Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical Investigation for Muharraq Governorate

By

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Declaration

This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy. It has been composed by myself and has not been submitted in any previous application for any degree.

Abstract

Organic Household Waste (OHW) fraction of the Municipal Solid Waste (MSW) has become a point of focus globally due to its harmful effects on the environment if it is not managed properly. OHW represents the highest waste composition amongst most of the high-income developing countries including Bahrain, signifying a major opportunity in the realm of conversion technologies. Thus, exploring the opportunity for OHW management through selecting the most preferable technology option for the Bahraini context based on its organic waste characteristics seems to be necessary, especially considering the harmful effects of dumping solid waste into the landfill; it may also represent a possible alternative to natural gas, which is the primary resource of energy used to generate power in Bahrain. This research aims to explore the opportunity for OHW management technology options using the "Case Study" methodology in Muharraq Governorate. By developing a parameter/technology matrix based on literature review and the experimental phase which will be achieved through OHW characterisation in the lab (that is considered important criteria of the preferred technology option selection), the results will then be matched with the matrix to select the most preferred technologies. The Economic Criteria is important for the technology selection decision making; thus, a cost-benefit analysis was conducted for each technology in the Bahraini context. The Social Criteria is also important in selecting the preferred technology for decision making; the public awareness measured for people in Muharraq Governorate as an important key factor to ensure the success of any waste management practices in the country. Furthermore, interviews were conducted with experts in order to explore the enablers and barriers to the OHW technology adoption in Bahrain. Research objectives were achieved via quantitative and qualitative approaches, including empirical sampling and lab analysis of OHW of Muharraq Governorate. This study involved chemical and physical characterization, surveys, questionnaires and semi-structured interviews, Microsoft office "Excel", SPSS including ANOVA, t-test and nvivo 12 for data analysis. The research may provide sufficient information for future adoption of evidence-based technology selection in order to manage OHW adoption in Bahrain, which contributes to the decision and policy-making processes. It may also provide a better understanding of OHW characterization in Bahrain, which may help further researches.

List of Abbreviations

$ - US Dollar

AOC - Assimilable Organic Carbon

AD - Anaerobic Digestion

AHP - Analytical Hierarchy Process

ANOVA - Analysis of Variance

ASTMD - American Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste

BMW - Bio-medical Waste

BOD - Biological Oxygen Demand

C & D - Construction and Demolition

C & I - Commercial and Industrial

C:N - Carbon to nitrogen ratio

CBA - Cost-benefit Analysis

CDM - Clean Development Mechanism

CFA - Confirmatory Factor Analysis

CDM - Clean Development Mechanism

CER - Certified Mission Reduction

CH_4 - Methane

CHP - Combined Heat and Power

CO_2 - Carbon Dioxide

COD - Chemical Oxygen Demand

DOC - Degradable Organic Carbon

DSR - Design Science Research

E-Waste - Electronic Waste

FA - Fatty Acids

GCC - Gulf Cooperation Council

GCCC - Gulf City Cleaning Company

GHG - Greenhouse Gas

GHSM - General Hierarchy Structure Model

GMI - Global Methane Initiative

OHW - Organic Household Waste

OHWM - Organic Household Waste Management

HW - Hazardous Solid Waste

IGCC - Integrated Gasification Combined Cycle

IPCC - Intergovernmental Panel on Climate Change

ISWM - Integrated Solid Waste Management

IVC - In vessel Composting

Kg – Kilogram

LFG - Landfill Gas

LHV and HHV - Lower Heating Value and Higher Heating Value

MBT - Mechanical Biological Treatment

MCDA - Multi-Criteria Decision Analysis

MRF - Mechanical Recovery Facility

MSW - Municipal Solid Waste

MSWM - Municipal Solid Waste Management

MWMUPA - Ministry of Works, Municipalities and Urban Planning Affairs

N_2O - Nitrous Oxide

NCV- Net Calorific Value

No. - Number

NO_x - Nitrogen Oxides

NPDS - National Planning Development Strategies

O_3 - Ozone

OECD - Organization for Economic Co-operation and Development

OFMSW - Organic Fraction of Municipal Solid Waste

OHWM - Organic Household Waste Management

PBP – Payback Period

RDF - Refused Derived Fuel

SO_x - Sulphur Oxides

SWM - Solid Waste Management

SWOT - Strength, Weakness, Opportunity, Threats

TAN - Total Ammonia Nitrogen

TOC - Total Organic Carbon

UNEP - United Nation Environmental Program

UNFCCC - United Nations' Framework Convention on Climate Change

USEPA - United States Environmental Protection Agency

VOC - Volatile Organic Compounds

WtE - Waste to Energy

WCTSA - Waste Characterization-based-Technology Selection Approach

CHAPTER 1: Introduction

1.1. Background

In the modern era, consumption habits of individuals resulting from the contemporary lifestyles have led to a severe problem of wastage, especially in large cities. This issue is now being addressed at the international level (UNEP, 2017; Al-Ansari, 2012). Solid waste management is considered to be a critical challenge that is faced by modern societies (Zafar, 2016) that is harmful to human health as well as to the environment at large. The increase in economic and developmental activities of a city reflects its growth and directly affects the production and consumption patterns, which in turn leads to an increase in waste generation.

The problem of waste generation and characterization has proliferated due to urbanization, population growth and inadequate management of waste, which is considered as one of the most compelling issues of urban environmental degradation. Waste generation can be classified from the perspective of solid waste generation into Municipal Solid Waste (MSW), Construction and Demolition Waste (C&D), Hazardous Solid Waste (HW), Bio-medical waste (BMW) and Electronic Waste (E-waste).

Poor waste management leads to various public health and environmental problems. Against this backdrop, appropriate practices of waste collection, disposal and implementation of sound solid waste management practices are imperative in every city (Al-Sabbagh, 2012).

It is widely accepted that MSW, including the household solid waste that generally consists of organic waste, poses a serious threat to the sustainability of cities worldwide. Thus, it is important to implement suitable waste management technology options in accordance to the waste's characteristics to mitigate the harmful impacts on environment, economy, and society.

In developing countries, a large part of the municipal solid waste flow is contrbuted by organic biodegradable waste, which originates from households, including peelings from fruits and vegetables, food remnants, and leaves (Bobeck, 2010). It is imperative to focus on OHW as it represents the majority of MSW composition in developing countries that gets dumped into the landfills, not to mention the environmental damage. This discipline provides a significant opportunity to explore the superior technology for the effective management of this problem.

Selection of the most preferable OHW management technology option suitable for the Bahraini context plays a vital role in the decision making pertaining to the waste management in the country. This research aims to explore the opportunity of preferred OHW management technology options based on OHW characteristics, considering the economic feasibility of the technology option to the country, and to explore the enablers and barriers to each technology adoption for Muharraq Governorate as a case study. Considering the fact that public awareness is a key enabler to technology adoption in any society, it seemed necessary to measure public awareness toward domestic waste management in Muharraq Governorate.

It has been acknowledged that waste characterisation is considered to be an essential criterion to select the superior technology for managing the OHW for successful and effective technology adoption (Zafar, 2016). From this perspective, it seems necessary to identify the optimum OHW characteristics for each technology by reviewing the literature and developing a parameter/technology matrix in order to match each parameter required by each technology to explore the most preferred technology using an empirical investigation model for Muharraq Governorate OHW for characterisation. Based on the literature review, it was observed that there was no specific matrix for the OHW and technologies, and it therefore, represents an advancement to the literature.

This research consists of three main phases: to begin with – theoritical phase, which includes the literature review which leads to develop the parameter/technology matrix. Empirical phase, which includes sampling, lab analysis and matching process which leads to the selection of a preferable technology for Bahraini context on the basis of waste characterization. This is folowed by a socio-economic phase, which explores the enablers and barriers to the technology adoption chosen. Cost-benefit analysis is applied to identify the feasibility of the selected technologies in Bahrain. This may help decision makers define a preferable technology for any future OHW strategy deployment. In addition, this research aims to evaluate public awareness toward the household waste management through a survey that targets the population of Muharraq Governorate's population.

This chapter provides an introduction to the current state of waste management and posits MSW as a global issue. Furthermore, an overview is provided for the OHW as well as technology options of its management.

1.2. MSW and OHW Management as a Global Issue

Waste management can be regarded as a 'basic human right.' Ensuring the provision of proper sanitation and solid waste management in addition to the provision of potable water, shelter, food, energy, transport, and communication forms part of an essential right for the society and the economy as a whole (UNEP, 2017).

According to UNEP (2017), Municipal Solid Waste (MSW) can be identified as: "a waste type that predominantly includes household waste (domestic waste), except industrial and agricultural wastes, with sometimes the addition of commercial wastes collected by a municipality within a given area".

Globally, it has been found that MSW is growing rapidly as compared to the rate of urbanization. Cities worldwide currently generate about 1.3 billion tonnes of solid waste per year. By 2025, this volume is expected to increase to 2.2 billion tonnes. Approximately 3 billion urban residents are generating 1.2 kg per person per day. This is likely to be raised to 4.3 billion urban residents by 2025, generating about 1.42 kg/capita/day of municipal solid waste (2.2 billion tonnes per year) (World Bank, 2012). However, landfills have been unable to adequately recycle materials to the soil towing to limited space and the high volumes of MSW generated. In addition, the gasses released by landfills include about 40percent to 50percent methane (CH4), a potent greenhouse gas (GHG) with the global warming potential 23 times that of CO2. (UNEP, 2017)

Figure 1.1 shows the Global Municipal Solid Waste Composition Percentages in 2012, while figure 1.2 illustrates the total MSW Disposed of worldwide.

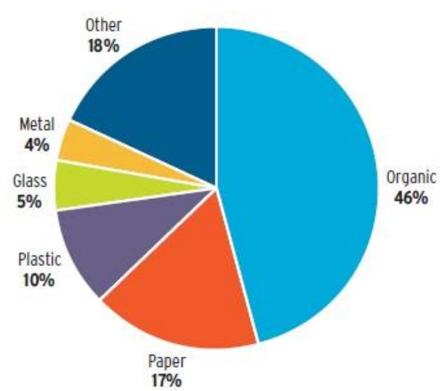

Figure 1.1: Global Solid Waste Composition Percentages (2012)

Source: (Hoornweg and Bhada, 2012)

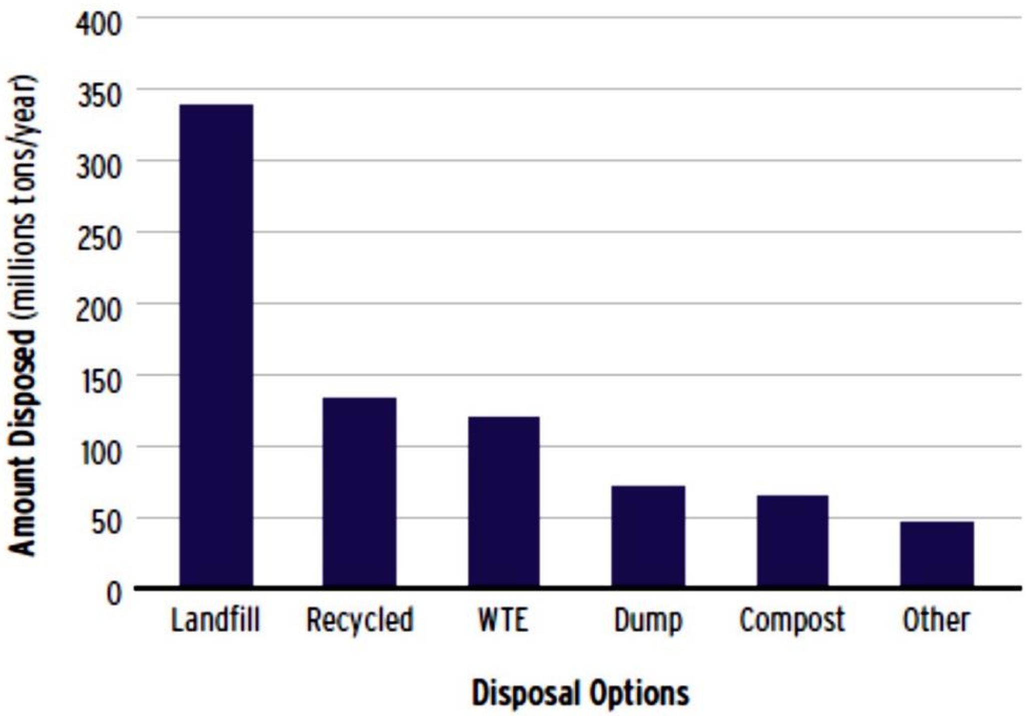

Figure 1.2: Total MSW Disposed of Worldwide

Source: (Hoornweg and Bhada, 2012)

According to World Watch Institute (2014), MSW tends to be generated in higher quantities in the wealthier regions of the world. Members of the Organization for Economic Co-operation and Development (OECD), a group of 34 industrialized nations, lead the world in MSW generation, at nearly 1.6 million tonnes per day. By contrast, sub-Saharan Africa produces less than one-eighth of the total amount, 200,000 tonnes per day. According to US Environmental Protection Agency (2007), Americans produced about 251 million tons of trash in 2012 alone. It is equivalent to the individual waste generation of 4.38 pounds per person per day.

The list of top 10 MSW-generating countries includes four developing nations (Brazil, China, India, and Mexico) owing to the size of their urban population and because of the fact that their city dwellers are prospering and adopting high-consumption lifestyles. (World Watch Institute, 2014). Parts of East Asia, Eastern Europe and the Middle East are exhibiting the highest rates of MSW growth.

The relentless increase in MSW generation rate worldwide may exacerbate the harmful impact on the environment as there is a high correlation between MSW generation rate and GHG emissions (Hoornweg and Bhada, 2012). Poor waste management leads to various public health and environmental problems. For this reason, proper practices in the waste collection, disposal and the implementation of sound solid waste management practices are an imperative need for every city (Al-Sabbagh, 2012).

Quantities of municipal waste generated in cities will continue to increase as countries become wealthier. This is attributed to the continuous growth in Gross Domestic Product (GDP) accompanied by a growing population and the increasing inclination towards city life. This increase is particularly prominent in low- and middle-income countries.

1.2.1 Waste Management in the GCC Countries

The GCC countries rank among the highest waste generating countries per capita in the world (Al-Sabbagh, 2012). It has been estimated that the total amount of waste generated in the GCC range from 90 million to 150 million metric tonnes annually, with the UAE being the highest generator per capita at approximately 2.2 kg. The amount of recycled waste is around 5percent of the total, with the rest being accounted for landfills or, even worse, to illegal dump sites. The amount of waste generated is expected to grow rapidly to anywhere between 1.5 and 2 times of the current volume in 2021.

The Kingdom of Bahrain forms part of the list of Gulf Co-operation Council (GCC) countries. Al Ansari (2012) has argued that changes in consumption patterns of countries in the Gulf Co-operation Council (GCC), have led to an increase in the MSW dumping. Thus, waste management protocols need to be re-evaluated in order to establish methods that contribute to minimizing greenhouse gas emissions, improving the efficiency of resource management, and designing more eco-friendly management plans in GCC states. (Table 1.1 illustrates the volume of solid waste by country)

Table 1.1: The Volume of Solid Waste in the GCC by Country

VOLUMES OF SOLID WASTE BY COUNTRY		
Country	Waste per capita (kg/day)	Total waste (million tonnes/year)
Bahrain	1.8	1.5
Kuwait	1.5	2.1
Oman	1.2	1.85
Qatar	1.8	2.5
Saudi Arabia	1.3	13
UAE	2.2	4.89

Source: (Eco-waste, 2018)

It has been highlighted that KSA and UAE are contributing over 80 percent of the total MSW in the GCC. Meanwhile the overall composition of waste in the GCC has not changed much. There might have been a slight increase in C & D waste and a proportional decrease in MSW, but the changes are in the range of a few percentages and vary by country, depending on the local environment (construction activity, industry size, population growth).

The composition of the waste would generally suggest that a large part of it is biodegradable. However, this is not reflected in common waste management practices in the GCC, where most waste goes to landfill. In countries like Bahrain, Qatar, and the UAE, landfill space is running low and this practice is becoming a major problem.

1.3. MSW Management Options

Generally, an effective management of solid waste includes planning, policy-making and execution, assessment, reporting, and legislation. Elements of solid waste management may include, wholly or partially, the control of waste generation, storage, collection, transfer and transport, processing (i.e. segregation), and proper disposal (Municipal Solid Waste Management Manual, 2014). These tasks may collectively be assigned to a single authority, or distributed among authorities that are closely associated with each other. In either case, it is the responsibility of the assigned authority to ensure that disposal of solid wastes is carried out in congruence with the best principles of public health, environment protection, and sustainable development.

Different research projects, technical studies and researches have been performed nationally and internationally in various parts of the world to investigate the best methods of solid waste management (ElQuliti, 2016).

Moreover, waste-to-energy technologies are used to convert municipal solid waste elements, such as paper, plastics, and wood in order to generate energy by thermochemical or biochemical conversion processes. The thermo-chemical techniques include combustion, gasification, and pyrolysis wherein high levels of heat could be produced in a short reaction time. The biochemical processes consist of anaerobic digestion (AD), hydrolysis, and fermentation. The most common technique of waste-to-energy is combustion, which entails the burning of municipal solid waste to create steam for heating or to generate electricity Williams (2005) demonstrated the efficacy of Waste Treatment Technologies: Pyrolysis, Gasification, Composting and anaerobic digestion in waste treatment and disposal while Cheng et al. (2014) pointed out at the MSW incineration as a very important waste management technology. An overview of MSW material flow and its different utilization and treatment options are illustrated in figure 1.3.

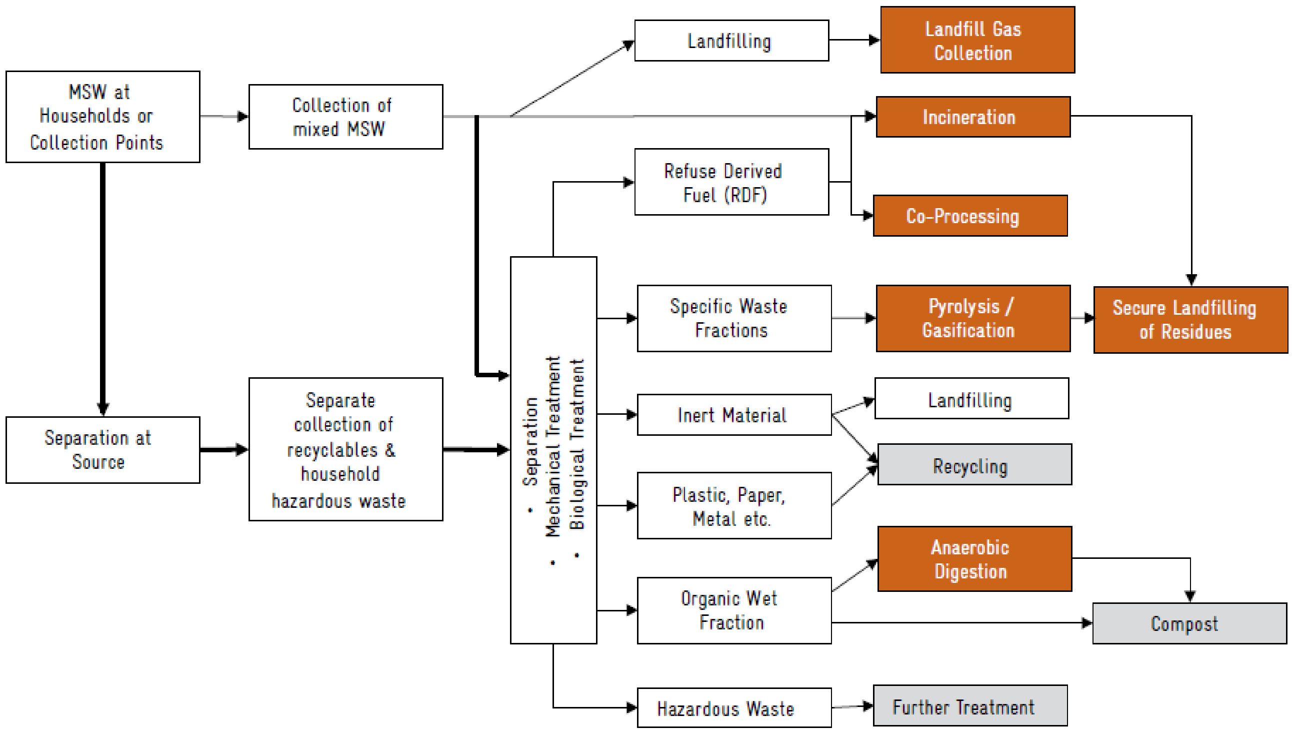

Figure 1.3: Overview of MSW material flow and its different utilization and treatment options.

