawbacks that affects the performance of ESP's are; high variation in particular's size, humidity and velocity in the gas.

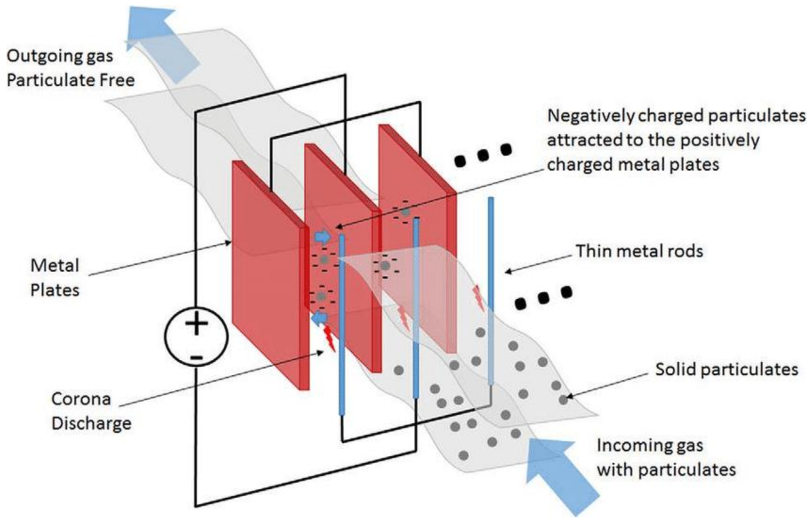

Figure (2.9): How the Electrostatic Precipitators work (Source: Becker, 2012).

Another way to control the PM is the fabric filters as in figure (2.10). They were developed in response to the strict regulations for PM in the U.S.A. Fabric filters work as the gas passes through them and the filter captures all the particulars, similar to a vacuum cleaner bag.

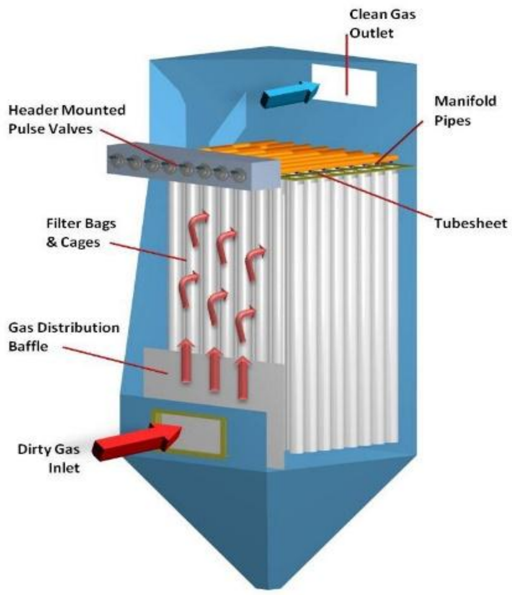

Figure (2.10): Fabric Filters (Source: Themodyne Boilers Website, 2019).

There are many types of fabric filters, generally, they are categorized by the way of cleaning; shaker, reverse gas or pulse jet. The first one does not suit mass burning incinerators without the use of other controllers since they have very high temperature. The other two clean the system using the gas flow through the bags but after being reversed, using an external fan with clean gas and compressed air. The fabric filters have many advantages; they have high efficiency even for small particular sizes and they are not sensitive for electric field resistivity. But they also have other disadvantages; they have not been widely applied in WtE applications so they have not been developed as other systems and they have the potential to fire if the flue gas was not chilled or quenched.

Another system for emission control is the Venturi wet scrubber, this system is less efficient than the previous two (ESP's and fabric filters). As seen in figure (2.11); they operate by washing out the particles. The system cannot be used alone and it needs other systems to support its operation.

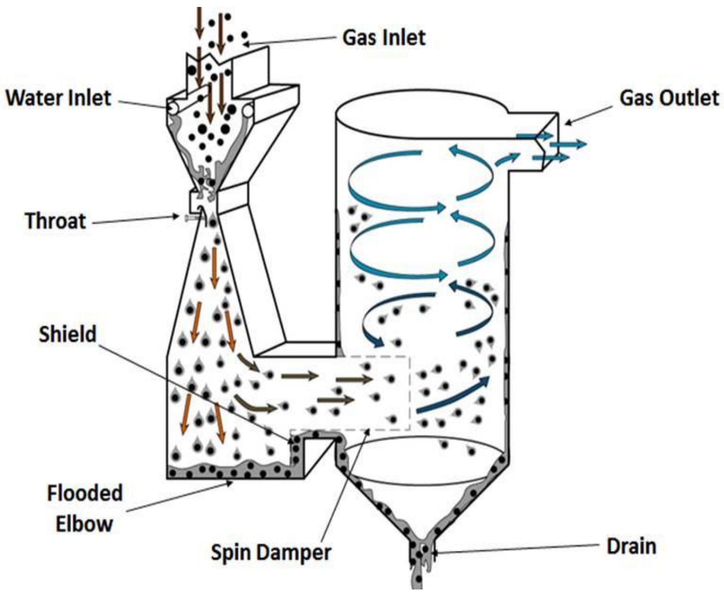

Figure (2.11): Venturi Wet Scrubber System (Source: SLY INC Website, 2018).

Other scrubbers do not use water, instead they use an alkaline solution like lime and they control acid gases, known as wet scrubbers. The acid gases and the solution react and form salt which are later collected (as a sludge) and dewatered and disposed in landfills as seen in figure (2.12).

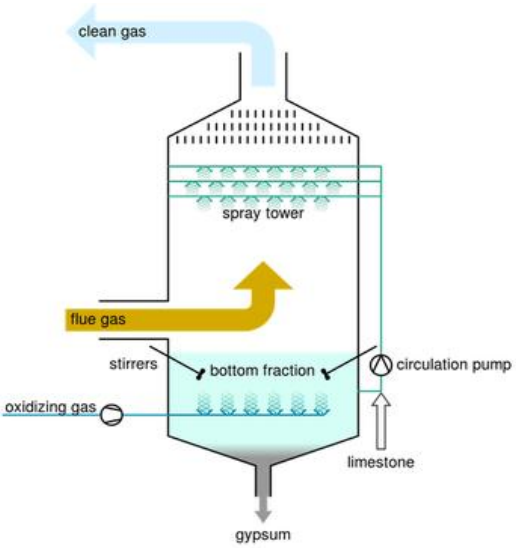

Figure (2.12): Wet Scrubber System (Source: Energy Education Website, 2018).

More complex systems are used to control the NO_x emissions, known as Catalytic reduction and selective non-catalytic reduction. Both ways, the ammonia and urea is used to break NO into N by injection solution to the furnace. The selective non-catalytic reduction is vastly used in the U.S.A with reduction percentage up to 50% while the Selective catalytic reduction is more familiar in Europe and Japan with efficiency up to 80%. Figure (2.13) illustrates the installation of Ammonia tanks in the WtE plants that uses either system.

Figure (2.13): Ammonia Tanks Installation in WtE Plants (Source: Rogoff and Screve, 2011).

In order to control other emissions like heavy metals, the spray dryers (scrubbers) are used, as illustrated in figure (2.14). They inject an alkaline solution in the gas streams, resulting in water evaporation and cooling of the combustion gases. With the evaporation, the heavy metals de vaporize and condensed into particulates, later, any system like electrostatic precipitator or fabric filter is used to collect and capture these particulates.

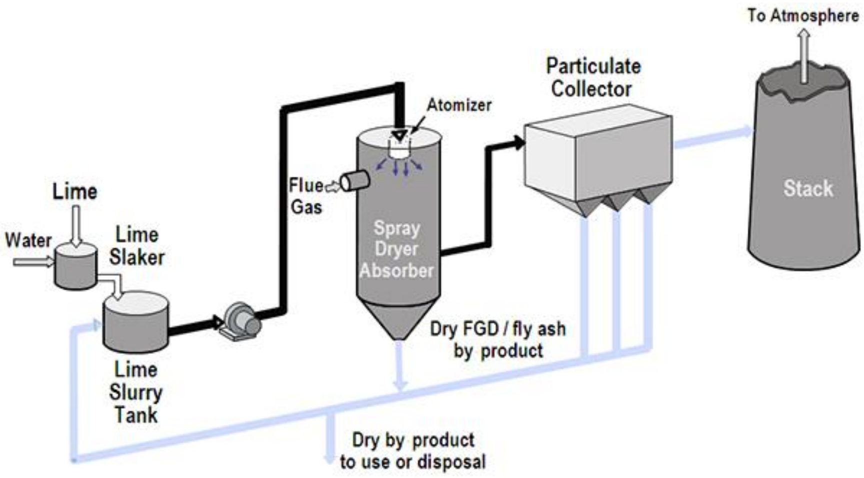

Figure (2.14): How Dry Scrubbers Operate (Source: CARMEUSE Website, 2018).

The dry scrubbers have high efficiencies averaging about 99%, and they are less costly as the life equipment can be extended and the corrosion potential is reduced. However, they have the potential for clogging and for the particles to build upon the walls and ductwork.

Other systems that use alkaline solution as lime and soda ash is the dry reagent or injection fabric systems. Alkaline reagent is used in the form of powder, and is injected into the flue gas duct in a continuous matter, in order to reduce the pressure drop through the fabric filter, a bulking agent is added, all in all increases the time between cleaning cycles. Both the bulking agent and the reagent result in a caked layer on the filter fabric, this layer acts as reactor bed and neutralizes the acid gases. The main features of such a system is its lower costs; equipment cost less compared to other system and the operation costs less since there is no need for internal moving parts and it also consumes less energy. Even so, some drawbacks of this system are that they have high potential for plugging and caking because of the moisture absorption and the main used item (powdered reagent) is relatively more expensive than scree used in semi dry systems (Rogoff and Screve, 2011).

On the other hand, some WtE plants install powdered activated carbon systems, as shown in figure (2.15), to control mercury emissions. The quantity of mercury emissions depends of the mercury content in the MSW. At high temperature these compounds vaporize since they have low vapor pressure and they have the ability to stay in the vapor phase in the air control system. The activated carbon is introduced in the upstream or downstream the dryer to reduce mercury content, it can achieve Hg savings up to 90%.

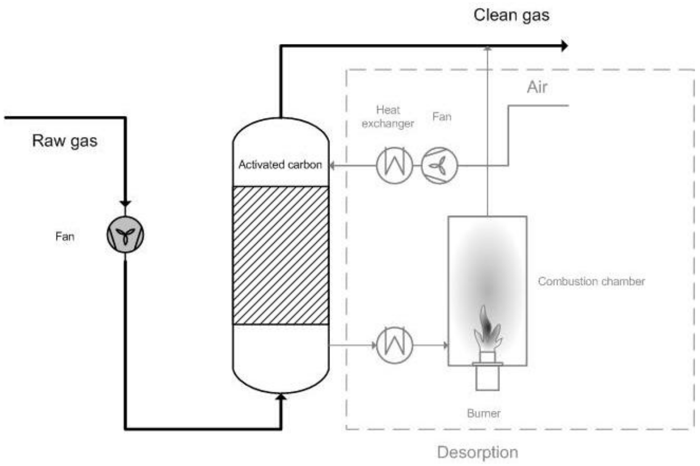

Figure (2.15): Schematic of a Carbon Injection System (Source: Olsen, 2006).

These were some technologies used in WtE plants to control air emissions from combustion process, nonetheless, there are other combustion control approaches to reduce CO emissions. One of these approaches is to use good combustion practices to increase the oxidation ratio and convert the maximum amount of CO to CO_2. One of these ways is to make sure of the convenient design of the WtE facility followed by good construction, operation and maintenance, that's why a lot of literature suggests that the planning and design of a good WtE plant might take up to 5 or 7 years at maximum. Responsible operators of WtE plant must keep in mind many factors to reduce CO emissions; keeping MSW feed at a stable rate, maintaining sufficient temperature in the combustor, providing enough combustion air and monitoring the level of MSW burn out.

All of the guidelines summarized above aims to provide optimum combustion at WtE incineration plant, the adaption of this logic side to side with the combustion emission technologies will guarantee the plant operates within standards and regulation, and that it will not exceed the emissions limits in the country. Unfortunately Palestine has not set regulations or standards for such technologies, since it have not been utilized yet, despite that, with good planning and design and the use of previous literature and success stories in other countries, the researcher hopes to give a holistic study of incineration scenario, and prove it supremacy when compared to the MSW management strategies and methods that are currently applied in Palestine.

2.4 WtE Technologies Comparison

The technologies summarized above can be compared in terms of their output, environmental and economic impact and health consequences. In this manner, Kumar and Samadder, (2017) reviewed incineration, gasification, anaerobic digestion and landfilling with gas recovery as options to generate energy. They used different case studies for both developed and developing countries to evaluate the technological options of WtE in terms of economic, environmental and health impacts. Their results indicated that in developing countries, the most feasible solid waste management solutions are anaerobic digestion and incineration for both organic and mixed waste, while gasification is best used for plastic, electronic equipment, wood waste and electric waste and landfilling is most suitable for inert wastes. They found that the characteristics and composition of municipal waste are main determinants of the best technique to be used. However, these countries still lack the appropriate infrastructure, control systems and maintenance of WtE plants. Moreover, the authors confirm the potential of MSW as a renewable energy source if WtE technologies are adopted, which will lead to fulfilling energy demand, reduce dependency on conventional energy sources and address the issue of solid waste disposal. Policy makers and authorities can take advantage of WtE to understand the current issues of energy and waste and overcome their challenges if they offer the financial support and improved technologies. Another comparison between WtE options was done by Lino & Ismail (2018), their findings were that electricity production from incineration equals 35 times that from bio digestion. Moreover, recycling can guarantee a financial gain of 201,439 US$ per month that equals to 1,120 Minimum National Salary.

A previous research used LCA methodology to evaluate the performance of incineration and landfilling technologies, it assumed the MSW that is ready for final disposal. The calculations considered emissions from incineration plant, transport of solid residues, emissions from landfilling and the avoided emissions that would be made if WtE plan replaced the power and thermal stations (Assamoi and Lawryshyn, 2012). Results assert on the benefit of using incineration to manage MSW, from an environmental point of view, incineration produces more electricity when compared to landfilling production, which means an observably greater environmental substitute. Also, incineration takes the advantage of plastic presence in MSW, while plastic has high energy content, it reduces the quantity of waste to be landfilled at the end of the day.

Lino and Ismail, (2018) proposed incineration and landfilling as two scenarios to manage MSW in Brazil. Considering the emissions to the atmosphere come from leakage of biogas from the landfill and the combustion to produce energy, they estimated a total of 38.385 $ktCO_2$/year from landfilling and 92.929 $ktCO_2$/year from incineration (summation of MSW incineration and combustion of auxiliary fuel LPG). One could think that incineration does harm the environment more than other technologies, however, another case study in Brazil has employed LCA to compare these two scenarios. Mendes et al., (2004) have found that if all waste is to be landfilled it will generate the highest environmental impact even if landfilling includes energy recovery it will slightly decrease its impact when it is compared to landfilling without energy recovery. In the same manner, it was found that incineration with final disposal of ash using landfilling has lowest encumbrance to the environment.

In the same manner, Cucchiella et al. (2016) conducted a comparison between landfills and WtE plants. Results confirm that WtE plant is more reasonable and sustainable technology than landfill without compromising reuse and recycling rates, these results were achieved by analyzing a case study that suggest WtE plant in Abruzzo region. In addition to that, it was found that mass burn of solid waste can generate the highest electricity capacity compared to Mass Burn with recycling and refused derived fuel (RDF) with biomethanation (Ouda, Raza and Nizami, 2015). They also confirm that 180 MW of electricity can be produced using incineration scenario, 11.25 MW of electricity based on incineration with recycling scenario in Jeddah city, KSA. Rajaeifar et al. (2017) reviewed the following technologies: AD, incineration and pyrolysis-gasification, in terms of electricity generation and GHG's reduction. The theoretical and technical potentials of electricity generation & reduction of GHG emissions were calculated and estimated using an LCA approach. Data in Iran was used as a case study, results assure that WtE technologies give the advantages of effective waste treatment and clean energy generation which is also economically viable. Approximately 0.5% of Iran's annual GHG emissions can be reduced, also, between 5,005 and 5,546 Gwh per year of electricity could be generated from MSW in Iran. In this field, Fernández-González et al. (2017) have analyzed anaerobic digestion (Biomethanization) and gasification approaches. The study compared these options with Biological and mechanical treatment which is the present method used in Spain. The study considered 13 small and medium municipalities in southern Spain using LCA. The obtained results confirm that utilizing WtE options would reduce GHG's emission, especially reducing CO_2 among other environmental advantages. In the same manner, according to these authors, WtE approaches lead to better generation of employment and fewer environmental requirements for the potential locations.

To investigate other ways for better utilization of MSW, Bajić et al. (2015) reviewed the common MSW practices, types and amounts. They investigated the energy potential of MSW that can ensure sustainable development and energy security in Serbia. According to their study, there were many reasons behind the failure of WtE processes made previously in Serbia, mainly due to the lack of a strong policy framework and the absence of financial and logistical planning. On the other hand, many other reasons made WtE more appealing, there seems to be positive changes of general public minds due to education and development levels, plus, the fact of energy demand and prices rising. All in all, made WtE option the best to integrate a waste management system with waste quantity reduction.

An economic analysis of WtE industry in China was made by Zhao et al. (2016), the study discussed the technology, benefit and cost of WtE plants. The economic analysis included rate on investment, net present value, internal rate of return and sensitivity analysis. The total costs of WtE plants are described in figure (2.16). The total cost of WtE can be divided into two main parts: investment costs and operational costs. The investment costs are the total costs of equipment, devices and construction costs, while operational costs is mainly the costs of raw materials, staff salaries, maintenance costs and other financial and environmental costs associated with environmental controlling and treatment. The government support in terms of policy and financial legalizations have positively affected the possibilities of WtE in Chinese markets. WtE is expected to have relevant margins and stable profits due to mature technologies and low operational costs in China since China-made equipment has 30–35% lower investment cost than imported equipment (Zhao et al., 2016). Also, when considering the factors of feed-in tariff and tipping fee, WtE projects can resist risks of changing external conditions since the government can control the market.

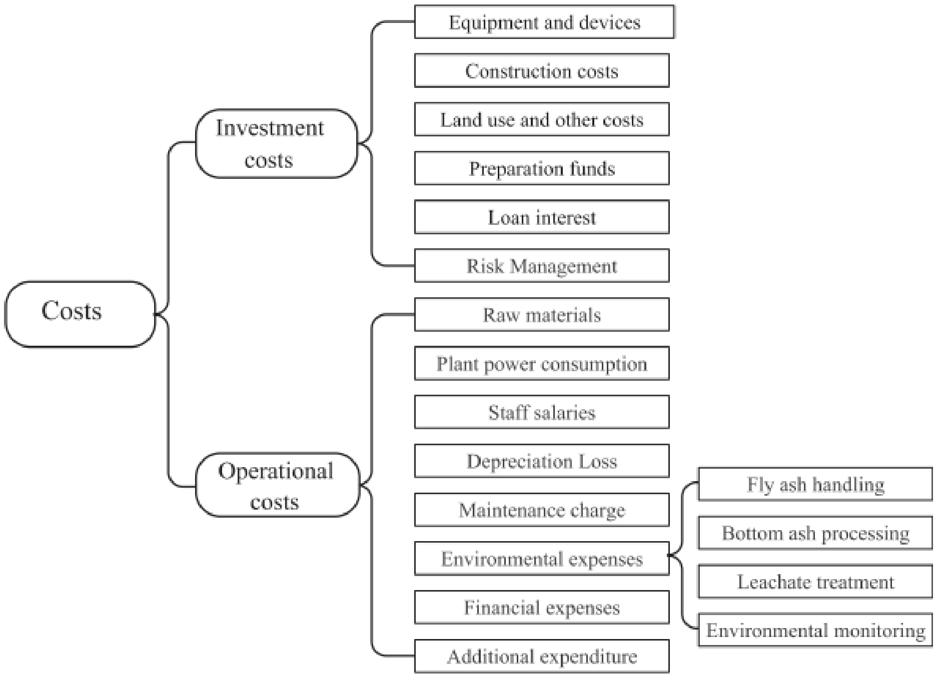

Figure (2.16): Structure of total cost of WtE plants (Zhao et al., 2016).

A research done by Cucchiella, D'Adamo and Gastaldi, (2014) had focused on the sustainable management of waste to energy facilities. The main problem was that more than 50% of waste is landfilled in Italy. This, for the authors' point of view, require urgent actions for correct environmental treatment of waste which can offer environmental and economic benefits. They proposed a national waste management plan to assess the sustainability of WtE plants; to reduce GHG's emissions, to estimate financial net present value and to estimate the new employment opportunities. Authors confirm that WtE technologies collect electrical and thermal energy from waste, which leads to energy independence like what other RES do. Moreover, they highlight that in order to sustain WtE plants in respect to old incinerators, there should be strict control to prevent any unwanted harmful impacts on public health and environment. To do so, the incineration plants should be located near waste generation points, this will mitigate the negative impact on human health and reduce emission in terms of CO_2 resulted from waste transporting over long distances. The trend towards environmental legalizations have led to more and more development of technologies and equipment for incineration plant through years. According to Tabasová et al. (2012), the continuous attention is necessary to obtain the balance and optimum solutions in terms of technology, economy and environment.

The selection of the conversion technology is not a simple decision, it requires tradeoffs between one agency's goals with others since the risks associated with WtE technology can be substantial, it is critical that it should be assessed carefully and reduced as much as possible (Rogoff and Screve, 2011). To do so, many criteria can be utilized. Degree and scale of operating experience is one of the most important issues that should be considered (Berry Patricia, 1986). WtE technologies have only been proven in pilot or laboratory operations, or with raw materials other than municipal solid waste. Other commercially successful technologies have only been operated in small facilities and the scale-up to larger sized plants may result in unexpected technical challenges. WtE plants normally suffers from relatively high probability of downtimes (Rogoff and Screve, 2011). Thus, reliability to dispose of municipal solid waste should be taken into consideration in the risk plan when choosing the technology (Zier, 1982). The technology selected must be capable to dispose of solid waste in a reliable manner without frequent mechanical downtimes, otherwise, waste should be diverted to landfills and cause many environmental problems.

The risk plan should also assess neighboring energy and material markets compatibility, where the chosen technology will determine the amount of generated energy and material, it should be kept in mind that, without equivalent market demands, generated energy and material will burden the system instead of being beneficial. And finally, the risk plan should take into consideration assessment of local environmental requirements and regulations, social acceptance, political obstacles, and initial investment.

Chapter Three

Current Palestinian Situation

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3.1 General Aspects

The Palestinian lands are characterized by being rich in natural resources specially the solar radiation, the sun provides almost 3000 hours of sunshine, these rays have an intensity of 2.63 kWh/ m^2/day in winter while in summer it provides 8.4 kWh/ m^2/day (WAFA, 2019). In the same manner, Palestine has an average monthly temperature that ranges between 5ºC (as minimum) and 30 ºC as maximum. Rainfall yearly average is around 450 mm (WAFA, 2019). This study is focused mainly on the West Bank which is bordered by Jordan in the East side. According to Palestinian Central Bureau of Statistics (2018), the population of Palestine at the end of 2017 was 4,781,248 inhabitants, distributed as follows: 2,881,957 inhabitants in West Bank and 1,899,291 in Gaza Strip. Each house has an average of 4.8 persons per household, while the statistics of 2016 shows a total GDP of 13,269$ (PCBS, 2016). The average salaries range between 25$ to 30 $ per day (World Bank, 2018). While Palestine is one of the countries in the Middle East, it is a way more different than any of the countries in the entire region. Based on the United Nation resolution 181 in 1947, Palestine was divided into three main parts, after decades on unsolved conflict, Palestinians land are divided to what are known now as West Bank and Gaza strip. Later on, Oslo accord in 1993 divided West Bank and Gaza Strip into three administrative categories, called A, B, and C. Land A is under full administrative and security control of the

Palestinian Authority (PA) and it constitutes about 18% of the land. Area B that is about 22% of the land and is under administrative control of PA, and C is under administrative and security control of Israel. This categorization limited the PA abilities of implementing development plans. Figure (3.1) shows the administrative and security responsibilities of the West Bank. It is obvious that area C constitutes most of the land, about 61%.

