Chapter 12: Case studies

Case 12.1: Biofuel for renewable energy in the UAE

The United Arab Emirates, referred to as 'UAE', is hot and dry desert, with a very high temperature reaching 50° Celsius and humidity reaching 100%, in the summer. UAE is a federal union of seven emirates where Abu Dhabi is the capital; the largest by size and which controls almost 90% of all the natural gas and oil reserve in the country. UAE is one of the main petroleum exporting countries in the GCC. According to a study conducted by the Energy Information Administration in 2016 (EIA, 2017), UAE produces 2.9 million barrels per day and domestic consumption is on average 423,000 barrels per day.

The UAE has an abundance of natural resources; 9.3% of the world's oil reserves and 4.1% of its gas reserves. These fossil fuel resources helped the country evolve from a rural undeveloped land populated by nomadic people to a modern developing country, experiencing unprecedented growth over the last four decades. UAE has a rich economy with a conventional source of income (oil and gas) which is generally seen as the backbone for its survival. UAE is facing serious challenges in term of commitment to sustainable development. Generally, there are three ways to reduce the CO2 emission from energy: either by producing energy in an efficient way, capturing the carbon and sequestration; or replacing the conventional energy market with the renewable energy market.

The UAE and GCC states have the highest CO2 emission per capita, contributing 2.25% of the total current CO2 emission of the planet, where the UAE alone contributing 0.4% (Al-Soud et al. 2009). Looking forward, Abu Dhabi has begun investing in Renewable Energy Technologies (RETs), hoping to continue as an energy world leader, but with clean renewable energy. (Mezher et al., 2009). The UAE decided to take steps to reduce the CO2 emission by investing in the renewable energy sectors.

This case study is based on the research conducted by the 1st and 3rd authors of this chapter, in 2018, in the UAE. The discussion of the findings of the primary data collected will be presented, after a discussion of the potential of RE in the GCC region and of possible options of RETs in the UAE; both mainly from secondary sources. The following section will introduce the details of the Florexx Biofuel Refinery project details which may be of interest to project managers in the RE sector. This is the most recent Biofuel Plant project in the Middle East with real life data.

Potential of renewable energy for the Gulf region

In the Gulf region, there is a unique target to implement the renewable energy. There are several initiatives to assess potential resources that have been carried out since the 1990s. In Bahrain, a study was conducted to evaluate the possibility of generating electricity and desalinated water by using the solar and wind energy. In Kuwait, a study was conducted by Japan's external trade organization to see the potential of generating power from solar thermal energy. (Al-Nassar et al., 2005). In Oman, the Directorate General of Civil Aviation and

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Meteorology, Sultan Qaboos University, and the Public Authority for Electricity and Water have conducted a study to assess the feasibility of implementing renewable energy. In Qatar, the national food security programme launched a solar resource assessment project to be conducted by the German Aerospace Centre – Deutsches-ZentrumfurLuft und Raumfahrte to assess the country's most favourable areas for solar energy projects. From 1993 to 2000, a joint project between the USA and Saudi Arabia aimed to upgrade the solar resource assessment capability of Saudi Arabia and to identify high-potential areas for RE application (Alawaji, 2001).

In the UAE, a preliminary assessment of solar and wind energy resources within UNEP's Solar and Wind Energy Resource Assessment (SWERA) programme was launched in 2007. The assessment was sponsored by Masdar as part of the Masdar initiative and the findings of the assessment were made available on the SWERA web site when completed. The research shows that there is a high potential for the UAE in renewable energy resources. In 2015, 14 projects were launched to help the UAE to generate energy from renewable resources.

Many projects in renewable energy were made and planned including the renewable energy arm of UAE – Masdar city which invested more than $250 million in renewable energy around the world. Masdar vision 2020 is to spend an estimated $30 billion. The following section will review the alternatives that UAE have among different RTEs.

Possible choices for the UAE in the renewable energy sector

Two main factors, among others, attracted the world to find alternative energy resources: climate change and fossil fuel depletion. UAE aims to develop and implement renewable energy since it will provide a positive impact on sustainability, stimulate the diversification of energy supply, improve rural and regional development and create an opportunity for a domestic industry and create job opportunities. Another factor that encouraged the UAE to develop renewable energy is the rapid economic and demographic growth over the past decade, with serious pressures on the existing electricity grid. In 2009, the UAE government announced the renewable energy policy by 2020 to produce 7% of the UAE annual energy for the power sector from renewable energy resources. In other words, renewable energy will be utilized along with fossil fuel to power electricity generation and water desalination plants.

At the same time, Abu Dhabi announced that 5% of its energy will be produced by renewable resources by 2030. (Ferroukhi et al., 2013). This announcement is entirely in line with two important features: the first trend is the growing awareness about the global environmental concerns, with more attention being paid to cleaner production, environmental remediation as well as waste reduction. UAE has one of the highest CO2 emission rate per capita in the world with total emissions growing over 150% between 1990 and 2007. The second trend is about the emerging consensus which goes beyond purely environmental matters to address a wide range of apprehensions that are jointly referred to as the search for sustainable development. Recently, the concept of sustainability is recognized in academic and policy circles in order to minimize the gap between the policy formulation and its actual implementation.

In the following, the different types of RETs will be briefly discussed in the context of the UAE

Photovoltaic energy (PV)

The report of the Arab Forum for Environment and Development (2013), confirmed that producing energy from PV is considered as one of the most reliable renewable energy technologies in the UAE. The petroleum institute in Abu Dhabi conducted a study to analyze the global horizontal irradiance (GHI) in different locations within UAE. The study found that May, June, and July contributed the most to the annual (GHI), while January, December, and November had the lowest value.

At the same time, the study showed that the UAE weather is featured by a high percentage – 82% – of clear days during the year. This result indicated that PV application in UAE is technically feasible. For instance, Masdar city solar PV plant, built on 210,000 square meters, is the largest of its kind in the Middle East, producing 17,500 MW/h of clean energy annually and offseting 15,000 tons of carbon emissions per year.

Concentrated solar power (CSP)

The German Aerospace Centre conducted a study about the efficacy of CSP technologies. They reported that CSP has proven its energy, economic and environmental benefits around the world and has a high potential to be very competitive with any new power plant, especially coal power plant. It's suitable for both demand electricity and water desalination. A series of CSP plants has been built in Abu Dhabi where there is abundant sun. These plants will supply part of the water desalination production and the energy required to generate electricity. Shams 1 was the first CSP project in UAE, completed in 2012, with a total cost of $500 – $700 million. It has 768 CSPs and aims to be the largest concentrated solar power plant in the world, generating power for 62,000 homes and extending over 2.5 Km^2. In addition to Shams 1, Masdar vision 2020, is to build additional CSP plants on yearly basis till they reach a capacity of 1500 MW over 400 Km^2, at a total estimated cost of $30 billion. (Table 12.2)

Country	Global Solar Radiation ($KWh/m^2/day$)	Direct normal solar radiation ($kWh/m^2/day$)	Solar energy (Wh/m^2)	Solar Power (W/m^2)
UAE	6.5	6.0	5.078	577

Table 12.2: Technical overview of the solar energy in the UAE

There are some challenges associated with CSP operation in the UAE: first, the weather will affect the solar radiation; second, a high cost construction due to the sand dunes in the desert. However, these projects will help to achieve the target of Abu Dhabi Government by 2020; at least 7% of power generation should be from renewable energy. In addition, the Dubai Clean Energy Strategy 2050 was launched to provide 7% of Dubai's total power output from clean energy by 2020. This target will increase to 25% by 2030 and 75% by 2050. In 2013, Dubai built the first phase of Mohammed bin Rashid Al Maktoum Solar Park with a capacity of 1000 MW. The second phase was built in 2017 with a total cost of $320 million consisting of 2.3 million PV, producing 200MW.

Biofuel

According to Kazim (2010), the UAE has a unique position to produce biofuels from algae. Algae do not need to grow in the ocean, which gives the UAE the ability to use non-habitable land such as the western region desert for algae growth. At the same time, this will not have a negative impact on the marine ecosystem of the Arabian Gulf. Thus, UAE has a high potential to become a world leader in the biofuel from algae industry, which will be good for the country's exports, but will also create a unique knowledge base of algae growth (Casey, 2013). The cost of producing energy from algae is estimated between $8 and $20 per gallon, with expected increase in profits after 3 – 4 years of production (Masdar report, 2015). The UAE is now seriously considering this technology to produce Biofuel (Casey, 2013).

Wind Energy

The wind is intermittent and does not blow all the time in continuous manner. It is imperative to distribute the wind turbines on a wide geographical area. The energy generated from the wind can compete with the energy produced from fossil fuel from an economic perspective. Countries with adequate wind speed more than 1,400 h per year are considered to have economically viable wind energy utility (Alnaser and Alnaser, 2009). Unfortunately, the UAE has recorded adequate wind speeds for 1,176 hours on an average yearly basis; the onshore wind speed in the UAE does not normally go beyond 5.0 m/s and could reach 7.5m/s on the shoreline with an average wind speed between 3.5 -4.5 m/s (Alnaser and Alnaser, 2009). Based on this data, the construction of wind farms in the UAE will not be considered as a good investment. UAE has 13.4% of the year suitable for full load wind operation. (Table 12.3). Hence, the wind can be an additional option in the UAE if constructed on a wide range, but a main renewable energy source.