Source: Mutz et al., (2017)

In the West Asian Region, the landfill is considered as an effective MSW disposal method due to its practicability and affordability. Al-humoud (2005) estimated that 47percent of the total MSW produced by GCC countries is compostable material and could be a potential feedstock for composting. Recycling MSW in these countries can save up to 20percent of land space required for disposal. However, the most comprehensive form of recycling available in such countries is the recycling of paper and cartons. According to a case study on MSW attitudes in Kuwait, 89percent out of a total of 1439 citizens are willing to separate food and dry recyclables from their daily waste (Koushki et al., 2004). Therefore, initiating segregation at source could be an initial step to ensure successful recycling in such countries (Al-Sabbagh, 2010).

1.4. Integrated Solid Waste Management

Integrated solid waste management (ISWM) reflects the need to approach solid waste in a comprehensive manner with a careful selection and application of appropriate technology, working conditions, and the establishment of a ‘social license’ between the community and designated waste management authorities (most commonly, local government). ISWM is premised on both a high degree of professionalism on behalf of solid waste managers and on the appreciation of the critical role that the community, employees, and local (and increasingly global) ecosystems play in effective solid waste management. It is important that ISWM be guided by clear objectives and based on the hierarchy of waste management grounded on 3 R’s: reduce, reuse, recycle - frequently adding a fourth ‘R’ for recovery (World Bank, 2012). Implementing such an integrated and comprehensive whole-system approach can help managers minimize waste production from the source and bring down its harmful effects (IPCC, 2009; Christensen, et al., 2009).

Most of the waste management guidelines and policies implemented in the GCC countries are built on the internationally-approved scientific approach adopted by the integrated waste management hierarchy (Figure 1.4). The waste hierarchy refers to the “3 R’s”-reduce, reuse and recycle, based on their order of importance (Hansen et al., 2002). This hierarchy establishes the desired priorities of waste management programs based on sustainability since problems pertinent to waste management cannot be solved solely by using technical solutions (Figure 1.4) (IPCC, 2013).

Although most of the MSW produced in these countries is generally decomposable and recyclable, almost whole quantities of waste are disposed of in the form of landfills (World Bank, 2012). Based on the 3R’s principle, Integrated Solid Waste Management (ISWM) system has been developed and may be considered as an advanced waste management system (UNEP, 2017).

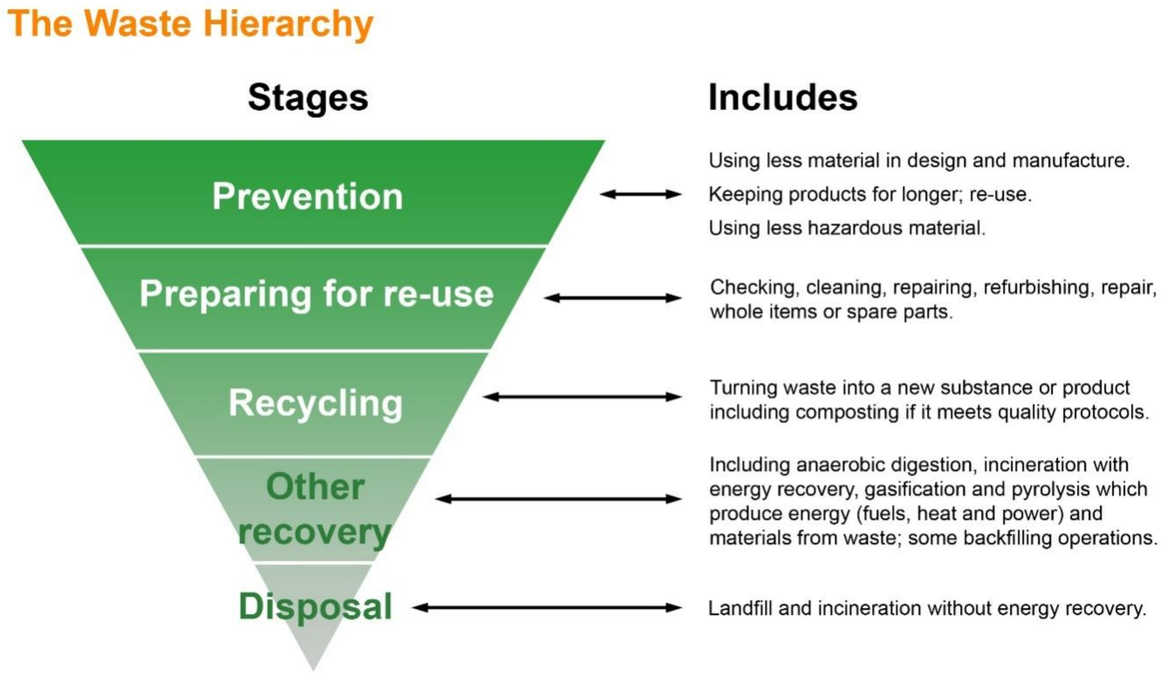

Figure 1.4: The Integrated Waste Management Hierarchy

Source:https://www.letsrecycle.com/news/latest-news/waste-hierarchy-challenges-and-opportunities/

The waste hierarchy outlines the environmental preference of recycling over incineration and land filling. From an energy recovery viewpoint, Arafat et al. (2013) claimed that it is best to recycle paper, wood, and plastic; to anaerobically digest food and yard wastes; and to incinerate textile waste.

1.5. Impact of Municipal Solid Waste

1.5.1. On Human Health, Animals and Aquatic life

There is a heightened risk to health and environment due to insufficient treatment and management of solid wastes. Generally, workers in this field are exposed to direct and potentially fatal health concerns (World Bank, 2012). As a result, these people need to be protected from direct contact with waste. Waste treatment in hospitals and clinics is another important source of risk. (El-Fadel et al., 1997)

With the incorporation of the MSW involving industrial uncontrolled hazardous wastes, high risks to human health may occur. The concentration of heavy metals in the food chain creates tangible risks to human health (El-Fadel et al., 1997). When these wastes and leachates are discharged into open dumping sites of MSW or drainage/ sewerage system, they end up creating a vicious cycle; making the recurrence of problems such as follows (Bingemer and Crutzen, 1987):

1. Chemical poisoning through inhalation
2. Cancer
3. Congenital malformations
4. Neurological disease
5. Nausea and vomiting
6. Eating fish with high levels of mercury
7. Plastic found in oceans ingested by fish and birds
8. High algae population in rivers and sea.
9. Degraded water and soil quality

1.5.2. Impact of Solid Waste on Environment

Waste decomposition is the main source of environmental pollution and the developing countries experience this problem more frequently. Despite the high level of advancements in terms of environmental standards, few current landfills within these countries meet these environmental standards. This problem is, partly, due to rapid urbanization and development (World Bank, 2012). Organic waste decomposition produces many gases collectively known as greenhouse gases (GHGs). However, the gas released by the degradable waste (mainly methane, $CH4$) is the primary cause of environmental concern. Normally, the proportion of methane under anaerobic condition in the landfill is 50 percent of the total gases (World Bank, 2012). However, in a high-moisture content landfill, methane proportion may increase beyond 50 percent (World Bank, 2012). The problem with GHGs is their contribution to the rapid climate change, in general, and global warming, in specific.

1.5.3. Green House Gases (GHG) Emissions

When solid waste (SW) is disposed in dumping sites and landfills, most of the organic material will be degraded, ranging in a wide span of less than one year to 100 years or more (Frøiland-Jensen and Pipatti, 2002). Most of the degradation processes will be bio-degradation involving bacterial activity. This biodegradation process will be either aerobic or anaerobic, which is predicated on the conditions of the site where the solid waste is disposed (Frøiland-Jensen and Pipatti, 2002).

The main degradation products of biodegradable materials are carbon dioxide (CO_2), water and heat for the aerobic process and methane (CH_4) and CO_2 (or the GHGs) for the anaerobic process (Bogner and Matthews, 2003; USEPA, 2016). A greenhouse gas can be defined as *"...a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range"* (IPCC, 2017). The anaerobic route is known to be a major cause of the greenhouse effect. The main greenhouse gases in earth's atmosphere can be summarized as following (IPCC, 2009):

1. Water Vapour (H_2O)
2. Carbon Dioxide (CO_2)
3. Methane (CH_4)
4. Nitrous Oxide (N_2O)
5. Ozone (O_3)

Universally, most MSW is discarded in non-regulated and ill-designed landfills, which generate landfill gas (LFG). LFG is produced when organic material decays anaerobically, consisting of 40percent to 60percent carbon dioxide (CO_2), 45percent to 60percent methane (CH_4) gas, and 2percent to 9percent other gases which are frequently emitted into the atmosphere (Metz et al., 2007). According to estimates from the IPCC, the methane emission from landfills accounts for 3–19percent of the anthropogenic causes globally and is known to be a huge contributor to global warming after agricultural activity and losses from fossil fuel distribution, respectively (Metz et al., 2007).

It has been postulated that, in the absence of the anthropogenically generated GHGs, the average temperature of earth's surface would be about 15 Celsius degree, as opposed to the current average of 14 Celsius degree (Karl and Trenberth, 2003). Methane, generated from MSW is 23 times more harmful than the same volume of carbon dioxide (IPCC, 2009). One of the key places for methane generation is landfills, which leak harmful GHGs to the atmosphere that then contribute to global warming. Currently, landfilling is the commonly used method to dispose off MSW in developing and industrial countries (Mor et al., 2006).

Since the effects of methane are not confined to a local place and end up crossing boundaries, which merits serious consideration. For instance, the CH_4 produced and released into the atmosphere contributes to global warming, and its emission needs to be estimated and reported (Bogner and Matthews, 2003). One of the main reasons for the significant climate change is global warming. Global warming can be defined as *".... a gradual increase in the average temperature of the earth's atmosphere and its oceans, a change that is believed to be permanently changing the Earth's climate"* (Gillis, 2015).

Today, global warming is, scientifically, better understood as a result of dedicated efforts of scientists all over the world. Despite a plethora of information on this topic, global warming remains a controversial issue. According to the IPCC, researchers are more than 95percent confident that global warming is mainly initiated by increasing concentrations of GHGs and other human industrial or anthropogenic activities (IPCC, 2013).

Moreover, methane is replete with high energy value, which makes it economically viable to be recovered and utilized (Ljungberg et al., 2009). For this reason, a good amount of methane produced in landfills can be trapped and used as a renewable energy source to produce electricity. The concentration of methane in the atmosphere is growing globally 0.6-0.8percent per year (Galle et al., 2001). The USEPA has estimated that the world-wide methane release from landfills was 30-70 million tonnes in the year 2000 (Themelis et al., 2007).

1.5.4. Impact of Waste Dumping

When waste is not managed carefully, it has negative effects on human health, especially for those living in close proximity to disposal sites. Waste, when not disposed of properly, has also a range of environmental impacts on air, water, and land; for example, a decay of organic waste contributes 5 percent to greenhouse gases globally. Waste is a significant economic drain, especially on city budgets: frequently, 50percent of a city's budget is spent on waste management. In addition, the inefficient use of scarce resources is reflected in materials discarded and abandoned as waste represents a substantial economic and environmental cost. Methane emitted from landfills accounts for 12 percent of total global methane emissions (World Bank cited in USEPA, 2012). Landfills account for nearly half of the methane emissions attributed to the municipal waste sector in 2010 (IPCC 2007). The level of methane emission from landfills varies by country, depending on waste composition, climatic conditions (ambient temperature, precipitation) and waste disposal practices.

The U.S. Environmental Protection Agency (USEPA) projects worldwide methane emissions from landfills to touch 800 million metric tonnes by 2020. Other than CH_4, gasses emitted by landfills can pose health risks to surrounding communities that are directly exposed to the site. Moreover, certain landfills produce leachate—a potentially polluting liquid that contains dissolved substances from water percolating through the landfill. This leachate may then enter the surrounding environment, threatening underground aquifers and other water supplies, causing a major health risk to both surrounding ecosystems and the human population (Hochman et al., 2015).

In social parlance, waste has a disproportionate impact on the poor and marginalized in cities, towns, and villages. Waste pickers earning a meagre income on the fringes of the waste management industry, particularly women, are frequently among those who experience most difficulty making a viable place for themselves in local economies.

Nevertheless, waste also represents a widely untapped opportunity. Proper waste management presents an opportunity to not only avoid the detrimental impacts associated with waste, but also to recover resources, realize environmental, economic and social benefits besides embarking on the journey to a sustainable future (AlAnsari, 2012; AlSabbagh, 2012).

1.6. Organic Household Waste

Organic waste is produced anywhere human habitation exists. The primary forms of organic waste are household food waste, agricultural waste, human and animal waste. Bobeck (2010) has argued that as a result of the critical increase in solid organic waste all over the world, the sustainable management of this organic waste is paramount in modern times. It involves preventing depletion of natural resources, minimizing risks to human health, reducing environmental burdens and maintaining an overall balance in the ecosystem (Sharp, 2010).

Organic waste is the primary component of municipal solid waste in developing Asian countries. Most of this waste is discarded by means of open dumping and landfill. As a result, it is generally a food source of pests and disease carriers such as houseflies and rodents. In addition, it degrades rapidly and generates foul odour.

On the other hand, waste can be used as a source of nutrients for soils and bio-energy (Sharp, 2010). In addition, proper management of this waste can significantly contribute to climate change mitigation. Some municipalities view these benefits as an opportunity to improving their waste management practices. Some of them implement organic waste utilization projects, such as composting and anaerobic digestion. However, since many authorities confront challenges and constraints during the implementation, other municipalities hesitate to implement similar activities (Sharp, 2010).

In recent years, problems attribted to the disposal of food waste to landfills has led to increased interest in developing innovative alternatives due to the high proportion of organic matter in food waste. First-generation food waste processing technologies include waste to energy (e.g., anaerobic digestion), composting, and animal feed. Based on the characteristics of food waste, an integrated approach should be adopted with a firm focus on food waste reduction and separation, recycling commercial and industrial food waste, volume reduction of domestic food waste and energy recovery from food waste.

With regard to GHG, organic household waste has contributed the most to the emissions from various types of waste. In most developing countries where the organic content of waste is high, improper management of waste (e.g., open dumping and landfill of organic waste without gas recovery and open burning of plastic waste) may lead to higher GHG emissions in the future. In Thailand, for example, MSW contains a high proportion of organic waste. The government is facing the predicament of GHG emissions from landfill, while most local states do not have sufficient budget and staff with the requisite technical and managerial skills to administer and improve the waste management systems. (Sharp, 2012)

Metson and Bennet (2015) contended that landfilling of organic waste needs large land areas. Proper treatment of organic waste leads to recovering energy from the decomposition process of organic waste, as well as essential plant nutrients for the agriculture sector, including nitrogen and phosphorus. There is a multitude of ways to recover energy and nutrients, but changing current practices necessitates changes in attitudes and practices by stakeholders.

Moreover, the Australian Waste National Report (2013) has argued that the organic waste category presents one of the greatest opportunities for further action owing to the following factors:

1. The amount currently being sent to landfill. For example, the amount of food waste sent to landfill as a proportion of total reported waste was between 30 and 46 percent for municipal solid waste and 15 percent for commercial and industrial waste
2. The impact on landfill, which includes the production of the potent greenhouse gas methane and potentially polluting leachate
3. The potential to avoid greenhouse gas emissions. For example, it is estimated that every tonne of mixed food and garden waste or only garden waste that is recycled avoids the emission of 0.25 and 0.33 tonnes of carbon dioxide equivalent respectively
4. The range of possible end uses for recovered materials, including redistribution by food charities with potential energy and water savings
5. The organic recovery efforts reducing the potential for contamination of otherwise readily recyclable materials, such as paper and cardboard
6. Cost savings from the reduced purchase of food products that are wasted e.g. A study on commercial and industrial (C&I) waste and recycling in Australia by the industry division estimated the input costs of food waste disposed off is $8.24 billion for waste to landfill, and $2.29 billion for recyced waste.

Urban organic waste is considered one of the elements of biomass feedstock. Biomass is the world's fourth-largest energy source, following coal, oil and natural gas. Biomass appears to be an attractive feedstock for three main reasons. First, it is a renewable resource that may be sustainably developed in the future. Second, it appears to have formidable positive environmental properties including reduced GHG emissions, reduced NO_x and SO_x based on the fossil fuels displaced. However, it is not imperious to some negative impacts, such as emission of polycyclic aromatic hydrocarbons including polycyclic aromatic hydrocarbons, dioxins, furans, volatile organic compounds, and heavy metals, especially when combusted in traditional stoves. Third, it appears to have a significant economic potential as long as fossil fuel prices will increase in the future.

1.7. MSW Profiling & OHW Characterization

Waste characterization is a method used to determine the types of materials being discarded in a waste stream and in what proportion; this may include physical and chemical characterization of a specific component,e.g. organic household waste. Resulted information can help policymakers and city planners reduce landfill waste, set up recycling programs, and conserve money and resources. In fact, a waste characterization study typically precedes waste diversion studies and strategies.

Characterization studies allow cities to map their entire waste stream as well as to identify gaps so that they can focus their efforts on diverting the most appropriate materials that will have the most significant impact. Depending on local conditions, material types selected for study can be based on the volume being generated, the difficulty of collection and processing, or recyclability and reuse potential. Each city has to determine as to which material types and selection criteria are most beneficial for their own purpose; having this information will make the process easier and improve diversion efforts. Thus, the criterion of waste characterization is mainly considered for technology selection in this research study as it is imperative for the success of technology operation by providing suitable feedstock to it.

1.8. Organic Waste Management Technologies

In general, six main OHW management technologies are considered as the most common worldwide. These technologies categorized under three main categories: Bioconversion technologies which include Anaerobic Digestion (AD) and Composting; Thermochemical conversion technologies which include Pyrolysis, Gasification and Incineration; and the Physical-conversion technology, which includes the Refused derived fuel (RDF). Each technology will be explained in greater detail to understand its requirements and operation. Figure 1.5 summarizes the OHW technologies considered in this research:

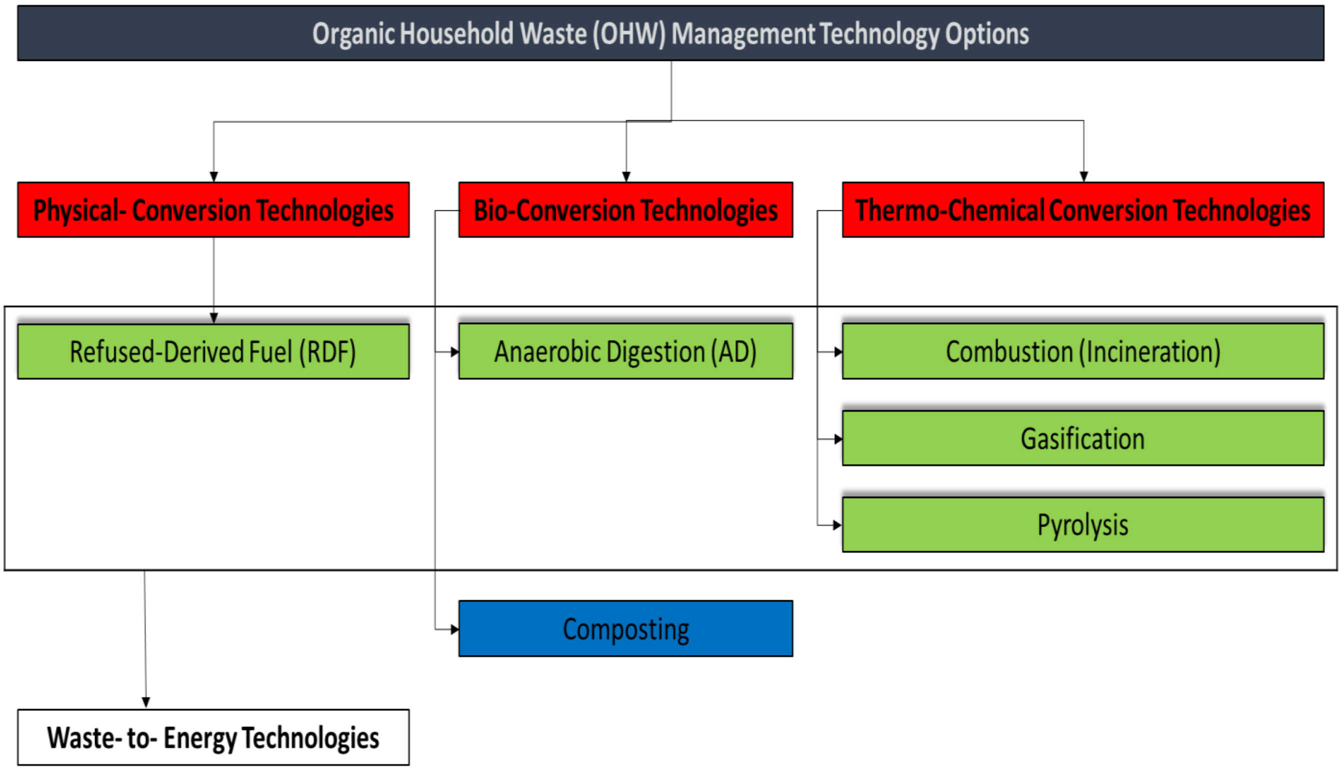

Figure 1.5: The OHW Management Technology Options Considered in this Research

These technologies are listed below with an overview:

1.8.1. Anaerobic Digestion (AD)

AD refers to the process by which organic material is broken down by micro-organisms in the absence of oxygen, thus producing biogas, a methane-rich gas used as a fuel, and digestate, a source of nutrients used as fertiliser (Mutz et al., 2017). Furthermore, it is an essential method to treat food waste due to its techno-economic viability and environmental sustainability. The relevance of biogas technology lies in the fact that it makes the best possible utilization of food waste as a renewable clean energy source (Zafar, 2015). This technology will be explained in greater detail in Chapter 2.