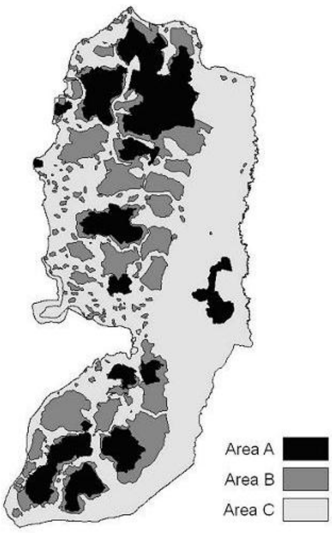

Figure (3.1): West Bank lands categorization (Source: Rosen, 2012).

3.2 Waste Situation

The waste considered in this research is the MSW, which can be defined as the waste collected by municipalities and other collection services. According the GIZ report in 2014 regarding solid waste management, the total waste production per day is around 1,950 tons, approximately 720,000 tons per year. The MSW production per capita is around 0.81 kg/day, these number increased to a total generation of 2,622 ton/day in the West Bank, which equals to 957,030 tons/year, while the generation per capita increased to 0.91 kg/day, in the other hand, Gaza generate 1,330 tons/ day almost 485,459 tons per year, while its average production per capita is 0.7 kg/day (MOLG, 2018). In fact, these numbers are expected to grow as the population growth and living standards continue to grow. The increase is assumed to be 4% as a total, 3% of it is due to the population growth while the remaining 1% is a result of the generation growth per capita. As stated by GIZ in 2014, the waste collection services cover almost 88% of rural areas and 93% of urban areas in Palestine. Less than 0.5% of the total collected waste in Palestine is composted, less than 0.5% is recycled, 33% is landfilled and 67% is randomly and open dumped according to the GIZ reports that discusses waste situation in Palestine.

As provided by the JICA and MOLG reports of 2018, figure (3.2) shows MSW fraction and percentages. The organic waste constitutes 50% of the total MSW, while glass and metals appear to have the lowest percentages. When thinking about a suitable waste management system, one must consider the different components that holds various energy content values. According to the International Solid Waste Association (ISWA) guidelines published in 2013, the calorific value of MSW differs according to its content; table (3.1) summarizes these values.

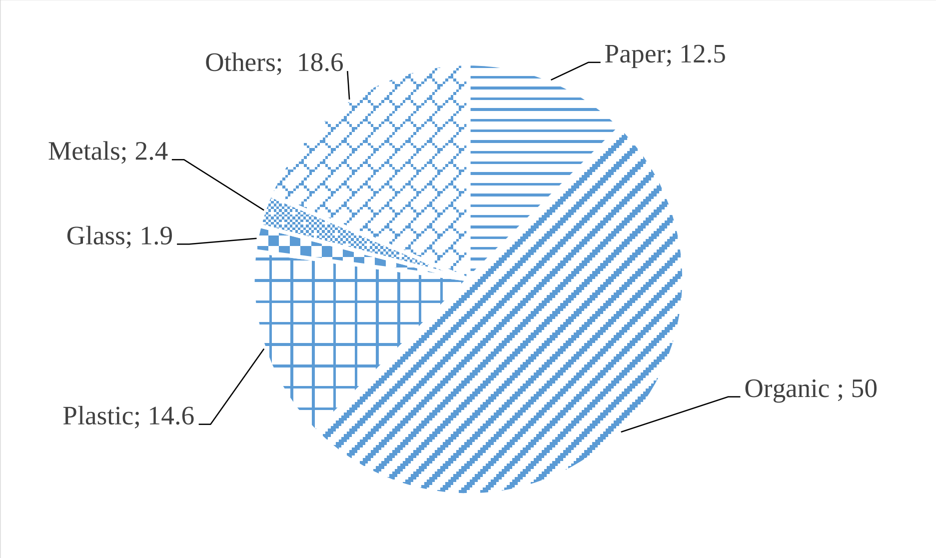

Figure (3.2): MSW Composition in the West Bank (%) (Source: MOLG, 2018).

Table (3.1): MSW composition percentages and calorific value (ISWA, 2013).

Fraction	Calorific value (MJ/kg)
Paper	16
Organic	14
Plastic	35
Glass	0
Metals	0
Others	11

When all details of figure (3.2) and table (3.1) are taken on the whole, it can be calculated that the MSW in the West Bank holds a calorific value of 11.16 MJ/kg. This value is rather high, and it could be due to high presence of plastics. This is a very important measure to be considered with regard to WtE options that could be applied especially incineration. Waste management responsibility currently lies in the hands of municipalities in the West Bank; however, some of this responsibility goes to one of the Joint Service Councils (JSC's) and UNRWA.

There are a total of 15 JSC in the West Bank that were established before 10 years under the responsibility of MOLG. They cover waste collection services with a range between 20-100% according to the municipality, but the average collection is considered of 65%, approximately 1,711 tons per day. While the LGU's handle some of the remaining MSW, it is quite different for refugee camps, the MSW collection lies in the hands of UNRWA, there are a total of 27 camps in Palestine, 19 of them in the West Bank that contains 129,536 inhabitants, these camps generate almost 43,025 tons annually. However, the other 8 camps in Gaza has a total population of 252,841 and generate almost 67,369 tons per year (MOLG, 2018).

Generally, the collection process is done using collection vehicles that bring waste to transfer site (if needed), then waste is transferred in large volume trucks to the landfill site. Figure (3.3) illustrates the Palestinian MSW management process. The treatment and transfer activities cost are invoiced to the municipalities. These costs are added the total costs of cleaning the city and the collection services. It is up to the municipality to define the rate to which these expenses should be translated to fees that are paid by households and any other beneficiary. Generally, these fees are added to the electricity bills each month. Figures (3.3) illustrates the process flow of waste management.

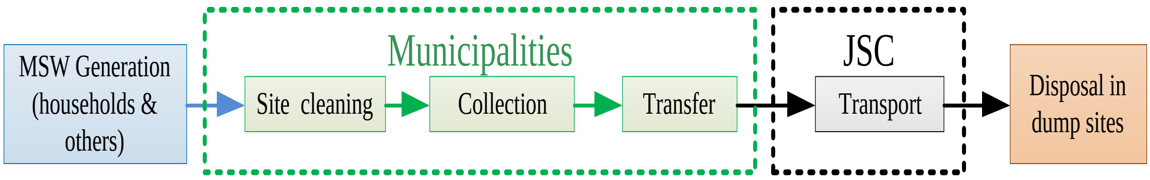

Figure (3.3): Palestinian Solid Waste Management Process Flow.

Neglecting the few initiatives to separate paper and cardboard in the collection, it can be assumed that the separate collection from the source is fully absent. Taking into account the importance of waste separation, this is a big challenge, and it is believed that it will take years before raising the awareness and efforts to be implemented.

In order to shorten the long-distance transport of waste, JICA helped PA and funded 13 Transfer Stations (TS), 6 of them are managed by JSC's, 4 are managed by LGU's and the last one (Alabdali) is controlled by Israeli side. The information regarding these stations are provided in table (3.2). The TS serve the municipalities and let them empty their collection trucks within short distance of the collection routes. Later in the station, the waste is weighed, packed, and then transferred into bulk load trucks. The importance of these transfer stations lies in the fact that they lower costs and give an important tool to manage waste streams since the transportation roads are long due to the difficult territorial situation in the West Bank.

Table (3.2): List of Transfer Stations in the West Bank.

Governorate	Name of TS	Final Disposal	Responsibility
Tulkarm	Tulkarm	Zahrat Al-finjan	Tulkarm JSC
Jenin	Western Jenin	Zahrat Al-finjan	Jenin JSC
Nablus	Alsayrafi	Zahrat Al-finjan	Nablus JSC
Qalqilya	*Qalqilya*	Zahrat Al-finjan	*Qalqilya* JSC
Tubas	*Tubas*	Zahrat Al-finjan	*Tubas* JSC
Jericho	No TS	Zahrat Al-finjan & Jericho landfills	Jenin JSC
Ramallah	Ramallah	Zahrat Al-finjan	Ramallah Municipality
	Albeireh	Zahrat Al-finjan	Albeireh Municipality
NE and SE Jerusalem	Aabdali	Almenya	Israeli Side
	Wadi Alnar	N.A	SE Jerusalem JSC
	Alram	Almenya	Alram Municipality
Hebron	Tarqumia	Almenya	Hebron and Bethlehem Higher Council
	Yatta	Almenya	Hebron and Bethlehem Higher Council
	Afahs	Almenya	Hebron and Bethlehem Higher Council

The quantities that are transferred through each of TS differs according to its location. The location of the area also affect the total distance (km) that is being crossed to reach the final destination point. Here, it should be noticed that Salfit governorate is not among the list, the main reason is because Salfit has a bad situation regarding MSW management. There is no TS and no final disposal point, almost all MSW is disposed in random dumpsites around the governorate. Which of course creates a lot of challenges and problems. In the same manner, Jericho governorate has no TS, however the MSW is directly sent to Jericho landfill while a small proportion of it (2.1 tons/day) is sent to Zahrat Al-finjan landfill through Alsayrafi TS in Nablus. The values of transferred quantities in Ramallah is distributed as follows: 100 tons/day goes for Ramallah TS and is transferred through 120 km to reach Zahrat Al-finjan , while the other 100 tons/day are sent to Zahrat Al-finjan through Albireh TS that crosses 80 km to reach final point. The same logic applies to Jerusalem, Alabdali TS recives 60 tons/day that are transferred to Almenya in a 35 km path, while Wadi Alnar TS is not functioned yet, it is located 30 km away from the landfill, Alram TS also receives 60 tons/day and are sent to Almenya landfill through 55 km path. Regarding Hebron, since it is the biggest governorate in the West Bank, three TS's serve this area; Tarqumia, Yatta and Alfahs TS's, each recives 100 tons/day, 200 tons/day and 350 tons/day respectively, and cross a distance of 39 km, 35 km and 33 km to Almenya landfill respectively. Table (3.3) shows the information regarding quantities and distances of TS's.

Table (3.3): Transfer Stations Received Quantities and Distance Data.

Area	Transferred (ton/day)	Distance (km)
Tulkarm	132	30
Jenin	50	35
Nablus	180	40
Qalqilya	123	60
Tubas	43	28
Ramallah	200	200
NE and SE Jerusalem	120	120
Hebron	650	107

The West Bank houses three operating Landfills (LF); Zahrat Al-finjan LF in Jenin which serves the North of the West Bank, Almenya LF that serves the South of West Bank and is located between Hebron and Bethlehem, Jericho LF for Jericho area. There has been efforts towards establishing another sanitary landfill Rammoun LF to serve the middle part of the West Bank, however, the project did not see light and does not seem to do so in the coming years due to a lot of political obstacles. Meanwhile, middle areas send their MSW to Zahrat Al-finjan or to Almenya LF's, or worst to random dumpsites. Table (3.4) summarized LF's data. Unfortunately, Zahrat Al-finjan LF is about to reach its maximum capacity within the coming few years. The one in Jericho has reached its maximum capacity; and also there is no possibility to expand it. As a result, the situation is characterized Palestinian authorities as being in crisis, the biggest concerns are the lacking capacity, the odors and the impact they cause on public objection. Also, the poor management of leachate and uncontrolled GHG emissions in the current dumpsites put local citizens' health and ground water in a danger.

Notwithstanding, others still believe that Zahrat Al-finjan and Almenya LF's can be expanded to serve more in the future, and predict the remaining lifetime to be 13.9 and 9.7 years respectively. Nonetheless, still with this optimistic thoughts, some remarks should be made; if there is a potential to develop more cell in the LF's it must be properly prepared, designed and constructed, this cannot be easily made and requires a lot of time. Also, the social concerns play a major role; people living in the area around Zahrat Al-finjan LF complains about the odors and nuisance. This discomfort is a result of inadequate daily treatment, the lack of LF encasement with gas tight covers and the absence of further treatment facilities for leachate which reach 100 m^3 per day. All of this will need huge investments and high operational costs.

Table (3.4): List of Landfills in the West Bank.

Stationary Landfill	**Site**	**Targeted Areas**	**Area of Service**	**Received Quantity (ton/day)**	**Administrative Authority**
Zahrat Al-finjan	Jenin	North area	Jenin, Tubas, Tulkarm, Qalqilya, Nablus, parts of Ramallah, Beitunya and AlBiereh	1,200	Jenin JSC.
Jericho	Jericho	Jericho	Jericho	55	Jericho JSC.
Almenya	Bethlehem	South area	Hebron, Bethlehem, SE and NE Jerusalem	1,000	Higher Council of Hebron and Bethlehem.
Rammoun	Ramallah	Middle area	Not established yet	N.A	N.A

On the other hand, as a result of the hurdles of the construction of the new Rammoun LF in the center of the West Bank, there has been many random dumpsites especially in Ramallah, Albierh and Salfit. Table (3.5) summarized quantities and locations of random dumpsites.

Table (3.5): List of Random Dumpsites in the West Bank.

Location	**# of Random Dumpsites**	**# of LGU's using them**	**Quantity (tons/day)**
Salfit	9	20	66
Nablus	12	20	77
Ramallah and Albireh	50	67	200

To summarize the current situation of collection, transfer and landfill activities in each governorate, Table (3.6) summarizes where these activities are performed.

Table (3.6): Collection, transfer and landfill information.

Palestinian Governorate in West Bank	Collection	Transfer	Landfill
Tulkarm	√	√	X
Jenin	√	√	√
Nablus	√	√	X
Tubas	√	√	X
Qalqilya	√	√	X
Salfit	√	X	X
Jericho	√	X	√
Ramallah	√	√	X
Jerusalem	√	√	X
Hebron	√	X	√
Bethlehem	√	X	√
√ : Being done X : Not being done			

3.3 Joint Services Councils

For better understanding of how MSW management operates, one must understand how waste collection and cost system is built and operated. As aforesaid, there are 15 different JSC's in the West Bank, all are under the responsibility of MOLG but they differ in their targeted service area and population, and so the tariff and cost system. Hence it is worth to mention some details regarding JSC's in the West Bank as reported by MOLG data book of 2018.

3.3.1 Jenin JSC

Jenin governorate is located in the North of the West Bank, and has 77 LGU's. The JSC in Jenin provides the collection services to 75 of them. Currently, there are two collection systems being used; the Fixed Time Fixed Place (FTFP) that covers 70% of Jenin area using different containers of sizes 32, 25, 10, 4 and 1.1 m^3, and 360, 240 L bins, the second is the House to House (HTH) system which uses different sizes of small bins, while the large containers (32, 25 m^3) are used for industrial and commercial purposes.

The collection services in Jenin is done frequently, with a range of 6 times per week in cities, and 3 times per week in villages. The daily collected quantity is 290 tons, all of collected waste is sent to Zahrat Al-finjan LF, 50 tons are sent through the TS that is located 35 km away from the LF, this TS serves the western villages and the JSC is responsible of it.

The MSW management system in Jenin has a total cost of 135 NIS/ton distributed as follows; the collection cost is 75 NIS/ton, transfer cost 30 NIS/ton and landfilling cost is 30 NIS/ton. The tariff imposed by the JSC on LGU’s is 170 NIS/ton for collection, while the tariff imposed on resident differs from one LGU to another. In addition, the total cost recovery percentage is 82%, and people pay a monthly fee between 15-18 NIS per household, it is included in their electricity bills each month.

3.3.2 Tubas JSC

There are 12 LGU’s in Tubas. The JSC in Tubas provides the collection services to all of them. Same as Jenin JSC, it used FTFP and HTH systems for collection, the first applies to 70% of area with 1.1 m^3 containers and 240 L bins, while the second covers the remaining area with 120 L bins and other small bins. The frequently of collection ranges between 6 times per week in cities, and 2 times per week in villages. The daily collected quantity is 39 tons, all of collected waste is sent to Tubas TS, and later to Zahrat Al-finjan LF which is 28 km away from the TS.

The MSW management system in Tubas has a total cost of 143 NIS/ton distributed as follows; the collection cost is 95 NIS/ton, transfer cost 17 NIS/ton and landfilling cost is 30 NIS/ton. The tariff imposed by the JSC on LGU's is 133 NIS/ton for collection, while the tariff imposed on resident differs from one LGU to another. In addition, the total cost recovery percentage is 92%, and people pay a monthly fee between 17-22 NIS per household, it is included in their electricity bills each month.

3.3.3 Nablus JSC

The JSC in Nablus provides the collection services to 32 LGU, 5 LGU's are served by Jericho JSC and 8 are served by Jenin JSC. FTFP system is used in 85% of Nablus area using 1.1 m^3 containers and 250 L and 120 L bins, the rest of the area is covers using HTH system with 80 L bins, 20 L and plastic bags. The collection frequency is between 7 times per week in cities, and 3-5 times per week in villages. The daily collected quantity is 93 tons, all of collected waste is sent to Alsayrafi TS, and later to Zahrat Al-finjan LF which is 40 km away from the TS. Almost 7 tons of the collected waste is disposed in dumpsites while 3 tons are recycled.

The total cost of MSW management is 140 NIS/ton distributed as follows; the collection cost is 66 NIS/ton, transfer cost 47 NIS/ton and landfilling cost is 27 NIS/ton. The tariff imposed by the JSC on LGU's is 140 NIS/ton for collection, while the tariff imposed on resident differs from one LGU to another. In addition, the total cost recovery percentage is 90%, and people pay a monthly fee of 15 NIS per household, it is included in their electricity bills each month.

3.3.4 Tulkarm JSC

The number of LGU's in Tulkarm is 31, the JSC in Tulkarm provides the collection services to 27 LGU. Tulkarm JSC collects 40% of waste, while their municipality collects the rest, however, all the collected waste are sent to the TS by Tulkarm JSC. The collection is done by FTFP system that is used in all JSC area using 4 and 1.1 m^3 containers and 240 L. The collection frequency is between 7 times per week in cities, and 2-7 times per week in villages. The daily collected quantity is 168 tons, all of collected waste is sent to Tulkarm TS, and later to Zahrat Al-finjan LF which is 35 km away from the TS.

The total cost of MSW management is 165 NIS/ton distributed as follows; the collection cost is 95 NIS/ton, transfer cost 37 NIS/ton and landfilling cost is 33 NIS/ton. The tariff imposed by the JSC on LGU's is 140 NIS/ton for collection, while the tariff imposed on resident differs from one LGU to another. In addition, the total cost recovery percentage is 98%, and people pay a monthly fee of 15 to 17 NIS per household, the same applies regarding electricity bills each month.

3.3.5 Qalqilya JSC

Qlaqilya has 25 LGU's, Qalqilya JSC serves all LGU's, however, one did not join the JSC yet which is Sannerya village, also some Bedouin communities that are located beyond the Israeli separation wall like Alramdin and Abu Farda is not served by the JSC. About 96% of the area is served using FTFP system using 1.1 m3 containers and 360 L bins, the HTH system serves the remaining area using different small bins.The collection frequency ranges between 6 times per week in cities, and 3 times per week in villages. The total collected quantity is 105 tons/day, all of it is sent to Qalqilya TS and then transferred to Zahrat Al-finjan Lf that locates 67 km from the TS.

The cost of managing MSW is 223 NIS/ton distributed as follows; the collection cost is 113 NIS/ton, transfer cost 57 NIS/ton and landfilling cost is 33 NIS/ton. The tariff imposed by the JSC on LGU's is 223 NIS/ton per month for collection, while the tariff imposed on resident differs from one LGU to another. In addition, the total cost recovery percentage is 100%, and people pay a monthly fee of 18 to 30 NIS per household included in the electricity bill.

3.3.6 Salfit JSC

There are 19 LGU's in Salfit, 90% of the area is served using FTFP system using 1.1 m^3 containers, also with small sizes of bins of HTH system in the remaining area. The collection frequency ranges between 7 times per week in cities, and 3 times per week in villages. The total collected quantity is 67 tons/day, badly, all waste is disposed using random dumpsites.

The cost of managing MSW is 87 NIS/ton, it all comes from collection service and there are no charges for transfer or landfilling. The tariff imposed by the JSC on LGU's is 10 NIS/ton per month for collection, while the tariff imposed on resident differs from one LGU to another. In addition, people pay a monthly fee of 12 to 15 NIS per household included in the electricity bill.

3.3.7 Jericho JSC

The JSC in Jericho serves 14 LGU's. The system used is FTFP and it is the main collection system since it covers 99% of Jericho using 1.1 m3 containers and some 4, 8, 10 m^3 containers. The other 1% of the area is served by HTH system using small bins of size 120 L. The frequency of the collection is 6 times per week in cities and 2 times per week in villages. The daily collected quantity is 55 tons, some are sent to Jericho LF while 2.1 tons are sent to Alsyrafi TS owned by Nablus JSC and later sent to Zahrat Al-finjan LF.

The total cost is 186.5 NIS/ton from collection to landfilling; 124 NIS/ton for collection and transfer from collection area to LF, 62.5 NIS/ton for landfilling. Alsayrafi TS has a fee 65 NIS/ton for transferring and landfilling, for Jericho area the total cost for managing MSW is 174 NIS/ton. Jericho municipality is charged by the JSC at a fixed value for collection; 25 NIS/ month for single household and 37 NIS/month for combined households. The cost recovery reaches 100% and the tariff imposed on residents differs according to the LGU, however it ranges from 12 to 20 NIS/ton included in their water or electricity bills.

3.3.8 Ramallah JSC

The number of LGU's in Ramallah is 70, Ramallah's JSC provides services to 60 LGU's. Full collection is provided by the JSC in 17 authorities and Albireh and Betunia with 6 compression vechile. The population is 71,517 with an average of 75 tons daily. There are 35 tons transferred to Zahrat Al-finjan LF and the rest is dumped in random sites. There are 43 authorities that use vehicles of JSC and supervised by JSC to serve 186,614 people. The total collected waste is 160 tons/day, they are collected by LGU's using the vehicles of JSC. Waste is collected around 7 times per week in cities and almost 2 times per week in villages. The total management system costs 195 NIS/ton, 85 NIS for collection and transfer from collection area to LF costs 80 NIS/ton and 30 NIS/ton for landfilling.

3.3.9 NE and SE Jerusalem JSC

In the NE and SE Jerusalem there are around 12 GU's, the JSC there provides services to all LGU members. The FPFT system is used with 1.1 m^3 containers to collect MSW and it covers 100% of the area. MSW is collected 7 times/ week in cities, 3-7 times / week in villages and 2 times / week in Bedouin communities. The total collected waste is 100 tons/day, the waste is transferred to Alabdali TS and then to Almenya LF that locates 25 km away from TS. Another station is Alram, 50 km away from Almenya LF, this TS is not used by the JSC but it is used by Alram municipality, however, it needs rehabilitation.

The MSW management costs 158 NIS/ton; the combined cost is 68 NIS/ton, the transportation cost is 60 NIS/ton while the landfilling cost is 30 NIS/cost. The tariff imposed on the citizens varies according to the location, but the average bill of the family is between 15-20 NIS, included in the water bills.

3.3.10 Bethlehem JSC

Bethlehem area has 36 LGU's, 12 municipalities and 24 villages' councils. The JSC uses FPFT system with 1.1 and 4.4 m^3 containers, 240 and 360 L bins to collect MSW and it covers 90% of the area, while 9% of area is served with HTH system using 240, 120, 60 L bins, the remaining 1% is served with 10 m^3 containers because it is a large industrial area. MSW is collected 7 times/ week in cities, 1-3 times / week in villages. The total collected waste is 127.5 tons/day. All collected waste is transferred to Almenya LF. The total cost of managing MSW is 146 NIS/ton; 116 NIS/ton for collection and transportation, 30 NIS/ton for landfilling. There is a fee of 120 NIS/ton imposed by JSC on the LGU's. It is only for collection since their landfill fee is paid to H& B HC that is responsible for operating the landfill. The tariff of the residents is from 15 to 30 NIS per household, it is added to their electricity bill.