Country	Wind speed (m/s)	Hour of Full load of wind per year	Wind power (W/m^2)
UAE	3.5-4.5	1,176	57

Table12. 3: Technical overview of the wind energy in the UAE

Biomass energy

Hydrogen can also be produced alongside biomass solids by means of biomass gasification. The obstacles faced by this technology are economical rather than technical due to high investment in the capital and high operation cost. According to statistics, the hydrogen energy that is produced through biomass resources has increased in the UAE by 85% in the 2000s up from 9% in the 1990s. Animal waste contributed 15%, vegetable residues waste made up 65% and cereals contributed less than 1% of the country's entire biomass resources (Kazim, 2003)

As a result, in the year 2000, the production of the hydrogen energy through biomass resources was considered uneconomical due to the high cost. However, the development of this technology since 2010 can reduce the cost of producing hydrogen at an economical rate even on small scale; leaving this option in the UAE open for further research.

Wave Energy

Kazim (2010) defined wave energy "*as a source of renewable energy that is extracted from deep-sea water waves and could be exploited for small-scale applications such as power for residential houses near shores*". Producing energy from waves is associated with obstacles such as irregularities in the wave amplitude, difficulty in constructing power devices and maintaining or mooring them, and difficulty in coupling the wave period with the electrical generator. In the UAE, Kazim, conducted a study on the wave profile of Dubai between the period from 1997 to 2000 in term of height, wavelength, energy period and amplitude, they found that a maximum possible wave power of 16.9 kW/m could be extracted from Dubai during the winter season (Kazim, 2005). Further research is required to investigate the feasibility of this option.

Following the review of the possible options for enhancing the energy sector in the UAE by shifting towards sustainable renewable energy sources, the following sections will discuss the main challenges and the key enablers that need to be considered in this pursuit.

Challenges facing the implementation of renewable energy

A number of challenges were identified in the relevant literature. In the UAE, the findings of most recent research, indicated that the adoption and development of renewable energy in the region are hampered by several obstacles which was congruent with the findings of other scholars as shown in Table 12.4, collated from previous works.

No.	Challenges	Sources
1	Market & Technological barriers	Patlitzianas et al., (2006),
2	Lack of awareness	Patlitzianas et al., (2006),
3	The absence of state sponsorship in the renewable energy sector	Qader, (2009), Mezher et al., (2011)
4	The absence of supporting policies from the state	Patlitzianas et al., (2006)
5	The lack of a legal policy framework for the promotion of renewable energy projects	Doukas et al., (2008)
6	The non-existence of a subsidy from the renewable energy projects	Shum, (2010)

Table 12.4: The challenging factors for the adoption of RE projects in the UAE

The challenges the Government of UAE should consider fall into three categories:

1 **The market and technological barriers**: the lack of awareness in the market, the absence of comprehensive market strategies as well as the intermittent nature of renewable energy source, which is power generated from sources like solar energy cannot provide the same level of power as the conventional fuels.

2 **The policy framework and legislation barriers**: the absence of comprehensive policies and strategies as well as the missing legal policy framework for the promotion of renewable energy are key challenges. The UAE still lacks a regulatory framework that encourages the private sector to invest in the renewable energy market. This requires the Government to consider comprehensive and long-term strategies towards a major change in the regulatory framework. The positive side is that the UAE government seems aware of this and progressing in the right direction.

3 **The financial barriers:** there are concerns about the high capital investment and the lack of a subsidizing mechanism. The findings indicated the need for huge investments, with certified technologies, and high operational cost. Experts in the UAE, interviewed in this study, believed that most of the renewable energy projects globally are successful because of government subsidies and the availability of skilled technicians / human resource. In the UAE there are no government subsidies and there is a lack of human skills which makes the production cost much higher than that of a conventional power.

The key enablers for the adoption of renewable energy

The key enabling factors for the adoption of the renewable energy projects, were identified from the literature. Data analysis in this UAE case study identified the same factors:

- Abundant solar resources
- Depleting hydrocarbon resources

- The rapid development of renewable energy technologies
- The drive to reduce greenhouse gases
- Heavy subsidization from the government
- The rapid growth of energy consumption
- To complement diversification strategies

Despite the domination of conventional resources in the UAE, there are many factors that can be considered as incentives to the mass production of renewable energy.

- To improve renewable energy investment from the private sectors, the government should implement tax reduction and launch subsidies along with spreading awareness of the green energy and how it aids in environmental conservation.
- There is a constantly rising energy demand in the UAE as a result of higher than average economic growth, and huge domestic development projects in the service and infrastructure sectors. Domestic energy consumption has grown by almost 75% since 2000, and is projected to more than double by 2020. (Kinninmont, 2010)
- Forever increasing global energy demand is leading to higher production rates, and the depletion of hydrocarbon resources. The reserve-to-production (R/P) ratio for oil reserves, an indicator of reserve sustainability if production continues at the same rate, has declined. (Al Masah, 2010). These indicators hide the large disparity between countries' resource endowments. While in the case of natural gas, UAE has already begun to import. By implementing the renewable energy technology, UAE will be self-sufficient with no dependence on natural gas resources.
- There is a continual rapid economic growth, substantial population growth, and hydrocarbon production, and according to the climate analysis indicators tool, UAE holds the second place with 27.5 metric tons CO2/capita emissions in the GCC region. (World Resources Institute, 2009). The UAE has to reduce carbon emissions and balance out the demand and supply of energy, which is not only economical but is also environmental friendly.
- UAE region has exceptional solar potential, with the sunshine spread across 320 days a year, and has a range of other renewable opportunities. The country has great financial and technological capacity to improve its renewable energy capabilities. UAE is currently playing a world leading role in the sector by establishing the first IRENA (international renewable energy agency) in the region, in Abu Dhabi.
- UAE has a target to produce 7% of its total energy from renewable electricity generation by 2020. At the same time Dubai has set a target to produce 1% of electricity demand with the solar power by 2020 and increase it up to 5% by 2030.
- Dubai has appointed the Regulation & Supervision Bureau in order to regulate the renewable energy policy in coordination with the Dubai Supreme Council of Energy. The aim for this policy is to encourage the investors and to raise the awareness about the benefits of renewable energy in the region.

The following section will present the details of the most recent Biofuels Refinery in the UAE, the ***Florexx Biofuels Refinery***, based on primary data collected by the authors and Florexx International Investment (2018).. Some commercial names were masked but their designation and role in the project has been identified. All details are real data.

The Florexx Biofuels Refinery

Introduction

The Florexx Biofuels Refinery project comprises of the design, development, financing, construction, ownership and operation of an advanced biofuels refinery at Khalifa Industrial Zone (KIZAD) in the emirate of Abu Dhabi, UAE, with an annual processing capacity of c.530,000 metric tons (MTA). The Project is being developed by Florexx Investment. The project meets market demand and has the following strength:

Market - the Project will mainly supply the US biofuels market with the potential to expand to other markets in North America, Europe, and the Middle East with special attention to the GCC markets.

Products - the Project will produce a set of drop-in products including Green Diesel, Green Jet, Green Naphtha and Green LPG. The products will benefit from a number of renewable incentives that are available in the US as well as European markets.

Parties - XYZ is to be the off-taker for the Project's products while the feedstock/s will be supplied by ABC plc on the other hand, EPC is the EPC contractor and, the Project will use the established UOP Honeywell commercial proved process technology.

Project location - the Project will be constructed on a 690 SqM leasehold plot at KIZAD, linked to Khalifa Port.

Stakeholders – Florexx Biofuel refinery has appointed a financial advisor, an export credit agency (ECA), a legal adviser, a technical adviser, an insurance adviser, an environment adviser and a project management consultant. The financial close for the project is scheduled for the end of Q4 2018. The pre-operation period is expected to be 30 months with Commercial Operations Date (COD) anticipated in 2021. In addition, the total project cost to be financed is approximately $700 million.

Key contractor

Florexx has agreed with the EPC contractor; the O&M contractor; and off-taker, and are progressing the due diligence of each legal agreement by the lenders due to diligence advisers. The EPC and O&M contracts will be structured on the basis of passing down risks from the off-take agreement and supply agreement, as appropriate, on a back to back basis.

In addition, a feedstock supply agreement has been agreed with ABC plc for a minimum volume which exceeds the feedstock requirements of the plant. At the same time, the off-taker agreement is on a 10-year 'netback take or pay' basis for 100% of the volume of the advanced biofuels.

Counterparty analysis

Analysis of the project commercial parties' structure will give a clear image of the project status and stakeholders

Developer sponsor

The sponsor is also the key investor of Florexx International Investment, LLC and of the key investor of a privately held diversified holding group of companies.

Over the past ten years, the sponsor's holding group has made investments in over 20 companies. The sponsor has a number of commercial ventures in the Middle East including investment activities, real estate, oil and gas, transportation, money exchange, travel and tourism, retail, hospitality, building materials and driving centres.

OT PLC: Off-taker

OT handles more than 6 million barrels of crude oil daily sourced from Africa, the Middle East, the Far East, Russia and the Americas which it then sells to refining companies globally. It trades with the major national oil companies, the integrated oil majors and the independent refiners and traders. It trades about 6.5% of the world's oil, and competes with other independent oil traders such as ABC plc.

EPC plc: EPC contractor

EPC plc is a major corporate group in construction contracting and asset management in the renewable energy, oil and gas, water, and infrastructure sectors in the Europe. It is involved in the whole value chain, from design and construction to operation and maintenance and has a presence in more than 30 countries.

EPC delivers turnkey EPC contracts that include in-house engineering, contracts and supply management engineering, testing and engineering for plant start-up, commissioning and performance tests.

EPC plc is listed on the stock exchange with a strong financial background

O&M plc: O&M contractor

O&M plc provides services to the oil and gas industry including operations of onshore and offshore wells, system integration services, engineering consultancy, and repair and maintenance services.

Florexx has agreed a contract with O&M, with a term of ten (10) years from the Commercial Operation Date renewable for an additional two (2) years on a rolling basis to operate and maintain the Biofuel refinery plant.

Florexx, in parallel and with full cooperation with O&M, will build its own expertise to operate and maintain the refinery over the long-term to sustain the refinery operations such that upon the expiry of the contract with O&M, Florexx may choose to utilize its expertise and core competencies developed and may keep O&M as a consultant.