1.8.2. Composting

The composting process is a complex interaction between the waste and the microorganisms within the waste. The microorganisms that carry out this process fall into three groups: bacteria, fungi, and actinomycetes. Notably, actinomycetes are a form of fungi-like bacteria that break down organic matter. (Zafar, 2015)

Composting can be categorized into three major segments: anaerobic composting, aerobic composting, and vermicomposting (Zafar, 2015). Aerobic composting denotes the process by which organic wastes are converted into compost or manure in the presence of air. In this process, aerobic microorganisms break down organic matter and produce carbon dioxide, ammonia, water, heat and humus, a relatively stable organic end-product (Zafar, 2018). While the organic matter is decomposed in the absence of air in anaerobic composting, organic matter may be collected in pits and covered with a thick layer of soil and left undisturbed for six to eight months. Anaerobic microorganisms dominate and develop intermediate compounds, including methane, organic acids, hydrogen sulfide and other substances (Zafar, 2015).

In Vermicomposting, certain species of earthworms are used to enhance the process of organic waste conversion and to produce a better end-product. It is a mesophilic process utilizing microorganisms and earthworms (Zafar, 2018). This method will not be considered in this research, since it is not common and entails complexities. The study will consider and refer to common composting (aerobic composting) as Composting in this study.

1.8.3. Combustion (Incineration)

Direct combustion is most commonly used technology for converting biomass to heat. During combustion, biomass fuel is burnt in excess air to produce heat. The first stage of combustion involves the evolution of combustible vapors from the biomass, which burns flames. The residual material, is burnt in the form of charcoal in a forced air supply to provide additional heat. The hot combustion gases are sometimes used directly for product drying, but they usually pass through a heat exchanger to produce warm air, hot water or steam.

According to Eco-waste, (2018), different technical approaches can be taken, but the most common waste-to-energy technology is incineration, which entails the burning of waste in the presence of high volumes of air, thereby producing flue gas and heat. The heat and hot gases boil water to produce steam, which then drives turbines to generate electricity. The technology is mature, efficient and waste does not need to be pre-treated prior to incineration. Moreover, more than 2,000 plants worldwide use this approach. 500 kilowatt hours of electricity are typically produced for each tonne of waste burnt.

1.8.4. Pyrolysis

Pyrolysis is the thermal decomposition of biomass that occurs in the absence of oxygen. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes (Yang et al., 2018); it occurs naturally during the first two seconds. The products of biomass pyrolysis include biochar, bio-oil and gases including methane, hydrogen, carbon monoxide, and carbon dioxide (Zafar, 2018)

1.8.5. Gasification

Biomass gasification involves burning of biomass in a limited air supply to give a combustible gas that comprises of carbon monoxide, carbon dioxide, hydrogen, methane, water, nitrogen, in addition to contaminants like small char particles, ash, and tars. The gas is then cleaned to render it suitable for boilers, engines, and turbines so as to produce heat and power (CHP) (Zafar, 2018).

Each of the above technologies has its optimum OHW characteristics requirements to operate optimally and deliver the best results. Thus, these technologies will be the first line in the matrix to ascertain their optimum ranges of the specific parameters to be discussed in greater detail in Chapter 2.

1.8.6. Refused-Derived Fuel (RDF)

RDF is the product of processing municipal solid waste to separate the non-combustible from the combustible portion, and preparing the combustible portion into a form that can be effectively fired in an existing or new boiler (EPA, 2018). Thus, RDF is considered as a physical preparation-stage technology normally held in a Mechanical Biological Treatment (MBT) plant to maximize the calorific value of the waste feedstock. This research study considered this technology for the feasibility and suitability of Muharraq Governorate's OHW. Further details of the above technologies will be mentioned in Chapter 2.

1.9. Research Overarching Aim and Objectives

Based on the background above, it was evident that it is vital to explore the opportunity for OHW management technology options that are deemed most appropriate for Bahraini OHW represented by Muharraq Governorate. Thus, the overarching aim of this research is to explore the opportunity for the preferred OHW management technology options predicated on the OHW characteristics of Muharraq Governorate, and to explore the enablers and barriers to the selected technologies adoption in Bahrain.

Supporting Objectives and Research Questions:

1. To develop an organic household waste "parameter/technology" selection matrix. (Chapter 5)

-What are the optimum OHW physical and chemical characteristics for each technology option?

2. To determine the characteristics of the organic household waste in Bahrain (represented by Muharraq Governorate OHW) in two seasons: Normal and Ramadan (fasting month) (Chapter 5)

-What are the OHW chemical and physical characteristics of Muharraq Governorate?

-Are there any differences in the OHW characteristics between regular days and Ramadan season?

3. To determine the preferred technology by short-listing and selection in accordance to the organic waste parameter/technology matrix. (Chapter 5)

4. To assess the economic feasibility of the selected technologies using cost-benefit analysis (Chapter 6)

5. Exploring barriers as well as enablers to the adoption of the selected OHW management technologies. (Chapter 7)

6. To measure the public awareness toward the household waste management via its components: knowledge, attitude, and behaviour, and find any significant correlation between the variables and public awareness components. These dependent variables (age, gender, residential place type, educational level, marital status, and monthly income) are one of the key elements that determine the success of any management practices in the country.

Figure 1.6 summarizes the research framework that illustrates the three phases in addition to their chapters, methods and objectives:

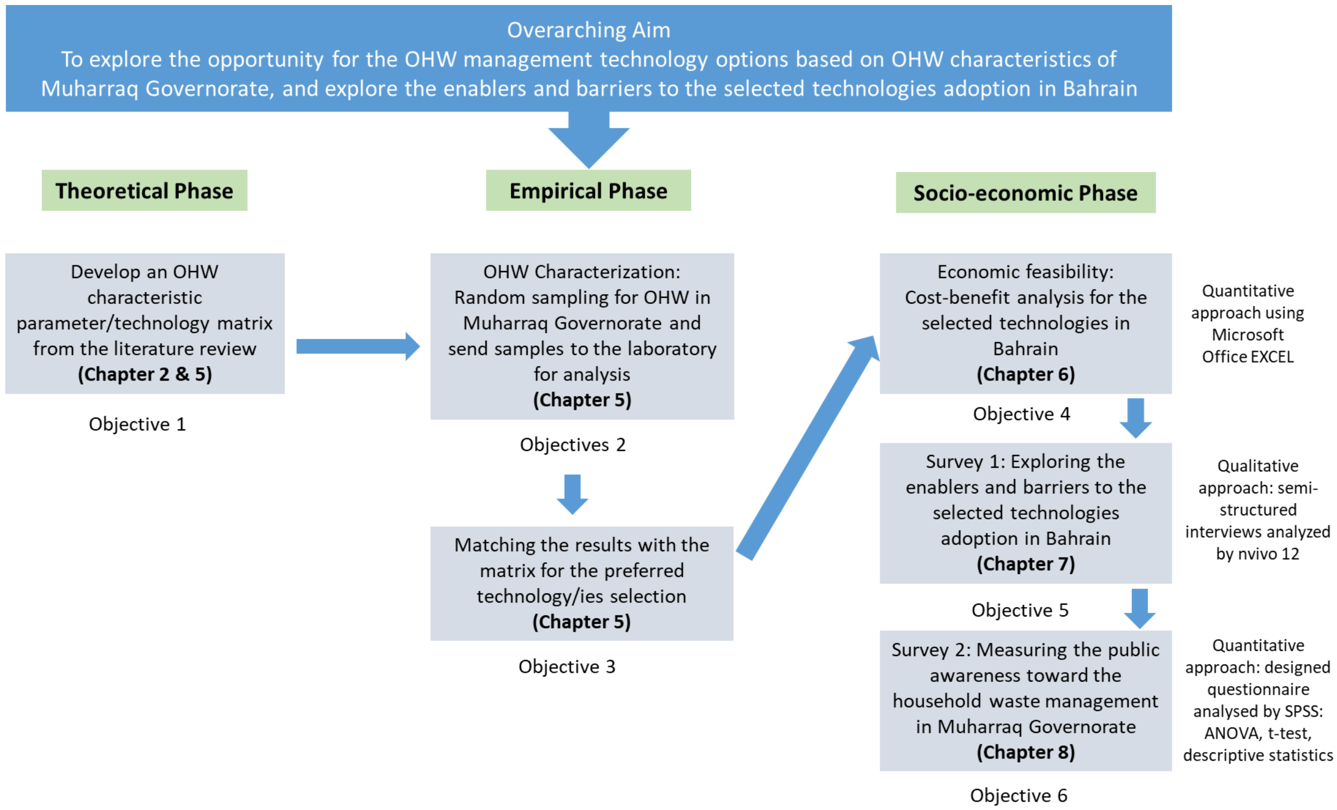

Figure 1.6: The Research Framework

1.10. Research Contribution to the Knowledge

This study is expected to advance the current and existing literature in the field of waste management, and provide a better understanding of the OHW characteristics in relation to the technology. The developed parameter/ technology matrix is an addition to the knowledge since the literature lacks a specific matrix of chemical and physical characterisation of the OHW in relation to the technlogies. Moreover, it provides a full overview of the OHW characterisation of Bahrain as a new context, something that has never been done before thus, it represents an important reference for decision makers when embarking upon future planning or strategy making. Furthermore, it provides significant information about the enablers and barriers to the OHW technology adoption in Bahraini context.

The review of the literature indicated that there is no specific detailed parameter/technology selection matrix for the organic household waste. In addition, no previous study has summarized the direct relation between the OHW characteristics and the preferable technology for its management. Furthermore, no previous research has explored the enablers and barriers directly related to OHW characteristics-based technology selected in any particular country or city. This may lead to the development of a model interrelating the parameter-technology and social factors that provides a convenient tool for decision makers as well as policymakers to take decisions about household waste management, which might contribute to the Muharraq municipality and country improvement in general.

The new context for a Bahraini governorate OHW characterization has not been studied before and thus, is a significant contribution to the literature. Selecting the best OHWM technology option based on the criteria of the OHW characterization is an added value. Exploring the enablers and barriers to the most preferred OHW technologies adoption and measuring public awareness toward the household waste management on knowledge, attitude and behaviour levels is being done for the first time in Bahrain, which reflects the nature, culture and specificity of the Bahraini society with regard of the waste management, another addition to knowledge within the Bahraini context. Therefore, it represents a good reference for researchers and the decision makers within Bahrain and throughout the region.

Nationally, this research marks a good beginning toward the realization of Bahrain vision 2030. One of the key endeavours of Bahrain vision 2030 is to improve the principles of sustainability, competitiveness, and fairness so as to ensure that every citizen can live a safe and secure life (Bahrain vision 2030, 2007). This vision also affirms that “Bahrain will continue to be home to a rich and ancient culture and a sustainable natural environment”. Numerous initiatives will be taken to support and protect the environment under this strategy. One of these initiatives is *"directing investments technologies that reduce carbon emissions, minimize pollution and promote the sourcing of more sustainable energy"*.

It is believed that GHG emission problem could be, to a great extent, mitigated by diminishing the amounts of the municipal organic solid waste, especially domestic waste. Improving awareness among Bahraini households is very essential for initiating a focused action to address the issue of GHG emissions from the organic solid waste as well as to develop pragmatic solutions to mitigate the problem. Currently, Bahrain lacks the proper waste management system and environmental awareness with respect to gauging the level of GHG emission. Besides, Bahrain being an island, nation is highly vulnerable to the effects of global warming caused by the GHG emission (Owolabi et al., 2012).

Therefore, the study is relevant and timely, and the anticipated outcome would benefit our country in particular.

1.11. Thesis Structure

This thesis comprises of nine chapters:

Chapter 1 is gives an overview of the current state of the waste problem globally, and provides brief information about all the research main topics: OHW management, technologies of waste management, the research problem, overarching aim and objectives, contribution to knowledge, and limitations.

Chapter 2 covers the Literature review. It provides a review of current literature assessing the current state of waste characterization in relation to OHW technologies in order to realize the first objective of this study, which is to develop the parameter/technology matrix, in addition to the literature pertaining to the enablers and barriers to technology adoption, and gauging public awareness.

Chapter 3 encompasses the research methodology. It provides an overview of the different methods and approaches employed to accomplish the aim and objectives.

Chapter 4 is the Case study. It presents an overview of the Kingdom of Bahrain generally and Muharraq Governorate specifically, as a case study. The current status of waste management practices and the related topics have been discussed in this chapter.

Chapter 5 presents the results that include the development of the matrix, the empirical Bahrain's OHW characterization results, as well as the matching stage that leads to the selection of the most preferred technologies premised on the waste characterization criteria by shortlisting them. In addition, this chapter undertakes a discussion on the results.

Chapter 6 covers the cost-benefit analysis of the selected technologies representing the economic criteria in order to support the decision making of technology selection for Bahrain.

Chapter 7 encompasses Survey 1 which aims to explore the enablers and barriers of the selected technologies adoption in Bahrain achieved by conducting semi-structured interviews with experts in waste management and technologies. The chapter also includes interviews analysed using nvivo 12, the qualitative analysis software, and the accompanying results and discussions.

Chapter 8 is Survey 2, which aims to measure public awareness towards waste management and its importance in Muharraq Governorate. It describes the application of statistical techniques to analyse the results to identify the most acceptable practices in the society, which may be associated with the respondents' attitude towards the adoption of new technologies; this in turn could reduce the barriers and improve acceptance of new OHW management technologies. The quantitative approach will be used by designing the study tool involving a questionnaire. It designed to measure the knowledge, attitude and behaviour of people. The chapter also includes survey results and discussion.

Chapter 9 provides the Conclusion and Recommendation - a summary of the key findings and conclusions of this thesis, and recommendations about the successful selection and adoption of the OHWM technologies in Bahrain. The entire Thesis Structure is shown in figure 1.7.

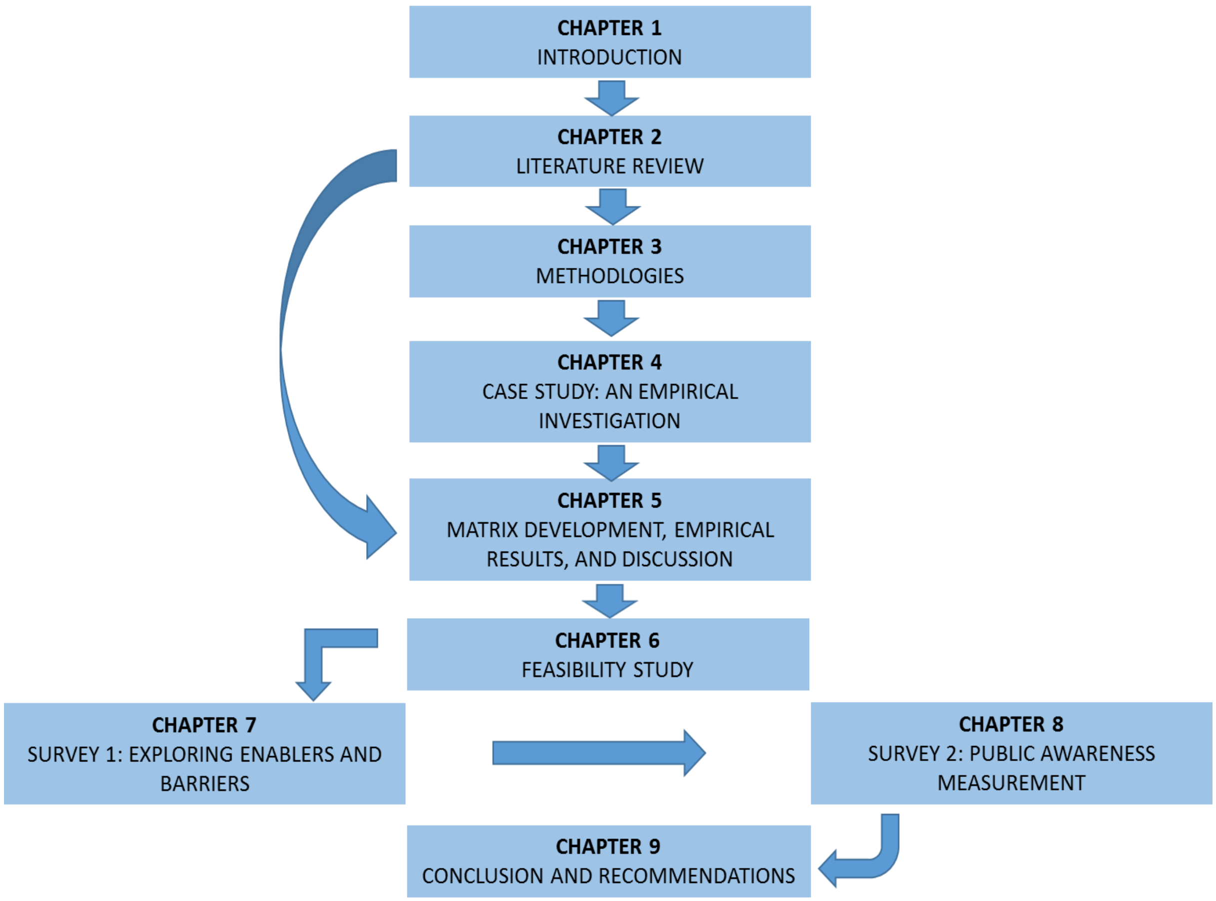

Figure 1.7: Thesis Structure

1.12. Chapter Summary

This Chapter provides a background on the status of waste management issue globally. It provides a brief justification as to why organic waste is to be prioritized in waste management process globally and locally, and identify possible solutions to address this problem. It emphasizes the contribution of this research to the knowledge. Moreover, it establishes the overarching aims and research objectives, in addition to the thesis structure.

CHAPTER 2: Literature Review

2.1. Introduction

This chapter contains three sections of literature review in order to explore the existing literature encompassing the different phases of the research. The first section emphasizes the technologies through which organic waste can be treated and managed. It also includes a review of the most important parameters that must be optimized for each technology to operate properly, as well as the relationship between the parameters and technologies. This section concludes with development of a “parameter/technology matrix” which realizes the first objective of this research.

The second section contains the literature review related to the exploration of the enablers and barriers to the technology adoption, which includes the hypothesis that shortlists the possible enablers and barriers based on the literature review to be verified later via Survey 1 in chapter 7. The third section comprises of the literature related to environmental public awareness and its importance as a key enabler to ensure the success of waste management technology adoption in the country.

Since the this research is a Case study of Muharraq Governorate- Kingdom of Bahrain, the entire information and literature review related to the case study is presented in Chapter 4. Therefore, this chapter will not emphasize it in particular.

2.2. Section 1: Organic Waste Management Technologies

This section aims to review the literature of the OHW management technologies in relation to the waste characterization. This section pertains to the first objective of this research; the parameter/technology matrix has been developed at the end of this section.

The technologies to manage the OHW were described briefly in Chapter 1. This chapter discusses the literature in which these technologies are shown to be dependent on some essential parameters. Each technology requires optimizing specific parameters in the feedstock to be able to work properly and efficiently without which, the technology will not work efficiently and thus; the expected outcome will not be achieved.