3.3.11 Hebron JSC

The total number of LGU's in Hebron is 55, the JSC serves only 32 of them. Both FTFP and HTH systems are used as follows; the first one covers 70% of area and used 1.1 and 4 m^3 containers. The remaining area is covered by the second system using 240 L bins. The frequency of MSW collection is 7 times/ week in cities, 2-3 times/week in villages and the total collected waste is 370 ton/day. All of the collected MSW is sent to Almenya LF, 50% are sent through one of the TS's in Hebron that are managed by H& B HC.

The total cost of managing MSW is 140 NIS/ton; 80 NIS/ton for collection, 30 NIS/ton for transportation and 30 NIS/ton for landfilling. There is a fee of 120 NIS/ton imposed by JSC on the LGU's, it is only for collection and transportation, while their landfill fee is paid to H& B HC that is responsible for operating the landfill. The tariff of the residents is from 16 to 25 NIS per household per month, it is added to their electricity bill.

Table (3.7) summarizes all the data of JSC's in the West Bank. It shows the targeted and served municipalities in each governorate.

Table (3.7): Data Summary for JSC's.

Governorate	No. of Targeted LGU's	No. of Served LGU's
Jenin	15	13
Tubas	3	3
Nablus	9	6
Tulkarm	31	27
Qlaqilya	25	24
Salfit	24	19
Jericho	3	3
Ramallah	70	60
NE and SE Jerusalem	12	12
Bethlehem	12	10
Hebron	21	13

3.4 MSW Disposal and Cost Systems

After all data of the JSC's was provided in the previous section, it is very important to check how the collected waste is being treated. The importance of understanding how waste is disposed of is to link it to the environmental aspects and see how the Palestinian MSW management system contributes to the environmental issues. The total collected waste as shown in figure (3.3) is 1,672 ton/day in all the 11 JSC's, the three landfills receives 1,383 ton/day of the total waste in the West Bank; 414 tons/day are being sent directly to the LF, 969 tons/ day are sent through TS's. The recycle process in the TS's is rather small, it sums to 13 tons/ day, there is no obvious or serious obligation to recycling techniques and it needs much work to spread this culture. Unfortunately, 276 tons/day are being disposed in random dumpsites, this is a critical issues that should be handled and it is believed that this research is the first step towards the solution.

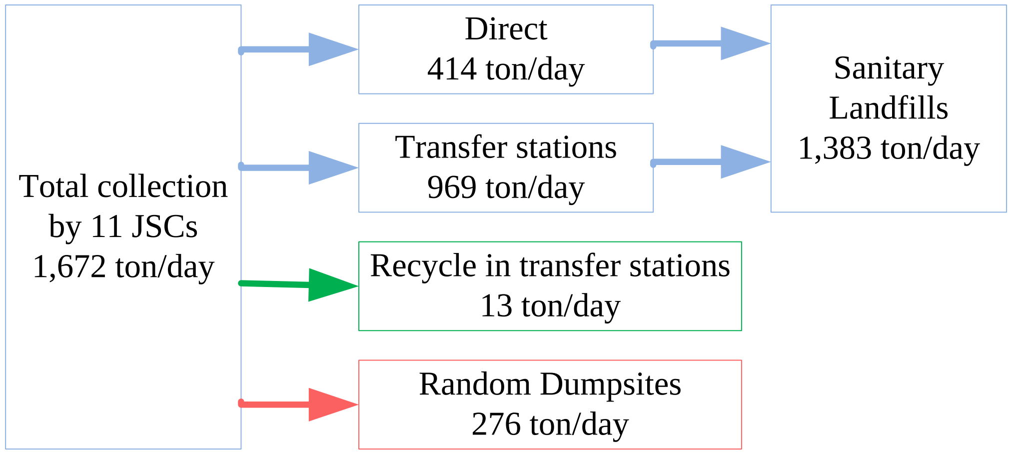

Figure (3.4): JSCs collected quantities waste flow.

Correspondingly, the average cost of managing MSW in the 11 JSC's is 149.6 NIS/ton. It is the same as operation and maintenance costs.

As aforesaid, Qalqilya spends the highest amount, equals to 223 NIS/ton, it is due to the high costs of transportation and landfilling compared to other JSC's. On the other hand, Salfit which has no transportation or landfilling costs spends the least amount, a total of 87 NIS/ ton is spend for collection of MSW only. This research aims at finding alternative solution to solve the struggle of high expenses, random disposal, environmental issues and social considerations.

3.5 Energy Situation

The energy sector can best be described by the scarcity of local resources that are available to be fully utilized, so Palestine is largely dependent on imported resources. In 2017, the electricity consumption reached 4,500 GWh with a peak demand of 930 MW according to PENRA statements (official but unpublished data). Also, the West Bank enjoys almost 24 hours of electricity without disturb although its available energy is 830 MW. Nearly all Palestinians has access to electricity as follows: 93% for rural population and 99% for urban population. However, it is assumed to have a growing consumption with a rate of 3.5% per year, this can be translated to an extra need for 150 GWh yearly according to the World Bank Group report in 2015. As aforesaid, almost 5,461,155 MWh (98%) of all electricity is supplied by the Israeli Electric Company (IEC), 54,229 (1%) MWh is imported from Jordan and 61,480 MWh (1%) is imported from Egypt. Figure (3.5) shows the imported energy in 2017 and its source, as noticed, Palestine is mainly dependent on IEC.

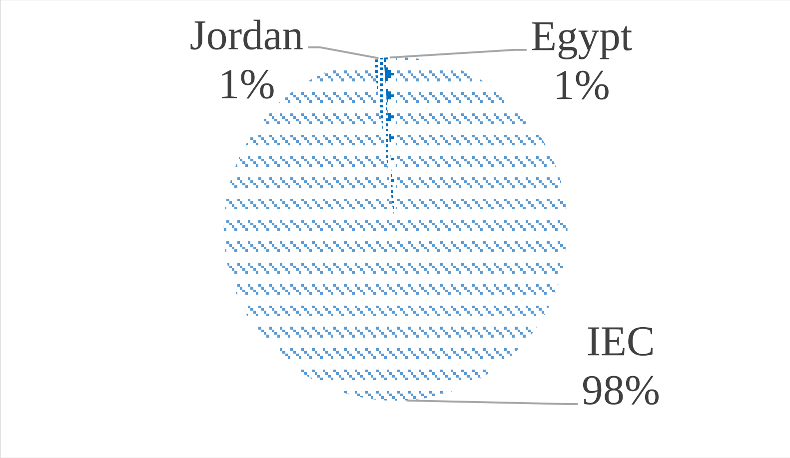

Figure (3.5): Palestine's Imported Energy (MWh) in 2017 (Source: PCBS, 2017).

The IEC owns high voltage grid (161 kV) and connects to the 11, 22, 33 kV Palestinian low and middle grids. The link between two grids is done with hundreds of small connections and it is strengthened by adding new substations; there are 4 new substations that connects the 161 kV with the 33 kV grids, the main purpose is to enable Palestinian Electricity Transmission Limited (PETL) to control all connection points in the West Bank. These substations are in Jenin (which is completed and is now operating), Hebron and Nablus (which are completed but still not operating) and Ramallah. Although the electricity was described being continuous, the Israeli control of the borders and passage points obstruct most of the plans and programs that the National Institutions prepare in order to achieve development in the sector. To understand the institutional operation of energy sector, figure (3.6) illustrates the process. The Palestinian Energy and Natural Resources Authority (PENRA) is the policy maker. It sets the action plans and rules related to energy sector, the main observer and regulator is the Palestinian Electricity Regulation Council (PERC) it sets prices and regulations, the PETL owns all transmission points, purchase and wholesale and operates grid while the distribution is done by several Distribution Companies (DISCO's): Jerusalem District Electricity Company (JDECO), Hebron Electricity Power Company (HEPCO), Southern Electricity Company (SELCO), Northern Electricity Distribution Company (NEDCO), and Tubas Electricity Distribution Cooperation (TEDCO).

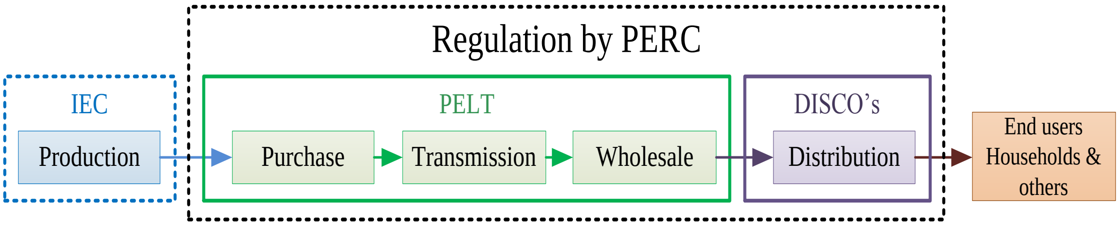

Figure (3.6): Energy Sector Chain.

According to the annual report of PERC in 2011, the main distribution companies in the West Bank are:

- *NEDCO*: was established in 2008 and started working in 2010, it serves almost 80,000 consumers, Nablus, Jenin, Salfit, Qalqilya, Tubas. The main source of power for the company has six connection points (medium voltage) and a capacity of 108 MVA from IEC.

- *SELCO*: established in 1998 and operated in 2004. The total number of consumers reach 13,000 in Hebron except for those who benefit from HEPCO. As NEDCO, the company has three medium connection points and a capacity of 13MVA from IEC.

- *HEPCO*: was established in 2000 and started its actual work in 2005 to serve consumers of Hebron and Halhul. It reaches to 35,000 consumers.

And it has five connection points, with a capacity of 89 MVA from IEC.

- *JDECO*: was originally in 1914 by Ottoman's laws. Total consumers are 215,000 consumers in Jerusalem, Ramallah, Bethlehem, and Jericho. It's the largest between DISCO's as it has two sources for power; one of 37 connection points and a capacity of 480 MVA from IEC, and the other of a single connection point with a capacity of 20 MVA from Jordan.

- *TEDCO*: Established in Tubas by the municipalities and it serves Tubas area and some areas of Jenin.

Although a large number of consumers are connected to one of the DISCO's companies but still some citizens are served from 305 municipalities in cities and village councils and not bounded to any distribution company. Figure (3.7) shows the distribution of consumers in the West Bank.

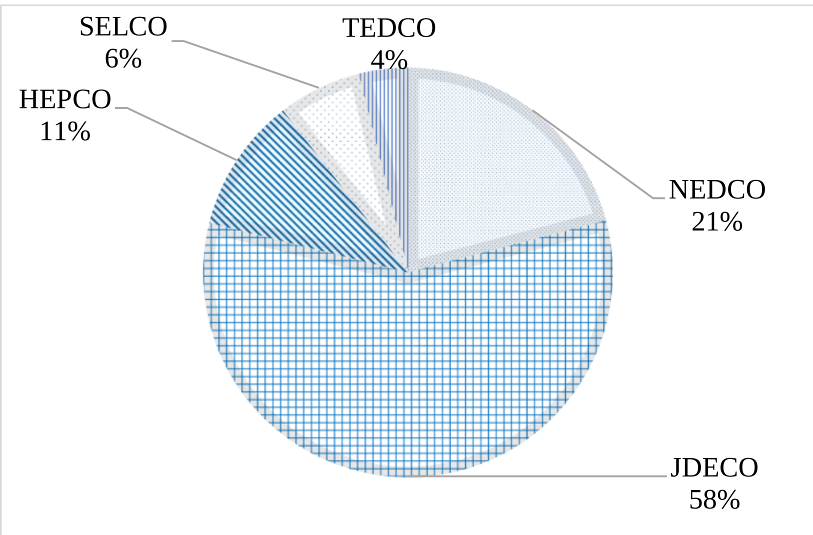

Figure (3.7): Percentage of Consumers in DISCO's (Source: PERC, 2018).

Regarding the electrical losses in the companies mentioned above, the average losses reach about 26% which equals 688.4 GWh in 2011 as stated in the reports of PERC.

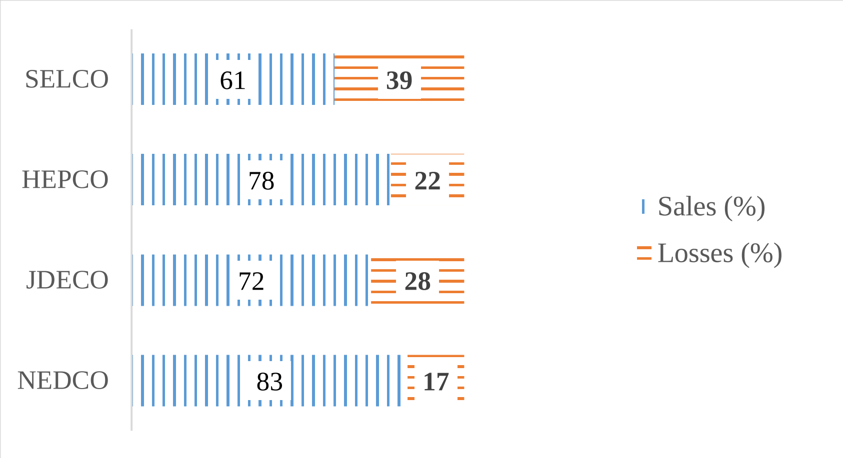

Figure (3.8): Percentage of Sales and Losses in DISCO's.

As for electricity tariff in Palestine the situation is as follows, DISCO's purchase power from IEC, the IEC charges a them with the same tariff applied to its end customers in Israel. Later, as the Palestinian Authority decided to have a single buyer and after the establishment of PETL, now PETL is in charge of power purchasing from all sources including IEC. As mentioned in the NEEAP, there are continuous negotiations between PETL and IEC to have a commercial agreement that will have lower electricity tariff for the imported power through the new 4 substations in Jenin, Nablus, Hebron and Ramallah. These substations will be high voltage and so the connections will be with the high voltage grid of IEC. The electricity tariff differs according to the sector, sectors are classified as: residential, commercial, industrial, water pumping, agriculture, street lighting and temporary services and all are illustrated in table (3. 8).

Table (3. 8): Palestinian end users electricity tariff by sector.

Sector	Price (NIS*/kWh)
Residential	0.5234 - 0.5487
Commercial	0.5794 - 0.5899
Industrial	0.4560 - 0.4954
Water Pumping	0.5359
Agriculture	0.4750
Street Lighting	0.4735
Temporary Services	0.7616

- **Each New Israeli Shekel (NIS) equals 0.28 US $.**

Since its establishment in 1994, PA devoted significant resources to develop the sector. Difficult political situation between PA and Israeli limited the development of the sector infrastructure, regulations, and policies. Furthermore, Israel controls the main energy resources and systems in the West Bank, which is the area of the land that the Palestinians want for a state with East Jerusalem as its capital. This makes it complicated for Palestine to produce any sort of electricity or energy and to have it imported from other countries in the region. In the same manner, Israel restricts the flexibility and diversity of energy resources. In addition, the costs of electricity and other sources of energy like fossil fuels are higher than any country in the region. When it is compared to local average income, it is worth to mention here that Paris Economic Protocol between Palestine and Israel asserts that the difference in the final price of gasoline and diesel fuels to consumers in Palestine and in Israel must not exceed 15% of the official final consumer price in Israel, while the Israeli average income is three to four times higher than the Palestinian average income. Finally, there are many other factors that adversely add up to this situation. For example, Palestine lacks a clear energy policy and properly functioning energy institutions. Moreover, the political situation creates an uncertain future for investments, which all in all makes Palestine a country that is more difficult than the rest of the countries in the Middle East when it comes to energy planning. Palestine targets at substantially increasing the production of renewable energy towards130 MW in 2020 and 500 MW in area's A, B and C together in 2030. Also here PV is expected to deliver a substantial 80% of these targets whereas 10% is to be covered by wind and 10% by biomass and biogas. The latter percentage is the category where Waste-to-Energy fits in, it represents 10-15 MW to be delivered in 2020. Considering an overview of the levelized costs of electricity in the West Bank, the dominant feed in of Israeli imported electricity is gradually increasing to a price of 10 cents per kWh, if any new feed-in alternative is introduces it will have to match this price at least. The other alternatives that will be utilized for energy generation must be able to present a levelized costs of electricity that is not greater that 7 or 8 cents, unless the Palestinian governmental policies asserts or accepts higher price for electricity generation from waste, for example.

Chapter Four

Methodology and Assessment Approach

Chapter Four
Methodology and Assessment Approach

4.1 Research Methodology

This research follows an exploratory approach since it is the first of its kind in Palestine. To the best of the researcher's knowledge, there are no previous studies about municipal waste to energy technologies in Palestine, and none have studied the potential of establishing and utilizing any of these technologies. Also, this study will intend on finding and exploring new data regarding the energy situation, prices and capacity in Palestine, moreover, collect and analyze the regulations of energy and electricity, strategies to implement renewable energy solutions. In the same manner, the researcher intends to study and analyze the regulations and laws related to waste management, energy generation and environmental protection. The research will be based on both qualitative and quantitative data collection and analysis. The qualitative approach will include semi-structured interviews with key persons in the fields of waste, energy and environment mainly in the Palestinian Authorities of Energy, Local Government, Environment, and the legal bodies that manage and regulate energy and waste sectors like the Joint Services Councils, Palestinian Electricity Regulation Council, Palestinian Electricity Transmission Company. The quantitative approach will take place in analyzing numeric data that contains the MSW generation in the main governorates, energy potential in each location, environmental analysis using suitable mathematical models that were previously adapted in literature and economic analysis as explained in the following sections. In order to deliver the expected outcomes of the research, the methodology is illustrated in figure (4.1).

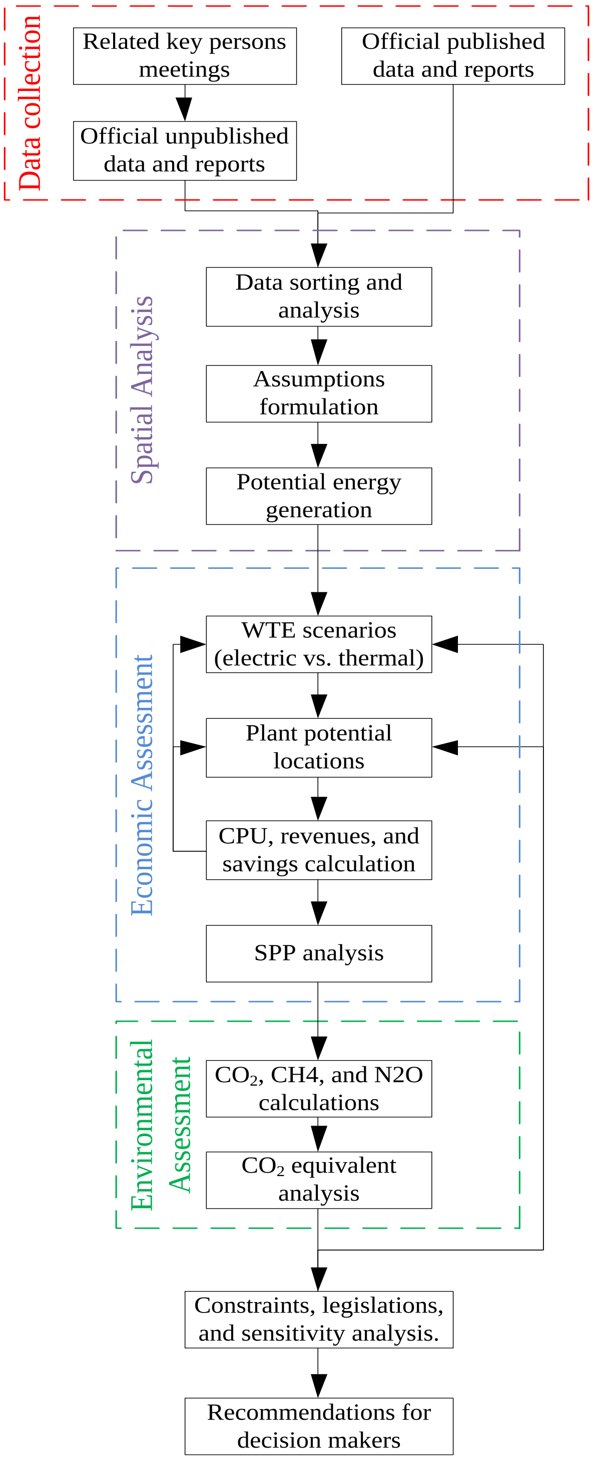

Figure (4.1): Adopted research methodology.

4.2 Data Collection

For the purpose of data collection, several semi structured interviews with a previously determined questions and scope were held with key individuals and officers who work in the related governmental bodies regarding energy, environment, and MSW management in Palestine. These include: PENRA, JSC’s, and EQA, MOLG, some municipalities and PETL. In addition to that, all national reports, surveys, policies and strategies regarding waste generation and disposal, electricity demand and capacity, and environment protection initiatives were reviewed. The published data from Palestinian Central Bureau of Statistics (PCBS), MOLG and JICA reports were the main sources of data that forms the starting point to understand the big picture in Palestine. International scientific publications and related reports were also reviewed at this stage to extract common related data and analysis methods.

4.3 Analysis Criteria

The analysis performed in this research includes quantitative approach. The quantitative approach will be used to calculate the technical, economic and environmental dimensions for each scenario using suitable equations.

The data collected regarding MSW generation rates and electric supply in the West Bank, spatial analysis was performed to conduct the technical analysis. The West Bank was divided according to its governorates since MSW generation and disposal are categorized on this basis. Potential available energy was estimated using equations (4.1- 4.5) including available quantities of MSW (Q_{MSW}), its collection and transfer weighted costs (CT_{cost}) in \$/ton, MSW composition and its energy content (En) in MJ/kg, conversion efficiency (η_{ele} and η_{therm}) for electricity and thermal generation efficiency, respectively. Two energy cases calculation were considered in the analyses, which are generating electric energy (MWh) and providing thermal energy (equivalent L diesel).

Regarding economic potential of WtE plant, it depends on many technical and cost parameters, the economic analysis considers the mentioned cases and assessed two different locations: Tulkarm and Jenin. As a result three different scenarios were suggested: small waste to electricity plant in Tulkarm transfer station, large waste to electricity plant in Zahrat Al-Finjan landfill in Jenin, and waste to heat plant in the industrial zone in Jenin. The analysis includes produced energy unit cost (CPU_{ele} and CPU_{therm} for electricity and thermal energy unit cost in \$/kWh and \$/L diesel equivalent, respectively), and produced energy unit selling price (P_{ele} and P_{therm} for electricity and thermal generated energy, respectively). In order to perform a rationale techno-economic assessment, equations (4.6) to (4.11) are used.

$$Q_{MSW} = \sum_{governorate=1}^{G} \left(MSW_{governorate}\right) \tag{4.1}$$

$$\mathrm{CT_{cost}} = \sum_{\mathrm{governorate=1}}^{\mathrm{G}} (\mathrm{MSW_{governorate}} \times \mathrm{CT_{governorate}})/\mathrm{Q_{MSW}} \tag{4.2}$$

$$En = \sum_{composition=1}^{c} En_{composition} \times pecentage_{composition} \quad (4.3)$$

$$E_{therm} = \frac{Q_{MSW} \times \frac{1000kg}{ton} \times En \times \eta_{therm} \times Ext_{\ rate}}{36} \quad (4.4)$$

$$E_{ele} = \frac{Q_{MSW} \times \frac{1000kg}{ton} \times En \times \eta_{ele} \times Ext_{\ rate}}{3.6} \quad (4.5)$$

$$CPU_{therm} = \frac{Q_{MSW} \times CT_{cost} \times (1 + OM_{ratio})}{E_{therm}} \quad (4.6)$$

$$CPU_{ele} = \frac{Q_{MSW} \times CT_{cost} \times (1 + OM_{ratio})}{E_{ele}} \quad (4.7)$$

$$Rev_{therm} = E_{therm} \times P_{therm} \quad (4.8)$$

$$Rev_{ele} = E_{ele} \times P_{ele} \quad (4.9)$$

$$Saving_{ele} = (P_{ele} - CPU_{ele}) \times E_{ele} \quad (4.10)$$

$$SPP = \frac{Investment}{Saving} \quad (4.11)$$

Where G represents the total number of governorates delivering its MSW to the WtE plant, MSW governorate is the daily generated waste from each governorate (ton/day), CT governorate is the collection and transfer cost of MSW for specific governorate ($/ton), composition represents MSW composition material, c is the number of composition material, percentage composition is the percentage of each composition material, E_{therm} and E_{ele} are the daily available thermal and electric energy in liter diesel equivalent and kWh, respectively. Extrate is the energy content in MSW extraction rate in percentage, reason for using this number is that MSW will not be sorted before its incineration, and due to unavoidable incomplete combustion, a proportion of MSW energy will be extracted only. OM ratio is the expected percentage of the cost that will be spent on WtE plant running administrative and maintenance costs, including labor wages and equipment costs, Rev_{therm} and Rev_{ele} are the daily revenues ($) from selling thermal and electric energy, respectively. Finally, $saving_{ele}$ is the estimated daily savings from generating electricity for the WtE plant.