Feedstock Supplier – ABC plc

ABC is a diversified natural resource company and a major producer and marketer of more than 90 commodities with operations in over 150 mining and metallurgical sites, oil production assets and agricultural facilities. It has more than 90 offices located in over 50 countries. A broad portfolio of products helps the company to serve a diverse customer base. An integrated network of operations across geographies serving various sectors helps the company cater to the needs of its large customer base and enhance its revenue.

ABC has the obligation to deliver up to 600,000 MTA of sustainable vegetable oils feedstock if ordered by Florexx, which creates a sufficient buffer for Florexx, whose feedstock requirements are 530,000 MTA.

Florexx has agreed upon a 10-year supply contract renewable for an additional five years for the supply of sustainable and commercial grade vegetable oils feedstock such as rapeseed/ canola oil, soya bean oil, palm oil, palm fatty acid distillate and other required vegetable oils upon availability, with ABC, plc.

Product and market overview

This Project will have a production capacity of c.400,000 MTA of advanced biofuels from the sustainable and commercial grade vegetable oils feedstock (Green Diesel, Green Jet, Green Naphtha and Green LPG). (Figure 12.1)

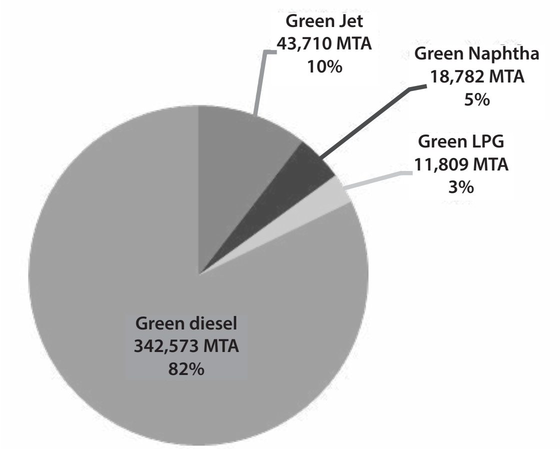

Figure 12.1: Florexx Biofuel Refinery - Breakdown of fuel products by volume for year 1

These green products will produce sustainable and commercial grade vegetable oils feedstock and have the following advantages (Table 12.5)

Products	Benefits	Industry Trends	Producers/ substitutes
Green Diesel	Can be used in modern automobiles without engine modifications, also can be stored and transported in existing tanks, pipelines, trucks, and pumps without infrastructure changes.	The global renewable diesel production is set to increase from 500 kbd today to 750 kbd by 2035 Global demand for transportation diesel will exceed 20 million barrel/day in 2025. Demand of Green Diesel fuel is mainly driven by regulatory announcements and tax credits.	Producers: Diamond Green Diesel, Neste Oil (annual production capacity 2m tons of NExBTL renewable diesel), ConocoPhillips, OMV. Substitutes: biodiesel and diesel
Green Jet	Used for blending in jet fuel in the aviation sector. Demand is mainly driven by enhanced performance and efficiency compared to fossil jet fuel.	Jet fuel consumption is forecast to reach 8 million barrels per day by 2030 (currently approx. 5.5 million barrels per day).	Producers: Neste Oil, Total, Dynamic Fuels, Solena, Virent. Substitutes: Fossil Jet Fuel.
Green Naphtha	Mainly used as feedstock for the production of petrochemicals, Also used in the aviation industry for faster take-off of jet fighters (e.g. F16).	Existing projects in the GCC region can act as offtakers for Florexx's Green Naphtha, such as the	Producer: Neste Oil. Substitutes (other sources of bio-based naphtha) such as fast pyrolysis of cellulosic biomass, conversion of lignin, etc.
Green LPG	Green LPG is chemically indistinct from LPG and its combustion emits 33% less carbon-dioxide than coal and 15% less than heating oil.	Global LPG consumption in 2013 increased by 2.8% year on year to reach 265 million tons per year. Globally, 3% of vehicles are powered by LPG	Producer: Neste Oil. Substitute: Conventional LPG.

Table 12.5: Advantages of green products

The total revenue generated (for year 1) by the fuel products is expected to be ~ $507 million. (Figure 12.2)

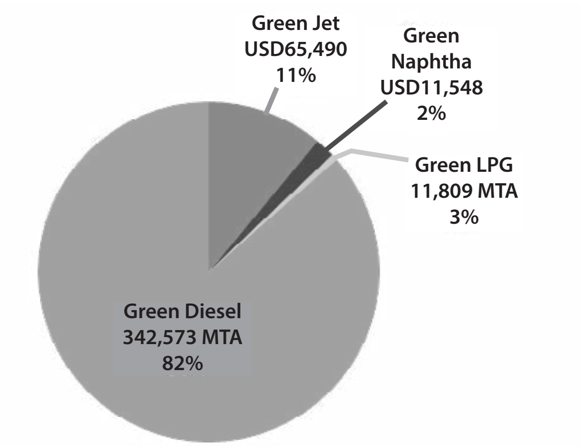

Figure 12.2: Florexx Biofuel Refinery - Total revenue breakdown for year 1 (USD '000)

The produced green fuels are ecologically safe and offer competitive prices. There is an existing green fuels requirement in Europe, Canada, USA, and Asia. According to Clean Edge Inc., a clean-tech market consultancy, the global Biofuels market alone is projected to grow to around USD 140 billion by 2021.

Location overview

The Project will be the first advanced Biofuels refinery to be built in the Middle East and is expected to have a lower cost of production compared to European and US refineries. The Project benefits from the strategic location of KIZAD or Khalifa Industrial Zone, Abu Dhabi, UAE. It is an integrated trade, logistics and operational hub enabling investments by leveraging the integrated services of KIZAD with Khalifa port. (Figure 12.3)

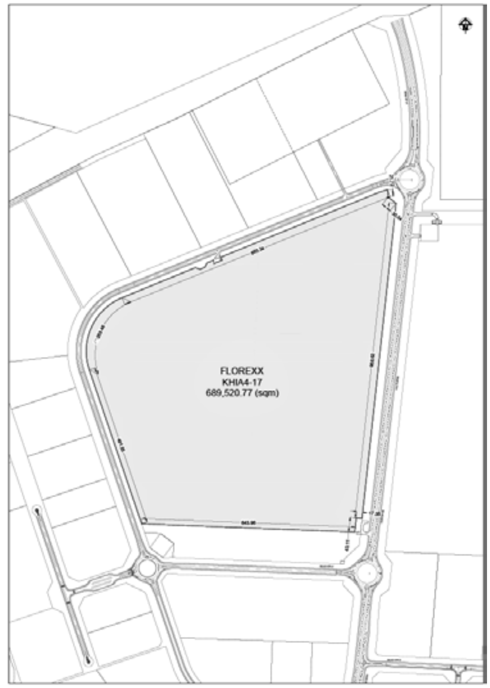

Figure 12.3: Florexx land in KIZAD - Khalifa Industrial Zone, Abu Dhabi, UAE.

Technical Overview

Figure 12.5 outlines the best case assumptions for the required process in terms of output products (based on year 1 volume).

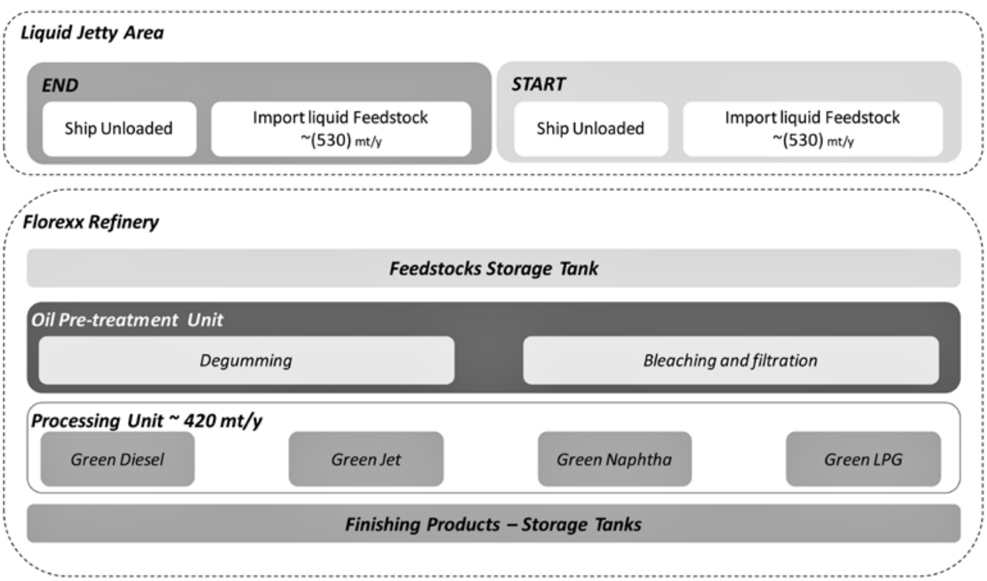

Figure 12.4: Florexx Biofuel Refinery - Technical overview

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The technical specifications envisaged offer several advantages, such as:

1. Feedstock flexible: Processes a wide range of sustainable and commercial grade vegetable oils feedstock, without limiting sourcing capability to one type of feed.
2. Ability to swing anywhere between maximum Green Jet and maximum Green Diesel production to meet market demand.
3. Commercially proven technology.
4. Complying with the Renewable Fuel Standard (RFS) Program issued by the United States Environmental Protection Agency. (EPA, 2015)

Conclusion

This case study highlighted the market, products, parties, project location and stakeholders for the only biofuel refinery in the UAE. In addition, it described an overview of the technical operation for the Biofuel refinery.