In general, there are two main categories of facility systems to manage the organic waste: waste-to-energy (WtE) technologies, and mechanical-biological treatment (MBT). WtE technologies aim to convert organic waste and biomass into inert gases and organic oils, gases, and fuels that can be further used to yield desired energy products. WtE requires knowledge of waste quantities and characteristics (Mutz et al., 2017). On the other hand, MBT is considered as a waste processing facility that combines a sorting facility with a form of biological treatment, such as composting or anaerobic digestion (AD). The refused derived fuel (RDF) is one of the MBT outcomes. AD technology can end up producing energy and/or digestate that can be used as a soil enhancer. (Figure 2.1)

MBT (Mechanical Biological Treatment): is the term used for a family of treatment systems that uses a combination of mechanical and biological processes to separate and transform the residual waste into several outputs. MBT is not a final disposal solution for the treated waste and can, therefore, be considered to be a mechanical biological pre-treatment, as evidenced in Germany and Austria. MBT is designed to treat mixed collected or residual municipal solid waste. The main aim is to extract further value from the waste and to recover the energy contained in it whilst facilitating recycling and diversion of waste from landfills. The mechanical processes are designed to separate the dry recyclables, such as glass and metals, while the biological processes aim at reducing water content and handling the organic-rich fraction of the incoming waste. In addition to the inorganic outputs, an MBT plant can produce an organic waste fraction, which is further composted or treated by anaerobic digestion. Composting and AD can be part of the same MBT facility (Al Seadi et al., 2013).

Campuzano and Martineze (2016) have argued that a sound knowledge of OFMSW characteristics is important to estimate the biogas production. Against this backdrop, the current research commenced from the waste characterization perspective to select the most preferred technology for Bahrain. Other criteria (population size and waste volume, availability of land, availability of workers and capacity, existing policies linked to waste management, marketing of product, and greenhouse gas reduction) will be considered and included within the domain of enablers and barriers to be explored via experts' interviews in the second part of the literature review.

Bioenergy derived from biomass provides a preferable energy alternative and can reduce greenhouse gas (GHG) emissions generated from fossil fuels (Patel, Zhang, and Kumar, 2016). The OHWM technologies can be divided into:

1. Bio-conversion technologies

2. Thermo-conversion technologies

The organic waste management technologies considered as possible options in this research are listed below in more detail:

2.2.1. Bio-Conversion Technologies

This category of technologies depends on using biological agents to convert biomass feedstock to energy, typically in the form of liquid and gaseous fuels. However, these technologies have the potential to produce electricity, heat, bioproducts, and fuels (Uemura, 2010). Two primary systems are currently employed for the treatment and recycling of organic waste. These are anaerobic digestion (AD) and composting, as described below with further about the optimum conditions for them to start developing the parameter/technology matrix in order to realize the first objective of this research:

2.2.1.1. Anaerobic Digestion (AD)

Anaerobic digestion is a series of biological processes wherein microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat; it can also be processed into renewable natural gas and transportation fuels.

Anaerobic Digestion (AD) is typically employed to treat organic waste and is increasingly gaining traction as it produces renewable energy. The AD is a complex biochemical process for the treatment of biodegradable waste which occurs in a vessel in the absence of oxygen. It primarily leads to the formation of mixture of carbon dioxide and methane gas known as "Biogas", which is typically used to provide electrical power generation, heat, and a solid and liquid digestate. The digestate quality is dependent on a source; segregated organic waste stream is available. The AD is unsuitable for the treatment of feedstock with high fibre content (mainly with high lignocellulose content) which causes the digester to clog (Uemura, 2010). Feedstock materials contaminated with such impurities are excluded from AD especially when digestate is to be used as fertilizer (Al Seadi et al, 2013).

According to the American biogas council, many different anaerobic digester systems are commercially available based on organic waste stream type (manure, municipal wastewater treatment, industrial wastewater treatment and municipal solid waste). Anaerobic digestion of the organic fraction of MSW provides an engineered and highly controlled process of capturing methane. It is claimed that the current trend is toward anaerobic digestion of source separated from organic waste streams, including food waste, yard trimmings and soiled paper. This is consistent with the findings of Al Seadi et al., (2013) who believed that best practice for AD digestible materials is separation at source.

Figure 2.1 illustrates the basic contours of the anaerobic digestion or so called biogas systems, according to the American biogas council:

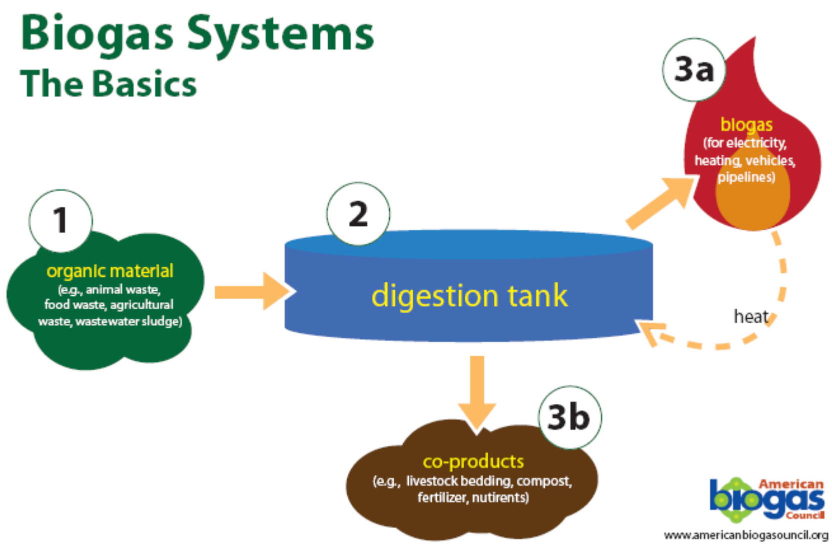

Figure 2.1: Anaerobic Digestion or so called Biogas System.

Source: https://www.americanbiogascouncil.org/images/genericDigestionProcess.gif

Anaerobic digestion of the organic fraction of municipal solid waste (OFMSW) is being widely utilized globally because this technology complies with the philosophy of sustainability. The energy recovered from anaerobic digestion of OFMSW is renewable and the effluent can be returned to the agricultural land, thus recovering the remaining organic matter and nutrients (Uemura, 2010).

According to Appels et al., (2011), energy from biomass and waste is one of the most dominant renewable energy sources to be used in future. It has been found that different types of biomass and waste are suitable for AD, including OFMSW, Waste oils, animal fats, crops and agricultural, manure and sludge.

The number of plants treating the digestible fraction of household waste in Europe grew from three biogas plants in 1990 to 195 in 2010, with a total capacity of 5.9 million tonnes per year, as well as a predicted expansion of current capacity every five years (Burrows, 2013). In 2010, about 3percent of the organic fraction of municipal solid waste produced in Europe was treated by the AD, representing 20 percent–30 percent of the biological treatment capacity of organic wastes from households (Al Seadi et al., 2013). Analogously, McKendry (2002) claimed that AD is a commercially proven technology and is widely used to treat high moisture content organic wastes that may reach 80– 90percent moisture.

Furthermore, AD technology strongly relies upon the input material. Therefore, it is crucial that the waste is separated before the treatment. Materials such as plastics will reduce process' efficiency (Hasan and Ahsant, 2015). This is consistent with the views of the American Biogas Council as per which pre-sorting is necessary to prevent clogging of the pumps and to reduce the amount of reactor volume occupied by inert material. Even source-separated waste inevitably contains metal and plastic contaminants and hence, must be pre-sorted.

The biogas produced by anaerobic digestion primarily comprises of ($CH_4 \approx$ 60percent by volume), carbon dioxide ($CO_2 \approx$ 40 percent by volume), and small traces of hydrogen sulphide (H_2S), hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), oxygen (O_2), water vapour (H_2O) or other gases as well as vapours of various organic compounds (Cioabla et al., 2012).

The American Biogas Council has specified the anaerobic digestion systems for MSW, which include:

1. Single-stage wet digesters: Typically simpler to design, build, and operate and generally less expensive, the organic loading rate (OLR) of single-stage digesters is impeded by the ability of methanogenic organisms to tolerate the sudden decline in pH resulting from rapid acid production during hydrolysis.
2. Dry fermentation: Type of single-stage digester, but distinctive from other AD categories because feedstock are in a solid state that can be handled using a front-end loader; normally, no additional water is added. Digestion takes place at 20-45percent total solids, and can be

done in either a batch or continuous mode. In the batch mode, materials are loaded into chambers before being inoculated and maintained until the end of the retention time. In continuous mode, fresh feedstock is continuously fed to the digester and the digestate is continuously removed.

3. Two-stage digesters: System separates the initial hydrolysis and acid-producing fermentation from methanogenesis, which enables higher loading rates for high nitrogen containing materials but requires additional reactors and handling systems. Another important design parameter is the total solids (TS) concentration in the reactor, which is expressed as a fraction of the wet mass of the prepared feedstock. The remainder of the wet mass is water by definition. Feedstock is typically diluted with process water in order to achieve the desirable solids content during the preparation stages.

Moreover, Cioabla et al., (2012) outlined the factors affecting the performances of an anaerobic digester. They claimed that these factors can be divided into three main classes: (i) feedstock characteristics, (ii) reactor design and (iii) operational conditions. Among the operational conditions, temperature and pH are found to be important parameters.

Putts and Martin, (2003) stated the conditions required for a successful AD. They contended that moisture content is considered as one of the most important factors affecting the waste stabilization which play an important role in:

1. Controlling cell turgidity;
2. Reacting in polymer hydrolysis;
3. Solubilizing and transporting nutrients, intermediates, products, inhibitors, enzymes, and microorganisms;
4. Modifying the shapes of enzymes and other macromolecules;
5. Exposing more of the waste surface to microbial attack.

Putts and Martin, (2003) added that the moisture content of raw MSW varies with waste composition, climatic conditions, and collection methods, but is usually 20–30percent too low for the efficient AD. Raising the moisture content of an anaerobic digester is known to increase the generation of methane. According to previous studies, the minimum moisture content is 36percent for a mechanically mixed, mesophilic digester fed with the putrescible fraction of MSW. They mentioned three temperature ranges for AD process that is predicated on the bacteria type:

1. cryophilic, less than 20 °C (very slow, so rarely used for digestion of MSW);
2. mesophilic, 20–45 °C (35 °C is generally used for mesophilic operation);
3. thermophilic, above 45 °C (55 °C is generally used for thermophilic operation), digestion is faster in the thermophilic range.

According to the American Biogas Council, captured biogas is transported via pipe from the digester, either directly to a gas use device, or to a gas treatment system (e.g. for moisture or hydrogen sulphide removal). According to them, high concentrations of sulphur lead to the formation of hydrogen sulphide in the digester, which cause the corrosion of the combustion device or other downstream equipment.

Hence, we can conclude that sulphur must be very low in order to have an efficient AD operation.

On the other hand, Speec (1985) believed that sulphur requirements for anaerobic digestion are not widely documented, and it appears to be required in concentrations that are much higher than previously thought.

Correspondingly, Putts and Martin (2003) have argued that the volatile fatty acids (VFAs) affects the AD in that they accumulate and lower the pH progressively which inhibit methanogens activity until it stops completely. For this reason, the VFAs concentration is an important indication of stability.

Meanwhile the chemical oxygen demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals, such as ammonia and nitrite. On the other hand, Biological oxygen demand (BOD) is a measure of the amount of biological substrate materials within a water or wastewater (Haggett, 1999). BOD is similar to the function of chemical oxygen demand (COD) in that both measure the number of organic compounds in water. The American Biogas Council has shown that the high Chemical Oxygen Demand (COD) and solids loading make the feedstock well-suited for treatment using anaerobic processes. Hence, a high COD is required in order to achieve a successful AD process.

Naroznova et al. (2016) believed that all organic materials in sorting guidelines for source separated organic household waste are degradable and fit to be used for AD.

However Al Seadi et al. (2013) believed that not all organic waste is suitable for the AD. Wood and lignin are not suitable for the AD, but for composting and combustion with energy recovery.

Influence of carbon to nitrogen ratio on digestion:

Nitrogen present in the feedstock has two benefits: (a) it provides an essential element for synthesis of amino acids, proteins, and nucleic acids; and (b) it is converted into ammonia which, as a strong base, neutralizes the volatile acids produced by fermentative bacteria, thus helping in the maintenance of neutral pH conditions essential for cell growth. An overabundance of nitrogen in the substrate can lead to excessive ammonia formation, thus producing toxic effects. Hence, it is important that the proper amount of nitrogen is in the feedstock to avoid either nutrient limitation (too little nitrogen) or ammonia toxicity (too much nitrogen). The composition of the organic matter added to a digestion system plays an important role in the growth rate of the anaerobic bacteria and the production of biogas. (Ross and Lofta, 1995)

The components of the feedstock are utilized selectively by different bacteria within the digester. This is especially true with regard to the different ratios of organic matter to nitrogen. Bacteria need a suitable ratio of carbon to nitrogen for their metabolic processes. The C:N (carbon to total nitrogen) ratio higher than 23:1 was found to be unsuitable for optimal digestion, and lower than 10:1 were found to be inhibitory (Lin and Lay 2004; Kimchie, 1984).

In a review of literature for ammonia optimum concentration for AD, only old references were found. A study by Wiegant and Zeeman (1986) concluded that ammonia acts as a strong inhibitor of the formation of methane. Wagner, Schwartz and Phoenix (1986) examined the ammonia stress on bacteria in an anaerobic sludge blanket reactor, concluding that the high concentration of ammonia caused inhibition of anaerobic activity, but did not result in irreversible damages to the biomass in the reactor (Loftas, Ross and Burles, 1995).

Sulfide (S), which is essential for most methanogens, is toxic above 200 mg/l and is insoluble when heavy metals are present (Stafford et al., 1981; Zeikus 1977).

Toxic compounds affect digestion by slowing down the rate of metabolism at low concentrations, or by poisoning the organisms at high concentrations. The methanogenic bacteria are generally more sensitive, although all groups involved in digestion can be affected. The major toxicants usually encountered with natural feedstocks include ammonia, volatile acids, and heavy metals.

Ammonia: Ammonia toxicity is found to be a common problem in feedstocks with high protein content. Ammonia is rapidly formed in a digester, by deamination of protein constituents. Free ammonia has been found to be more toxic than ammonium ion and thus, ammonia toxicity thresholds are very sensitive to pH below 7.0. In general, free ammonia levels should be kept below 80 ppm in order to prevent inhibition concentrations of free ammonia and ammonium ion that are related by equilibrium reactions and pH (Anderson et al., 1982).

Volatile Acids: High concentrations of volatile acids are known to be associated with toxicity effects due to reduced pH (pH <6.8) (Hobson and Shaw 1976). Thus, the pH must be above 6.8 to avoid AD inhibition.

Heavy Metals: Certain heavy metals are toxic to anaerobic organisms, even at low concentrations. Heavy metal ions inhibit metabolism and kill organisms by inactivating the sulfhydryl groups of their enzymes in forming mercaptides (Mosey et al., 1971). Toxic effects are hence affected by the solubilities of heavy metals under various digester conditions (Hayes and Theis, 1978). Many heavy metals form insoluble sulfides or hydroxides under pH conditions in the range of those found in digesters. In order to avoid heavy metal toxicity, sulfates must be added to form non-toxic complexes or insoluble precipitates. Arsenic, boron, manganese, chromium, cobalt, nickel, zinc, selenium, cadmium, barium and lead are commonly found heavy metals in the MSWs (Quaghebeur et al., 2013 cited in Baawain, 2017)).

Facchina et al., (2013) argued that trace metals are essential for the enzyme co-factors involved in the biochemistry of methane formation in the context of a balanced anaerobic digestion process. They observed that a restoration of methane yield premised on the volatile solids (VS) of the OSW added was observed following the addition of minerals (Ni, Co, and Fe) in the mesophilic reactor, but not in the thermophilic reactor, suggesting that the requirement for minerals is higher in thermophilic anaerobic digestion as compared to mesophilic digestion. It is suggested that Ni is the most important mineral for the OSW's anaerobic digestion of (Uemura, 2010), which is in conformity to the views of other researchers that Nickel is an essential trace metal required for methanogens (Speec, 1985).

C:N ratio: Wang et al., (2014) found that the efficiency of anaerobic digestion may be limited due to the inadequate amount and diversity of waste from a single resource. This is insufficient for large-scale digesters, as well as the drawbacks of using single substrates, such as improper carbon-nitrogen (C:N) ratios, low pH of the substrate itself, poor buffering capacity, and heightened concentrations of ammonia. Although many studies indicated that the optimal C:N ratios in methane fermentation were 25~30, the depletion of carbon and nitrogen could be affected by operating conditions, such as temperature, leading to inhibitory effects. It has been reported that high fatty acid (FA) concentration could inhibit thermophilic more steadily than mesophilic digestion. Because the concentrations of TAN and FA are predicated on the content of organic nitrogen in the reactor and on C:N ratios, the amount of substrate carbon and nitrogen content may also interact with temperature. This interaction results in different concentrations of ammonia and FA, as well as the inhibitory effects. Loftas, Ross and Burles (1995) reported that the maximum required C:N ratio for AD is 40.

Substrates with low C:N ratios contain relatively high concentrations of ammonia, exceeding concentrations necessary for microbial growth, and probably inhibiting anaerobic digestion (Wang, 2014).

One of the methods that is used by researchers to avoid excessive production of ammonia during AD is to increase the C:N ratio of feedstock. This can be achieved by co-digesting with other waste feedstock high in biodegradable carbon in order to improve the performance of the AD. Co-digestion of chicken waste or cattle slurry with fruits and vegetable wastes is another way of improving C:N ratio. The benefits of increasing C:N ratio through co-digestion with complementary feedstock is to obtain high biogas yield and reduce potentially toxic ammonia concentration. (Wang et al., 2012)

According to Lin and Lay (2004), some parameters were essential, such as the carbon to nitrogen (C:N) ratio and the biodegradability of mixtures. Failure in the AD may refer to low pH, insufficient alkalinity, ammonia inhibition, as well as the accumulation of volatile fatty acids (VFAs) within the digesters. The optimum pH range in an anaerobic digester is 6.8 to 7.2. However, the process can tolerate a range of 6.5 up to 8.0 (Cioabla et al., 2012).

In order to explore the methane potential of OHW, Hansen et al., (2007) conducted a study and found that methane potential of OHW is 495 ml CH_4/g OHW. Theoretical methane potential achieved for paper bags was found to be 63 percent, 84 percent for starch, and 94 percent for glucose. This might be useful to estimate the energy produced from OHW.

Many countries around the world have started using biogas from food waste, such as Sweden, France, Norway and the US. In addition, Woon and Lo (2016) have proposed a framework for renewable biogas fuel production in Hong Kong based on food waste collection and recycling. Food waste was separated from MSW in green bags before being valorized into valuable resources. They then sent OW treatment facilities for biogas generation by the AD, which is to be used as a vehicle for biogas fuel.

Meanwhile organic waste may need some pretreatment to fit the AD. Bioethanization of the OFMSW is an introduction to the AD. Co-digestion enables co-treatment in a more feasible manner. Mechanical-Biological-Physical and Chemical types of pretreatment are intended to increase the biodegradability and yield (Alvarez, 2005).

A new pre-treatment technology is water pulping of source that separates OHW prior to the AD. This helps in the rejection of more than 95percent of non-biodegradable impurities in OHW resulting in the generation of bio-pulp ready for the AD. BMP of the biopulp was 469mlCH_4/g (ash-free mass) (Naroznova et al., 2016).

Moreover, McKendry (2002) argued that as an energy source, the main material properties of interest during subsequent processing relate to:

• Moisture content

• Calorific value

• Proportions of fixed carbon and volatiles

• Ash/residue content

• Alkali metal content

• Cellulose and lignin

For dry biomass conversion processes, the first five properties are of particular interest, while for wet biomass conversion processes, the first and last properties are of prime concern.

McKendry (2002) believed that the relationship between biomass moisture content and appropriate bio-conversion technology is essentially straightforwardin that thermal conversion requires low moisture content feedstock (typically<50percent), whhereas bio-conversion can utilize high moisture content feedstocks. Thermal conversion technologies can also use feedstocks with high moisture content, but the overall energy balance for the conversion process is adversely impacted.

McKendry (2002) mentioned another important parameter: calorific value (CV). CV is an expression of the energy content, or heat value released when burnt in air. The CV is usually measured in terms of the energy content per unit mass, or volume; hence MJ/kg for solids, MJ/l for liquids, or MJ/Nm3 for gases. The CV of a fuel can be expressed in two forms, the gross CV (GCV), or higher heating value (HHV) as well as the net CV (NCV), or lower heating value (LHV). The HHV is the total energy content released when the fuel is burnt in air, including the latent heat contained in the water vapour; therefore, it represents the maximum amount of energy potentially recoverable from a given biomass source. The actual amount of energy recovered varies with the conversion technology, as will the form of that energy i.e. combustible gas, oil, steam, etc. In practical terms, the latent heat contained in the water vapour cannot be used effectively, which is why LHV is the appropriate value to use for subsequent use. CV has been found to be proportional to the moisture content such that if moisture content is high, CV will be low McKendry (2002).