These alternatives were compared in terms of the CPU and estimated savings ($) that would be achieved, the calculations took into consideration the local prices in the West Bank. The last steps included reviewing all legislations and constraints of the study, then suggesting suitable recommendations for decision makers. Also, these scenarios generated which focus on modifying current Palestinian energy generation law. The summary section included in the results and discussion chapter will give the gist of all the analysis.

The environmental analysis was conducted using Tier 1 method as stated by the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, this part was focused on determining the environmental impact represented by the CO_2eq indicator. First, the emissions of CO_2, CH_4 and NO_2 were calculated using equations (4.12- 4.15) as explained in the literature of IPCC method, then each of these gases were converted to equivalent CO_2 emissions using the suitable factor, the first CO_2 emissions amount calculated from equation (4.12) depend on waste type to be incinerated, the factors of the equations were assumed according to the IPCC. Then, the methane emissions were calculated using equation (4.13), the amount of methane emission rates were converted to CO_2eq using a GWP factor of 21 as stated by the IPCC instructions. In the same way, using equation (4.13) the Nitrous Oxides emissions were calculated and converted to CO_2eq using a GWP factor of 310 based on the same instructions. Last but not least, the total CO_2eq emissions from a WtE facility includes the sum of the CO_2 emissions, methane emissions, and N_2O emissions.

Another important aspect of the analysis to understand the superiority of the incineration plant suggested in this research was to compare it to the current practices of landfilling in Palestine. As aforesaid, there are three main landfills in Palestine besides other random sites for MSW disposal. The IPCC has provided two methods but the researcher chose to follow their default method, which is based on estimating the landfill gas (CH_4) that is released from landfills based on the theoretical gas yield, and assumes that CH_4 is released the same year the waste is disposed. This method has the advantage of producing reliable estimates of the annual methane emissions if the total amount of waste and its composition do not change over time. Equations (4.14) and (4.15) were applied to calculate methane emissions (kg CH_4/ kg MSW /year). Taking into consideration the fact that the Palestinian landfills generate CH_4 but do not recover it due to technical problems, which means that all generated CH_4 is emitted to the environment. The final comparison was made between the three cases, the suggested emissions from incinerator, the emissions from landfill and the emissions caused by the electricity generation means currently available in Palestine which is basically imported and generated using coal, natural gas, and small proportion or renewables and produces

The environmental assessment of WtE technology that would be used is an essential parameter of decision making. There have been many studies that compare incineration and landfilling performance in terms of their environmental contribution, mainly emissions generation. A previous research used LCA methodology to evaluate the performance of incineration and landfilling technologies, it assumed the MSW that is ready for final disposal. The calculations considered emissions from incineration plant, transport of solid residues, emissions from landfilling and the avoided emissions that would be made if WtE plant replaced the power and thermal stations (Assamoi and Lawryshyn, 2012). Results assert on the benefit of using incineration to manage MSW, from an environmental point of view, incineration produces more electricity when compared to landfilling production, which means an observably greater environmental substitute. Also, incineration takes the advantage of plastic presence in MSW, while plastic has high energy content, it reduces the quantity of waste to be landfilled at the end of the day.

To better understand how incineration gives a share in the environment, Rendek et al., (2006) mentioned that the main products of incineration are solid residues, bottom ash, fly ash and gaseous products that include almost 12% CO_2. CO_2 emissions from WtE facilities can be estimated using the Tier 1 method, as described in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for

National Greenhouse Gas Inventories, the CO_2 emissions are calculated on the basis of waste type, using equation (4.12).

$$CO_2 Emissions = MSW.\sum(WF_i.dm_i.CF_i.FCF_i.OF_i)\frac{44}{22} \quad (4.12)$$

Where CO_2 Emissions is in (Gg/year), MSW is in (Gg/year), WFi is the fraction of waste type/material of component i in the MSW (as wet weight incinerated), dmi is the dry matter content in the component i of the MSW incinerated, CFi is the fraction of carbon in the dry matter (that is, carbon content) of component i, FCFi is the fraction of fossil carbon in the total carbon of component i, OFi is the oxidation factor (fraction), and i is the component of MSW incinerated (for example, paper, textiles, food waste, wood, yard waste, disposable diapers, rubber and leather, plastic, metal, glass, and other inert waste). Values of these factors are obtained from Table (2.5).

Table (4.1): MSW incineration CO_2 emissions model estimating factors (IPCC, 2006).

Composition	dmj	CFj	FCFj	OFj
Paper & paper board	0.90	0.46	0.01	1.00
Food	0.80	0.50	0.20	1.00
Wood	0.40	0.38	-	1.00
Yard and garden	0.40	0.49	-	1.00
Plastics	1.00	0.75	1.0	1.00
Metals	1.00	-	-	1.00
Glass	1.00	-	-	1.00
Other inert waste	0.90	0.03	1.00	1.00
Non-combustible organics	0.85	0.50	0.50	1.00

Methane (CH_4) and Nitrous Oxides emissions (N_2O) are also essential to be calculated when assessing MSW incineration. To do so, equation (4.13) is applied for each one individually.

$$CH_4\ (or\ N_2O) = \sum(IW_j . EF_j) . 10^{-6} \qquad (4.13)$$

Where emissions are in (Gg/yr), IWj is the amount of solid waste of type j incinerated in (Gg/yr), EFj is the aggregate methane (or Nitrous Oxides) emission factor (0.188 kg CH_4 / ton of waste for methane and 0.068 kg of N_2O / ton of waste for nitrous oxides), and j is the category or type of waste incinerated: MSW, Hazardous Waste (HW), Industrial Waste, and Sewage Sludge. The methane emission rates were converted to CO_2e using a GWP factor of 21 (IPCC, 1996), similarly, the N_2O emissions are converted to 21.08 kg CO_2e/ton of waste, demonstrating that N_2O has a much higher impact than methane. Finally, the total CO_2eq emissions from a WtE facility include the sum of the CO_2 emissions, methane emissions, and N_2O emissions.

To compare incineration emissions with current landfilling methods, landfill gas (LFG) which is methane should be estimated. LFG can be captured and used for energy generation or flared on-site to reduce GHG emissions. The LFG collection is technically-feasible starting from some years after landfill opening and can continue after landfill closing, typically 25 years (Scarlat et al., 2015).

The IPCC has provided two methods for estimating CH_4 emissions from solid waste disposal. The default method which is a mass balance method that estimates the amount of LFG emitted from landfills based on the theoretical gas yield and assumes that CH_4 is released the year the waste is disposed. It produces reliable estimates of the yearly emissions if the total amount of waste and its composition do not change over time. Also, it introduced the first order decay model, which provides estimates of the actual annual CH_4 emissions, but requires long time-series data over the lifetime of the landfill site (20–25 years). The default method has been considered more appropriate for this research. The CH_4 generation from waste degradation in landfills was then calculated using equations (4.14) and (4.15), respectively.

$$Q = W.DOC.DOC_f.MFC.F.S \quad (4.14)$$

$$DOC = 0.4A + 0.17B + 0.15C + 0.3D \quad (4.15)$$

Where Q is the methane generation (kg CH_4/kg waste/year), W is the waste amount deposited per year (kg/year), MCF is the methane Correction Factor (dimensionless), DOC is the degradable organic carbon in waste under aerobic conditions (dimensionless), DOC_f is the fraction of DOC decomposing under anaerobic conditions (dimensionless), F is the fraction of CH_4 in the landfill gas (dimensionless), S (equals 16/12) is the stoichiometric factor to convert carbon into CH_4 (dimensionless), A is the share of carbon content in paper and textiles in waste (%), B is the share of carbon content in garden and park waste (%), C is the share of carbon content in food waste (%), and D is the share of carbon content in wood and straw waste (%). The methane correction factor (MCF) accounts for the fact that landfills actually produce less CH_4 than theoretically possible, because a fraction of waste decomposes aerobically in the top layers. Depending on the type of landfill, this factor ranges between 0.4 for unmanaged, shallow sites to 1.0 for managed sites.

Since not all the organic matter can decompose, the DOC considers the fraction of organic carbon that is accessible to biochemical decomposition, which depends on the composition of waste.

In a real landfill, only a fraction of DOC actually decomposes under anaerobic conditions (DOC_f) and is converted to CH_4 and CO_2. In this study a default value of DOC_f of 0.5 as recommended by IPCC on the basis of several experimental studies, is considered. LFG consists mainly of CH_4 and CO_2. The CH_4 fraction (F) in the landfill gas can vary between 0.4 and 0.6, depending on several factors including again waste composition. In this study, the default value in the IPCC Guidelines of 0.5 is applied. Finally, a share of CH_4 generated from landfill is oxidized in the top layers of landfills and an Oxidation Factor (OX) of 0.1 was considered here, as recommended by the IPCC to estimate the avoided emissions of CH_4 into the atmosphere. In practice, the various landfill gas collection systems cannot recover the whole amount of methane. The efficiency of landfill gas recovery can vary between 40% and 90% with an average of 75%. EPA has estimated that landfill gas collection efficiency varies between 67% and 90% depending on the type of landfill cover and the type of LFG collection system employed. In this study, no LFG recovery was assumed to simulate the real situation. Applying equations (4.14) and (4.15) to the Palestinian context result into 0.1581 kg CH_4 / kg MSW / year. It is worth to mention here that Zahrat Al-Finjan landfill was originally designed to produce and recover CH_4 for energy generation. Unfortunately, the project faced technical complications at its early operating phases; CH_4 is generated but never recovered. This means that all generated CH_4 is emitted to the environment. To implement rationale environmental assessment, CO_2 equivalent emissions from current electricity source must be obtained. As mentioned before, 89% of electricity is imported directly from Israel, where it generates electricity using coal, natural gas, and small proportion or renewables. According the Organization for Economic Co-operation and Development (OECD) data of 2016, Israel produces 0.767 kg of CO_2 / kWh electricity generated. This method was adapted in this research to compare the incineration technology to landfilling emissions and to the current electricity imports emissions in terms of CO_2 eq.

Further analysis was made for the purpose of assessing the feasibility of the proposed WtE plant. Since this is the first research of its kind in Palestine, there were no previous models developed to calculate its feasibility. That is why previous literature were adopted. The researchers developed ten scenarios assuming different values of MARR, tipping fees and feed in tariff. In each of them, the LCOE, annual net value and net present value were calculated and compared. This process aims to generate the best scenario to encourage the investment in such a project. However, the investment and operational costs of the WtE plant was unknown and could not be calculated preciously since there is no previous experiences in WtE technologies in Palestine. The most relative calculations were made in Iran, Haghi, (2012) developed equations based on the practical experiences of WtE incineration plants in Iran. These equations are based on the capacity of the plant, where it is the only variable that determines the value of investment and maintenance costs as in equations (4.16) and (4.17), respectively.

$$Investment = 2.3507 Capacity^{0.7753} \quad (4.16)$$

$$Annual\ operation\ and\ maintenance = 0.0744 Capacity^{0.8594} \quad (4.17)$$

The capacity is in the unit of metric ton per year, and investment and operation and maintenance costs are represented by million \$. The capacity of the proposed WtE plant in Tulkarm is 527 ton/day, which equals 478 metric ton/day. One more influential economic indicator that helps in determining the plant feasibility is the LCOE, in which the total initial investment and operation and maintenance costs are calculated on an annual basis (\$/year). Then, divided by estimated annual electricity output (kWh/year). LCOE was calculated using equation (4.18).

$$LCOE = \frac{\sum_{t=1}^{n} \frac{Investment_t + Fuel_t + O\&M_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Electricity_t}{(1+i)^t}} \quad (4.18)$$

Where (t) is the year number, investment in the annual worth of initial investment over the project life time (n) in the units of \$/year, fuel is the annual fuel cost in \$/year, O&M is the annual operation and maintenance costs in \$/year, (i) is the minimum attractive rate of return, and electricity is the annual generated electricity in kWh/year.

Different economic scenarios were generated. In each one the investment (\$) was fixed. Also, the capacity of the plant fixed and project life time is 20 years. Each scenario considers changeable values of MARR, tipping fees of MSW and the selling price of the generated electricity. And in each scenario the LCOE ($/kWh), net annual value ($/year) and net present value (million $) were calculated.

Chapter Five

Results and Discussion

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Results and Discussion

5.1 Spatial Analysis

According to the collected data from MOLG reports and publications in 2019 viewed earlier, waste generation in Palestine will reach 3,952 ton/day (1,442,480 ton/year), from which, the West Bank generates 2,622 ton/day or (957,030 ton/year). With an estimated annual growth equals to 4% as explained before, the annual generation is estimated to reach 3,190 ton/day by the year 2024. The reason behind focusing on the year 2024 specifically is that on average 5 years are required in order to establish a WtE plant and run it successfully as mentioned in the literature chapter. Figure (5.1) shows the estimated annual MSW growth in the West Bank (ton/year) between 2019 and 2029. Going back to the current landfills operational conditions, where Zahrat Al-finjan and Jericho landfills are almost and already overloaded, respectively. It is obvious that the West Bank governorates will face a serious environmental and health problems in the coming few years. MOLG studies claim that there is no possibility to expand or update the current landfills, along with the social constraints by the local citizens in the near residential areas. Moreover, the complicated political situation between the PA and Israeli government has lowered this national challenge priority. Thus, building new landfills in area C, which is the most suitable area due to its lower population density, will face many Israeli obstacles.

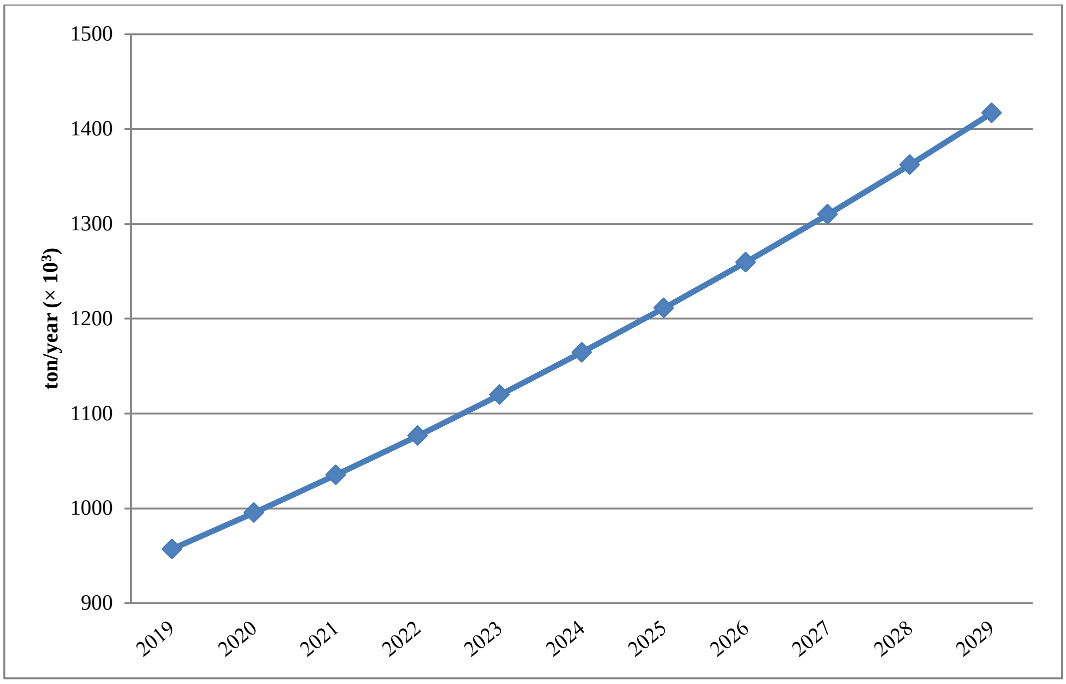


Figure (5.1): Estimated annual MSW generation 2019 – 2029.

Based on the Palestinian average compositions and calorific value of MSW fraction presented in Figure (3.2) and Table (3.1), weighted average has been used to calculate the energy content in MSW in Palestine, it gives a total of 11.16 MJ available in each kg of MSW. This calorific value is critical, especially when compared to other fossil fuels such as diesel fuel that contains almost 36 MJ/L. in electric energy terms, where each kWh contains 3.6 MJ, it means that diesel fuel contains 10 kWh/L and Palestinian MSW, especially in the West Bank area, contains 3.1 kWh/kg MSW. Of course, these values did not take into consideration any conversion efficiency when producing electricity from both sources.

For the sake of clarity, the researcher analyzed waste generation, citizens' population, and current dumping sites spatially. Figure (5.2) shows the spatial analysis that describes briefly the current MSW descriptive data. It can be seen that Ramallah governorate transfers waste a long distance to its dumping site which is Zahrat Al-Finjan. Israeli occupation is the main reason for that. Because Israel did not allow the planned dumping site near Ramallah to operate till now, and based on MOLG expectations and previous experience with such issues, the situation is expected to be the same for the coming years. It can be noticed also that Zahrat Al-finjan operates on approximately 88% utilization of its maximum capacity, and there is no possibility to expand its capacity due to local citizens' resistance and other technical and land availability constraints, this situation puts a lot of social pressure on the PA. Moreover, although Salfit governorate is located within the middle northern area of the West Bank which makes it close to Zahrat Al-Finjan and Jericho dumping sites, it does not transfer its waste to any dumping site; instead, its local generated wastes are disposed illegally and randomly in an unhealthy and risky manner. Two main reasons caused this situation, the first one is the fact that most of Salfit governorate area is categorized as C region under Oslo accord, thus, PA has no power to prohibit random dumping sites behavior, and it is very clear that the Israeli government which is responsible for running this type of area does not give enough attention to its local health and environmental problems, they only focus on their own security issues. While the second reason is due to the high expenses that Salfit municipality cannot handle. At least, the second reason can be eliminated and reduce its effect by supporting Salfit municipality with enough technical and financial resources to handle its MSW management system expenses. Both the initial cost such as fleet updating, municipal waste containers updating, and employees training, and operational costs such as employees' salaries, trucks fuel expenses, and equipment maintenance costs.

Spatial analysis shows that the southern area of the West Bank will not suffer from dumping site overloading problems, Al-Menya landfill utilization is only 9% until now of its planned capacity, which means that it will serve the southern governorates for a relatively long time. However, it should be kept in mind that it is still under building, thus the 9% utilization is from its planned capacity, the project needs at least another five to eight years to finish. But when it comes to the middle and northern governorates, both available sites are either overloaded, or will be soon, with almost no possibility to build a new dumping site due to land A scarcity, low PA power in areas B and C, and political situation complexity between PA and Israeli government, explicitly when taking into consideration the existence of Israeli settlements in the West bank area, which is a very sensitive issue for both sides. According to the MOLG declarations, every time the PA tried to get permission for building a new site, the Israeli government agreement was conditional to serve its settlements side to side with the Palestinian local communities, which is not acceptable for PA since it asks for removing all settlements and consider it illegal according to the international law. In this context, it is worth to mention that adopting another solution which is transferring proportion of the middle and northern governorates MSW to Al-Menya site is impractical due to the long distance, Israeli checkpoints, and weak transportation connecting infrastructure, system running costs will be unaffordable for such a scenario.

Spatial analysis also included all West Bank transfer stations, which plays a vital role in controlling transferred quantities, and so, it keeps transfer costs relatively within the PA abilities by transferring bulk quantities instead of small distributed quantities. Transfer stations will become much more important if sorting and recycling activities has been taken into consideration. In addition to cost differences between governorates, it is also clear that there is a difference in average MSW generation rate per capita between governorates. The West Bank average for the year 2019 reached 0.91 kg / capita / day.

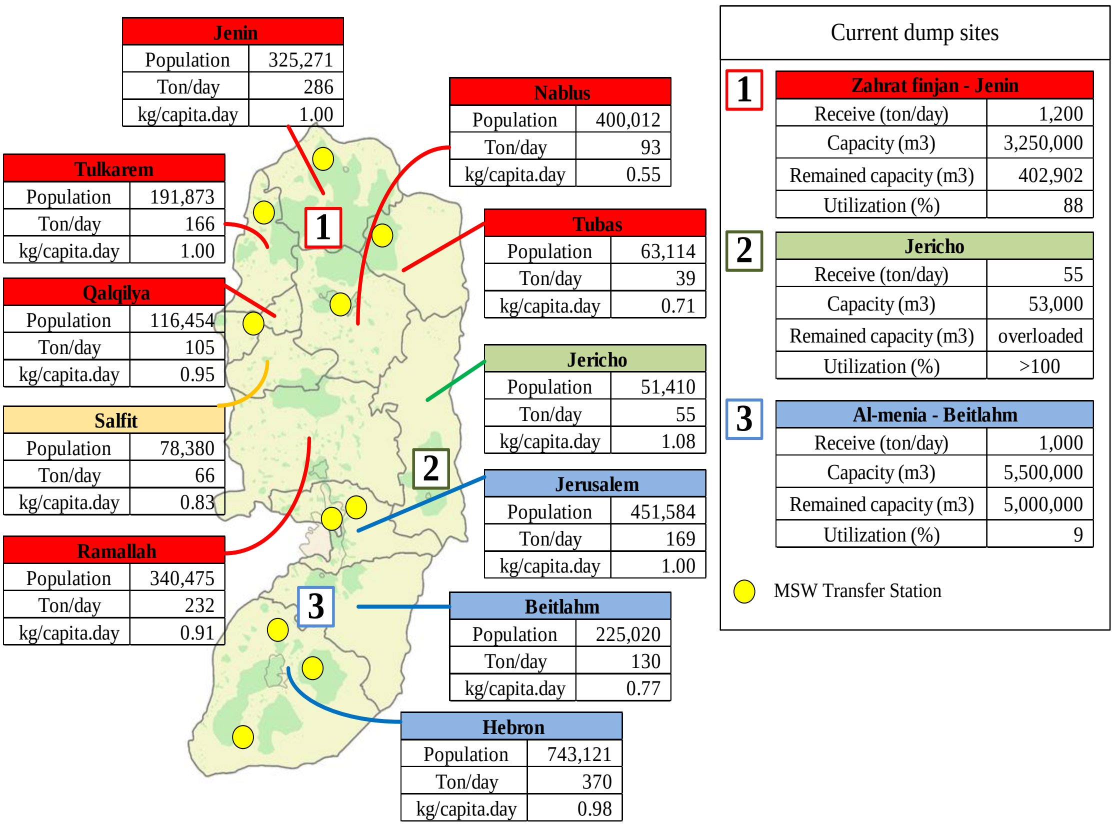


Figure (5.2): MSW descriptive data governorates spatial analysis.