Case 12.2: Waste-to-Energy (WTE)Technology in Dubai

Introduction and Background

Dubai is one of the UAE's seven emirates, and has a population of 1.7 million out of UAE's 5 million population, It is considered the second largest emirate after Abu Dhabi, UAE's capital. Nowadays, Dubai has grown steadily to become a cultural hub and a global city in the Middle East and Gulf region. Dubai's economy was based on the oil industry, but the revenues from oil and natural gas nowadays is only less than 7% of the emirate's total revenue, as Dubai's oil reserves are diminishing and are expected to be exhausted within the next 20 years. (Neukirch, 2014). Therefore, the aspects of rapid population growth, strong consumerism trends and fast paced urbanization are major factors which are contributing in generating higher amounts of waste in the city. Approximately, the waste generation in Dubai is 2.7 kg of Municipal Solid Waste (MSW) per capita per day, which is a relatively high number, and is likely to increase. Therefore, a major solution should be to diversify its energy resources before the exhaustion of its oil reserves and to provide a waste management solution (Waste & Recycling ME, 2014). This case study is based on academic research conducted by the 2nd and 4th authors of this chapter in 2014.

Project need

The need for a proper solid waste management and a sustainable energy solution is an essential objective in a growing city like Dubai, where the necessity of deploying a new alternative for open dumping is getting more important with the increasing environmental impacts resulting from the existing MSW waste management practices, the need to diversify energy resources, and the sustainable initiatives and targets that are set by the Emirate. The Dubai Supreme Council of Energy has formulated the Dubai Integrated Energy State 2030 with the aims of diversifying energy resources, so by the year 2030, gas will be providing 71% of Dubai's total power, nuclear energy will be providing 12%, clean coal 12% and solar energy 5%, and efforts will be carried out to reduce the energy demand by 30%. Hence, the

Dubai Municipality (2013) is keen to improve the efforts aimed at the sustainability of energy resources. Other renewable energy resources will have to be considered such as the Waste-to Energy (WTE) technology. Thus, a feasibility study to explore the opportunity and possibility of implementing the first WTE plant in Dubai would initiate the first step in adopting this technology. The UAE was ranked the third highest energy consuming country in the world in 2011 with 16 TOE/capita.

In addition, Dubai's Strategic Plan 2015 is willing to ensure an appropriate focus on the sustainable development within the context of the city's economic growth, and its Waste Management Master plan 2030 target of zero to landfill, will lead Dubai to act in a sustainable manner, aiming to integrate sustainable energy solutions into its energy supply and demand by expanding the use of renewable energy and energy efficiency in local growth patterns. To achieve Dubai's Municipality 2030 Zero Waste to Landfill Target, in 2016, Dubai announced that it is setting the stage to build one of the largest WTE plants in the Middle East, as the US$21 billion global WTE market is forecast to increase by nearly 60% over the next eight years. Dubai Municipality is building a Dh2 billion facility to convert solid waste into energy in Warsan District two, according to Wam, the state news agency. This was in line with the emirate's move to reduce landfill waste by 75% over the following five years). In 2018, it was announced that the implementation period will take three years and the plant will be operational in the second quarter of 2020, during which it will receive 2,000 metric tonnes of municipal solid waste per day in the first phase to produce 60 megawatts. The waste incineration project is the first of the four projects to produce green energy.

Please check figure - at 2k tonnes per day, Dubai would be producing 1/3 of the world's MSW

Waste-to-Energy Technology

Waste to Energy (WTE) is a sustainable energy system that recycles waste, diverts it away from landfills and represents a renewable energy source which cuts greenhouse gases, reduces environmental impacts and provides an additional source of energy to the UAE. The worldwide growth of WTE facilities has increased considerably in the past 30 years as an alternative for disposal of waste in landfills. Two forces have driven its development:

- The need to get rid of the increasing quantities of waste generated by humans which exceeds 2.1 billion tons of Municipal Solid Waste (MSW) annually; and
- The necessity to use sustainable and renewable resources of energy. (Tekin, 2011)

The WTE technology is defined as the "*conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes*." (USEPA, 2014) Indeed, the WTE plants actively recover and generate energy from the MSW to produce electricity, fuel or useable heat and hence contribute to the reduction of carbon emissions, and simultaneously offer a sustainable solution for waste management rather than using landfills as a final waste disposal option. In addition, it serves to avoiding methane emissions, which accounts to 15% of the current GHG global emissions, and avoiding other associated negative environmental impacts such as pollution of soil and groundwater. (Bonam, 2008). The major WTE technologies include the Incineration, gasification, pyrolysis depolymerisation, anaerobic digestion, landfill gas recovery, biomass to alcohol fuels and mechanical biological treatment.

Global current status

There are around 2,200 WTE plants operating around the world in 40 different countries which have a global capacity of approximately 195 million tons of waste per year, and yet

WTE is intensely developing in growing economies as environmental awareness is mounting in response to the significant global increase in MSW quantities and to the concerned waste & energy policies. (EcoProg, 2013). Figure 12.6 illustrates the fast growth rate of the WTE technology from the year 2010 to 2016:

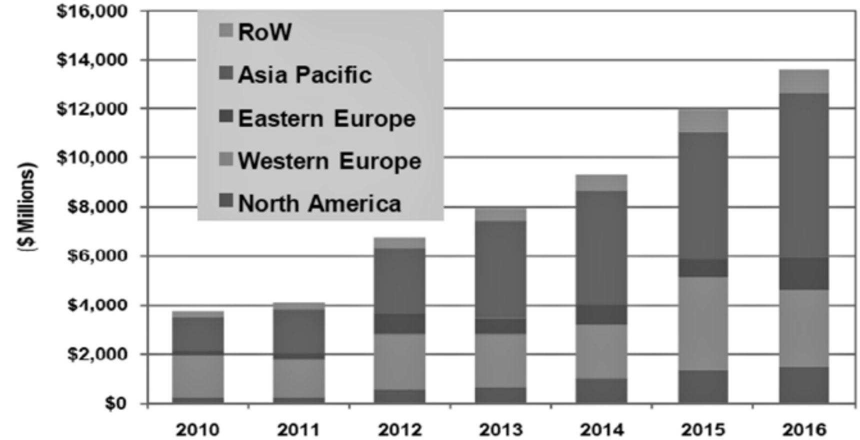

Figure 12.5: WTE revenue by region, world markets: 2010-2016. Source: (EcoProg, 2013)

WTE process	Feedstock	Energy product	Estimated* annual capacity, tons	Continents/countries where applied
Combustion on moving grate	As received MSW	High pressure steam	<168 million	Asia, Europe, America
Rotary kiln combustion	As received MSW	High pressure steam	>2 million	Japan, U.S.A., E.U.
Energy Answers Process (SEMASS)	Shredded MSW	High pressure steam	>1 million	U.S.A.
RDF to grate combustion	Shredded and sorted MSW	High pressure steam	>5 million	U.S.A., E.U.
Circulating fluidized bed	Shredded MSW or RDF	High pressure steam	>11 million	China, Europe
Ebara fluidized bed	Shredded MSW or RDF	High pressure steam	>0.8 million	Japan, Portugal
Bubbling fluidized bed	Shredded MSW or RDF	High pressure steam	>0.2 million	U.S.A.
Mechanical biological treatment (MBT or BMT)	Shredded and bioreacted MSW	RDF to cement kilns and coal power plants	>5 million	E.U.
Direct smelting process	RDF	High pressure steam	>0.9 million	Japan
Thermoselect gasification	As received MSW	Syngas (CO, H2,CO2)	>0.8 million	Japan
Plasma-assisted gasification	Shredded MSW	Syngas (CO, H2,CO2)	>0.2 million	Canada, Japan, France
Global WTE capacity			**<195 million**	

Table 12.6: Capacity, energy production and feedstock of existing WTE technologies. Source: Columbia University, (Themelis et al., 2013)

Looking at the European Union renewable energy production target for the year 2020, WTE technology is expected to contribute 3.6% , however the contribution at a country's level is yet considered to be significant. The global WTE market is summarized in Table 12.6. This indicates that the developed nations have widely adopted WTE technologies in attempts to climb up the Waste Management Hierarchy, which prioritizes the options of sustainable and environment-friendly waste management options over the least favourable, which is the landfilling, where only 20% of global landfilling is estimated to be sanitary. (Themelis et al., 2013). Yet the international experience has proved that after all the possible higher levels of the hierarchy are carried out, a large fraction of solid waste would still need to be diverted away from landfills, but fortunately this possesses potential energy content that could be recovered and utilized.

According to the International Energy Agency, the WTE market is growing massively, and the power produced from global WTE facilities has increased from 2000 to 2006 by 100 terawatt hours, i.e. 35% increase.

Middle East Experience

The Middle East (ME) has witnessed the existence of WTE plants in the GCC region, where the first WTE 34MW Incineration plant has been operational in Qatar since 2011. Following that, a number of developments in this field were limited to the UAE (detailed in the following section) and Kuwait, which is still in the tendering phase for building its first WTE plant. Other ME countries such as Egypt and Lebanon have been carrying out pre-feasibility studies for waste-to-energy projects but which are not operational yet due to political situations. (Loukil and Rouached, 2012)

Rationale for incineration technology

This study selected incineration technology because it is a well-established, widely proven and efficient technology with around 2,000 plants globally and a throughput of 195 million ton of waste per year, therefore it is considered to be the leading technology amongst the WTE technologies (Bee'ah, 2014). The review of the relevant literature identified that the incineration technology has the following advantages over the others:

- Capability to treat different waste streams
- Mature technology and plenty of international existing plants are available
- Production of significant amount of energy
- Less cost compared to other technologies
- Clear process line and low level of risk or uncertainty

The comparison was based on the following criteria:

1 Technical criteria
   a. Efficiency & amount of energy recovered
   b. Risks and uncertainty
   c. International experience level and maturity
   d. Pre-treatment requirements
   e. Capability to treat several waste streams
   f. Upstream waste management

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2 Environmental criteria
  a. Air emissions
  b. Contribution to global warming
  c. Pollution and production of hazardous contaminants
  d. Production of wastewater

3 Social criteria
  a. Public acceptance

4 Financial criteria
  a. Capital cost
  b. Operational cost
  c. Revenues

Aims and benefits of the project

The feasibility study to build a WTE Incineration Plant in Dubai aims to identify the Emirate's economic and environmental opportunities for implementing the project, thus providing the following key benefit:

- First-hand experience: there are no pre-existing feasibility studies for a WTE Incineration Plant in Dubai. This is the vital initiation stage to decide upon the project that will introduce and initiate the implementation of this WTE Incineration plant.