Fixed carbon and volatiles are important characteristics to be measured in organic household waste that may affect the decision to select the suitable technology. Volatile matter (VM) of a solid fuel is the portion driven-off as a gas by heating (to 950 "C for 7 min), whereas the fixed carbon content (FC) is the mass that remains after the releases of volatiles, excluding the ash and moisture contents. Laboratory tests are used to determine the VM and FC contents of the biomass fuel. Fuel analysis that is based on VM content, ash, and moisture, with the FC determined by difference, is termed as the proximate analysis of a fuel. Elemental analysis of fuel, presented as C, N, H, O, and S along with the ash content, is termed as the ultimate analysis of a fuel. VM and FC contents provide a measure of ease with which the biomass can be ignited and subsequently gasified, or oxidized, depending on how the biomass is to be utilized as an energy source. (McKendry, 2002)

Chemical oxygen demand (COD) denotes a measure of the amount of oxygen required to oxidize all organic material into water and carbon dioxide, and thus, a measure of the amount of organic material within a substance. A study of COD may allow the completion of mass balances of anaerobic digesters containing organic solid wastes. This will allow for a better understanding of the system and facilitate the optimization of the digester as a whole (Harnadek et al., 2015). Weimin Wu, a senior researcher from Stanford University, Department of Civil and Environmental Engineering was asked to comment on the research gate panel online: What is the soluble COD range for any wastewater to be suitable for anaerobic digestion? He answered, *"It depends on the objective; if it is to recover biogas from the wastewater, the high concentration from 1,000-50,000 mg/L or even higher will be okay. Considering solubility of methane in water (20-30 mg/L), a low concentration is not good for methane recovery."* This is the only evidence that was found from the literature reviewed to be used in developing the matrix.

2.2.1.2. Composting (Aerobic Digestion)

Aerobic composting, or aerobic digestion, is a bio-oxidative process. During this process, a large portion of the degradable organic carbon is converted into carbon dioxide and water. During the composting process, methane can be generated in composting piles due to the partial anaerobic conditions; when the moisture is high, the ventilation is not enough. Heat is produced during composting, which elevates the temperature of the pile to more than 60 °C. This helps reduce the concentration of pathogens (microorganisms that causes disease) inside the composter (Hochman et al., 2015; Zafar, 2015). As the substrate becomes the only source of food to the microorganisms in composting, the nature of substrates is the most dominant factor in any composting process (Gajalakshmi and Abbasi 2008). For this reason, the organic waste characteristics paramount for ensuring good composting. There are two ways of composting, according to the Database of Waste Management Technologies http://www.epem.gr/waste-c-control/database/html/Composting-03.htm

a. Windrow Composting

Windrow composting is widely employed for the treatment of plant matter from gardens, parks and amenity areas. A windrow is a long pile of shredded organic waste with a triangular cross-section. The shape of the windrow allows passive airflow as hotter gases exit from the top of the windrow, allowing the flow of air to the sides. Windrows are typically turned at frequencies ranging from a few days to weeks. Turning promotes pathogen destruction by moving the material from the cool outside to the hot core, thereby restoring permeability. Turning is undertaken by a number of methods; self-propelled windrow turners either lift the material up and drop it back down behind the machine or raise it onto an elevator that drops the material to one side.

Following treatment, the composted material is typically screened to achieve an even product size and then recycled to land, being used as a soil conditioner, mulch and, in some cases, employed to produce soils. Importantly, a windrow composting system only requires an area of concrete and some mobile plant to allow the success of an operation. As the composting process requires a minimum level of moisture, maintaining the required moisture content can be problematic in arid countries. Windrow composting process is summarised in figure 2.2:

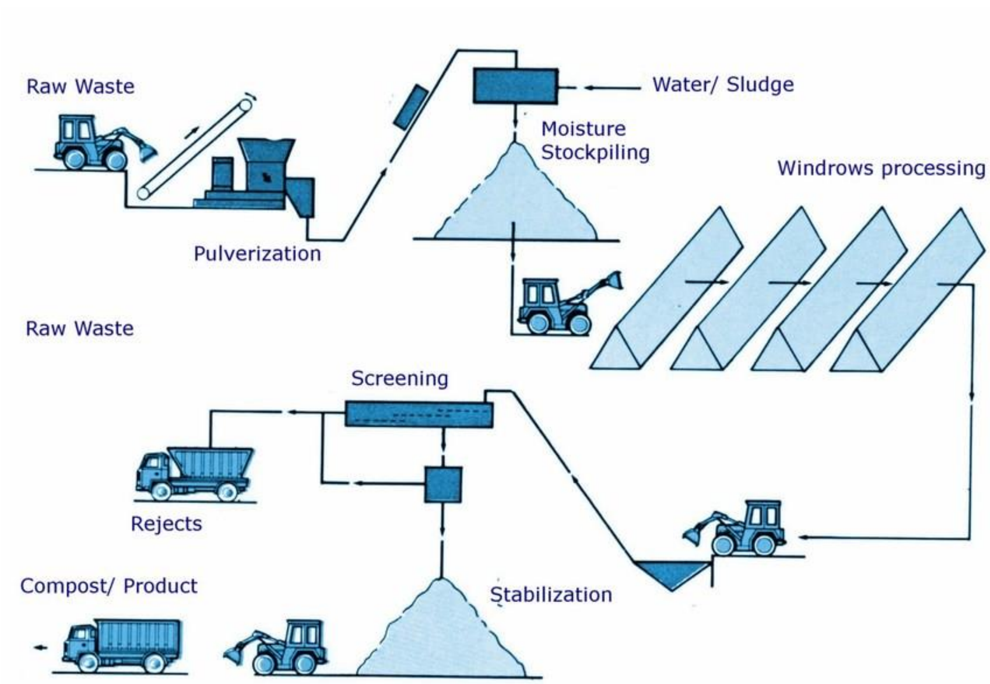

Figure 2.2: Open Windrow Composting Process.

Source: Kakosimos, (2015)

b. In-vessel Composting

In-vessel composting (IVC) is widely used for the treatment of organic waste which entails biosecurity or odour issues impacting their treatment. In practice, IVC embraces a variety of techniques wherein the organic waste is composted in an enclosed vessel or tunnel. Enclosing the process requires the employment of aeration and process control systems, which renders the process more expensive than windrow composting. The IVC is more controlled than open windrow composting and can be designed to achieve specified temperatures in order to facilitate pathogen destruction. It also minimizes the risk of vermin and birds gaining access to organic wastes, which may pose the risk of animal diseases, such as those contained in uncooked foods and other animal products or wastes.

IVC has a global application for the treatment of source segregated organic waste; its use is growing with the increasing need for reducing organic waste from landfill increases. For IVC to operate successfully, structural material such as green waste or wood chip is needed. The quality of the output of the IVC is predicated on the input material and therefore, good quality compost is only produced from source of segregated organic waste.

This method is particularly recommended for source segregated organic waste. It can also be potentially used for organic waste that is separated from mixed waste streams if there are markets for the composted product.

Figure 2.3 shows the in-vessel composting (IVC) process

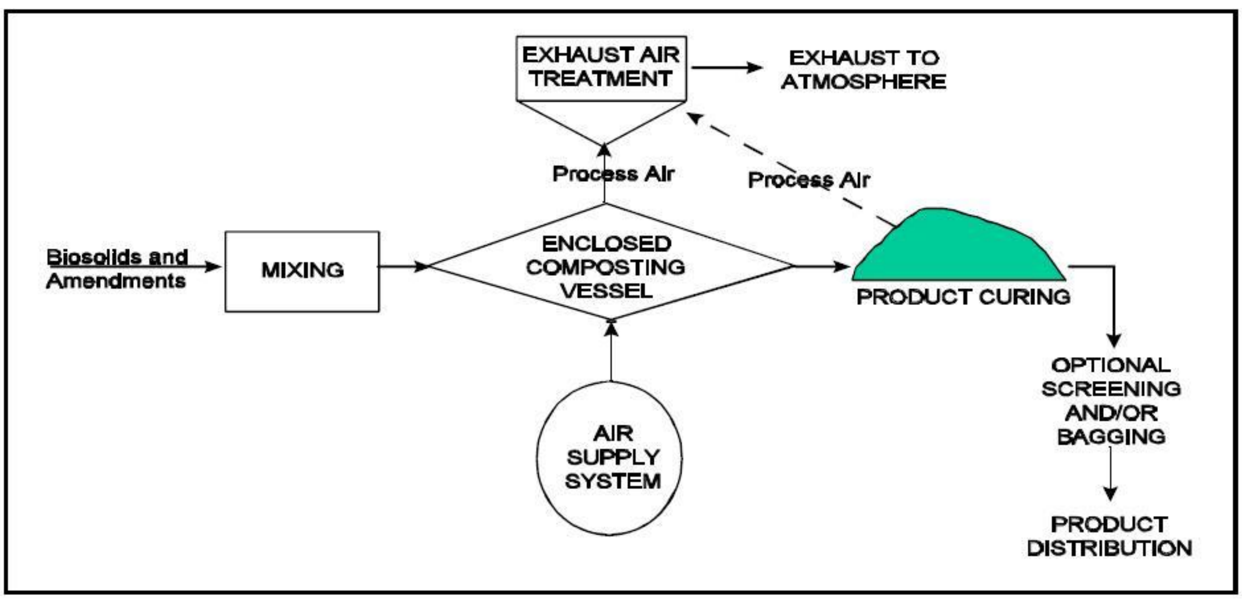

Figure 2.3: In-Vessel Composting (IVC) Process

Source: CTCN, https://www.ctc-n.org/technology-library/waste-management/solid-waste/landfill-composting

Meanwhile Figure 2.4 summarizes the concept of composting

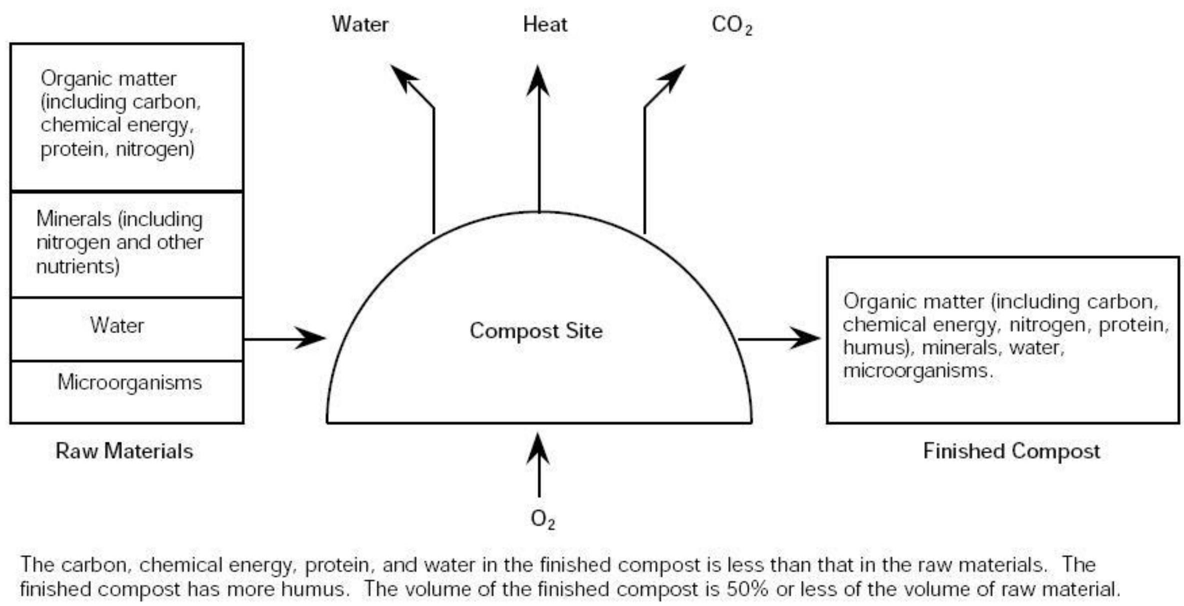

Figure 2.4: The Concept of Composting

Source: CTCN, https://www.ctc-n.org/technology-library/waste-management/solid-waste/landfill-composting

According to Frederick and Keener (2016), the most important composting process parameters are the following: temperature, moisture content, aeration and oxygen• pH and C:N ratio.

Therefore, the parameters and characteristics of organic waste that are essential for the composting technology are listed below to denote the optimum ranges for the technology:

Carbon: Nitrogen (C:N) ratio: The relative proportion of carbon and nitrogen is a major controlling factor in the composting process (Hansen et al., 2002; Ekinci et al., 2000; Agnew and Leonard, 2003). Carbon primarily serves as an energy source for the microorganisms, while a small fraction of the carbon is incorporated into the microbial cells. Nitrogen is paramount for microbial population growth. If nitrogen is limited, microbial populations will remain small and decomposition rates for available carbon will be lower. Excessive nitrogen is lost from the system as ammonia gas. According to Golueke (1973), rapid and entire humectation of substrates by the microorganisms primarily depends on it, initially having a C:N ratio between 25 and 35. Importantly, C:N ratio between 25:1 and 31:1, with the 30:1 ratio is considered optimal because the active bacteria digest carbon twenty-five to thirty times faster than nitrogen. Leaves, straws and woody materials serve as a major source of carbon, whereas grass and food scraps serve as the major source of nitrogen. For this reason, it is important to provide carbon and nitrogen in appropriate proportions. With C: N ratios below 20:1, the available carbon is fully used without stabilizing the entire quantum of nitrogen. The excess nitrogen may be lost to the atmosphere as ammonia or nitrous oxide, and odour can also pose a challenge.

Moisture: Moisture is one of the composting variables that affect microbial activities to a considerable extent. It provides a medium for the transport of dissolved nutrients necessitated for the metabolic and physiological activities of microorganisms. The microbial decomposition process augments the interdependence and mutual control between two of the main composting parameters: oxygen levels and temperature.

Bobeck (2010) argued that the optimum moisture content for composting must be of 50-60 percent, while Frederick and Keener (2016) mentioned that the optimum moisture for composting is between 34-65 percent. Moreover, water content is important because the microorganisms can only dissolve nutrients from the liquid phase. Oxygen level needs to be sufficient enough to ensure aerobic decomposition. Importantly, the temperature should reach up to 60°C from the microbial activity.

pH: The composting process is relatively insensitive to pH within the range commonly found in mixtures of organic materials, primarily due to the broad spectrum of microorganisms involved. The preferred pH level is in the range of 6.5-8.0; pH level should be between 5.5 and 8 (Bobeck, 2010). pH becomes a consideration with raw materials containing a high percentage of nitrogen. A high pH, above 8.5 encourages the conversion of nitrogen compounds to ammonia. (Parker, 2017)

As is the case with the AD, composting also needs low heavy metals content since high heavy metal concentrations inhibit the microorganisms' enzymes and in effect, stymie the entire process. (Bobeck 2010; Khan et al., 2016)

Brinton (2000) compared the compost heavy metal content in MSW between source-separated composting in relation to American standards. This comparison gives an indication of the heavy metals content of the waste so it can be compared to the heavy metals content of Muharraq governorate's OHW, which will be presented in chapter 5. Table 2.1 outlines the heavy metals content in MSW of America:

Table 2.1: Heavy Metal Content in MSW vs. Source-Separated Compost in Relation to Standards in America

Element	Mixed MSW Compost (Avg 4 regions) mg/kg	Bio-Waste Compost (Avg 4 regions) mg/kg	German Standard mg/kg
Pb	420	83	150
Cu	222	41	150
Zn	919	224	500
Cr	107	61	150
Ni	84	26	50
Cd	2.8	0.4	3
Hg	1.9	<0.2	3

Abdel-Shafy et al., (2014) argued that the general advantages of anaerobic technology in comparison to the aerobic processes are: lower energy input, lower waste sludge production, yield of biogas with a calorific value of about 5000–6000 kcal m^3 (6–7 kW/m^3) as a valuable energy source, particularly for gas power station with heat recovery and no odour nuisance due to a closed reactor system. Previous studies reported that certain heavy metal ions can inactivate enzymes, thus inhibiting the growth of bacteria such as Cu, Pb, Cr VI and Zn, consequently inhibiting the anaerobic digester.

According to Götze et al. (2016), data of chemical waste characterization is available from China, Europe, and North America, whereas very little or no data is available from other regions.

According to Asian Development Bank, 2011, MSW in South Asia contains 70 percent organic waste, which is why composting and the AD is considered highly suitable. Both need source segregation in order to improve the quality of the product and the biogas productivity. Composting and AD need low heavy metals content given the fact that high heavy metal concentrations inhibit the microorganisms' enzymes, thereby impacting its process.

According to Asian Development Bank, (2011), moisture in the South Asian organic waste was found to be 70- 80 percent, thus hinting that both composting and AD are suitable options.

Zafar (2017) believed that there is no alternative to the AD and composting for management of organic fraction of MSW. Since AD and composting necessitates a high C: N that may reach 25-30, low C: N ratio can be increased and moisture can be decreased to acceptable levels (for the AD and composting) through the addition of dry leaves, grass clippings, sawdust, paper and wood chips. High levels of moisture can also be reduced by solar drying of raw MSW for a period of 24-48 hours prior to its composting or anaerobic digestion. These pre-processing steps will not impose a financial burden.

2.2.2. Thermo-Conversion Technologies

These technologies depend on high temperatures to convert biomass feedstock into energy, typically in the form of electricity and heat. However, these technologies have the potential to produce electricity, heat, bioproducts, and fuels as well (USEPA, 2017). These technologies mainly include Combustion, Pyrolysis, and Gasification. In addition, they share similar feedstock characteristics requirements. Additional details are as follows:

2.2.2.1. Combustion (Incineration)

Direct combustion is the best established and most commonly used technology for converting biomass into heat. Furthermore, the most widely employed method of WtE is the combustion of waste (MWMUP, 2015). During combustion, biomass fuel is burnt in excess air so as to produce heat. The first stage of combustion involves the evolution of combustible vapours from the biomass, which burns as flames. The residual material is burnt in the form of charcoal in a forced air supply to supply additional heat. The hot combustion gases are sometimes used directly for product drying, but they are usually passed through a heat exchanger to produce hot air, hot water or steam. The combustion efficiency primarily depends on the level of contact between the oxygen in the air and the biomass fuel. The main products of efficient biomass combustion are carbon dioxide and water vapour; however, tar, smoke, and alkaline ash particles are also emitted (Zafar, 2015). The heat energy is transferred to water which then drives a steam turbine. Three primary methodologies are used to achieve this: moving grate, fluidized bed and rotary kiln, with moving grate being most widely employed (MWMUP, 2015).

Grate Incineration

Is the most common and proven technology for burning mixed solid waste (Figure 2.4). Whilst there are examples of fluidized bed incinerators (Figure 2.5) operating on mixed solid waste, the technology is slightly less proven due to some technical and commissioning problems. Combustion systems are typically large scale, with a single line often having a capacity in the region of 100,000 tpa (MWMUPA, 2015).

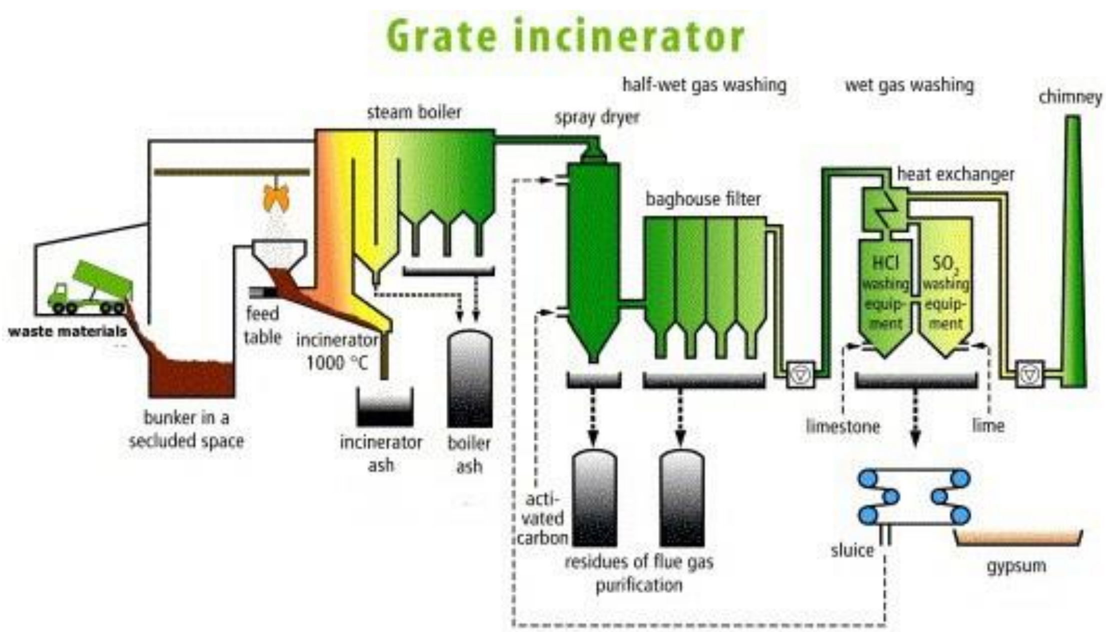

Figure 2.5: The Grate Incineration Process.