The cost analysis of the current West Bank MSW management system shows that collection, transfer, and landfilling are the main terms. Collection is the responsibility of municipalities in the main cities, LGUs in rural areas and villages, and UNRWA in refugee camps. Collected MSW are then moved to transfer stations or directly to the dumping site. When transferred to dumping sites, the tipping fees must be paid per ton of MSW. Figure (5.3) shows the system cost analysis for each governorate. It can be noticed that collection and transfer are the most dominant when compared to tipping fees. However, collection and transfer costs are almost constant and will be the same even when operating a WtE plant. It represents the costs of labors, drivers, equipment maintenance, and diesel fuel related to MSW collection and transfer from one geographic location to another. Without upgrading the current transfer equipment, there will be no difference. The only difference in costs items when operating a WtE plant is the tipping fees which can be saved. Due to higher proportion related to collection and transfer costs, a significant savings can be achieved by upgrading municipalities and JSC’s MSW management systems. Especially when taking into consideration that collection and transfer costs are not constant between governorates, which means that the financial effect of current fleet situation and employees abilities significantly affects total cost. This could be essential if the WtE plant is not attractively feasible enough to support its economic situation. Discussing the current situation of the municipalities and JSC’s MSW management systems is out of the scope of this research.

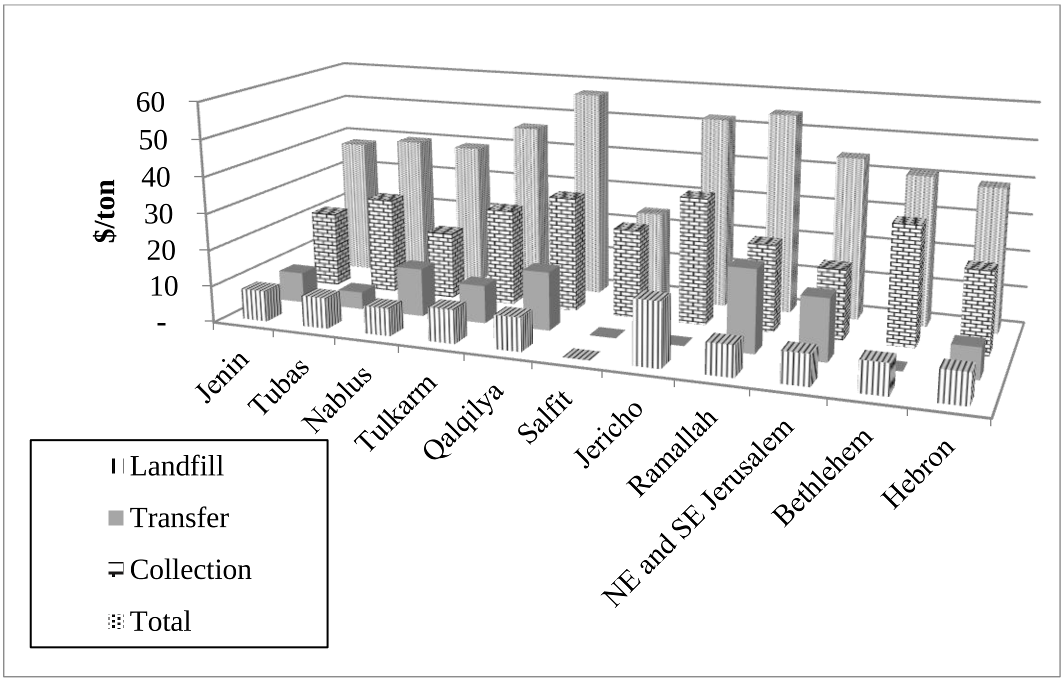


Figure (5.3): West Bank MSW management cost analysis.

Another challenge in the current MSW management system that puts pressure on PA to take a decision regarding building a WtE plant is the generated quantities transfer rate. It means the proportion of MSW collected, transferred, and disposed in a healthy manner in one of the three available landfills. WtE plant is a sustainable solution instead of the random unhealthy landfills and currently-overloaded and almost fully-utilized official landfills. The MSW generated quantities are more than the transferred and disposed in the dumping sites, which gives decision makers flexibility in sizing the WtE plant capacity to reach the most sustainable choice. Figure (5.4) illustrates the current situation of each governorate from generation and transferred quantities point of view, and the travelled distance from the transfer station or municipality centers to the final destination disposal dumping site. It is obvious from figure (5.4) that Jenin, Bethlehem, and Salfit governorates do not run any distance to transfer their wastes, this is because there landfills are within their borders, for Salfit, it does not transfer its generated MSW due to PA low control and weak financial abilities which were mentioned before.

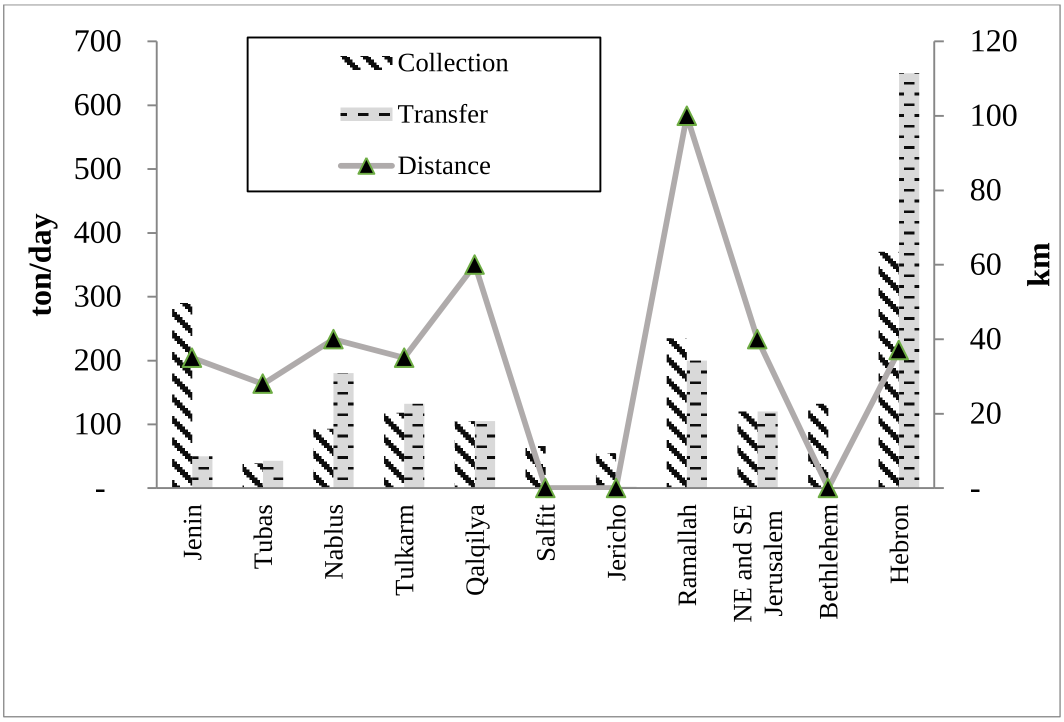


Figure (5.4): Current MSW generation versus transfer quantities and distance travelled to final destination.

To fully study and understand the potential of establishing a WtE plant in the West Bank, three scenarios where considered. Two of them are about generating electricity from MSW, and inject it into the local electric grid to support the Palestinian nearby electric load, while the third scenario is about generating thermal energy by burring MSW in distributed incinerators for industrial use purposes. This scenario requires a collection of industrial plants located near each other and requires a significant thermal load, in other words, an industrial zone. The three scenarios are described with explanation of their expected pros and cons in Table (5.1).

It can be noticed from the analysis, that building the WtE in Tulkarm transfer station is the most rational where initial investment is lower, no social resistance will be faced, and there is already an electric power shortage in Tulkarm. According to Tulkarm municipality the shortage is estimated at 10 MW maximum. It now searches for alternative energy sources to support its grid connections and cover the increasing demand, the fact that Tulkarm suffers from electricity shortage especially in summer where most electricity is used for cooling purposes as Tulkarm has a very high hot and humid weather in summer. In spite of this, this scenario disadvantages are similar to the other electricity generation scenarios in Jenin, which are the absence of knowledge and low power generation efficiency, moreover, such technologies and Rankine cycle based power plants needs a source of water to compensate losse, which is available in Tulkarm for the proposed plant size, but not in Jenin. It can be seen that Zahrat Al-Finjan scenarios face many challenges due to the fact that local communities near it protested many times against environmental, economic, health, and social impacts of it.

For the waste to thermal energy scenario, West Bank has larger potential demand for electricity than its potential demand for thermal energy, where industrial sector consumes less than 4.7% of the total national consumption as stated by PENRA’s strategy in 2016. In addition to that, many legislations, policies, and incentive programs need to be modified to make it more attractive to consider. Local industries should feel the benefits of fulfilling their thermal demand from MSW instead of fossil fuels. Many challenges will rise in the face of this scenario, including and not limited to MSW burners initial cost, transportation cost and requirements, and the most important is that it will burden Environment Quality Authority (EQA) with economic and technical duties for periodic inspection and testing to burners emissions. And so, it can be noticed that although adopting a waste to heat scenario might be technically much easier, its additional requirements make it not practical from technical point of view and not feasible from financial point of view.

Another technical benefit for Tulkarm WtE plant is that it is a medium-size station compared to any other solution in Zahrat Al-Finjan, thus, it can be assumed as a pilot project to accumulate experience and utilize it in other sites in the West Bank or even Gaza Strip in the future. Despite all of the above discussion that makes Tulkarm scenario is the most rationale, all three scenarios where considered in the research analysis.

Table (5.1): WtE plant potential scenarios description and pros/cons analysis.

Scenario, location	Included Governorates	Pros and cons analysis
Waste to electricity Zahrat Al-fFinjan - Jenin	• Jenin • Nablus • Tulkarm • Tubas • Qalqilya • Salfit • Ramallah	Pros: • MSW already transferred to the site. • If will lead to Zahrat Al-Finjan closure, it will get local community support. Cons: • If it intends to cover all MSW quantities, initial investment is very high. • If it intends to cover proportion of MSW and support Zahrat Al-Finjan limited capacity, it will face local community very high resistance because of the already existing environmental and health problems. • New technology to the Palestinian context since there is no power generation plant in Palestine yet. • Waste to energy conversion efficiency is relatively low. • There is no need for large potential of energy near Jenin governorate, and injecting resulted electricity in local grid to transfer it for longer distances will add up electric grid losses, which are very high and equals 26% in Palestine (PERC,2011)
Waste to heat Zahrat Al-fFnjan - Jenin	• Jenin • Nablus • Tulkarm • Tubas • Qalqilya • Salfit • Ramallah	Pros: • MSW already transferred to the site. • If will lead to Zahrat Al-Finjan closure, it will get local community support. • More simple technology with respect to the Palestinian context. • Waste to energy conversion efficiency is relatively high. • Low initial investment because targeted customers are local industrial plants and they will at least contribute in buying the incinerator. Cons: • Potential customers/demand is local industrial plants, to compensate gas/diesel fuel, so, new legislations and incentive programs need to be launched, and mostly to establish an industrial zone. • Distributed MSW burning inside industrial facilities will complicate national EQA environmental emissions monitoring and control efforts, and require new environmental legislations and laws.

Waste to electricity Transfer Station - Tulkarm	• Tulkarm • Nablus • Qalqilya • Salfit	Pros: • MSW already transfer from different municipalities and local governorate councils to the site. • Tulkarm electric network suffers from power shortage since many years.* • Plant capacity will be relatively medium size, and so initial investment is relatively medium. Cons: • New technology to the Palestinian context since there is no power generation plant in Palestine yet. • Waste to energy conversion efficiency is relatively low.

*According to unpublished data from Tulkarm municipality electric network department, the electricity shortage is estimated at 10 MW.

In order to compare the scenarios, essential assumptions were made regarding efficiency, diesel fuel caloric fuel value, diesel fuel cost, electricity cost, USD to local currency New Israeli Shekel (NIS) exchange rate, energy generation efficiencies, and time required to implement each scenario. Table (5.2) illustrates assumptions used in analyzing and comparing the potential scenarios. However, it is worth to mention that real diesel fuel market price equals 1.374 $/L. But, in the waste to thermal energy scenario, a lower price was considered for the equivalent calorific value as a motivation to use it instead of diesel fuel. So, 0.7 $/Liter equivalent was considered as a market value which is almost 51% of the diesel fuel real price.

To be practical, amount of energy extracted in a useful way from MSW was assumed to be 75%. Plant operational and management costs were assumed to equal 10% of MSW management costs, based on Palestinian average salaries, this number is relatively high, especially when taking into consideration that MSW management costs remained the same, thus, it covers MSW collection and transportation, salaries, and equipment maintenance costs. Regarding conversion efficiencies, it was assumed 50% and 20% for thermal and electric energy conversion, respectively. Although these efficiencies are low, but investing in WtE technologies is a bit risky from financial point of view, thus, considering worst case scenarios is a wise option as a factor of safety.

Table (5.2): Assumptions for comparing potential WtE scenarios.

Analysis item	Value	Comment / Unit
Annual MSW generation growth	0.04	The same growth rate for all governorates.
Base year	2019	
Future year estimation	2024	Normally, 5 years are needed to build and operate waste to electricity plant. It is assumed the same time interval for waste to heat scenario since it require new legislations, awareness raising, and MSW sorting implementation.
Diesel C.V	36	MJ/Liter
Nis to USD ($) exchange rate	3.56	Nis/$
Diesel value	4.98 1.374	Nis/Liter $/Liter
Equivalent liter of diesel market value	2.5 0.7022	Nis/Liter equivalent $/Liter equivalent Assuming that same amount of energy in one liter of diesel fuel will be sold by 2.5 Nis / L equivalent to encourage local industry to make a shift
Electricity price PA pay to IEC	0.38 0.1067	Nis/kWh $/kWh
Electricity price PA pay to Palestinian energy generation investors	0.342 0.0961	Nis/kWh $/kWh
Electricity generation efficiency	0.20	Normally it is 20% to 25%, 20% efficiency was adopted in research analysis.
Heat generation efficiency	0.50	Normally it is between 50% to 70 % (Cheng and Hu,2010), 50% efficiency was adopted in this research
Electric plant operational cost	0.10	As % from MSW management cost
Extracted energy per kg MSW	0.75	As % from MSW energy content in MJ/kg
MSW management cost future ratio	1.03	Inflation rate is assumed to be 3% per year
MSW transfer rate	1.0	Complete transfer rate is assumed in the analysis

Analysis is based on the expected MSW generation rate of the year 2024; the reason behind this is previous experience for many countries that indicate the need of almost five years from planning to operating a WtE plant (Rogoff and Screve, 2012). Figure (5.5) shows the result of analyzing the three scenarios on a daily basis for each governorate. Electricity $ value was calculated based on the price that PA pays to IEC. It is obvious that larger amount of $ equivalent is available when considering thermal energy plant. However, the Palestinian market for such a demand is very limited, which makes this solution impractical.

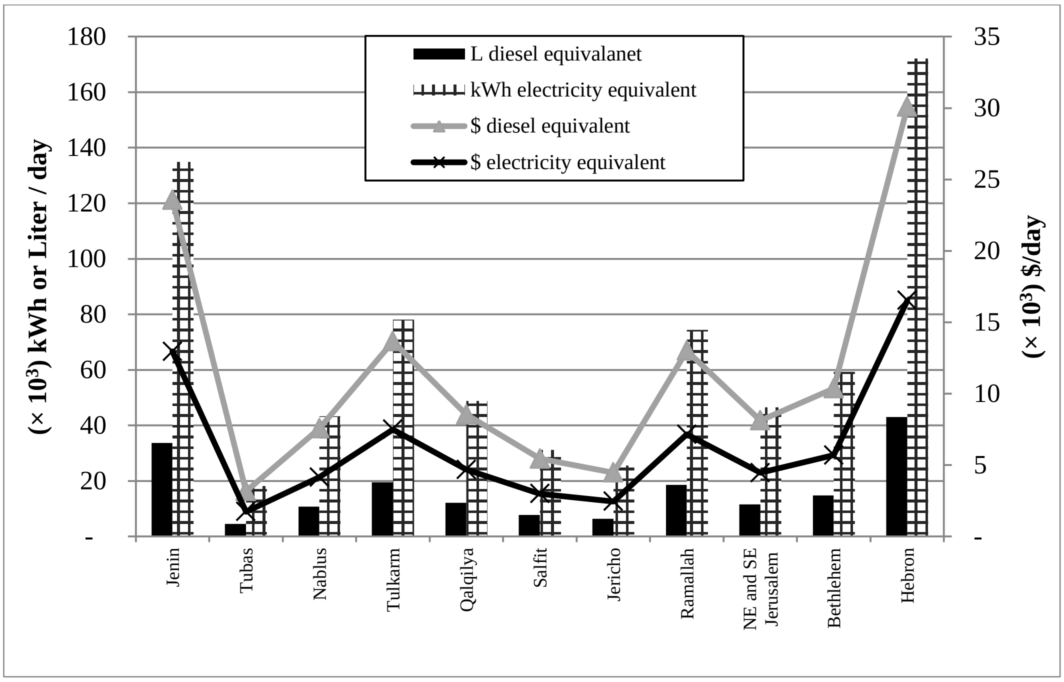


Figure (5.5): WtE plant scenarios analysis – daily basis.

Presently, analysis on the West bank scale is crucial in clarifying the whole estimated results for each scenario. For Practical issues and as uncertainty analysis, taking into consideration MSW non-combustible material and wet contents sensible and latent heat loads, 75% extraction rate was assumed. This rate means that only three quarters of the energy contained in MSW will be extracted, lowering it from 11.16 MJ/kg to 8.37 MJ/kg. Based on that, Table (5.3) illustrates the summarized analysis of each scenario. For kWh normalized costs, it is obvious that values of 0.0770 or 0.0786 $/kWh for the first and third scenarios, respectively, are much lower than purchasing prices from the IEC which equals to 0.1067 $/kWh. However, it should be kept in mind that this cost only covers WtE estimated operation and running costs, initial investment is still not included yet.

For second scenario which is based on thermal energy analysis, results show that one liter of diesel equivalent cost equals to 0.3082 $/L equivalent, while its local market value equals to 1.4 $/L. However, implementing the third scenario which is the most rationale (as described in Table (5.3), and taking the current investor selling price which must be 10% less than IEC price (0.0961 $/kWh) generates 4,271 $/day (1,558,915 $/year) as revenues.

Table (5.3): Scenarios analysis on a national (West Bank) scale.

Analysis scenarios	**Location**	**Available MSW**	**Energy output**	**Equivalent ($/day)**	**Cost $/ton MSW**	**Cost ($/day)**	**Revenues ($/day)**	**Normalized cost**
Waste to electricity	Zahrat Al-Finjan - Jenin	1,122 ton/day	521,616 kWh/day	50,112	36	40,184	9,927	0.0770 $/kWh
Waste to heat	Zahrat Al-Finjan - Jenin	1,122 ton/day	130,404 L/day	91,209	36	40,184	51,025	0.3082 $/L
Waste to electricity	Transfer station - Tulkarm	527 ton/day	245,055 kWh/day	23,534	37	19,263	4,278	0.0786 $/kWh

Calculating economic performance indicators is important for decision makers and investors. SPP was calculated assuming different initial investment values. Table (5.4) and Figure (5.6) show calculated economic performance indicators. In Figure (5.6) scenarios 1 and 3 are considered under two different conditions, the first one assumes that PA will keep its current energy generation law which states that energy generation must be from Palestinian private sector only, and PA will buy energy with 0.0961 $/kWh, which is 10% lower than their buying price from IEC (0.1067 $/kWh). The second condition assumes that PA will give incentives to this WtE plant specifically and buy energy from it at the IEC's price. Results show that this small price difference has significant effect on SPP. For example, for the third scenario (WtE in Tulkarm), if initial investment equals to 12 million USD's, SPP period will equal to 4.9 years if PA buys energy with the same price as from IEC, and this number extends to 7.8 years if the current energy generation law is considered. These two conditions are indicated as High Price (HP) and Low Price (LP) in Figure (5.6).

Table (5.4): Estimated annual revenues in USD from each scenario

Analysis scenarios	Annual revenues $
Waste to electricity – Zahrat Al-Finjan	3,534,085
Waste to heat - Zahrat Al-Finjan	18,164,922
Waste to electricity – Tulkarm transfer station	1,520,553

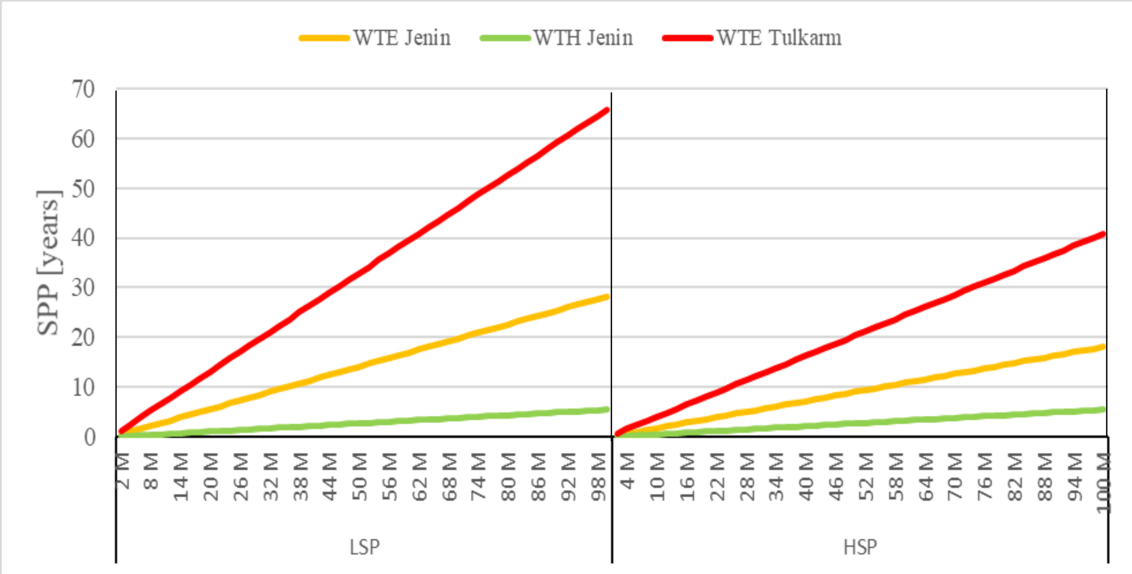
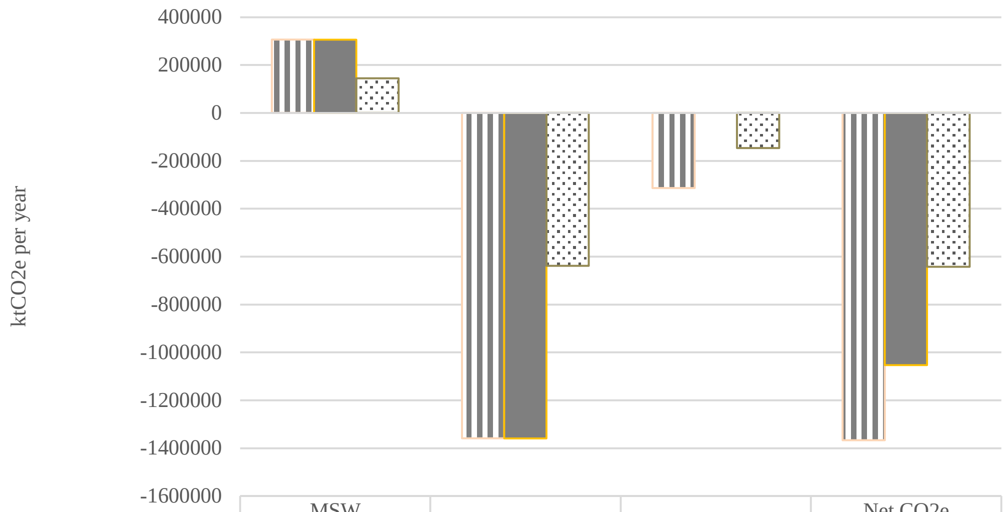


Figure (5.6): SPP analysis for waste to electricity scenarios versus investment in millions ($).