Upon the decision to implement the project based on the above, the benefits will include:

- Provides a solution to the conventional waste management system in Dubai and the increasing waste generation (currently 7,800 ton of MSW per day).
- Reduces the negative impacts of landfills (odour, litter, dust, CH_4, insects, soil and groundwater contamination).
- Diversifies energy resources & reduces dependence on fossil fuels.
- Serves Dubai's national vision and targets for 2030 (Waste Management Master Plan of Zero to Landfill 2030 and the Energy Diversification Target of 2030).
- Environmental benefits such as reduced GHG emissions.

The purpose of this project can be summarised in the following:

- Reducing the quantity of wastes sent to landfills hence providing a sustainable waste management solution.
- Diversifying energy resources in Dubai and reducing the dependence on conventional energy resources.
- Reducing GHG emissions and environmental impacts associated with landfills.
- The byproducts, such as the ash, can be safely treated, disposed of and recycled in construction aggregate, replacing the raw (virgin) aggregate thus reducing the demand on landfills.

Environmental impacts of Dubai's current Waste Management System

Dubai's Emirate generates around 7,800 tons of MSW per day which are collected and disposed of in the overloaded sites such as Al Qusais Landfill, hence it will definitely require implementing a WTE technology to replace the existing conventional waste management system and procedures. (Dubai Municipality, 2014). Dubai's recycling plant currently absorbs 1,000 tons of recyclables per day, therefore around 6,800 tons is estimated to be sent to landfills per day. (Waste & Recycling ME, 2014)

Greenhouse gases

The organic materials accumulated in landfills decompose and form GHG such as carbon dioxide (CO_2) and methane (CH_4). When MSW is incinerated, the aggressive GHG methane gas is not produced. Therefore, once a WTE Incineration Plant is operational it would greatly aid in reducing the GHG in Dubai. (Bonam, 2008; Yang et al., 2012)

Other environmental impacts

Other health and environmental impacts and risks that are caused by the landfills will be efficiently mitigated when the current conventional system of waste disposal in Dubai is replaced with the WTE incineration technology. (Antoine Beylot, 2013).

The health and environmental impacts are:

- GHG (as described above)
- Leachate and surface runoff
- Noise
- Landuse
- Litters and dust
- Odour nuisance and probably smoke
- Vermin and insects
- Increased traffic and transportation caused by the waste collection trucks.

A schematic diagram of environmental impacts from landfills is shown in Figure 12.6.

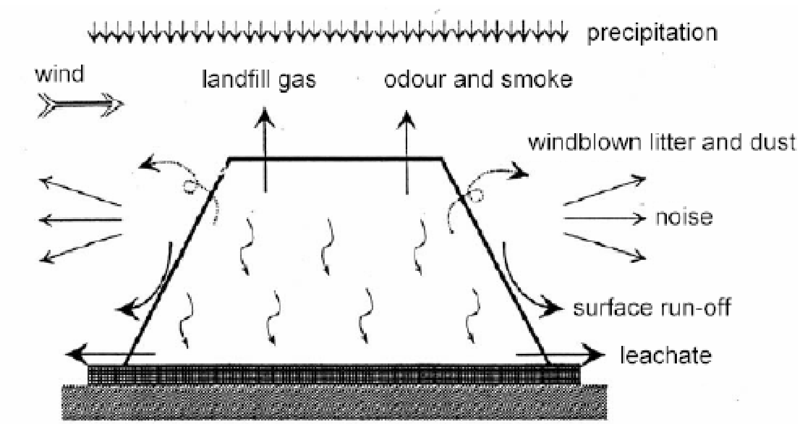

Figure 12.6: Environmental Impacts of landfills

Environmental benefits of a WTE incineration plant

Utilizing the WTE technology would bring many environmental and health benefits to Dubai's Emirate, summarized in the following:

- The incineration of waste generates electricity and hence reduces the GHG and CO_2 emissions from the conventional electricity production plants, The WTE plant avoids 1 ton of CO_2 of equivalent emissions for every ton of MSW incinerated. The CO_2

reduction from the proposed WTE plant is calculated and presented in a different section of this report. (Psomopoulosa et al., 2011)

- The volume of waste sent to landfill will be reduced by 30% as the proposed plant is designed to treat 30% of the current waste generated in Dubai, therefore reduces the methane and other GHG emitted from existing landfills in Dubai and eliminating their negative environmental impacts.

The waste management hierarchy favours the WTE on landfilling but it prioritizes the source reduction of waste, recycling and composting as they promote efficiency in the waste disposal system. However, for the remainder of the waste stream and after the source reduction, reuse and recycling of waste is maximized, the best alternative is to go for WTE instead of landfilling. The waste hierarchy is presented in Figure 12.7.

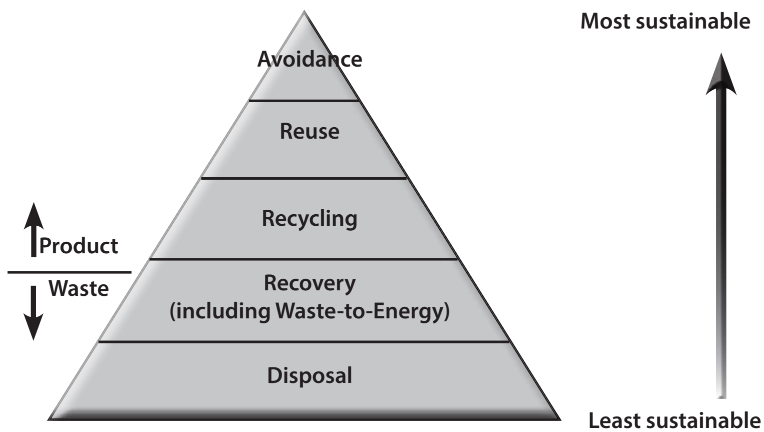

Figure 12.7: The hierarchy of waste management (Zunft, 2009)

Purpose of feasibility study

The main purpose of this work will be in line with the Dubai Municipality's initiative to assess the potential of establishing a WTE plant in Dubai and investigating the feasibility of operating a WTE Incineration plant for the production of electricity, and therefore serving as an initiative for attracting the local government, companies and investors to fund this project as part of the integrated approach and innovative waste management system which will be considering the following objectives:

- The intended users or beneficiaries of this work are primarily the Dubai Municipality waste management authority and other interested investors or institutions involved in financing the public utility projects.
- The whole purpose is to give an outline of the key pre-conditions which should be met in order to make sure the long-term and short -term feasibility of MSW incineration and will further provide a closer understanding at the waste incineration technology as well as the `essential infrastructure required. (Abu Hejleh, 1998)

The feasibility of establishing a WTE plant in Dubai

Generally, the feasibility study will assess the maturity of the existing waste management system, the waste generation quantity and quality (calorific value) and the plant's economic and environmental assessment.

The methodology for carrying out this feasibility study is summarized below:

1. Analysing the factors required for establishing a WTE Plant.
2. Analysing the challenges and potential risks.
3. Calculating the calorific value of MSW in Dubai and its viability.
4. Providing a WTE plant design, assessing the technical viability (energy recovery).
5. Providing investment calculations: cost estimation, payback period, and net present value.
6. Providing carbon reduction calculation.
7. Assessing the overall results and feasibility of the project.

Factors required for establishing A WTE Incineration Plant

Mainly the initial three factors that should be taken into account are:

- **The existing infrastructure for collection of MSW.** The chart in Figure 12.8 has been used to evaluate the readiness of the existing waste management system in Dubai to establish a WTE Incineration plant. The result shows that before introducing the incineration technology, the waste disposal system and landfills should be improved and upgraded to ensure building an integrated and a sustainable waste management system in Dubai.