Source: Lew, (2016)

Biomass combustion refers to burning fuel in a boiler, furnace or stove in order to produce heat. The heat can be utilized as hot air, hot water, steam or electricity. Wood, agricultural residues, wood pulping liquor, municipal solid waste (MSW) and refuse-derived fuel (RDF) are some instances of feedstock for combustion. Combustion requires high temperatures for ignition, sufficient turbulence to mix all of the components with the oxidant, and enough time to complete the oxidation reactions.

Biomass combustion starts by heating and drying the feedstock. After the removal of all of the moisture, temperature rises for pyrolysis to occur in the absence of oxygen. The major products are hydrogen, CO, CO_2, CH_4 and other hydrocarbons. In the end, char and volatile gases are formed and they continue to react independently (Siirala, 2013). The volatile gases meanwhile need oxygen to achieve complete flame combustion. Mostly CO_2 and H_2O result from complete combustion. The solid char burns as well, resulting in CO and CO_2. The two most frequently used incineration systems are fluidized bed and grate-firing. (Johnsson, 2007)

In order to determine the most important parameters pertaining to the incineration of waste, Themelis et al., (2013) mentioned that it is necessary to determine the organic waste calorific value. Moreover, the moisture is a very important parameter in that the feedstock's moisture content should be low and pre-drying may be necessary in some cases. (Johnsson, 2007)

In addition, Themelis et al. (2013) showed that the chemical formula $C_6H_{10}O_4$ is an approximate of the organic compounds in MSW. Therefore, full combustion of the organic compounds in MSW can be presented by the following equation:

$$C_6H_{10}O_4 + 6.5O_2 = 6CO_2 + 5H_2O$$

This reaction is highly exothermic and the calculated heat of combustion is 2.7 MJ/kilomole of an organic compound at the combustion temperature of 1000°C. Since the molecular weight of $C_6H_{10}O_4$ is 146 kg/kilomole, the "theoretical" heat of reaction (i.e. in the absence of non-combustible materials and moisture) is calculated to be 18.5 MJ/kg. The calorific value of MSW can vary widely from country to country and city to city.

In the case of grate combustion WtE, the MSW bags and other waste is discharged from the collection vehicles into the waste bunker within a fully enclosed building. Typically, the waste bunker is large enough to hold over a week's feedstock. An overhead claw crane loads the solids into the feed hopper of the WTE furnace, after which a ram feeder situated at the bottom of the hopper pushes the wastes onto the moving grate. Notably, the grate can be inclined or horizontal and either air-cooled or water-cooled. The mechanical motion of the grate, and the gravity force in the case of an inclined grate, slowly moves the bed of solids via the combustion chamber. The high-temperature oxidation in the combustion chamber reduces objects as large as a big suitcase to ash discharged at the lower end of the grate.

Fluidized Bed Combustion

The fluidization process converts a bed of solids into a fluid by introducing a gas flow through the bottom of the bed (figure 2.6) According to Mutz et al., (2017), MSW incinerator is designed to treat mixed and largely untreated domestic waste in addition to certain industrial and commercial wastes. The energy content is a key parameter, the so-called lower calorific value (LCV) in MJ/kg. In order to ensure autothermic combustion of the waste LCV should not be below 7 MJ/kg on average over a year. For comparison purposes: The LCV of 1 kg of fuel oil is about 40 MJ/kg. In developing countries, the LCV of unsorted MSW is often below this threshold value due to a dominant organic content with high moisture as well as a significant level of inert waste fractions such as ash or sand.

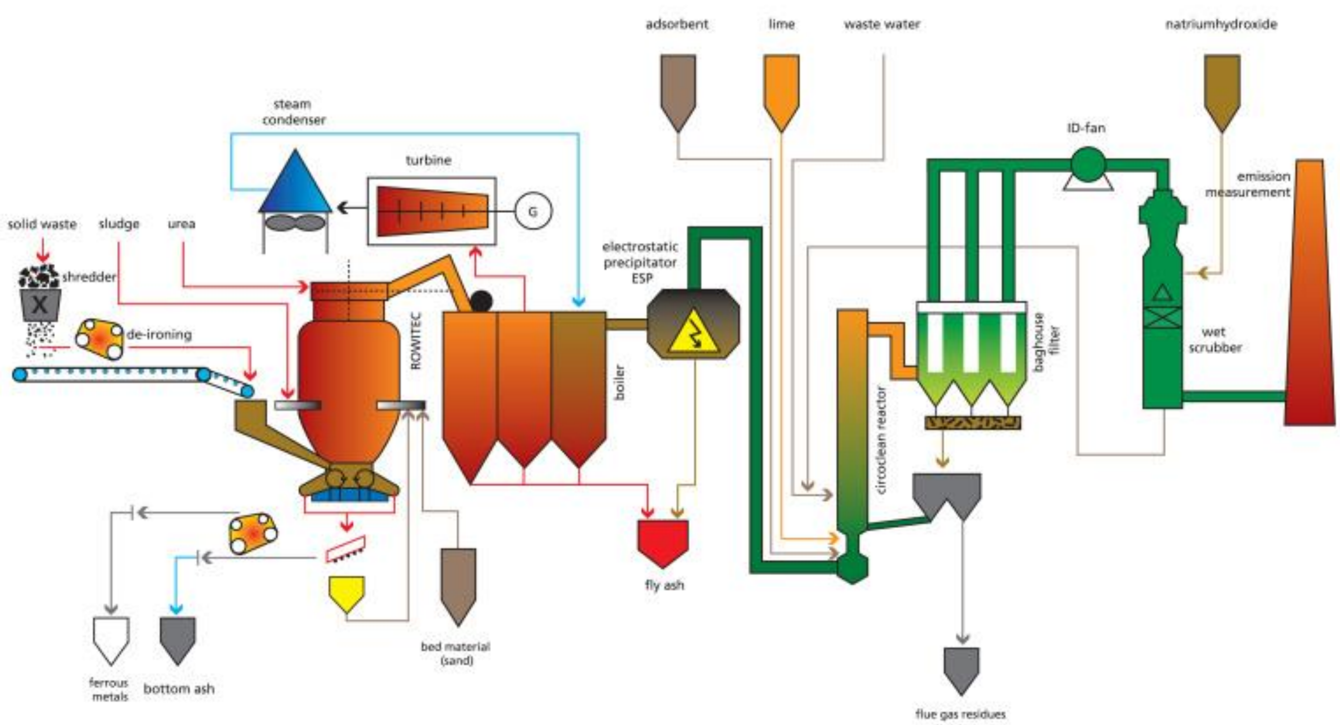

Figure 2.6: Fluidized Bed Incinerator

Source: http://www.indaver.be/en/installations-processes/waste-to-energy/fluidised-bed-incinerators/

Therefore, from the literature review, it can be concluded that the most important parameters related to the incineration are moisture content and calorific value.

2.2.2.2. Gasification

Gasification is essentially a two-stage process with a fuel gas production plant coupled with a gas boiler. This technology involves the material's partial oxidation. This means that while oxygen is added, the amounts are not sufficient to allow the fuel to be completely oxidized and allow full combustion.

Typically, the gas generated from gasification (syngas) can be used as a fuel gas or a feed to chemical processes. The other product is a solid residue of non-combustible material, which contains a relatively low level of carbon.

Biomass gasification involves burning of biomass in a limited air supply to give a combustible gas consisting of carbon monoxide, carbon dioxide, hydrogen, methane, water, nitrogen, in addition to contaminants like small char particles, ash, and tar. The gas is cleaned to make it suitable for use in boilers, engines, and turbines to produce heat and power (CHP).

Biomass gasification provides a means of deriving more diverse forms of energy from the thermochemical conversion of biomass as compared to conventional combustion. The basic gasification process entails devolatilization, combustion, and reduction. During devolatization, methane and other hydrocarbons are produced from the biomass via heat which leaves a reactive char. During the process of combustion, volatiles and char are partially burned in air or oxygen to generate heat and carbon dioxide. During the reduction phase, carbon dioxide absorbs heat and reacts with the remaining char in order to produce carbon monoxide (producer gas). The presence of water vapor within a gasifier leads to the production of hydrogen as a secondary fuel component. (Zafar, 2016, Pisupati and Tchapda, 2014)

Two main types of gasifiers can be used to carry out this conversion: fixed bed gasifiers, and fluidized bed gasifiers. The conversion of biomass into a combustible gas involves a two-stage process. The first one is called pyrolysis, which takes place below 600°C when volatile components contained within the biomass are released. These may include organic compounds, hydrogen, carbon monoxide, tar and water vapor. During the second stage of the gasification process, this char is reacted with steam or burnt in a restricted quantity of air or oxygen so as to produce further combustible gas. Depending on the precise design of gasifier chosen, the produced gas may entail a heating value of 6 – 19 MJ/Nm^3 (Zafar, 2016). Gasification systems are typically based on units of 35,000 - 40,000 TPA.

Gasification of solid wastes offers several advantages over traditional combustion processes for MSW treatment. It occurs in a low oxygen environment that limits the formation of dioxins and of large quantities of SO_x and NO_x. Furthermore, it requires merely a fraction of the stoichiometric amount of oxygen necessary for combustion. As a result, the volume of processed gas is low, necessitating smaller and less expensive gas cleaning equipment (Zafar, 2016).

Gasification generates fuel gas that can be integrated with combined cycle turbines, reciprocating engines and, potentially, with fuel cells that convert fuel energy into electricity more efficiently when compared to conventional steam boilers.

The gas resulting from gasification of municipal wastes contains various tar, particulates, halogens, heavy metals and alkaline compounds, which can lead to agglomeration in the gasification vessel and clogging of fluidized beds in addition to heightened tar formation. In general, no slagging occurs with fuels having ash content below 5 percent. MSW also has a relatively high ash content of 10-12 percent.

Gasification is being used internationally for the treatment of residual mixed solid waste, particularly in Germany, Norway as well as a number of plants in Japan. Although Gasification process is becoming increasingly prevalent, it is not considered to be as efficient as incineration. Gasification is more sensitive to feedstock CV than incineration owing to the requirement to produce a homogenous syngas. This leads to the production of lower net efficiency/higher parasitic loads with lower CV material. Therefore, gasification usually requires pre-treatment. This method is recommended for the treatment of more homogenous waste feedstock. (Zafar, 2016; Tanigaki et al., 2017)

Figure 2.7 shows the gasification process:

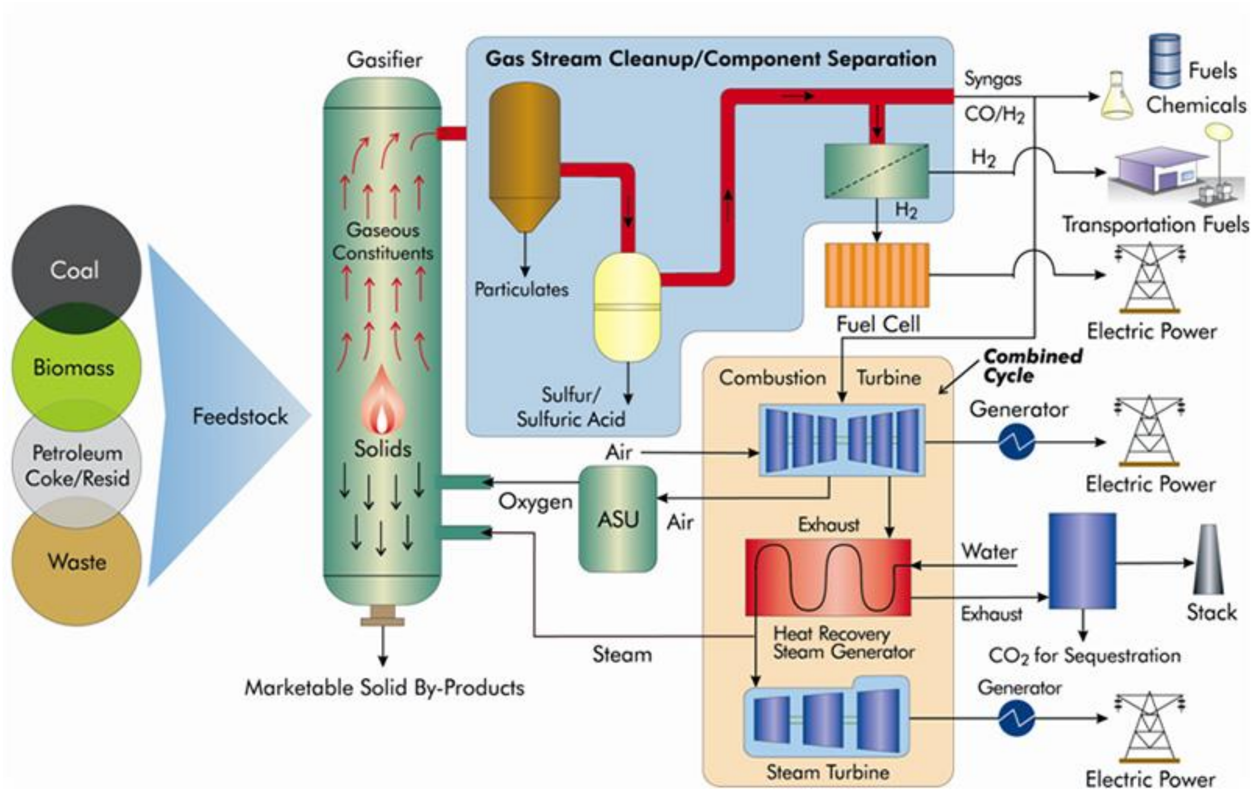

Figure 2.7: The Gasification Process

Source:https://www.netl.doe.gov/research/coal/energysystems/gasification/gasifipedia/intro-to-gasification

2.2.2.3. Pyrolysis

Pyrolysis is one of the potential routes of harnessing energy and useful chemicals from biomass. The primary objective of biomass pyrolysis is to produce liquid fuel, which is easier to transport, store and can be used as an alternative to an energy source. Pyrolysis refers to the material's thermal degradation in the absence of oxygen. Typically temperatures between 300ºC to 800ºC are used during pyrolysis of materials like MSW. Based on the operating conditions of temperature and residence time, varying quantities of syngas, pyrolysis oils and char (solid residue consisting of non-combustible materials and carbon) is formed. They can be processed further to produce useful products and energy. The syngas is a mixture of gases including carbon monoxide, hydrogen, methane as well as a broad range of other volatile organic compounds (VOCs).

Pyrolysis is not a fully proven technology to treat residual mixed solid waste. It is being developed and is yet to be used on a large scale. Pyrolysis capacities are typically 5,000 to 15,000 tpa per line. Pyrolysis is highly sensitive to the CV of the feedstock waste, which implies that pre-treatment is definitely required, with a known feedstock.

Pyrolysis offers a flexible and attractive way of converting solid biomass into an easily stored and transported liquid, which can be successfully used to produce heat, power, and chemicals.

The pyrolysis process is very dependent on the moisture content of the feedstock, which should be close to 10 percent. At higher moisture contents, high levels of water are produced and at lower levels, there is a risk that the process may only produce dust instead of oil. High-moisture waste streams, such as sludge and meat processing wastes, require drying before subjecting to pyrolysis.

The efficiency and nature of the pyrolysis process depend upon the particle size of feedstock. Most of the pyrolysis technologies can only process small particles to maximum size of 2 mm considering the need for rapid heat transfer through the particles. The demand for small particle size means that the feedstock needs to be size-reduced before being used for pyrolysis.

Pyrolysis processes can be categorized into two: slow pyrolysis or fast pyrolysis. Fast pyrolysis is currently the most widely used pyrolysis system. Slow pyrolysis, on the other hand, takes several hours to complete and results in biochar as the main product. Meanwhile fast pyrolysis yields 60 percent bio-oil and takes seconds to complete. In addition, it yields 20 percent biochar and 20 percent syngas. Bio oil is a dark brown liquid and can be upgraded to either engine fuel or to a syngas through gasification processes and then biodiesel.

Pyrolysis oil may also be used as liquid fuel for diesel engines and gas turbines to generate electricity. Bio oil is particularly attractive for co-firing as it is relatively easy to handle and burn than solid fuel. It is also cheaper to transport and store. Furthermore, bio-oil is also a vital source for a wide range of organic compounds and specialty chemicals.

Syngas is a mixture of energy-rich gases (combustible constituents include carbon monoxide, hydrogen, methane and a broad array of other VOCs). The net calorific value (NCV) of syngas is between 10 and 20MJ/Nm3. Syngas is cleaned to remove particulates, hydrocarbons, and soluble matter, before being combusted to generate electricity. Diesel engines, gas turbines, steam turbines and boilers can be used directly to generate electricity as well as heat in CHP systems using syngas and pyrolysis oil. Furthermore, syngas may also be used as a basic chemical in petrochemical and refining industries.

Of late, biomass pyrolysis has garnered much attention due to its high efficiency and good environmental performance characteristics. It also provides an opportunity to process agricultural residues, wood wastes and municipal solid waste into clean energy. In addition, biochar sequestration can make a significant difference in the global fossil fuel emissions and act as a major player in the global carbon market with its robust, clean and simple production technology (Zafar, 2016).

Pyrolysis and gasification represent refined thermal treatment methods as viable alternatives to incineration; they are characterized by the transformation of waste into product gas as an energy carrier for later combustion; for example, a boiler or a gas engine. Plasma gasification, which occurs at extremely high temperature, is gaining much prominence these days.

Electricity can be produced from waste through direct combustion, and the released heat is utilized to produce steam in order to drive a turbine. This indirect generation has an efficiency level of about 15percent to 27percent, with modern plants attaining the higher end of the range. The electrical efficiency rate from incineration is usually higher as compared to gasification due to lower operating temperatures, steam pressure and overall energy required to run the plant.

Gasification and pyrolysis processes produce a combustible synthetic gas (syngas) that can either be used to produce electricity through the aforementioned process or further refined and upgraded to for direct generation in a gas turbine or engine. Greater efficiency is realized from direct combustion in gas turbines or engines, as opposed to from a steam turbine (World Energy Council, 2016).

Direct combustion of biomass has been undertaken worldwide; however, problems can arise during the burning of biomass containing high amounts of heavy metals without any pre-treatment. For this reason, some thermal conversion methods such as pyrolysis and gasification are given precedence over the direct combustion of biomass. The pyrolysis process of biomass is highly complex and depends on several factors, such as the composition of the lignocellulosic material, heating rate, and the content of the inorganic material, among others. The main elemental constituents of biomass minerals are Si, K, Ca and Mg with minor amounts of S, P, Fe, Al and Mn (Lievens et al., 2009).

Moreover, the ash content of biomass is known to impact both the handling and processing costs of the biomass energy conversion. For a biochemical conversion process, the solid residue represents the quantity of non-biodegradable carbon present within the biomass. This residue is greater than the ash content because it represents the recalcitrant carbon which cannot be degraded further biologically, although it can be burnt during thermo-chemical conversion. Based on the magnitude of the ash content, the available energy of the fuel is reduced proportionately. In a thermo-chemical conversion process, the chemical composition of the ash can pose significant operational problems. This is especially true for combustion processes, where the ash can react to form a 'slag', a liquid formed at elevated temperatures, which can then reduce plant output and lead to heightened operating costs. (McKendry, 2002)

The alkali metal content of biomass i.e. Na, K, Mg, P and Ca, assumes great significance for any thermo-chemical conversion processes. The reaction of alkali metals with silica present in the ash produces a sticky, mobile liquid, which can lead to blockages of airways in the furnace and boiler plant. Notably, while the intrinsic silica content of a biomass source may be low, contamination with soil introduced during harvesting can significantly increase the total silica content. While the content of intrinsic silica within the material may not be a cause for concern, the increased total silica content may lead to operational difficulties (McKendry, 2002).