Regarding the environmental aspect of these alternatives, the CO_2eq was calculated (ton/year). Figure (5.7) shows the results of CO_2eq for MSW incineration, landfilling, current electricity generation method and the net emissions. CO_2eq for burning equivalent diesel fuel instead of MSW was not calculated since this scenario proved to be not practical from technical point of view. It is obvious that net emissions are negative, which means that building WtE plant will significantly reduce (save) GHG emissions. The significant net value came as a result that the current situation of Zahrat Al-Finjan dumping site is to generate CH_4 and release it with no restrictions to the environment. As an example, the third scenario will save a total net emissions of 642,043 ktCO_2e/year.



	MSW incineration	MSW LandFill	Electricity IEC	Net CO2e emissions
WTE Zahrat Al-finjan	306261	-1359341	-314041	-1367121
WTH Zahrat Al-finjan	306261	-1359341	0	-1053080
WTE Tulkarem TS	143830	-638389	-147483	-642043

Figure (5.7): CO_2eq Emissions from Different Options for Different Scenarios.

5.2 Scenario Based Analysis

Previous analysis is essential in understanding the potential of building and operating a WtE plant in Palestine. It was shown that energy and environment point of view, the intended plant is very promising. But, due to the fact that estimated operation and maintenance or can be called electricity generation cost for the third scenario equals to 0.0786 $/kWh, and PENRA purchasing price equals to 0.0961 $/kWh, detailed economic analysis is required before deciding if the plant is feasible or not. In other words, initial investment must be included to decide its economic feasibility. To do so, equations (4.16) and (4.17) were used to estimate initial investment, operation and maintenance costs respectively.

The capacity is in the unit of metric ton per year, and investment and operation and maintenance costs are represented by million $. One more influential economic indicator that helps in determining the plant feasibility is the Levelized Cost of Energy (LCOE), in which the total initial investment and operation and maintenance costs are calculated on an annual basis in the unit of $/year, then, divided by estimated annual electricity output in the unit of kWh/year. LCOE was calculated using equation (4.18).

Since the third scenario, which is building a WtE plant in Tulkarm transfer station, is the most rational; a full economic study was performed to investigate its feasibility. 10 scenarios were analysed where it varies in the Minimum Attractive Rate of Return (MARR), MSW to plant tipping fees, and generated electricity selling price. The following discussion shows every scenario with detailed description.

- ***Scenario # 1: Current electricity generation law and no tipping fees.***

This scenario assumes that WtE plant will sell its generated electricity under the current Palestinian electricity generation law price limit, which equals to 0.0961 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will save the tipping fees and pay nothing to the WtE plant. Table (5.5) shows the scenario summary analysis inputs and outputs.

Table (5.5): Economic analysis description for first scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.0961	$ / kWh
Tipping fees	N.A	Free of tipping fees
	N.A	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	1.76	Million $ / year
Net Present Value	-130.12	Million $ loss

It is obvious from analysis presented in table (5.5) that the project is not feasible. In fact, it burdens the potential investors significant amount of money which equals at present value to 130.12×10^6 $ over 20 years of estimated life. In other words, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cashflow diagram and cumulative cashflow diagram are shown in figures (5.8) and (5.9), respectively.

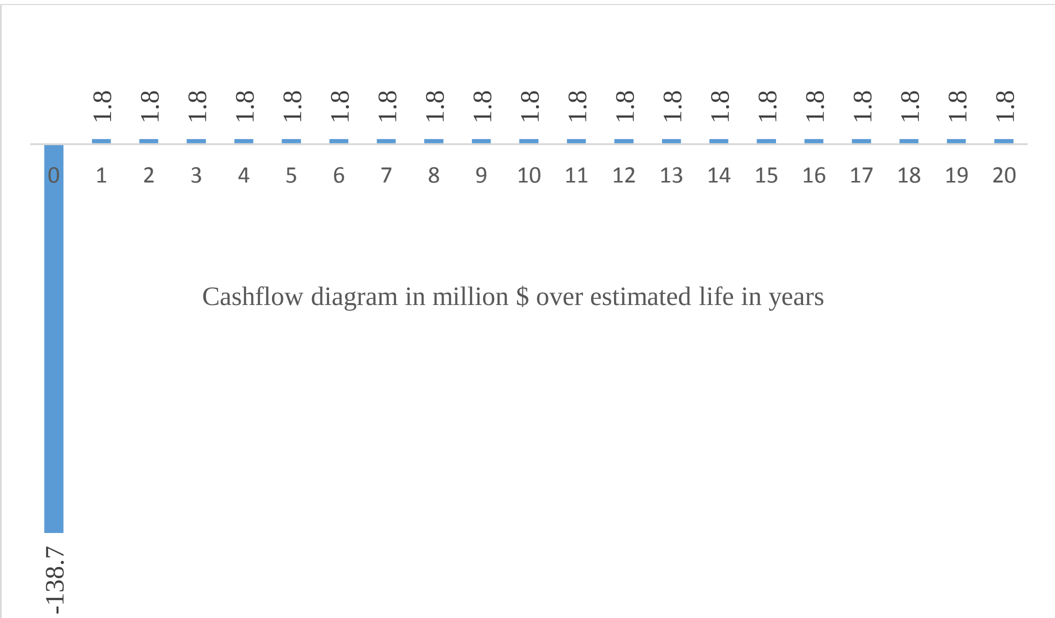


Figure (5.8): Cash flow diagram of economic analysis for first scenario.

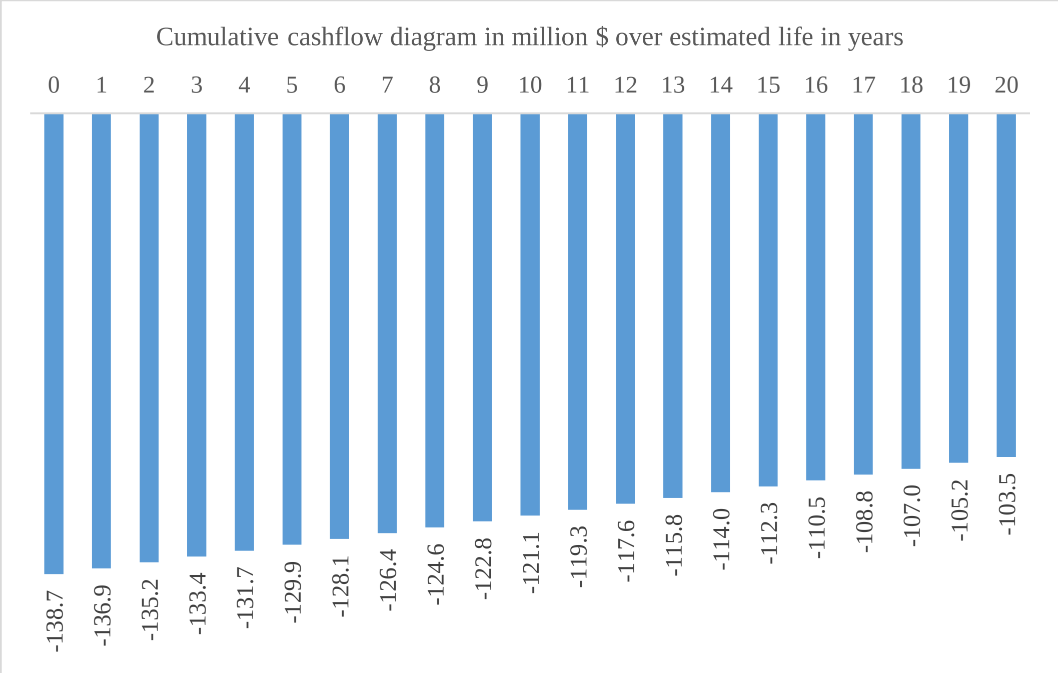


Figure (5.9): Cumulative cash flow diagram of economic analysis for first scenario.

- ***Scenario # 2: Current electricity generation law and tipping fees (5$/ton).***

This scenario assumes that WtE plant will sell its generated electricity under the current Palestinian electricity generation law price limit, which equals to 0.0961 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will pay 5 $ per ton of MSW to the WtE plant, this scenario is considered a win-win scenario, where the WtE plant will earn 5 $ per ton, while municipalities, LGUs, and JSCs will save 4 $ per ton in comparison to current tipping fees payed to Zahrat Al-finjan dumping site. Table (5.6) shows the scenario summary analysis inputs and outputs. Although the tipping fees will generate 961,775 $ per year as extra revenues, the scenario is still not feasible with a net present value equals to -125.44 million $ over plant estimated life time.

Table (5.6): Economic analysis description for second scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.0961	$ / kWh
Tipping fees	5	$ / ton MSW
	961,775	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	2.72	Million $ / year
Net Present Value	-125.44	Million $ loss

Under these circumstances, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cashflow diagram and cumulative cashflow diagram are shown in figures (5.10) and (5.11), respectively.

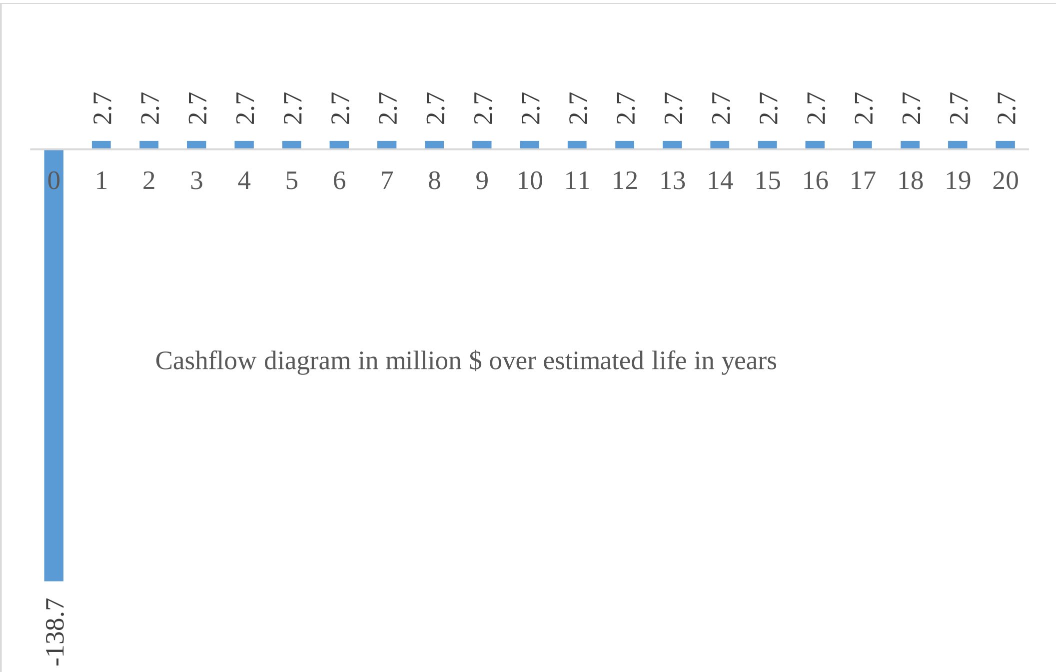


Figure (5.10): Cash flow diagram of economic analysis for second scenario.

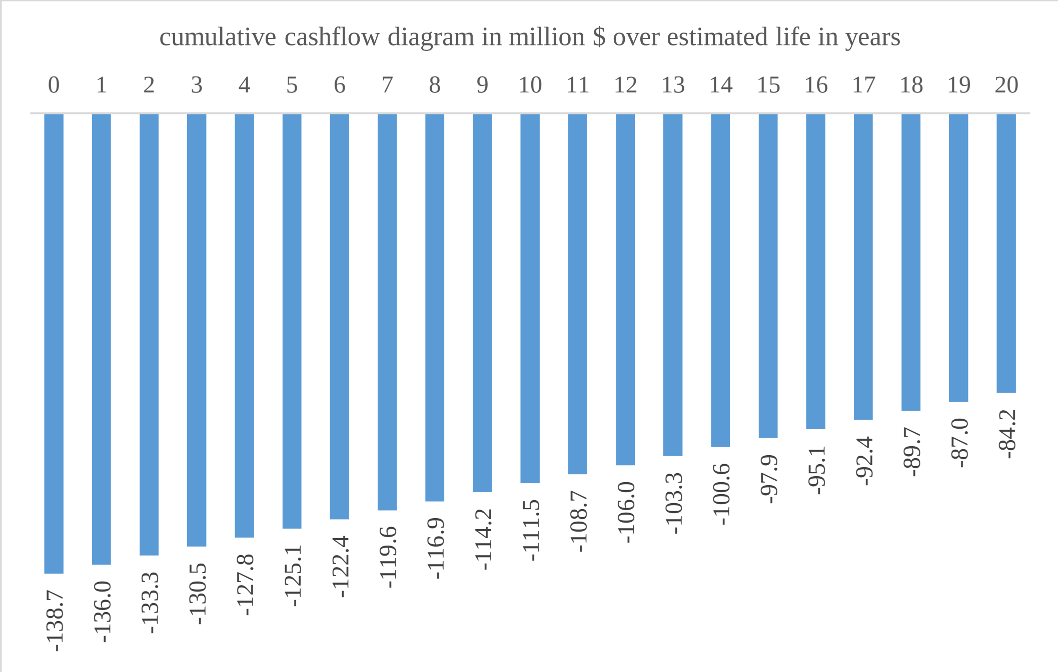


Figure (5.11): Cumulative cash flow diagram of economic analysis for second scenario.

- ***Scenario # 3: Current electricity generation law and tipping fees (9 $/ton).***

This scenario assumes that WtE plant will sell its generated electricity under the current Palestinian electricity generation law price limit, which equals to 0.0961 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will pay the current value of the tipping fees to the WtE plant instead of Zahrat Al-finjan dumping site, this value equals to 9 $ / ton of MSW. Table (5.7) shows the scenario summary analysis inputs and outputs.

Table (5.7): Economic analysis description for third scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Parameter	**Value**	**Unit / comments**
Electricity feed in tariff	0.0961	$ / kWh
Tipping fees	9	Free of tipping fees
	1,731,195	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	3.49	Million $ / year
Net Present Value	-121.69	Million $ loss

It is obvious from analysis presented in table (5.7) that the project is not feasible. In fact, it burdens the potential investors significant amount of money which equals at present value to 120.69 × 10^6 $ over 20 years of estimated life. In other words, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cash flow diagram and cumulative cash flow diagram are shown in figures (5.12) and (5.13), respectively.

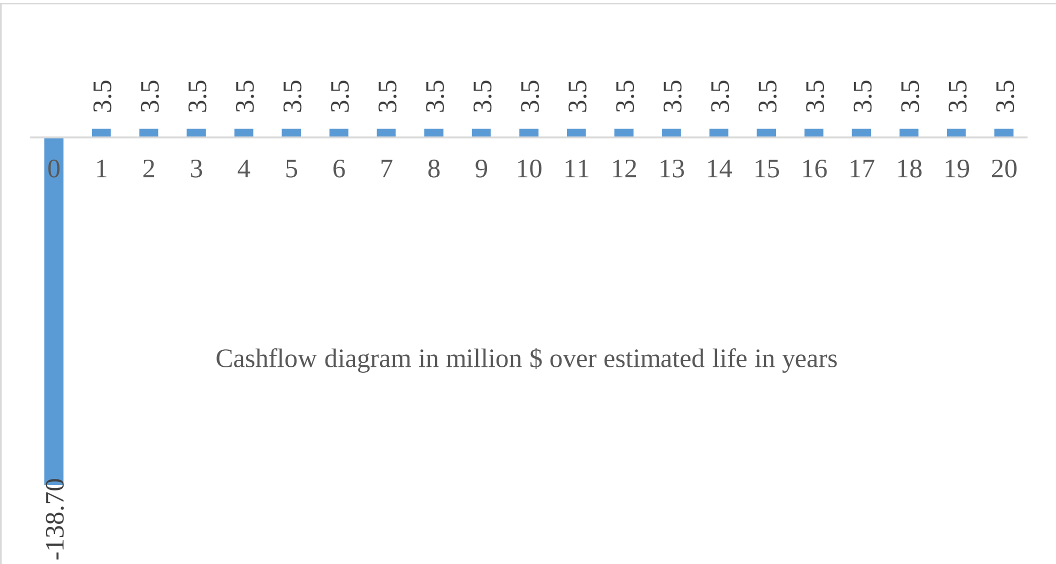


Figure (5.12): Cash flow diagram of economic analysis for third scenario.

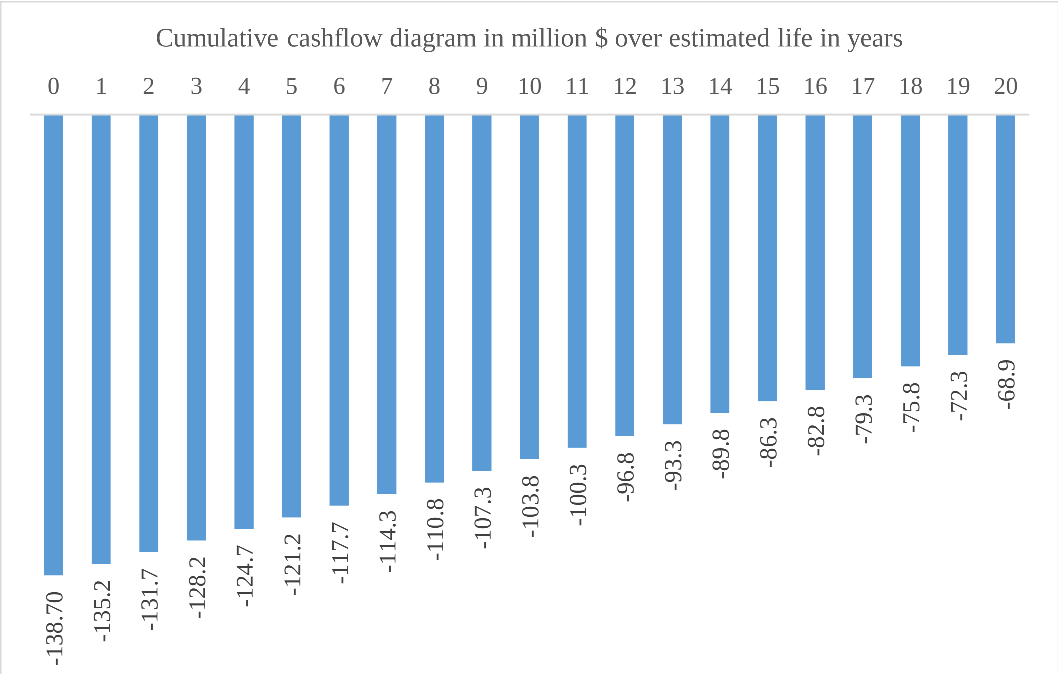


Figure (5.13): Cumulative cash flow diagram of economic analysis for third scenario.

It can be noticed under previous scenarios circumstances, proposed WtE plant is not feasible at all. In fact, the analysis revealed that increasing the tipping fees did not make a significant difference. And so, further scenarios were analysed considering different electricity tariff and MARR.

- ***Scenario # 4: IEC electricity tariff and no tipping fees.***

This scenario assumes that WtE plant will sell its generated electricity as the same price PA pays for IEC, which equals to under the current Palestinian electricity generation law price limit, which equals to 0.1067 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will save the tipping fees the pay to Zahrat Al-finjan dumping site. Table (5.8) shows the scenario summary analysis inputs and outputs.

Table (5.8): Economic analysis description for fourth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.1067	$ / kWh
Tipping fees	N.A	Free of tipping fees
	N.A	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	2.72	Million $ / year
Net Present Value	-125.47	Million $ loss

It is obvious from analysis presented in table (5.8) that the project is not feasible. In fact, it burdens the potential investors significant amount of money which equals at present value to 125.47×10^6 $ over 20 years of estimated life. In other words, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cash flow diagram and cumulative cash flow diagram are shown in figures (5.14) and (5.15), respectively.

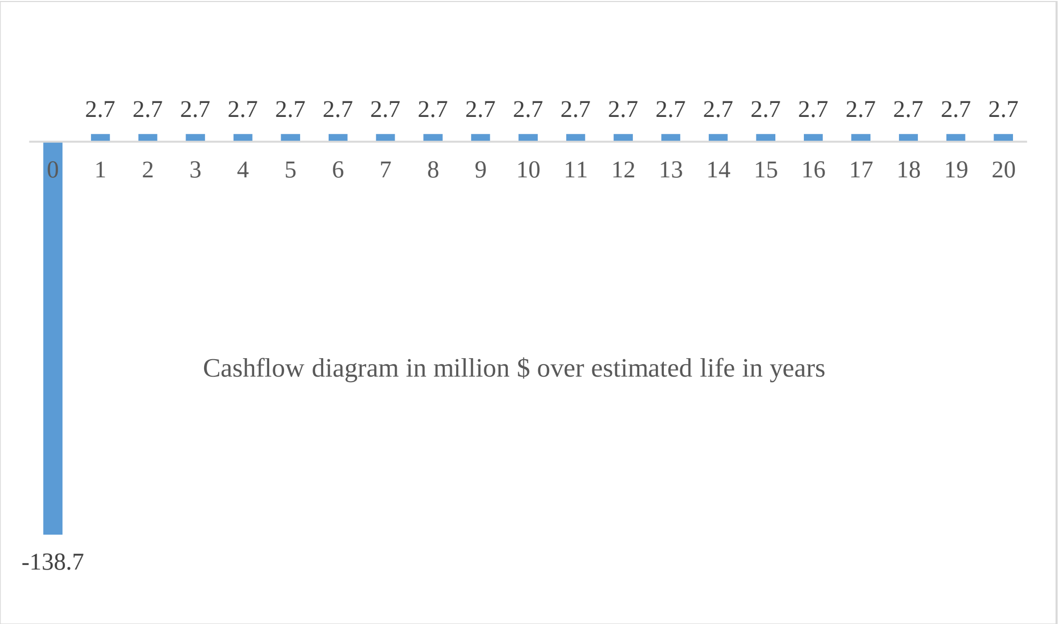


Figure (5.14): Cash flow diagram of economic analysis for fourth scenario.

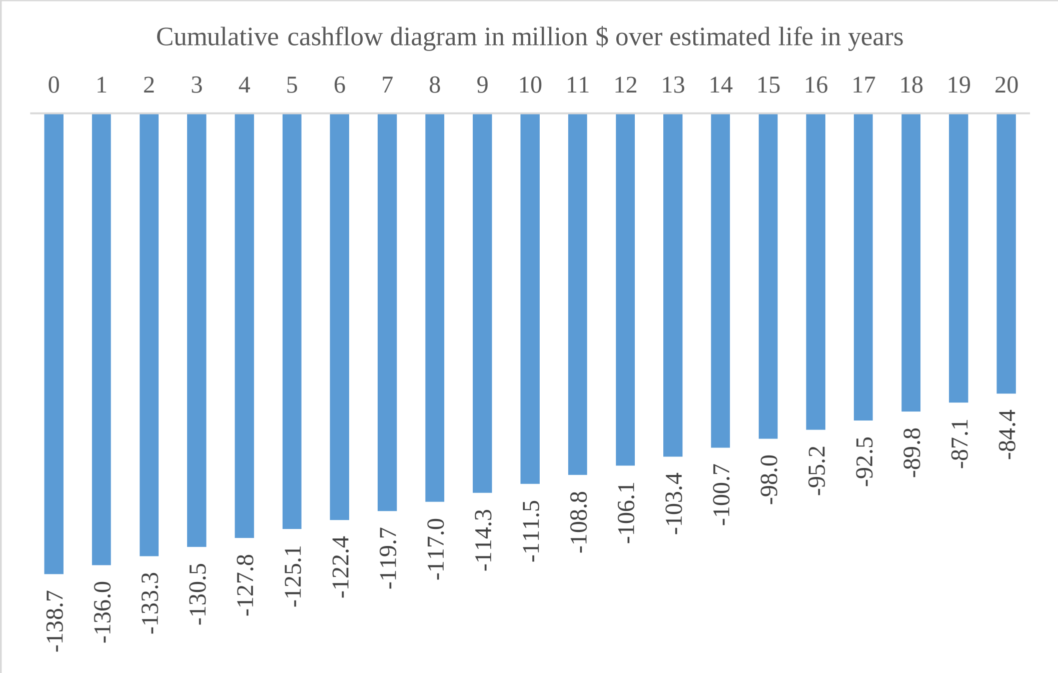


Figure (5.15): Cumulative cash flow diagram of economic analysis for fourth scenario.