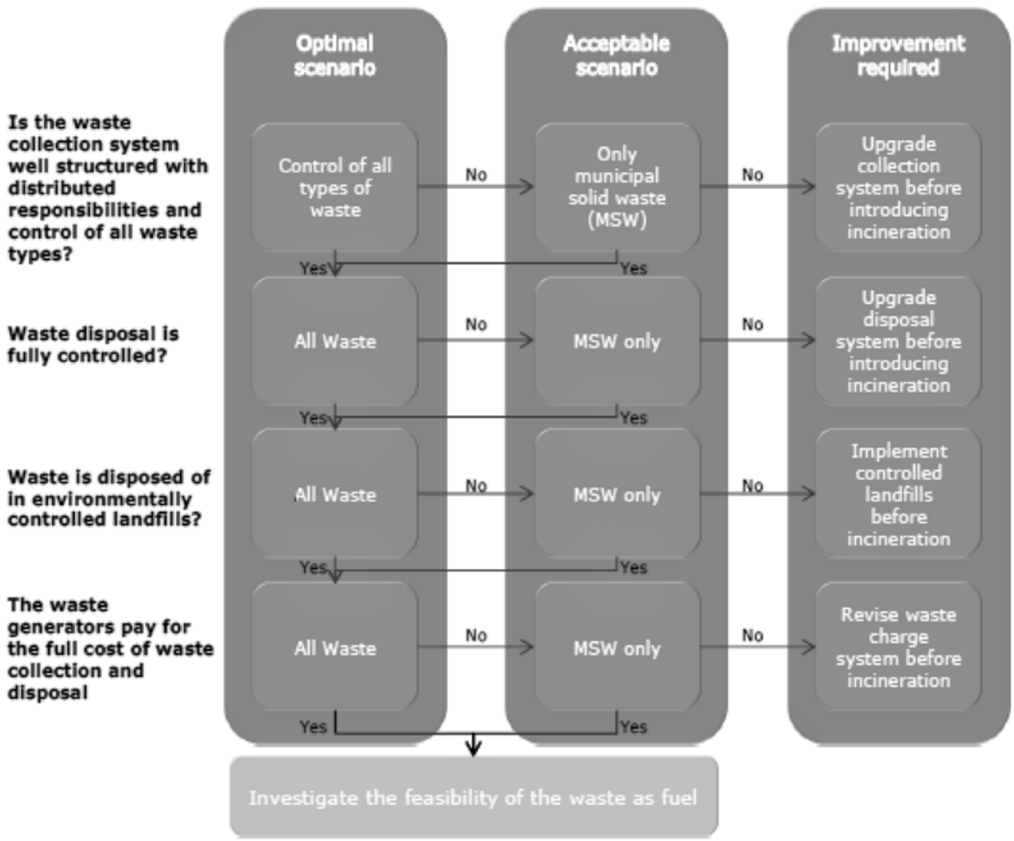

Figure 12.8: Assessment of the existing MSW management systems (Kamuk, 2013)

Can you supply a higher resolution image please?

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- **Use and sale of energy:** The energy that is produced by the WTE incineration plant can be converted to power (electricity), or used as steam (mainly for industrial uses) or used in district cooling or heating (which are not available in Dubai). However for planning the establishment of a WTE incineration plant in Dubai the choice considers the long term perspective, which is converting the energy to electricity and feeding it into the local grid.

An investigation to study the feasibility of converting waste to fuel by checking the organic composition of waste is provided in this report. Tables 12.7 and 12.8 present the main categories of waste generated in Dubai and its characteristics. (Saifaie, 2012)

The waste composition analysis which was carried out in 2012 has shown that 35% of the general waste stream in Dubai was organic waste, which shows a good potential to convert waste to fuel, where the plant's income would depend on the energy's recovered sale and unit price.

Table 12.7: Waste generation in Dubai (Saifaie, 2012)

Waste type	Quantity (tonnes)
General waste	2,689,808
Commercial and domestic waste	6,638,471
Horticultural waste	175,022
Liquid waste	154,119

Table 12.8: Waste characteristics in Dubai (Saifaie, 2012)

Material type	Percentage
Papers	24.3
Plastics	24.2
Glass	3.4
Metal	2.4
Organic waste	35.4
Rubber	1.0
Wood	1.0
Textiles	3.2
Leather	0.9
Residual/inert	1.9
Special wastes	0.2
Miscellaneous	2.2
Total	100

- **Presence of national regulations to regulate the operation of the facility**: Dubai has not developed any national regulations specific to waste incineration and WTE technologies since such technologies have not been broadly introduced yet. However different international norms and standards could be referred to and followed, such as the ones developed by the US Environmental Protection Agency (USEPA) and the European Commission (2006).

Challenges of establishing a WTE Plant

As a new project, a number of challenges and potential risks are associated with establishing a WTE incineration plant despite being a proven technology. The risks are basically economic and pollution risks. These can be mitigated via effective planning and sound engineering. The major potential risks are listed in Table 12.9:

Challenges	Mitigation
1 Risk of poor financial support.	High capital costs can be managed by proper long term planning. Dubai will be looking forward to adopt the project as part of its national vision for diversifying energy resources and Waste Management Master Plan 2030.
2 Expert and skilled staff are essential for the plant's operation and maintenance stages.	Foreign experts can be brought to Dubai Staff can be trained
3 The waste organic composition (calorific value) should meet the minimum requirement which could be challenging.	Waste composition was investigated and calorific value is 6.6 MJ/kg, which is within the accepted range based on the ISWA.
4 Possibility of pollution in case the Air Pollution Control (APC) unit fail to work.	The plant will be equipped with alarm systems and pollution sensors to minimize the impact of pollution in case of failure. Continuous emissions monitoring will be carried out as part of the environmental regulations in Dubai for industrial plants.
5 Since the plant will be operating under high temperatures and pressure then safety is a major concern.	The plant will be following strict HSE procedures to mitigate the high safety risks and concerns and also as part of Dubai's HSE regulations for industrial plants. The plant will be having its specific Emergency Response Plan.
6 Social impact and public not so positive perception of the WTE.	DM should promote an awareness program on the WTE technology to introduce it to people and make them aware of its environmental benefits and eliminate their safety and pollution concerns.

Table 12.9: Investigation of challenges associated with establishing a WTE plant

Lower calorific value of waste

The quantity, organic composition and calorific value of waste is a major factor that the viability of the MSW incineration plant should investigate, and usually the economic state of the city is directly related to the calorific value of waste. When the waste is combusted, its ability to maintain the incineration process without using any supportive fuels depends on the number of chemical and physical parameters of MSW, of which the most important factor is the lower calorific value. The minimum lower calorific value for an incineration process also depends on the design of the furnace, where low grade fuels require the plant to be designed to minimize the heat loss and allows the waste to dry out before the incineration process starts. The water vapour generated from MSW incineration and the moisture content of fuel which disperses with the flue gases accounts for the energy content that represents the difference between the fuel's lower and upper calorific value. The upper calorific value as per the DIN 51900 is defined as the released energy content for every unit weight via the overall incineration of fuel, The average calorific value should be at least 7 MJ/kg but not below 6 MJ/kg. Table 12.10 shows the approximate common calorific value for the MSW fractions.

Table 12.10: Approximate calorific value for MSW fractions (Kamuk, 2013)

Fraction	Calorific value (MJ/kg)
Paper	16
Organic material	4
Plastics	35
Glass	0
Metal	0
Textiles	35
Other material	11

Looking at Tables 12.7 and 12.8, which show the waste characteristics and a breakdown of the MSW waste in Dubai, and calculating the approximate calorific value based on Table 12.10 then the parameters shown in table 12.11 can be estimated:

Table 12.11: Calculation of Dubai's waste calorific value (assuming plastic is recycled).

Waste Fraction	Percentage	Quantity kg/day	Calorific value MJ/kg	Calorific value per day MJ/kg
Paper	24.3%	1,895	16	3.88
Organic material	35.4%	2,761	4	1.41
Plastics	24.2%	1,888	35	-
Glass	3.4%	265	0	-
Metals	2.4%	187	0	-
Textile	3.2%	250	19	0.6
Other material	7%	546	11	0.77
Total		7,800		6.66

Table 12.11 shows that the calorific value of the waste in Dubai is estimated to be within the acceptable range, at 6.6 MJ/kg, excluding plastic waste, as it is recyclable. In practice, even if it is recycled a percentage of plastic waste will still be available in the total MSW. The result shows that the total calorific value of the MSW in Dubai is viable and that it is feasible to incinerate the MSW and convert it into energy.

Before the initiation of the project, there should be a detailed laboratory waste analysis and sampling of the MSW generated in Dubai, to calculate an accurate lower calorific value. Figure 12.9 further illustrates the steps that should be taken into consideration to assess if the waste is viable to be converted into energy.

Energy sale assessment

Since Dubai has no district cooling and where energy will most likely be fed into the local grid then seeking energy as power using a steam boiler and a turbine seems to be the optimum option. Figures 12.10 illustrate the steps required before making this decision.

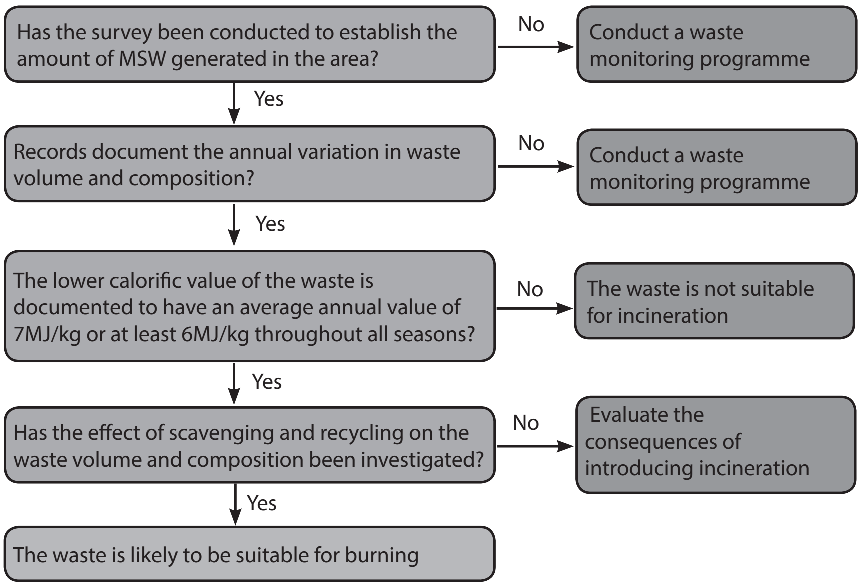

Figure 12.9: Assessment of waste as fuel

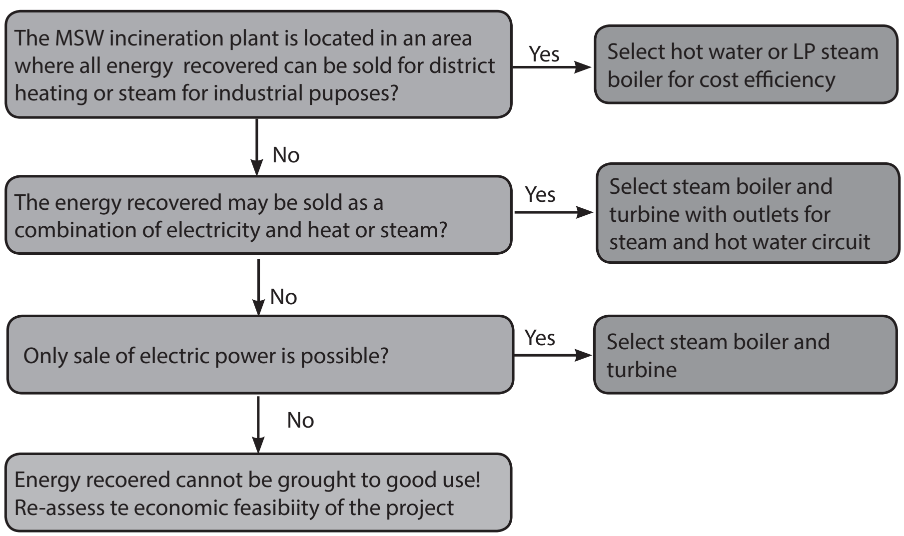

Figure 12.10: Assessment of the recovered energy's sale (Kamuk, 2013)