According to Aleluia and Ferrão (2016), MSW in developing Asian countries tends to be richer in terms of biodegradable organic matter, which usually accounts for more than 50 percent of the total waste composition, suggesting that biological methods are more appropriate for treating this organic fraction. By contrast, thermal combustion technologies, which are extensively applied in high-income countries, are technically and economically challenging to deploy owing to the lower calorific value of waste streams that are rich in organics and moisture.

Figure 2.8 illustrates the pyrolysis process:

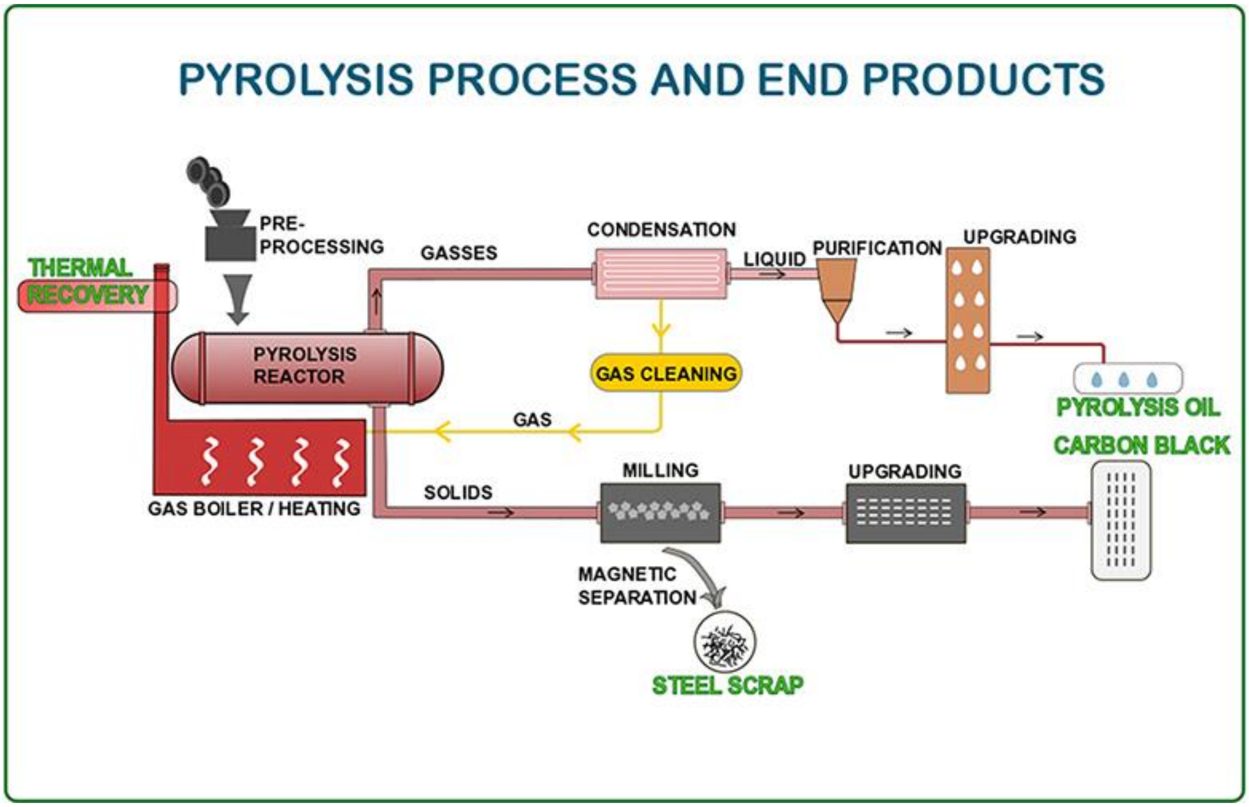

Figure 2.8: The Pyrolysis Process and End Products

Source: http://www.adamatic.fi/pyrolysis

In order to summarize the differences between Incineration (Combustion), Gasification and Pyrolysis, Table 2.2 list the differences as follows:

Table 2.2: Differences between Incinerations (Combustion), Gasification and Pyrolysis

Pyrolysis	Gasification	Combustion
Normally no air	Sub stoichiometric air Exothermic/Endothermic	Excess air Very exothermic
Only heat (external or internal)	Lower total volumetric flow	Higher volumetric flowrate
Want liquid, gases not desired	Lower fly ash carry over	Fly ash carry over
Pollutants in reduced form (H2S, COS)	Pollutants in reduced form (H2S, COS)	Pollutants in oxidised form (Sox, Nox etc)
Higher char	Char at low temperatures Vitrified slag at high	Bottom ash
Scale: ~10 tonnes/day	Scale: ~100 tonnes/day	Scale: ~1500 t/day
No additional oxygen (only heat)	Some additional oxygen (or air)	Much additional oxygen (or air)

Source: World Energy Council, (2016)

Based on the literature review of the optimum conditions and characteristics of the feedstock necessary to operate thermal technologies, it has been observed that there are very limited resources that emphasize the direct relationship between the waste characterization and the technologies. All of the literature review outcomes regarding the development of parameter/technology matrix will be presented in Chapter 5. Meanwhile the last type of technologies is shown below:

2.2.3 Physical-conversion Technologies: Refused Derived Fuel (RDF) from the Material Recovery Facility (MRF)

The mechanical processes are designed to separate the dry recyclables, such as glass and metals, in the MRF (Al Seadi et al., 2013). RDF production from MSW is found to be most active in member states of EU with high levels of recycling and MSW source separation (i.e. Austria, Germany, Netherlands are the best examples), given that the recycling activity generates non-recyclable high calorific residues that can be considered suitable as RDF.

RDF usually denotes the segregated high calorific fraction of MSW, commercial or industrial process wastes.

A high content of chlorine or mercury in the waste can cause operational or environmental problems. Therefore, PVC-plastic residues are not suitable for co-processing. Quality standards define the characteristics of RDF, such as the content of trace metals, chlorine, and sulphur. A calorific value of RDF of about 10 - 15 MJ/kg is particularly desirable for economically sound operation (Mutz et al., 2017).

In addition, the the total quantity of RDF produced from MSW in the European Union has been estimated to about 3 million tonnes. The capacity for RDF production from MSW is increasing in countries such as Austria, Belgium, Finland, Italy and Netherlands, with new MBT plants being built. There is some limited co-incineration of RDF from MSW in Europe. In the UK, RDF from processed MSW is reported to be incinerated in fluidized bed incinerators for energy generation, in multi-fuel district heating plants and paper mill boilers in Finland as well as in a few cement kilns in Austria, Belgium, Denmark, Italy, and Netherlands. It is not always possible to secure an outlet for RDF and some quantity to be stored. The total quantity of RDF co-incinerated has been estimated to be about 70 percent of the quantities produced. In future, the quantity of RDF burnt is expected to increase mainly in Belgium, Italy and the UK. Plans are also being made to use RDF from MSW in other non-combustion processes, such as gasification and pyrolysis (Gendebien et. al., 2003).

Nevertheless, the decision for a municipality or waste management company to produce RDF through MBT or to rely on MSW incineration in order to adhere with the landfill directive will depend on whether the costs of the MBT process are less than that of incineration or thermal treatment (Gendebien et. al., 2003). There are additional incentives for a municipality to choose MBT as a more flexible solution to mass-burn incineration. RDF can be produced from municipal solid waste (MSW) using a number of different processes consisting of:

a. Separation at source

b. Sorting or mechanical separation
c. Size reduction (shredding, chipping, and milling)
d. Separation and screening
e. Blending
f. Drying and pelletizing
g. Packaging
h. Storage

Figure 2.9 illustrates the generic process flow of MBT for the generation of RDF.

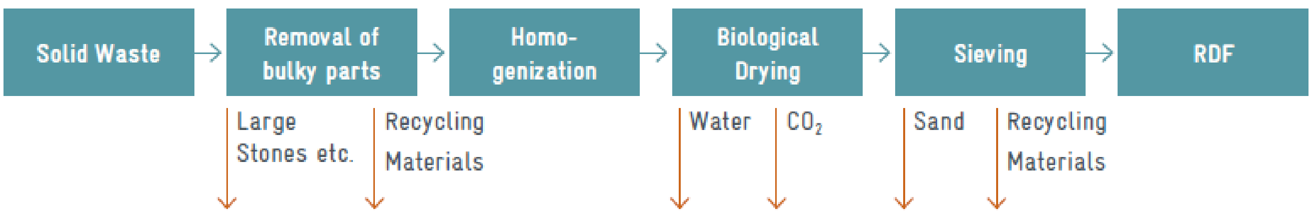

Figure 2.9: Generic process flow of MBT for the generation of RDF.

Source: Mutz et al. (2017)

The waste material is screened to remove the recyclable fraction (e.g. metals), the inert fractions (such as glass) and separate the fine wet putrescible fraction (e.g. food and garden waste) containing high moisture and high ash material before being pulverized. The wet organic materials can then undergo further treatment, such as composting or anaerobic digestion and be used as a soil conditioner for the purpose of landfill restoration work or be landfilled. In some cases, the putrescible fraction is kept in place to dry the mass of material through biological treatment (Gendebien et. al., 2003).

The important characteristics for RDF as a fuel are calorific value, moisture, ash content, sulphur, and chlorine content. These values vary in congruence with the sources (i.e. households, offices, construction, etc.), according to the collection system (mixed MSW, source separated) and treatment applied (screening, sorting, grinding, drying) (Gendebien et. al., 2003).

This technology is also categorized as physicochemical conversion technology, which involves a number of processes to improve the physical and chemical properties of solid waste. The combustible fraction of waste is converted into high-energy fuel pellets, which may then be used in steam generation. This waste is first dried to reduce the high moisture levels. Sand, grit, and other incombustible matter are then mechanically separated before the waste is compacted and converted into pellets or RDF. Fuel pellets have several distinct advantages over coal and wood because it is cleaner, free from incombustibles, has lower ash and moisture content, is of uniform size, and is cost-effective, and eco-friendly (Zafar, 2017).

Frankenhaeuser and Manninen (1996) argued that RDF is technically and economically feasible and environmentally friendly fuel for co-combustion in the wake of low CO emission that showed clean and efficient combustion, along with low SO2 emission. HCl emission increased with an increase in the chlorine content of fuel mixture. Heavy metals were concentrated to the fly ash in unreachable form. Dioxin emissions were found to be at the normal power plant level and far below the strict incineration limit. Long-term co-combustion of 10 percent RDF did not cause any high-temperature chlorine corrosion of the superheater (500°C) of the boiler. It was found to be useful, technically possible and environmentally friendly to combine resource and waste management in the form of fuel recovery for energy production in solid fuel-fired power plants.

One tonne of RDF used as fuel in fluidized bed boilers has a calorific value of 16.6 MJ/kg, while the calorific value of one ton MSW used as fuel in grate-fired boilers was calculated as 9.15 MJ/kg. The total amount of extracted energy as regards heat and electricity for the grate-fired incineration was computed to be 2.54 MWh/tonne, whereas it was calculated to be 4.63 MWh/ton using the fluidized bed incineration (Hasan and Ahsant, 2015).

RDF is not considered to be economically attractive because this technology needs dry feedstock, and organic waste is not very suitable for it. (Asian Development Bank, 2011)

2.3 Organic Waste Characterization Case Studies

According to the national waste report of Australia, 2013, around 14 million tonnes (Mt) of organic waste was generated in Australia, of which 6.63 Mt (47 per cent) was disposed of to landfill, 6.14 Mt (44 percent) was recycled, and 1.24 Mt (9 percent) was used in energy recovery.

Roberts and San (2015) studied the characterization of chemical composition as well as energy content of green waste and MSW from great Brisbane in Australia. He argued that deployment of the thermo-chemical WtE system requires characterization of the waste stream. Despite the use of gasification, there is no data on thermochemical properties. In this study, MSW was hand-sorted and classified into 10 groups, including non-combustibles. Samples for each combustible category were randomly collected from five batches of MSW piles each of size 150Kg. Samples were stored into 25L airtight plastic containers immediately upon collection in order to prevent gains and losses in moisture from the atmosphere. The total moisture content of any solid waste is one of the most significant variables that affect the energy content of the material. Chemical properties were measured and the results were as follows: moisture was variable between 29 percent-46 percent, the main contributor to the variation of energy content ranged from 7.8-10.7 MJ/Kg. LHV (lower heating value) of all MSW was 7.9MJ/Kg. Moisture in food was 70percent, in garden waste-60percent, and in plastic -2.2percent.

In another study conducted by Jansen et al.(2004) to assess the source's sampling and chemical analysis, separated organic household waste; sampling procedure focused on a truckload of waste and included shedding, mixing, blending, drying, as well as milling prior to OW analysis. They tested the following parameters: ash content, crude fibres, crude fat, protein, sugar, starch, enzyme-digestible organic matter, P, N, C, H, S, CV. Ten samples of the same truckload were obtained by splitting samples. One sample analysed was as many as six times over a period of one year. Results did not show any variance in the chemical analysis over a year. No single step in the sampling procedure was able to contribute with excessive variance. While variance varied with the analytical parameters, uncertainty was low for most parameters.

Belous et al. (2011) also examined the organic waste composition and properties. The parameters that were measured included: waste granulocyte and morphology, moisture content and loss on ignition, wastewater content, total organic carbon (TOC), P, N, the heat of combustion of waste, and heavy metals.

2.4 Preferred Technology Selection

Based on the literature review, it was observed that there were very limited references that set criteria to select the most preferred waste management options and considered waste characterization as the criteria for technology selection. One of the important references was the Asian Development Bank (2011), by the Australian Government. Apart from discussing several available technology options for the south Asian countries, this report analysed technology options for organic waste management after setting the selection criteria. It emphasized three main technologies: anaerobic digestion (AD), composting and refused derived fuel (RDF). The report mentioned how to select the right organic waste treatment system based on this selection criteria. Waste composition is one of the main criteria listed in this report.

According to Asian Development Bank, 2011, *"The physical composition and chemical characteristics of the municipal waste will enable local government officials and private operators to decide which organic waste technology will be most suitable for a particular city."*

This report provided evidence that cities with a population of 100,000 to above two million can adopt the most common technology in order to treat waste. It was shown that from 500TPD to above 1100 TPD is an integrated way of comprising waste treatment plants of Biomethanation (AD) and Refused Drive Fuel (RDF).

For solid waste incineration, the lower calorific value (LCV) of waste must be at least 1450 kcal/kg (6MJ/kg) throughout all seasons. The annual average LCV must not be less than 1700 kcal/kg (7 MJ/ kg).

It was reported that the waste in developing countries, particularly South Asia, is characterized by a significantly higher density and moisture, primarily organic waste with low calorific values (700– 1,000 kilocalories). Considering these physical and chemical characteristics of the waste in the region, incineration - which is ideal for the dry matter with high calorific value - is not a suitable option.

As a conclusion from the above discussion, it has become apparent that each technology has its optimum parameters measures in order to become effective. These optimum parameters measures have been assembled and presented in a matrix in Chapter 5, which realizes the first objective of this research.

2.4.1 Overview of some Methodologies used to select the Best Technologies

According to Ali et al. (2010), the criteria for the 'best' technology may differ depending on the specific requirements. It has been found that technology selection involves gathering information from various sources about the alternatives, and then evaluating alternatives against each other or some set of criteria. The best way to select the best suited technology is according to local conditions and circumstances.

SHTEFIE Criteria General Model

Factors Criteria include:

S-Social Skills of the worker, officer needs, and preferences; treatment cost, convenience, willingness to pay, number of patients

H-Health- Hospital facilities, hygienic related concerns, diseases carried by waste

T-Technological- waste type, availability of spare parts and materials, availability of local knowledge and expertise, existing procedure of disposing the waste, power requirements; including electricity, fuel etc.

E-Economic- Quantity and quality of waste, overall reputation of hospital and fame affected by waste, the structure of economy, land, labour and capital requirements

F-Financial- Finance available, a method of funding, ability and willingness to pay

I-Institutional- Existing roles and responsibilities of organization and management, relationships between organizations, legislation, policies, and regulations

E-Environmental- Global warming, air pollution including smog, water pollution, odour pollution

This research represents a developed criterion that considers all of the above factors under the "enablers and barriers" title, and might need further improvement to develop a technology selection model.

In another study conducted by Rafiee et al. (2016), named Sustainability Assessment of Technologies (SAT); a suitable methodology was adopted for integrating technical, environmental, social, and economic considerations with the primary focus on environmental issues and developmental aspects. This methodology consisted of three main steps: screening, scoping and detailed assessment. In order to adapt the methodology to national conditions, country-specific parameters and constraints, we incorporated some changes in its criteria and used the modified methodology in order to select the best alternative.

Samah et al. (2013) argued that the main predicament with solid waste management today is to identify and select the most appropriate solid waste treatment technologies and disposal methods in selected areas. The Analytical Hierarchy Process (AHP) was used as the tool to facilitate this decision making task. It is a method developed to support multi-criteria decisions; an effective and practical approach that takes into consideration, complex and unstructured decisions. One model was developed as General Hierarchy Structure Model (GHSM) to select the appropriate solid waste treatment technology. This model was structured into a hierarchy that comprises of goals, criteria, sub-criteria, and alternatives. Based on the level of political support, technical expertise, environmental impact, market potential, community involvement and cost criteria, GHSM accords priority to recycling, composting, incineration or combination of technologies.

Moreover, Generowicz and Gaska (2015) contended that finding solutions for regional waste management systems entails making difficult decisions that must evaluate alternative solutions to select the most preferred among them. This assessment can be made by using measurable economic, environmental and social criteria, which collectively form part of a multi-criteria analysis. In order to examine the variants of the waste management system in Zabrze, the criteria was proposed for evaluation in the following groups:

1. Economic criteria - evaluating the economic aspects of the system variants, their costs, and capital expenditures
2. Environmental criteria - the assessment of emission volumes to the environment as a result of operating individual installations of the system;
3. Social criteria - defining the degree of public acceptance of the variants of waste management in Zabrze

Martowibowo and Riyanto (2011) incorporated the MCDA and AHP framework to select the MSW treatment in the city of Bandung. They determined four main categories to optimize the technology selection. These criteria are Technology, Economics, Environment, and Social.

According to Alevridou et al. (2011), criteria represent decision makers or other stakeholders' points of view as per which establishing comparisons become adequate and viable. There are two main approaches to determining the set of criteria, reflecting the two ways of building an MCDA problem. A top-down approach is compatible with 'value-focused thinking' wherein criteria are built in a hierarchical structure, known as 'value tree' - leading from primary goals to main objectives - which in turn are further broken down to specific criteria. The bottom-up approach supports 'alternative-focused thinking', as per which criteria are identified through a systematic elicitation process, and may subsequently be grouped into broader categories (Danae, 2004). In waste management MCDA, top-down approach is the most commonly used approach, starting with defining the primary goal which is the selection of the best available waste treatment option. Furthermore, Babalola (2015) used a Multi-Criteria Decision Analysis (MCDA) to evaluate various waste management options as well as their availability in Japan. He claimed that several criteria were identified and initially grouped into the following nine categories: politics, society, culture, economics, environment, technology, public health, finance, and land use.

This research is an exploratory research wherein the selection of the preferred OHW management technology for Bahrain will be based on a single criterion - waste characterization - and then the enablers and barriers to the technologies adoption will be explored in order to select the most suitable technology for the Bahraini society.

Meanwhile the next section will cover the literature review that covers the social phase:

2.5. Section 2: Exploring the Enablers and Barriers to the Technology Adoption

Metson and Bennett (2015) investigated in a case study held in Montreal, Canada about the existing habits of individuals, and their conception of waste as dirty, observing that the lack of knowledge about management of waste in general represents major barriers to waste management. Furthermore, organic matter separation from solid waste and recyclables is essential to divert food and yard waste from landfills, and treat organic matter appropriately. The public culture plays an important role in the success of any management practice e.g. separate organic waste collection and composting. It was found that the concerns over organic waste bins being smelly and attracting flies, maggots, and rodents are widespread, exacerbating the challenge of changing existing habits of not segregating organic from non-organic waste. The lack of information and knowledge about waste separation and composting also impedes the adoption of the waste management plan.