- ***Scenario # 5: IEC electricity tariff and tipping fees (5 $/ton).***

This scenario assumes that WtE plant will sell its generated electricity as the selling price PA pays to IEC, which equals to 0.1067 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will pay 5 $ per ton of MSW to the WtE plant, this scenario is considered a win-win scenario, where the WtE plant will earn 5 $ per ton, while municipalities, LGUs, and JSCs will save 4 $ per ton in comparison to current tipping fees payed to Zahrat A;-finjan dumping site. Table (5.9) shows the scenario summary analysis inputs and outputs. Although the tipping fees will generate 961,775 $ per year as extra revenues, the scenario is still not feasible with a net present value equals to -120.67 million $ over plant estimated life time.

Table (5.9): Economic analysis scenario description for fifth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.1067	$ / kWh
Tipping fees	5	$ / ton MSW
	961,775	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	3.68	Million $ / year
Net Present Value	-120.79	Million $ loss

Under these circumstances, it is obvious that the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cash flow diagram and cumulative cash flow diagram are shown in figures (5.16) and (5.17), respectively.

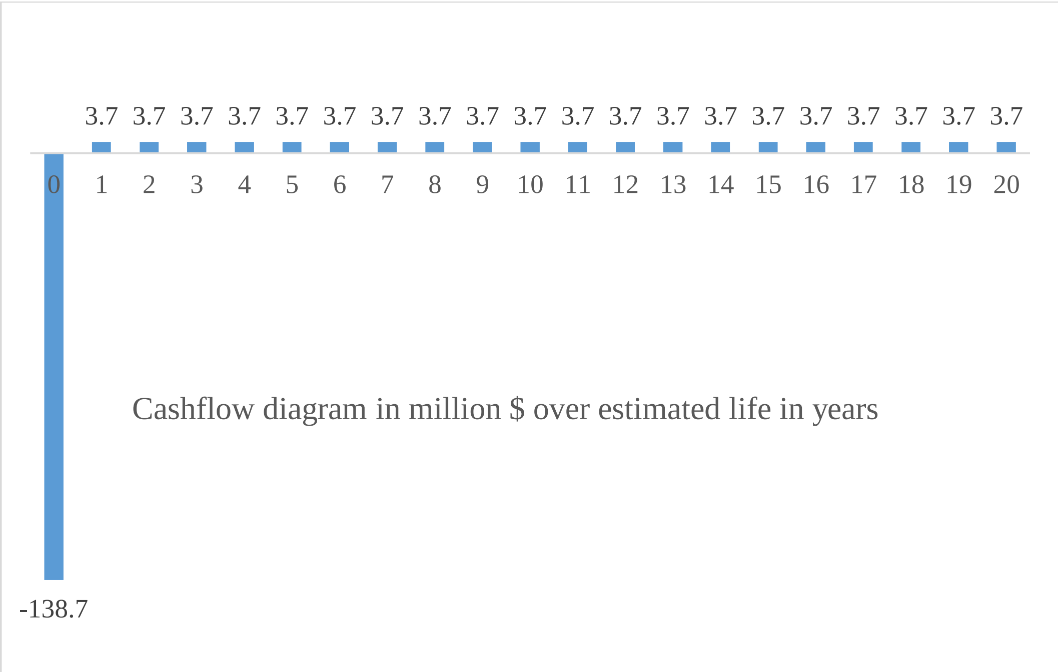


Figure (5.16): Cash flow diagram of economic analysis for fifth scenario.

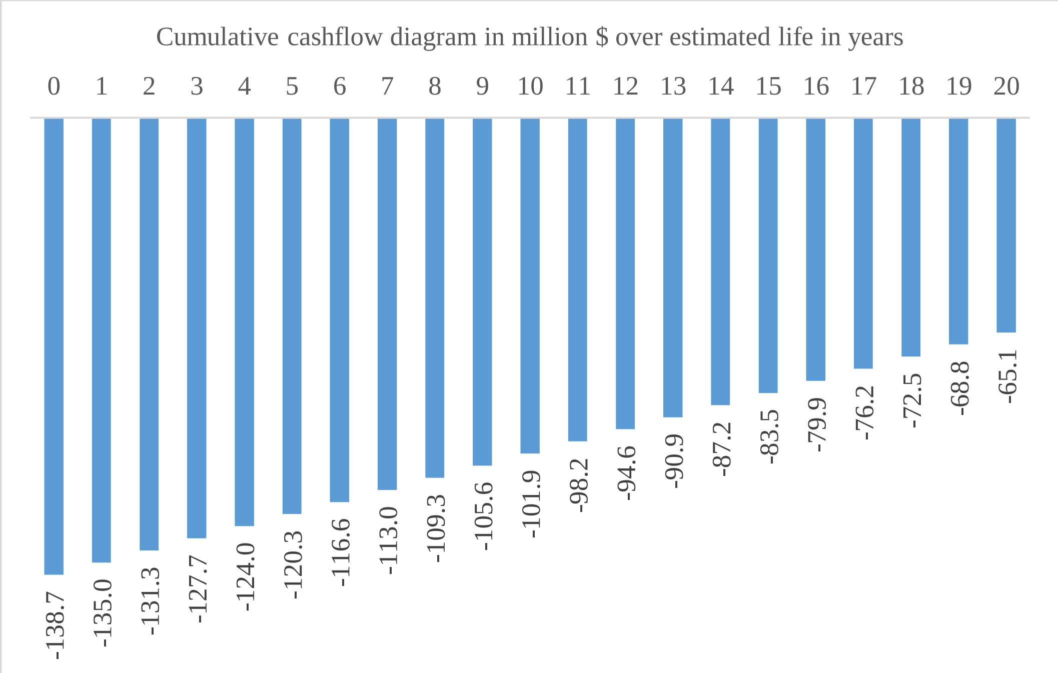


Figure (5.17): Cumulative cash flow diagram of economic analysis for fifth scenario.

- ***Scenario # 6: IEC electricity tariff and tipping fees (9 $/ton).***

This scenario assumes that WtE plant will sell its generated electricity to PA at an equivalent price to IEC, which equals to 0.1067 $/kWh. Regarding MSW tipping, this scenario assumes that municipalities, LGUs, JSCs will pay the current value of the tipping fees to the WtE plant instead of Zahrat Al-finjan dumping site, this value equals to 9 $ / ton of MSW. Table (5.10) shows the scenario summary analysis inputs and outputs.

Table (5.10): Economic analysis description for sixth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.1067	$ / kWh
Tipping fees	9	Free of tipping fees
	1,731,195	$ / year
LCOE	0.039	$ / kWh
Parameter	**Value**	**Unit / comments**
Annual net value (Revenues minus costs)	4.45	Million $ / year
Net Present Value	-117.04	Million $ loss

It is obvious from analysis presented in table (5.10) that the project is not feasible. In fact, it burdens the potential investors significant amount of money which equals at present value to 117.04×10^6 $ over 20 years of estimated life. In other words, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cash flow diagram and cumulative cash flow diagram are shown in figures (5.18) and (5.19), respectively.

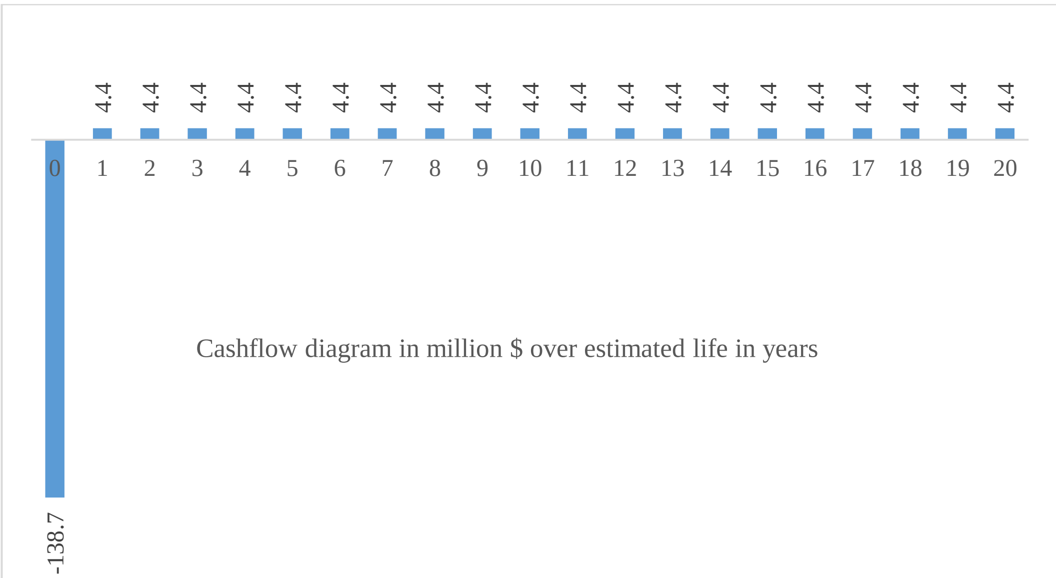


Figure (5.18): Cash flow diagram of economic analysis for sixth scenario.

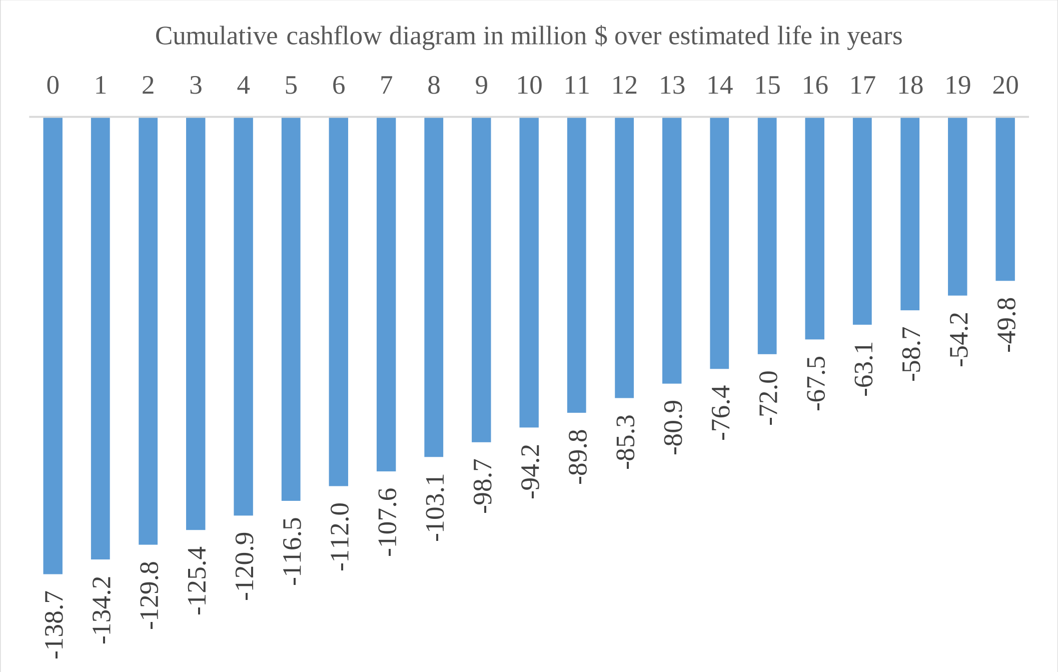


Figure (5.19): Cumulative cash flow diagram of economic analysis for sixth scenario.

It can be noticed under previous scenarios (4-6) circumstances, the proposed WtE plant is not feasible at all. In fact, it proved that considering IEC selling price which means modifying the current Palestinian power generation law will not be enough to make a WtE attractive for investors. And so, in the previous six scenarios, it was shown that neither the tipping fees not the electricity selling price at current conditions are able to make the plant feasible. Thus, additional scenarios were analysed considering governmental incentives.

- ***Scenario # 7 Photovoltaic equivalent electricity feed-in tariff and tipping fees (15 $/ton).***

As the intended WtE plant site is in Tulkarm governorate, its municipality offers a feed-in tariff for photovoltaic medium scale system that equals to 0.1264 $/kWh. This scenario assumes that WtE plant will sell its generated electricity to PA at this price. Moreover, since all previous scenarios proved that the plant is not feasible, this scenario assumes that municipalities, LGUs, and JSCs will update their fleet in order to reduce their collection and transfer expenses, and thus, be able to pay 15 $ / ton of MSW as a tipping fees. Table (5.11) shows the scenario summary analysis inputs and outputs.

Table (5.11): Economic analysis description for seventh scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	20%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.1264	$ / kWh
Tipping fees	15	Free of tipping fees
	2,885,325	$ / year
LCOE	0.039	$ / kWh
Annual net value (Revenues minus costs)	7.36	Million $ / year
Net Present Value	-102.86	Million $ loss

Although this scenario assumed very high incentives where electricity feed-in tariff equals to 0.1264 $/kWh and tipping fees equals to 15 $/ton, WtE plant still far from considered feasible. In fact, it burdens the potential investors significant amount of money which equals at present value to 120.86×10^6 $ over 20 years of estimated life. In other words, the project will never recover its capital investment. Thus, it will not be attractive neither for the PA, nor for any other investor, including private sector. Cash flow diagram and cumulative cash flow diagram are shown in figures (5.20) and (5.21), respectively. From cumulative cash flow diagram, it can be noticed that the WtE plant will recover its investment at the beginning of the year 19th. However, it is still not feasible.

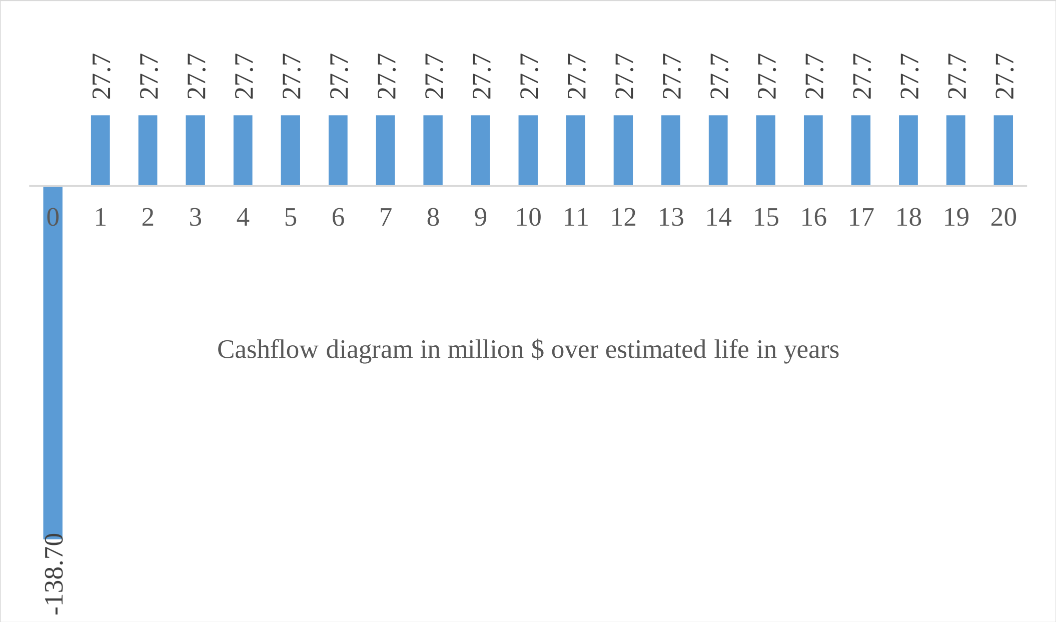


Figure (5.20): Cash flow diagram of economic analysis for seventh scenario.

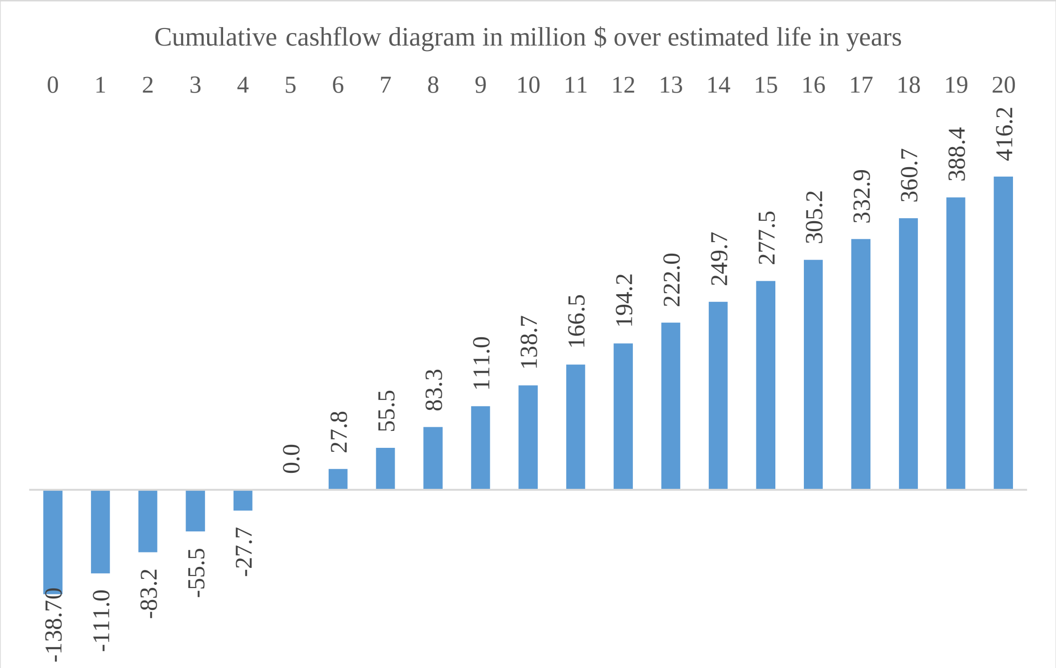


Figure (5.21): Cumulative cash flow diagram of economic analysis for seventh.

Considering all previous scenarios, LCOE which depends only on initial investment, annual net revenues, and annual generated electricity was constant and equals to 0.039 $/kWh. Considering and even increasing tipping fees did not help the WtE plant to become feasible. Higher incentives must be considered. It should be noticed that previous scenarios considered 20% MARR, the reason behind choosing this specific value, is the fact that private sector investors would prefer to recover their investment in five years or less. Scenario # 8 considers this condition.

- ***Scenario # 8 Capital recovery in five years and tipping fees (5 $/ton)***

Repeating the same analysis under the condition to achieve capital recovery during five year showed that electricity feed-in tariff must be 0.3758 $/kWh. It is still higher than LCOE at 20% MARR which equals to 0.039 $/kWh, thus, 10% MARR is considered in this scenario, and so, LCOE has reduced to 0.026 $/kWh. While MSW tipping fees that should be considered equals to 5 $/ton of MSW. Table (5.12) shows the scenario summary analysis inputs and outputs.

Table (5.12): Economic analysis scenario description for eighth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	10%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.3758	$ / kWh
Tipping fees	5	Free of tipping fees
	961,775	$ / year
LCOE	0.026	$ / kWh
Annual net value (Revenues minus costs)	27.74	Million $ / year
Net Present Value	97.50	Million $

This scenario is feasible, since its net present value equals to 97.50 × 10^6 \$ equivalent. However, the analysis considered the condition that capital recovery will occur in five years. This is clear in the cash flow diagram and cumulative cash flow diagram shown in figures (5.22) and (5.23), respectively. From cumulative cash flow diagram, it can be noticed that the WtE plant will recover its investment at the end of the fifth year.

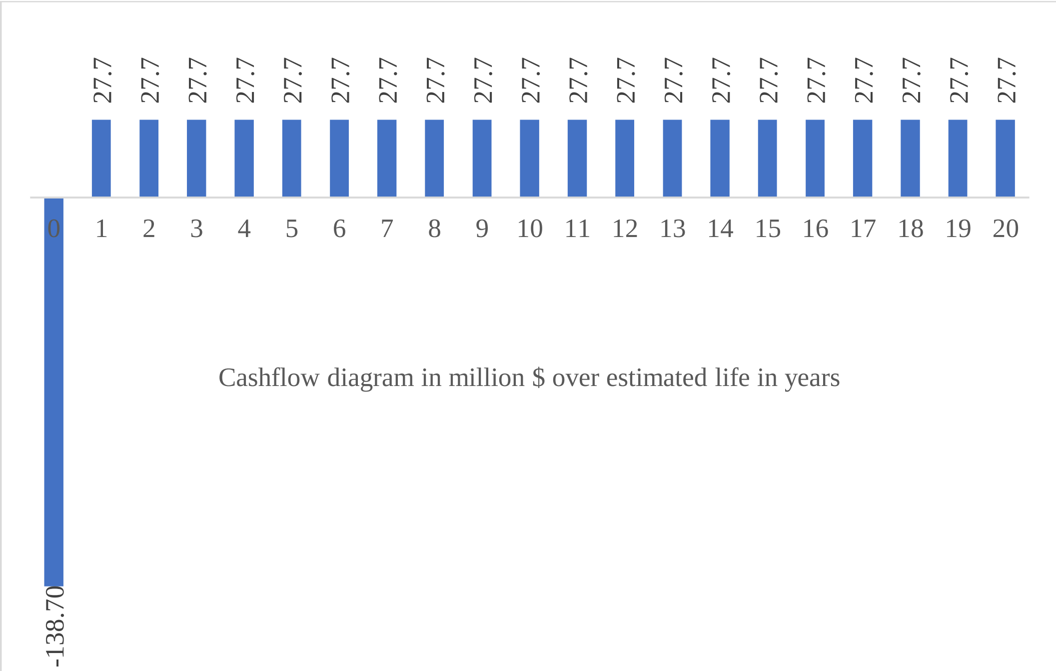


Figure (5.22): Cash flow diagram of economic analysis for eighth scenario.

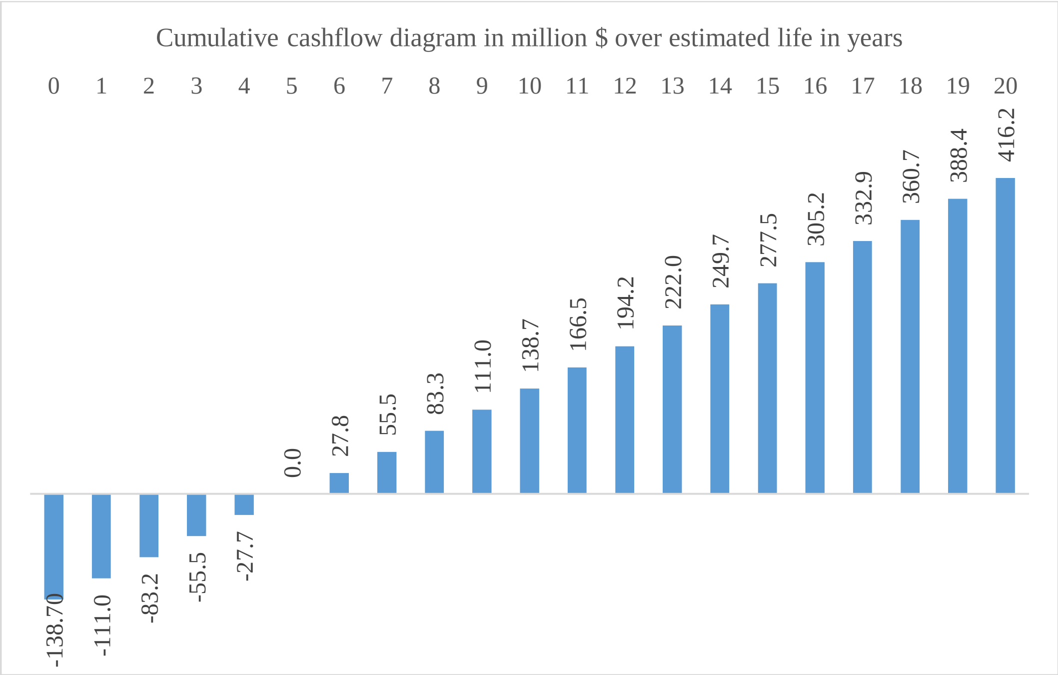


Figure (5.23): Cumulative cash flow diagram of economic analysis for eighth scenario.