Investment calculations

The investment calculations are a very important section of the WTE Incineration plant feasibility study in order to check the viability of the plant from an economic aspect. The calculations will be tailored to the assumptions and estimations made in this project.

Different methods for investment calculations can be used, including cost estimation, payback period and Net Present Value (NPV) where the discount rates will be assumed, however the calculations will be made without taking taxes into consideration, as they are not applicable in Dubai. The lifetime of the project is assumed to be 20 years.

Cost estimation

High capital cost and investment are associated with the waste incineration involving high construction, operation and maintenance costs. Therefore the net treatment cost for every metric ton of waste for waste incineration is much higher than landfilling.

Factors affecting the investment costs

The actual cost for investment of a WTE incineration plant is dependent on a number of factors such as the capacity and size of the plant, the total MSW metric tons generated each year and the calculated lower calorific value of the MSW. It is important to note that, based on the World Bank WTE incineration guideline, the lower the capacity of the plants the more expensive they are compared to high capacity plants. The type of machinery associated with investment cost depends on the method of energy production and sale; whether it is to produce heat, power, or a combined heat and power production. In addition, the level of required emission quality affects the cost of the equipment needed for the flue gas treatment. In our case design, the factors are further analyzed.

Energy production

The proposed plant is to produce steam primarily for production of electricity. Therefore, the machinery and equipment to be obtained are mainly associated with the steam boiler, turbine units and cooling units. An estimate of the cost parameters of equipment involved in electrical output is presented in Table 12.12 to provide a general understanding of the approximate costs of each of the WTE Incineration plant components.

Table 12.12: Estimates of the WTE incineration plant investment costs (Udomsri et al., 2010)

Component/subsystem	Scale parameter	Specific cost
Gas turbine	Electrical output	260$/kW$_e$
HRSG	Thermal output	80$/kW$_e$
Steam equipment and others	Electrical output	220$/kW$_e$
Civil works, controls & balance of power system	Electrical output	114$/kW$_e$
MSW, ash , material hauling	MSW capacity	10$/(t/y)
MSW combustor & related civil works	Thermal output	110$/kW$_e$
MSW boiler & flue gas duct	Thermal output	130$/kW$_e$
MSW flue gas treament & related civil works	Flue gas flow	50$/(m^3/h)

Initial calculation of the equipment required based on Table 12.12 is carried out based on the plant's yearly power production (43 MW or 43,000 kW):

Gas turbine: 260$ × 43,000 = 11,180,000 $

Steam equipment and others: 220$ × 43,000 = 9,460,000 $

Civil works, controls and balance of power system: 114$ × 43,000 = 4,902,000 $

MSW, ash material hauling: 10$ × 43,000= 430,000 $

MSW flue gas treatment and related civil works: 30$ × 9,000 m3/h = 270,000 $

The total capital cost = 26,242,000 $.

Operating and maintenance costs

These include the fixed and the variable operating costs, and the maintenance costs. The fixed operating costs include the cost of salaries and administration, which depend on the number of employees, the number of experts and unskilled engineers and staff, and the level of wages/salaries in Dubai. The variable operating costs includes the cost of chemicals used in the flue gas treatment system, cost of water and wastewater treatment, residue disposal and maintenance costs such as those associated with maintenance of equipment, the buildings and other facilities.

The investment cost graph (Figure 12.11) of the World Bank Technical Guidance Report for MSW Incineration was used. Since the plant's annual capacity is 730,000 metric tons of waste per year then the investment/ capacity cost is 280 million US $.

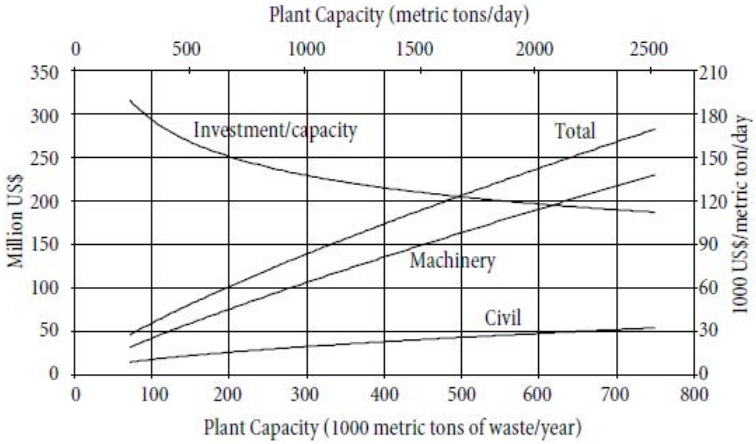

Figure 12.11: Investment costs (Kristaliana Georgieva, 1999)

Another calculation is required to validate the investment cost value previously calculated. This is based on figures provided by the International Solid Waste Association (ISWA). The costs for middle income countries with a calorific value and a labor cost higher than those of low income countries is in the magnitude of 400 to 600 USD per yearly tonnage capacity. The cost for European and North America which is around 600-900 USD per ton of waste generated in a year The World Bank considers UAE to have high income.

However, for the sake of this study, the investment cost figure for low and middle-income countries will be used for this plant due to the closer nature and lifestyle of the local population and residents within the UAE to the former rather than the latter. A detailed investigation of the demographics of the UAE population (countries of origin, culture, etc.) can verify and justify this claim, but this falls beyond the scope of this study.

Since the plant's yearly MSW generation is 730,000 tons, the investment cost should be $730{,}000 \times 400 = 292$ million US $. This high investment cost has taken into consideration that the plant will be equipped with a highly advanced combustion and air pollution control system, and operate for an availability of more than 90% (8,000 hours a year).

The two methods used to calculate the investment costs have given close figures. The value of 292 million US $ will be used in the following financial calculation.

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Payback Period

The payback period is defined by the time required for an investment to pay off, where the calculation is based on the yearly cash flow. The equation used to calculate the payback period is:

Investment cost / yearly cash flow = payback time

According to the Dubai Energy State Report 2014, the price for 1 kWh of electricity is AED 0.45. As calculated previously, the plant's capacity is 379,600 MWH or 379,600,000 kWh per year. If this electricity is sold to the local grid for the price in Dubai, the plant's income from the sale of electricity is 379,600,000 × 0.45 = 170,820,000 AED or 46,800,000 US$. The yearly cash flow is the sales income minus the costs for the plant such as the staff salaries, chemicals, transportation to and from landfill, maintenance and the support fuel costs. A percentage of 15% of the yearly income will be used to represent these costs, hence the yearly cash flow is 46,800,000 – 46,800,000 × 0.15= $39,780,000.

The payback period would be 292,000,000 / 39,780,000= 7.3 years.

Net Present Value

The net present value (NPV) will assess the economic feasibility of the project based on a yearly rate of return or a pre-determined discount rate. If the result of NPV is positive then it means that the investment is economically feasible. The discount rate used in the NPV calculations is 6%, where this discount rate was chosen to take into account the uncertainty of the future cash flow. The equation used to calculate the NPV is provided below:

$$\sum_{n=0}^{y} \frac{CF}{(1+r)^n} = PV$$

$I - PV = NPV$

r = Discount rate
y = economic lifetime, depreciation time
I = Investment cost
CF= Yearly Cash Flow

The economic lifetime of the plant is 20 years and the NPV is $60,189,801. Since the NPV value is positive it proves that the project is economically feasible.

Carbon reduction

Although WTE Incineration plants produce clean energy, they have environmental impacts from the emissions of GHG and pollutants, but if environmental comparison is made over the lifetime of the project then it will definitely show that the WTE incineration plant, being a sustainable project, will significantly lead to CO_2 and GHG reductions in comparison with the existing landfills. However, the extent of the CO_2 emissions released from MSW incineration depends on the technology used and the composition of waste.

When MSW is landfilled and not incinerated, methane is emitted to the atmosphere. According to the ISWA methane is a far more potent GHG, and contributes 23 times more to global warming than CO_2.

The CO_2 balance net reduction will consider the GHG emissions for every MWH generated by the WTE, against the CO_2 produced by a conventional coal power plant and the alternative of landfilling or in other words the avoidance of landfilling.

Carbon reduction calculation

The carbon reduction or the carbon credit is calculated based on the factors given by the United Nations Framework Convention for Climate Change (UNFCC), as seen in Figure 12.12. The findings indicated that:

1. 0.6 tons of CO_2/MWH is emitted from WTE plants (middle column). If the proposed plant's electricity production is 379,600 MWH then the CO_2 annual emissions are 227,760 tons of CO_2.
2. MSW in landfill emits the equivalent of 3.3 tons of CO_2/MWH. Therefore the landfill emissions saves from the same amount of waste as the WTE proposed plant is 1,252,680 tons of CO_2 per year.
3. If the proposed WTE plant generates electricity, it will replace an electricity power station that is run by oil or natural gas. Assuming oil is used then the CO_2 annual emissions saved is 1 ton of CO_2/MWH which equals to 379,600 tons of CO_2 per year.

As a result, the net CO_2 reduction expected from the establishment of the proposed WTE Incineration plant in Dubai is: _ 227,760 +1,252,680 + 379,600 = 1,404,520 tons of CO_2 per year. This proves that the project is highly sustainable, environmentally feasible and provides a cleaner resource of energy in Dubai.

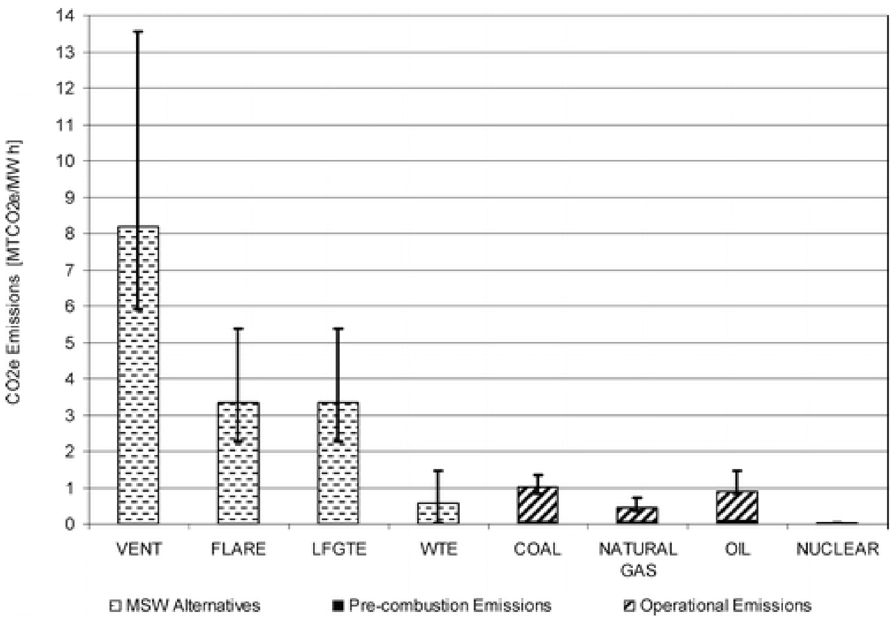


Figure 12.12: CO_2 emissions (metric tons CO2/MWH) of different energy resources

Assessing the overall results and feasibility of the project - SWOT Analysis

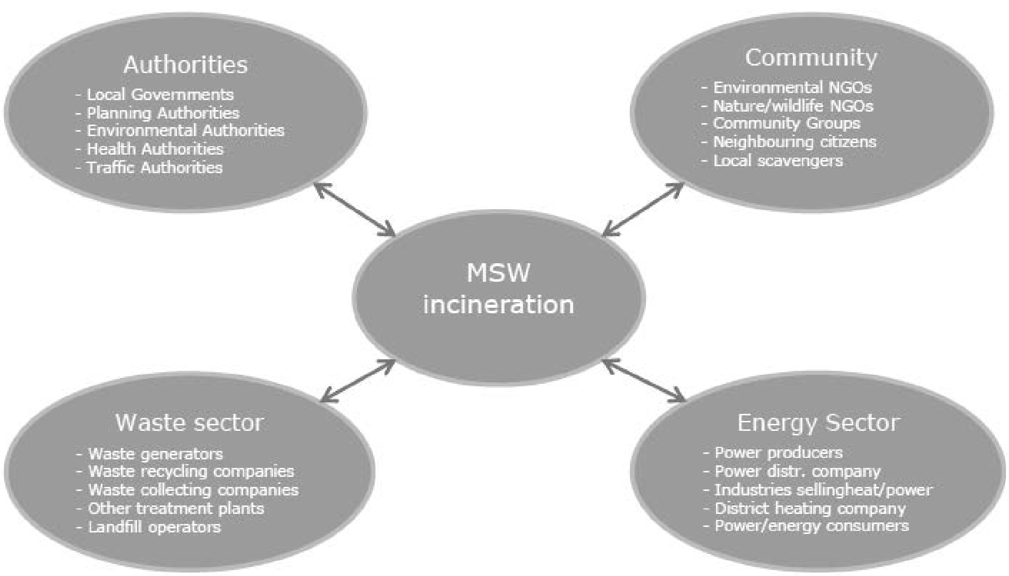
A SWOT analysis has been performed to evaluate the strength, weakness, opportunities and threats associated with the project (Table 12.13).

Table 12.13: SWOT Analysis

Strengths - New source significant amount of energy - Treats multiple waste streams - No direct contact with waste is required, reducing health concerns associated with waste management. - Mature, established and a reliable technology - No pre-treatment of MSW is required - Reduces volume of waste up to 90% - Reduces environmental negative impacts associated with landfills	**Weaknesses** - No local regulations related to the WTE technologies in Dubai. - By-products bottom ash and fly ash. - Incineration requires a sophisticated air pollution control system and gas cleaning monitoring. - High capital costs - Generally, low electrical efficiency (≈35%) - If waste has low lower calorific value, then the efficiency of the plant reduces
Opportunities - Serves Dubai's National Vision and Targets for 2030 (Energy diversification and zero to landfill) - Auxiliary heat can be used to sustain the process - Provides an improved and integrated waste management system - Reduction in CO2 and GHG emissions - Bottom ash can be recycled & diverted away from landfill and used in aggregate & concrete - Improve the sustainability reputation of Dubai - Reduces Dubai's dependence on fossil fuels - Can treat infectious or hazardous waste.	**Threats** - Poor management would lead to environmental pollution and foul odour - Seasonal variability in waste composition might lead to unstable performance of incineration - Safety concern - Public opposition. People living in Dubai are not much aware of the WTE technology. - Other WTE technologies might receive enhanced support more than the incineration putting it at a competitive disadvantage - If waste input quantities fall below design levels, technical problems can happen

Stakeholder Map

The stakeholders expected to be involved are represented in Figure 12.13.



Can you supply a higher resolution image please?

Figure 12.13: Typical stakeholders involved ina MSW incineration plant (Kamuk, 2013)

Recommendations

The project for building the WTE Incineration Plant in Dubai will undergo three phases: feasibility assessment; preparation and implementation. This case study served as a feasibility assessment and a preliminary investigation of the proposed WTE plant. The study showed that the project is feasible ,taking into consideration these recommendations:

1. The lower calorific value should be calculated in a practical method in laboratories by sampling and analyzing the MSW composition generated in Dubai to ensure the accurate lower calorific value is included in the design calculations.
2. Dubai Municipality is recommended to generate its own regulations and legislations for WTE technologies.
3. Dubai Municipality is recommended to carry out an awareness program on WTE incineration technology before the initiation of the project.
4. The second phase of the project (preparation) will involve the detailed drawings and specifications of the project. It is recommended that a specialist engineering consultancy experienced in building international WTE plants should be assigned the detailed planning, designing and construction of the project.
5. Emergency response plans should be prepared specifically for the proposed project.
6. Sorting of MSW input is recommended to ensure that recyclables are completely segregated before they are incinerated.
7. The Air Pollution Control (APC) equipment should be up to the latest and highest standards to ensure air quality allowable limits in Dubai are not exceeded.
8. Dubai is recommended to improve its existing landfills into controlled landfills as the proposed WTE plant will treat only 30% of the MSW generated.

Suggested project milestones

To wrap this case study, we present a high-level project plan that indicates the main three main phases with a breakdown of each phase into key milestones where the main delivers of each milestone as well as the duration are listed (Figure 12.15).

Phase and Step		Purpose and Issues to Consider	Duration
Feasibility Phase	Prefeasibility Study	Waste quantities, calorific values, capacity, siting, energy sale, organization, costs, and financing	6 months
	Political Decision	Decide whether to investigate further or to abort the project	3 months
	Feasibility Study	Waste quantities, calorific values, capacity, siting, energy sale, organization, costs, and financing in detail	6 months
	Political Decision	Decide on willingness, priority, and financing of incineration plant and necessary organizations	6 months
Project Preparation Phase	Establishment of an Organization	Establishment of an official organization and an institutional support and framework	6 months
	Tender and Financial Engineering	Detailed financial engineering, negotiation of loans or other means of financing, and selection of consultants	3 months
	Preparation of Tender Documents	Reassessment of project, specifications, prequalification of contractors and tendering of documents	6 months
	Political Decision	Decision on financial package, tendering of documents and procedures in detail and final go-ahead	3 months
Project Implementation Phase	Award of Contract and Negotiations	Prequalification of contractors. Tendering of documents. Selection of most competitive bid. Contract negotiations.	6 months
	Construction and Supervision	Construction by selected contractor and supervision by independent consultant	2 1/2 years
	Commissioning and Startup	Testing of all performance specifications, settlements, commissioning, training of staff, and startup by constructor	6 months
	Operation and Maintenance	Continuous operation and maintenance of plant. Continuous procurement of spare parts and supplies.	10–20 years

Figure 12.15: General implementation project plan for establishing a WTE Incineration Plant. Source: adapted from (Kristaliana Georgieva, 1999)

References

The refernces for these case studies can be found in Chapter 12 of *Principles of Sustainable Project Management*.

Arab States of the Gulf: constraints & efforts, *Energy Policy*, 34(18), 3719-26.