- ***Scenario # 9 Just capital recovery (10% MARR) and interest and tipping fees (9 $/ton)***

This scenario considered that the municipalities, LGUs, and JSCs will continue to pay 9 $/ton of MSW as a tipping fees, and that the investor is the PA, in which it is interested in solving the environmental problems created by the current MSW management system, and just have a zero value net present worth. Analysis results show that electricity selling price should equal to 0.2393 $/kWh, which is higher than IEC price. 10% MARR was considered in this scenario, and so LCOE equals to 0.026 $/kWh. Table (5.13) shows the scenario summary analysis inputs and outputs.

Table (5.13): Economic analysis description for ninth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	10%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.2393	$ / kWh
Tipping fees	9	Free of tipping fees
	1,731,195	$ / year
LCOE	0.026	$ / kWh
Annual net value (Revenues minus costs)	16.3	Million $ / year
Net Present Value	0.11	Million $ loss

Principally, this scenario is feasible, since its net present value equals to 0.11 million $. However, such an economic indicator is not feasible for private sector investors, and for PA as an investor, it requires modifying and developing many national policies and legislations. The cash flow diagram and cumulative cash flow diagram are shown in figures (5.24) and (5.25), respectively. From cumulative cash flow diagram, it can be noticed that the WtE plant will recover its investment during the ninth year.

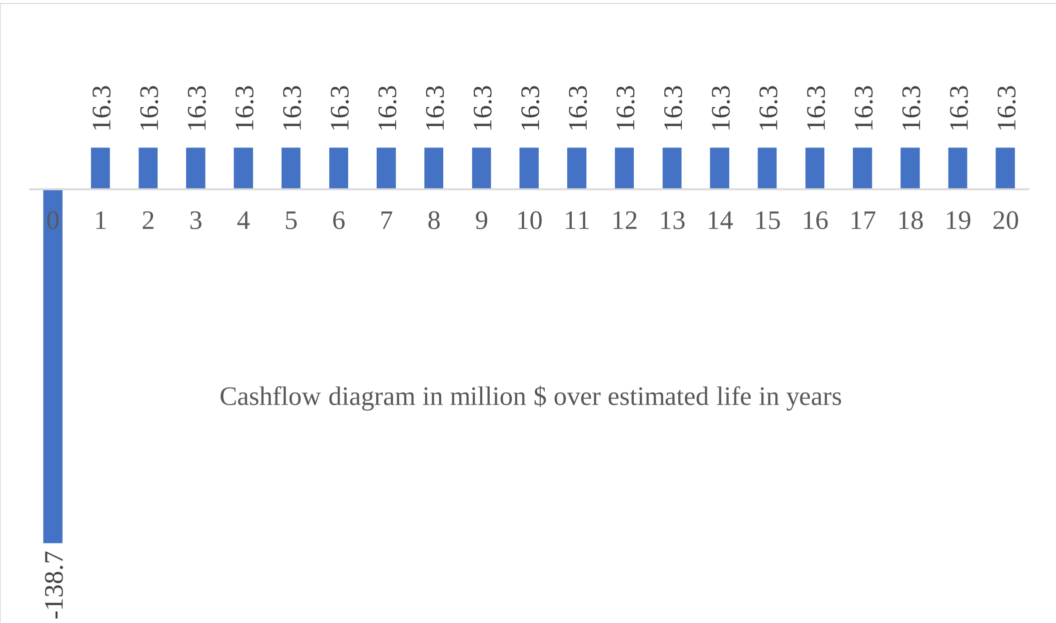


Figure (5.24): Cash flow diagram of economic analysis for ninth scenario.

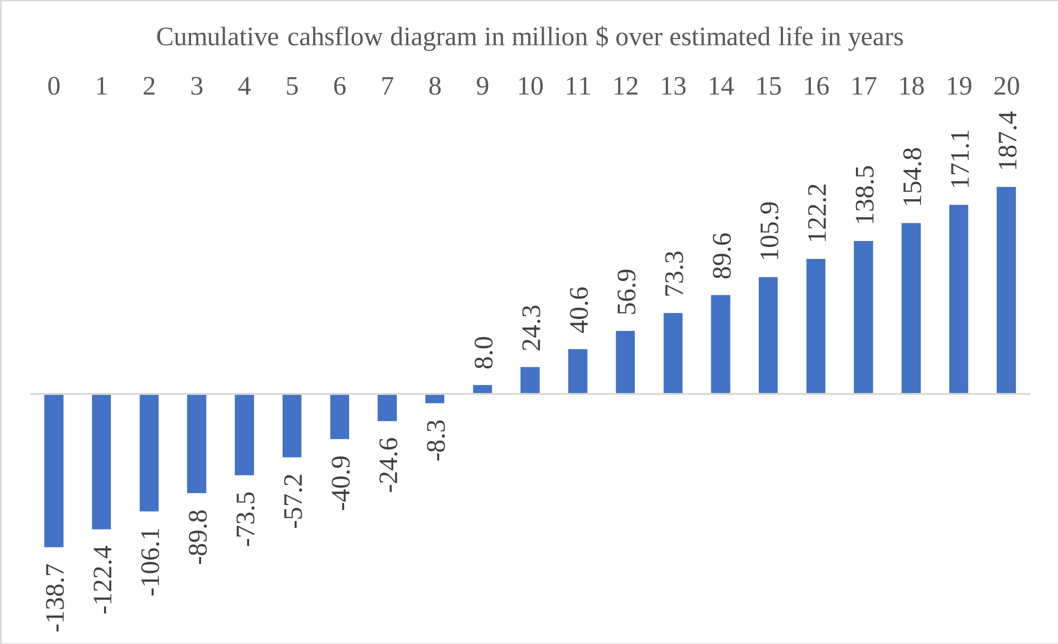


Figure (5.25): Cumulative cash flow diagram of economic analysis for ninth scenario.

- ***Scenario # 10 Just capital recovery (5% MARR) and interest and tipping fees (9 $/ton)***

This scenario considered that the municipalities, LGUs, and JSCs will continue to pay 9 $/ton of MSW as a tipping fees, and that the investor is the PA, in which it is interested in solving the environmental problems created by the current MSW management system, and just have a zero value net present worth. Analysis results show that electricity selling price should equal to 0.1815 $/kWh, which is higher than IEC price. 5% MARR was considered in this scenario, and so LCOE equals to 0.20 $/kWh. Table (5.14) shows the scenario summary analysis inputs and outputs.

Table (5.14): Economic analysis Description for tenth scenario.

Parameter	Value	Unit / comments
Plant capacity	527	Ton MSW / day
	192,355	Ton MSW / year
MARR	5%	Annual percent rate
Project life time	20	years
Electricity feed in tariff	0.1815	$ / kWh
Tipping fees	9	Free of tipping fees
	1,731,195	$ / year
LCOE	0.20	$ / kWh
Annual net value (Revenues minus costs)	11.13	Million $ / year
Net Present Value	0.06	Million $ loss

Principally, this scenario is feasible, since its net present value equals to 0.06×10^6 \$ equivalent. However, such an economic indicator is not feasible for private sector investors, and for PA as an investor, it requires modifying and developing many national policies and legislations. The cash flow diagram and cumulative cash flow diagram are shown in figures (5.26) and (5.27), respectively. From cumulative cash flow diagram, it can be noticed that the WtE plant will recover its investment during the year number 13.

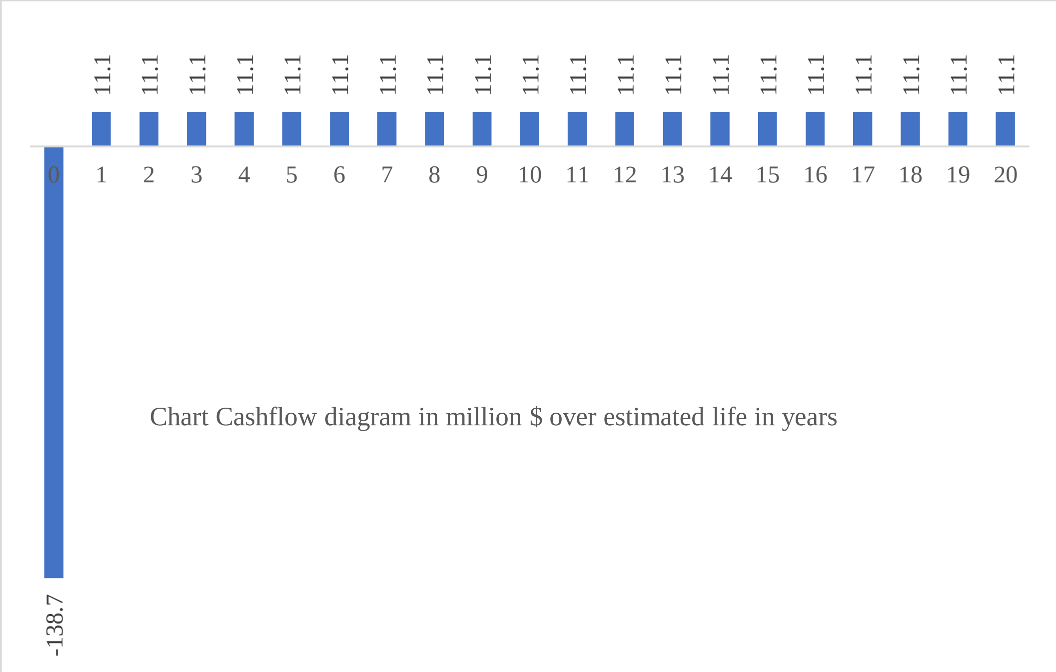


Figure (5.26): Cash flow diagram of economic analysis for tenth scenario.

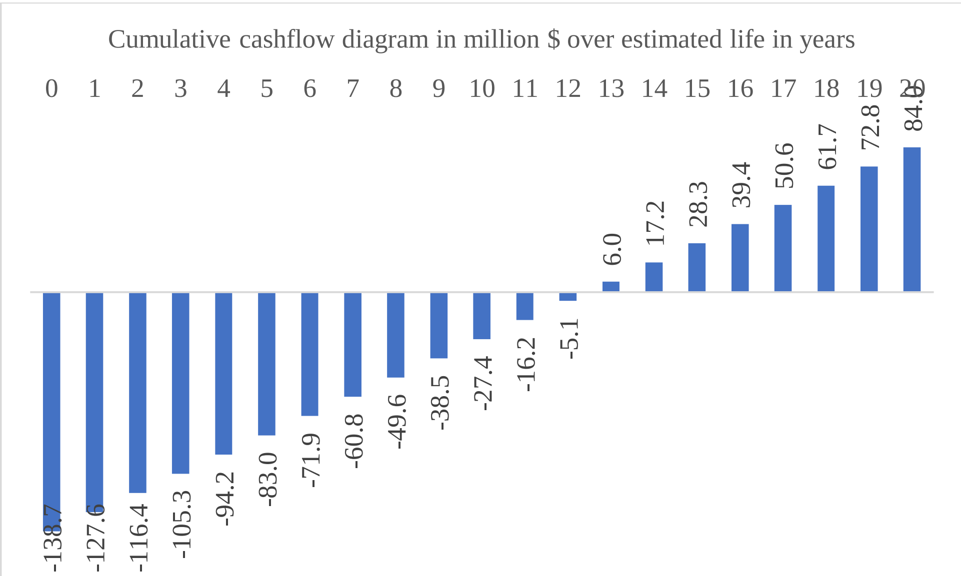


Figure (5.27): Cumulative cash flow diagram of economic analysis for tenth scenario.

Herein a summary of the whole scenarios are included, table (5.15) shows a summary of the critical economic indicators that were used, mainly: MARR (%), LCEO ($/kWh), Profits (million $/year) and present value (million $).

Table (5.15): Summary of Scenario based analysis.

Scenario #	MARR (%)	Feed-in Tariff ($/kWh)	Tipping Fees ($/ton)	LCEO ($/kWh)	Annual Profits (million $)	Present Value (million $)
1	20	0.0961	0.0	0.039	1.76	-130
2	20	0.961	5	0.039	2.72	-125
3	20	0.0961	9	0.039	3.49	-121
4	20	0.1067	0.0	0.039	2.72	-125
5	20	0.1067	5	0.039	3.68	-120
6	20	0.1067	9	0.039	4.45	-117
7	20	0.1264	15	0.039	7.36	-102
8	10	0.3758	5	0.26	27	97
9	10	0.2393	9	0.26	16.3	0.11
10	5	0.1815	9	0.2	11.13	0.06

Some remarkable notes must be made to sum up, at high values of MARR, e.x: 20% or above, the project tends to lose and be not feasible. As MARR values reduces to 10% and 5%, the project shifts from negative present value to positive; indicating that the project is somehow feasible. Changing other variables like feed-in tariff affects more directly, if the PA decides to consider the current feed-in tariff or current IEC purchasing tariff, the project is not feasible. Otherwise, the PA must set values for Feed-in Tariff that are at least 0.24 $/kWh. In the same manner, the increase or decrease in tipping fees value did not have any effect on the projects' feasibility. All in all, indicates that the most significant factor to be studied is feed-in tariff. The PA must legalize new and updated incentives to assure projects' success, and without such initiatives the project will not see light.

Chapter Six

Conclusion and Recommendations

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6.1Conclusion and Recommendations

The population growth and rapid increase on energy sources in Palestine have created energy shortages in some governorates like Tulkarm. Not only does the West Bank suffer from shortages in electricity, but also from the inconvenient and non-friendly MSW disposal manners. The study made a spatial analysis of the West Bank and considered waste and energy sector in each of them in terms of: collected MSW, transfer stations, landfills sites and energy supply. The importance of this step was to identify the location and capacity of the suggested WtE plant, later on that regard, there were three options to analyse: waste to electricity in Tulkarm, Waste to electricity in Zahrat Al-finjan landfill in Jenin and waste to heat plant in the industrial zone in Jenin. Based on the analysis and rational judgments; the waste to electricity plant in Tulkarm was chosen to continue the analysis. This choice did not come out of the blue, as a matter of fact, Tulkarm has a total supply of 32 MW from IEC but according to its hot and humid weather in summer and the huge demand on electric loads it experiences a shortage of almost 10 MW as stated by Tulkarm Municipality. On the same page, the proposed WtE plant in Tulkarm has many advantages; the plant will have a small scale compared to other options, which in turn means lower risks on importing such advanced technology and new knowledge for the first time, lower risks means lower losses, if occurred, also, it would be a great chance to try and build experience and knowledge on such technologies. In addition, after studying the waste to heat option, it was found that it will bring no big advantages to the current industries. To explain, Palestine has small industries that are not big or mature enough to consume such huge loads of heat, blankly they are mostly family business that contained from one generation to another and did not grow so much in capacity or markets due to hard political and economic situations.

Other significant factor in the MSW management system is its cost; the total cost of managing MSW is the sum of the collection, transfer and landfill costs. As viewed earlier in this thesis, most of the total cost in incurred by collection and transfer costs. This was very clear during the scenario based analysis; the tipping fees values had no impact on the projects' feasibility.

Adding to all of these, CO_2eq values were calculated. The proposed plant in Tulkarm produces 143,830 ktCO_2eq. When compared to landfilling which is the currently practiced method and to the emissions from imported energy from IEC that uses fossil fuels, the plant has a total savings of 642,043 ktCO_2eq. These numbers are very critical because they show how the plant contributes to environment, it produces emissions and so have less impact on global warming and other environmental issues, which in all assures the plant environmental sustainability.

Following the previous analysis was the scenario based analysis, where ten scenarios were made, each included different values of MARR, feed-in tariff, tipping fees and the net profits and present values were calculated. Noticeably, changing the value of MARR from 20% to 10% or 5% affected projects' profitability and feasibility, at lower values of MARR the project started gaining back its investment and had low present values that could be enlarged by many recommendations that will be discussed in the next section. As a summary, the investor or funder of such a project must not have high hopes and set high values of MARR. In the same manner, the feed-in tariff was changed, setting its value to the current purchasing tariff will keep the project in loss conditions. It is believed that the minimum value of feed-in tariff should be at least 0.24$/kWh. The final factor was the tipping fees, since it plays no major role in the total MSW management system, it was found that changing its value didn't change or prove projects' profitability or feasibility. Another issue to mention here is the importance of considering the environmental sustainability also, taking into account the economic results will make the project out of league and hard to convince stakeholders, however, considering the reduced emissions amount will change the decision; this plant will not only reduce GHG emission and specially carbon dioxide, but also it will be targeted as a new and friendly method for MSW disposal, and so, reduce the costs of handling issues such as leachate or ground water quality, methane emissions and soil quality that are commonly discussed in the current Palestinian landfills. That's why it is found that from an economic point of view, the project needs incentives and initiatives to support its performance, the PA must work really hard to set new incentives and start new initiatives towards creating public awareness to the importance of environment protection and utilization of RES in any form.

Finally, the researcher recommends to conduct other studies regarding MSW sorting whether it was from source or in plant, also, to study the impact of selling sorted materials like glass and metals which has no calorific values, this way the plant might gain another source for income and profits, while at the same time has social impact on Palestinian society to offer jobs for the community. In the same way, other important studies to be made are about combining more than one technology, e.x: having incineration and gasification technologies at the same plant. This will support the previous sorting idea; while some materials can be incinerated, others might be used either way.

To have a clean vision of the importance of such a project, the economic impacts of the current environmental problems resulted from landfills and inconvenient disposal ways must be studied. Such studies will ease the understanding of the effects that landfills play on environment and human health. Finally, since the collection and transfer costs are the highest in MSW cost system in Palestine, many updated must be made on the roads they follow, the potential of building new transfer stations to lower the cost, upgrading the vehicles used in collection and other suggestions that can be made according to the necessity.

6.2 Limitations

Some remarks should be made on this thesis: firstly, since there are no previous studies regarding environment impact of landfills and current disposal ways, the researcher followed the theoretical equations set by the IPCC regarding waste emissions. Secondly: the analysis considered all fraction of waste with no sorting, however it is recommended to study the impact of sorting in this regard. Thirdly: the economic analysis was based on values of initial investment in Iran as it was the closest geographical area to Palestine that has operating WtE plants, so changing these values might affect some indicators.

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Appendices

Appendix (A)

Table A1: Governorates population and waste information.

Governorate	Population	Waste Generation (2019) (ton/day)	Waste Generation (2024) (ton/day)	Waste Generation per Capita (kg/day)
Jenin	314,866	290	353	1.00
Tubas	60,927	39	47	0.71
Nablus	388,321	93	113	0.55
Tulkarm	186,760	168	204	1.10
Qalqilya	112,400	105	128	0.95
Salfit	75,444	67	82	0.83
Jericho	50,002	55	67	1.08
Ramallah	328,861	160	195	0.91
NE and SE Jerusalem	435,483	100	122	1.02
Bethlehem	217,400	128	155	0.77
Hebron	711,223	370	450	0.98

Table A2: Governorates electric supply information.

Governorate	Electric Supply (MWh/year)
Jenin	309,452
Tubas	63,339
Nablus	380,910
Tulkarm	183,479
Qalqilya	110,123
Salfit	70,719
Jericho	51,637
Ramallah	343,772
NE and SE Jerusalem	422,555
Bethlehem	214,253
Hebron	692,594

Appendix (B)

Table B1: Total cost of current waste management system for each governorate.

Governorate	Total Cost ($/ton)
Jenin	38
Tubas	40
Nablus	39
Tulkarm	46
Qalqilya	57
Salfit	24
Jericho	52
Ramallah	55
NE and SE Jerusalem	44
Bethlehem	41
Hebron	39

Table B2: Total waste quantities for each governorate.

Governorate	Collected (ton/day)	Transferred (ton/day)
Jenin	290	50.0
Tubas	39	43.0
Nablus	93	180.0
Tulkarm	118	132.0
Qalqilya	105	105.0
Salfit	66	-
Jericho	55	2.1
Ramallah	235	200.0
NE and SE Jerusalem	120	120.0
Bethlehem	132	-
Hebron	370	650.0

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إعداد
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قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في الإدارة الهندسية بكليّة الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.
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الملخّص

تهدف هذه الدراسة إلى البحث في الممارسات الحالية لإدارة النفايات المنزليّة في الضفة الغربيّة في فلسطين. كما أنها تبحث في إحتمالية توليد الطاقة من النفايات باستخدام الحرق المتحكّم به كأحد الطرق التكنولوجيّة لتوليد الطاقة من النفايات. إن المنهجيّة المتبعة قائمة على التحليل الكمّي و النوعي للحصول على النتائج المرجوّة. وقد تم جمع التقارير والكتب الرسميّة المنشورة وغير المنشورة من مختلف الوزارات والهيئات الحكوميّة والمحليّة لإتمام هذه الدراسة، وعقد مقابلات مع أصحاب الاختصاص والعلاقة في الجهات الرسميّة والحكوميّة ذات الاختصاص. تمّ عمل الدراسة من خلال التحليل المكاني للضفة الغربية مع الأخذ بعين الاعتبار توزيع الكهرباء، إنتاج النفايات، مواقع المكبّات و محطات الترحيل الموجودة حالياً، تم استخلاص ثلاثة سيناريوهات لإقامة محطة مقترحة لحرق النفايات من أجل توليد الطاقة: محطة إنتاج كهرباء من النفايات في محافظة طولكرم، محطة إنتاج كهرباء من النفايات في مكب زهرة الفنجان في محافظة جنين، محطة إنتاج حرارة من النفايات في المنطقة الصناعية في محافظة جنين. تمّ فيما بعد تحليل هذه السيناريوهات بأبعادها البيئية والإقتصادية حيث ثم عمل التحليل البيئي وحساب كمية انبعاثات غاز ثاني أوكسيد الكاربون (طن مكافئ) من خلال تطبيق طريقة (Tier One) الصادرة عن الفريق الحكومي الدولي المعني بتغير المناخ(IPCC) ، هذا التحليل يهدف إلى مقارنة تكنولوجيا الحرق المقترحة في هذه الدراسة بالطرق المستعملة حالياَ للتخلص من النفايات وهي الطمر ومكبّات النفايات الموجودة في الضفة الغربية. لاحقاَ تم إعداد دراسة ماليّة لحساب كمية الإيرادات والأرباح من كل سيناريو ومعرفة فترة الإسترداد. ثمّ تم اقتراح عشرة سيناريوهات كل منها يشتمل على قيمة (LCOE) و (MARR) لمعرفة قيمة الأرباح

الصافية وتقرير إذا ما كان الاستثمار ناجحاَ أم لا.

إنّ هذه الدراسة هي الأولى من نوعها والتي تهدف إلى التحقيق في الإمكانيـــة البيئيـــة والإقتصادية لإنشاء محطة توليد طاقة من النفايات المنزلية في فلسطين، تحديـــداَ فـــي الضـــفة الغربية، و قد خلصت نتائج هذا التحليل العميق إلى أهمية و ضرورة التدخل الحكومي لدعم مثل هذه الاستثمارات الضخمة حيث أنّ هذه المحطة تحقق نفعاً كبيراً من الناحية البيئية وتسهم كثيراَ في تخفيض انبعاثات ثاني أوكسيد الكاربون مقارنةَ بالطرق التقليدية المتبعة حالياَ في فلســطين، إلاّ أنّ استثماراَ بهذا الحجم يحتاج إلى دعم مالي و لوجيستي من الحكومة لضـــمان نجاحـــه و استمراريته.