Mutz et al. (2017) stated that WtE technologies can improve waste management in the fast-growing cities of developing and emerging countries but added that its application is complex and must consider, amongst others, the following barriers:

1. Lower calorific value in MSW than in industrialized countries owing to the high moisture (high organic content) and mineral content in waste (e.g. ash, construction and demolition waste);

2. Substantial seasonal change in waste composition (i.e. changing consumption patterns during festival seasons, seasonal crops);

2. Limited practice of waste segregation at source, a precondition for anaerobic digestion;
3. Weak business and operation models;
4. Lack of knowledge on operating and maintaining WtE plants;
5. High investment and operating costs which cannot be recovered by existing waste fees and generated additional income from energy sales alone;
6. Neglecting livelihood issues for marginalized persons and informal sector workers based on the availability of recyclables in the waste;
7. Lack of monitoring and weak enforcement of environmental standards, leading to public health issues.

These barriers might be the same of Bahraini context since the lack of waste separation at source coupled with the lack of information and public awareness represented by people perception, attitude and behaviour may play a key role in the successful adoption of OHW management technology. This hypothesis will be tested in Chapter 7 through experts' interviews in order to shortlist the main enablers and barriers toward each technology's adoption in Bahrain using the nvivo 12 qualitative methodology tool.

The lack of evidence based studies that resulted in listing the main enablers and barriers to waste technologies adoption in the GCC countries contribute to the much-needed knowledge in this area that can enable researchers and decision makers in these countries to reach a successful technology adoption in future apart from helping them overcome the barriers.

A review of the literature found descriptions of barriers and enablers to waste technology adoption in addition to the above as follows:

Zafar (2016) is one of the very few researchers and experts who theoretically discussed the challenges of waste management sector in the GCC area. He argues that GCC waste management sector is currently facing multiple challenges in the form of:

1. Lack of clear and reliable framework by which the solid waste sector is administered from the collection, transformation to disposing or treatment phases

2. The absence of effective and comprehensive legislative frameworks governing the solid waste sector and the inadequate enforcement mechanisms, which are no less important than the legislation themselves

3. Management activities of MSW are considered public services which are directly controlled by governmental institutions. Such management arrangement is considered weak as it lacks market mechanisms, and in cases like these, economic incentives cannot be used to improve and develop the MSW management services

4. Inadequate human and organizational capacities and capabilities

5. The paucity of accurate and reliable background data and information on the status of solid waste such as the rate of generation of different solid waste constituencies, assessment of natural resources and land-use, and transportation needs, scenarios of treatment, and growth scenarios of solid waste linked to several driving forces. Needless to say, data and information are crucial elements for developing the MSW management system, including the adequate monitoring of the sector.

6. Inadequate waste strategies/management infrastructure: In most GCC countries, existing waste handling capacities are found to be insufficient. Currently, the recyclable recovery rate is low. Furthermore, in the absence of local recycling facilities, there is no alternative except to dump the recyclable material at Landfills.

7. Waste recycling is expensive: Though recent years have seen an increase in the number of waste recycling facilities, the economics of recycling is still not very favourable. In many cases, recycling waste is more expensive than buying the product.

8. The underdeveloped market for recycled products: Insufficient demand for recycled products within the local market is another reason, which has hampered the growth of the waste recycling industry.

9. Public attitude: Economies in the GCC countries are oil dependent due to the high reserves of fossil fuels. For several decades, alternatives such as solar and wind were not considered and oil was the only feasible option. Recently and due to drop in oil prices, more consideration is being given to renewable sources. Similarly, waste was mainly landfilled as it was an easier choice; yet, due to a known complication associated with such treatment, more suitable measures were considered. Therefore, there is a need for an effective comprehensive “education and awareness” program in regard to these two issues (Zafar, 2016).

According to West Asia Regional Assessment Report (2015), it was found that barriers to developing modern integrated waste management systems in West Asia are political (P), economic (E), social(S) and technological (T) or (PEST), as they are further discussed below:

Political and institutional barriers:

There are weaknesses and gaps in the legislation in some countries and the need to connect with the informal sector so as to create economic opportunities for improving health care provision is not supported by effective commitments to procure; at the same time, decisions made on the lowest price at tender may provide inadequate infrastructure and technology for integrated waste management; procurement indecision is eroding confidence in the financial viability of projects; implementation of contracts is often frustrated by inter-entity roles and responsibilities; data management generally is found to have significant gaps, is variable and poor; financial systems and budgeting meanwhile need to reflect the cost of developing modern integrated waste management systems.

Environmental barriers:

The quantity of waste is increasing alongside population growth, with most waste streams poorly managed and sent to landfill, resulting in the loss of land use and pollution from uncontrolled fires, emissions and groundwater contamination; hazardous wastes are poorly managed with low capacity for treatment and disposal; the future environmental liability of facilities is being transferred to the private sector indiscriminately and hastily, thereby undermining viability and insurance cover. Most West Asian states have limited site options for land dumps. As of now, the main disposal methods for municipal solid waste are open dumping and sanitary landfill. Overall, the environmental condition of uncontrolled dumpsites is extremely vulnerable, with severe environmental pollution. On open dumping grounds, foul odours and air pollution are dangerously affecting the surroundings. Rodents are spreading pathogens to adjacent areas and workers are highly exposed to diseases and hazardous waste. Some cities in the Gulf region dispose of their waste in sanitary landfills. The landfills are generally well operated and maintained. However, leachate treatment may not be commonly practiced in some cities in the wake of resource constraints. Leachate from open dumping or sanitary landfill may lead to serious water pollution in the absence of proper treatment. Financially comfortable cities with land scarcity have opted for incineration or treatment facilities for municipal solid waste diverted from landfill. In addition, extensive air pollution control systems are installed in the incinerators. The issue of dioxin, however, is not adequately addressed. After incineration, about 10 percent of the residue still needs to be disposed of in a secure landfill.

Socio-economic barriers:

There are new potential markets for waste currently dumped or sent into the landfill that can be recovered using treatment technologies; opportunities exist to engage with the informal sector to promote economic development; recycling of materials separated at source could be increased to create new industries by utilizing these additional recyclables as raw materials, simultaneously improving health and safety standards; there is a need to improve financial confidence in integrated waste management by raising tariffs from waste producers – this will help the authorities fund facilities with the necessary treatment technologies and encourage regional cooperation.

Technological barriers:

There is a need to adopt or upgrade to suitable technologies with regional recycling and composting, including improving separation at source; all dumpsites need to be phased out and remediation plans must be developed encompassing landfill mining and long-term maintenance to contain and manage pollutants, and establish new amenities; there is also a need for regional control of the management and treatment of hazardous wastes; the use of modern GIS-based tracking will improve the logistic efficiency of all waste vehicles; at the same time, organic solids in the municipal solid waste stream may be ideal for the production of activated carbon or carbon nanotubes that could then be used to address water issues within the region.

Society and the wider economy would benefit greatly from sound waste management practices. These benefits would include the economic value of recycled materials and energy, reducing the cost of resource recovery and overall costs – quite apart from the long-term costs of inaction. One of the major issues for developing countries, including West Asian countries, is the difficulty encountered in tackling the economic cost of not addressing waste management problems. Evidence suggests that these problems are far greater than the financial cost of environmentally sound waste management. To that end, several indicators and methods have been employed to estimate the economic cost of these problems. These methods include abatement costs, willingness to pay for a clean environment, or the market value of property in context to its location far away from or in close proximity to waste sites. However, many of these indicators may not give coherent results. Therefore, it is suggested that each case study should use a method that meets specific objectives.

Moreover, according to UNEP (2017), it was found that waste management in Bahrain is hindered by the following factors:

1. Low level of Commitment: there is a disconnect between the high-level policy makers and the lower entities responsible for waste management (NGOs, people, industries, etc..) that hinders commitment to the implementation of a sustainable waste management policy and the provision of necessary resources.
2. Weakness in Governance: at Entity level - uncoordinated governance and conflict of interest due to regulatory, operational, duplication and overlapping of responsibilities.
3. The scarcity of data: entity managers lacking data management, effective controls and monitoring systems, tools, and resources to do the job. The data requested for this report from the entities indicated a significant lack of detail, consistency, and systems for control, monitoring and recording, and poor and inconsistent historical records

Furthermore, WtE technologies can improve waste management in fast-growing cities of developing and emerging countries but its application is complex and must consider, amongst others, the following specific circumstances:

» Lower calorific value in MSW as compared to industrialized countries due to the high moisture (high organic content) and mineral content in waste (e.g. ash, construction, and demolition waste);

» Substantial seasonal change in waste composition (i.e. changing consumption pattern during festival seasons, seasonal crops);

» Limited practice of waste segregation at source, which is a precondition for anaerobic digestion;

» Weak business and operation models;

» Lack of knowledge on how to operate and maintain WtE plants;

» High investment and operating costs which cannot be recovered by existing waste fees and generated additional income from energy sales alone;

» Neglecting livelihood issues for marginalized persons and informal sector workers who are dependent on the availability of recyclables in the waste;

» Lack of monitoring and weak enforcement of environmental standards, leading to public health issues.

Mutz et al. (2017) argued that high initial investment costs tend to be a major barrier to developing MSWI projects in developing countries. Attempts are being made to bring low-cost MSWI projects to the market with a basic technical standard for low-income countries; however, there is limited experience with these solutions and it remains to be seen if these plants can successfully meet the necessary technical and emissions standards in the long term.

Moreover, Mutz et al. (2017) claimed that the operation of highly complex MSWM technologies requires well developed technical and management skills. It is much more complex than the operation of a sanitary landfill. Only managers, engineers and technicians with proven capabilities and experiences should be assigned key functions. If these qualifications are not available locally, international experts must be contracted on a long-term basis and capacity building program needs to be launched. Thus, it can be concluded that the lack of the well-trained manpower represents the main barrier to incineration technology adoption.

Environmental legislation in most developing and emerging countries do not explicitly deal with the application of MSW incineration technology. This makes the entire process of impact assessment and operation licensing more complicated and time-consuming. During the unavailability of comprehensive and legally binding standards, these should first be developed and follow the application of internationally recognized standards. An example of orientation can be the European waste incineration directive (Industrial Emissions Directive). It also needs good capacity for monitoring and enforcement within public institutions (Mutz et al., 2017).

Therefore, Survey 1 was conducted in order to explore the enablers and barriers to OHWM technologies adoption in Bahrain. The methodology used to design and analyse this survey is found in Chapter 3, while the survey results and accompanying discussion are presented in Chapter 7.

2.6. Section 3: Public Awareness Measurement

Hasan (2004) argued that public awareness is the key to successful waste management. He claimed that public awareness and participation are critical components in any waste management program apart from appropriate legislation, strong technical support, and adequate funding. "*Involve people in their own community decisions and actions, to avoid "not my business"– syndrome, and ensure "maximum participation"* (Al Seadi et al., 2013). It is useful to raise awareness about the purpose of the separation of food waste before the actual implementation.

Raising awareness about municipal solid waste management is an essential component of effective waste management. Moreover, community participation has a direct effect on efficient solid waste management plan (Wahid, 2015).

Korai et al. (2017) concluded that lack of pre-planning, infrastructure, public awareness and many other factors have become the root factors for worsening municipal solid waste management in Pakistan. Abe and Didham (2013) stated that public awareness of appropriate solid waste management practices is the starting point and fundamental ingredient of a sound material-cycle and resource-efficient society. Furthermore, they argued that public awareness is the foundation of public capacity, which enables the public to undertake actual actions of each element of the 3Rs. Consequently, such actions become the input for the advancement or "performance" of 3Rs for a sound material-cycle society. Central and local governments, environmental NGOs, entrepreneurs, and mass-media, influence public awareness through their policies, practices, and operations, which leads to "capacity development".

According to Abe and Denham (2013) the public can be defined as *"all individuals within society: ordinary citizens, state and municipal government officials, politicians, NGO staff, business executives and employees, including small and medium enterprise (SMEs) owners. In order to discuss "awareness",* we cannot exclude any individuals who have opinions on the environment—all opinions count". In order to define "Public Awareness", it is helpful to define other related terms, which include:

Public Awareness – acquired knowledge and concerns of individuals concerning 3Rs, sustainable production and consumption, and resource efficiency.

Public Knowledge – acquired experience and a basic understanding of individuals concerning 3Rs, sustainable production, and consumption, and resource efficiency.

Public Attitude – acquired values, expression of concern and interests, and motivation of individuals for actions concerning 3Rs, sustainable production and consumption, and resource efficiency.

Public Action – actions were taken by individuals with regard to their behaviours, consumption choices, and lifestyle practices to accommodate or support 3Rs, sustainable production and consumption, and resource efficiency. (Abe and Denham, 2013)

Amasuomo et al. (2015) argued that awareness and education is an important tool for increasing public participation in sustainable waste management programs. Moreover, they concluded that the barriers preventing public participation in sustainable solid waste management include the lack of information on how and where the wastes are to be disposed of, the unwillingness of public due to wastes and environmental levies, lack of adequate support from the government and other stakeholders, and poor government policies, amongst others.

Figure 2.10 shows the relationship between waste management technologies and public awareness.

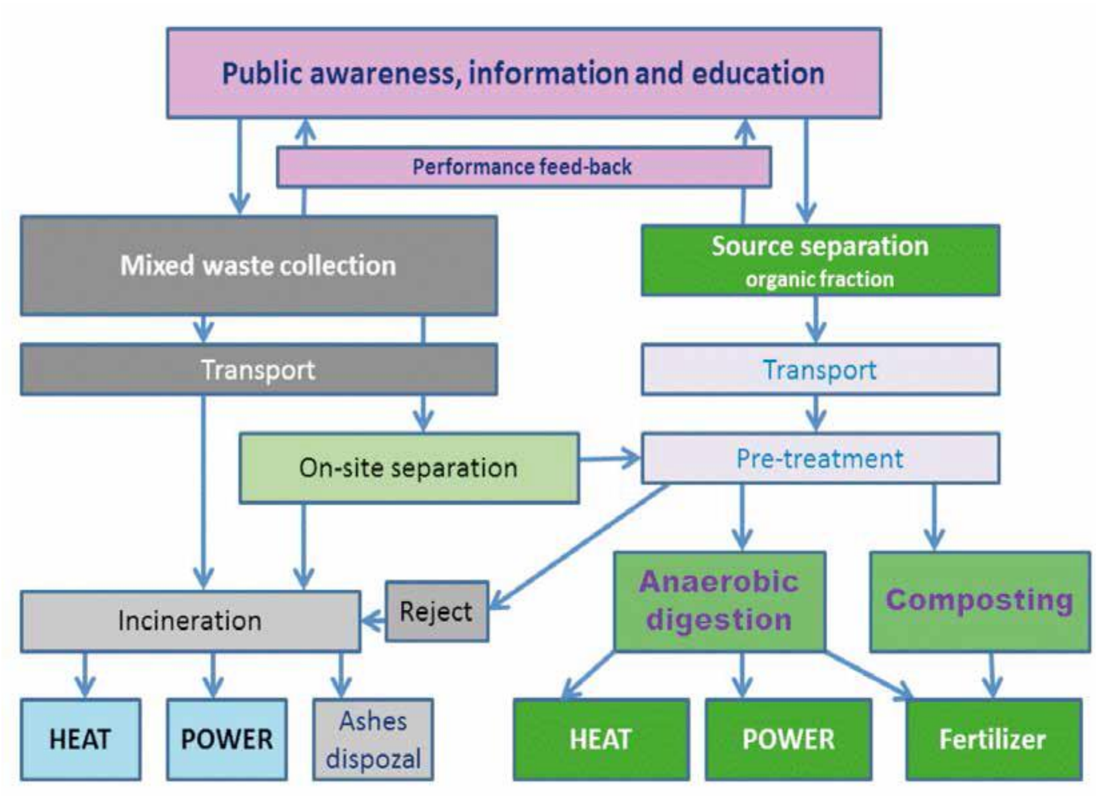

Figure 2.10: Flow diagram of MSW management with energy recovery

Source: (Al Seadi et al., 2013)

The economics of source separation of digestible household waste is highly dependent on existing waste management policies and the socio-economic frameworks offered by such policies. Municipalities have good reasons to introduce source separation of digestible wastes and create premises for their use as feedstock for the AD. Source separation of wastes is important for meeting the necessary standards of quality required by waste recycling (Al Seadi et al., 2013).

As per Umuhire and Fang (2016), different studies have proved that enhancing public Environmental Awareness will lead to increased public support for the purpose of environmental protection. Their study develops a questionnaire to investigate current levels of student's awareness by measuring their concerns, knowledge and attitude.

Song et al (2016) discussed the residents' attitudes and willingness to pay for solid waste recycling via a questionnaire survey.

Han Z et al. (2018) used questionnaires and statistical methods to measure public awareness in China. They argued that public awareness of domestic waste characteristics and management PADWCM is a prerequisite for domestic waste management plan.

Varey, et al. (2003) conducted a survey in order to provide a baseline assessment of current public attitudes and barriers to paying for waste collection and to suggested areas for improvement which includes an indicative snapshot of trends in public awareness across an array of socio and geo-demographic regions of Metro Manila.

The survey covered the following aspects:

• Section A - Identification and knowledge about waste collection and disposal

• Section B - Existing situation regarding waste collection and disposal

• Section C - Waste segregation and recycling

• Section D - Willingness to pay for waste collection and disposal

However, in this research, survey 2 encompasses all of the above sections within the three main components of the public awareness: Knowledge, Attitude, and Behaviour. Chapter 3 includes the details of the methodology used for and the design and analysis of survey, while Chapter 8 contains the survey results and discussion.

CHAPTER 3: Research Methodology

3.1. Introduction

This chapter consists of four main sections to cover the methodologies used in all the research phases. First section 3.1 contains a brief overview of the entire spectrum of methodologies used in this research in order to realize the research objectives. Next, section 3.2 emphasizes the philosophy of research methodology, ontology and epistemology. Section 3.3 includes the empirical investigation methodology that aims to characterize the OHW of Muharraq Governorate which in turn realizes the second objective of this research, and leads to attainment of the third objective through matching the empirical investigation results with the matrix that was previously developed from Chapter 2, and can be found in Chapter 5. Section 3.4 includes the economic feasibility method used to achieve the fourth objective and found in Chapter 6 while 3.5 specifies the methodology used to explore the enablers and barriers to the selected technology's adoption in Bahrain, which then accomplishes the fifth objective. Finally, 3.6 is about the method used to measure public awareness that realizes objective 6 (its results and discussion can be found in Chapter 8). The overarching aim and supportive objectives with chapters are illustrated in figure 3.1, while figure 3.2 shows the connections between the methodologies of different chapters.

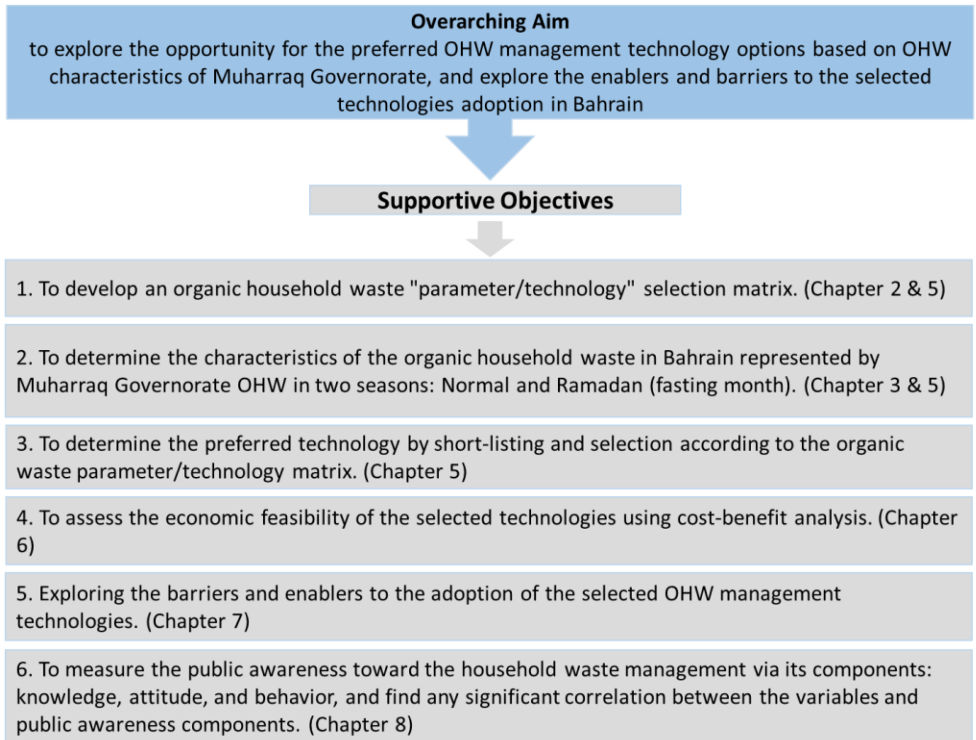

Figure 3.1: Research Overarching Aim and Supportive Objectives with Thesis Chapters.

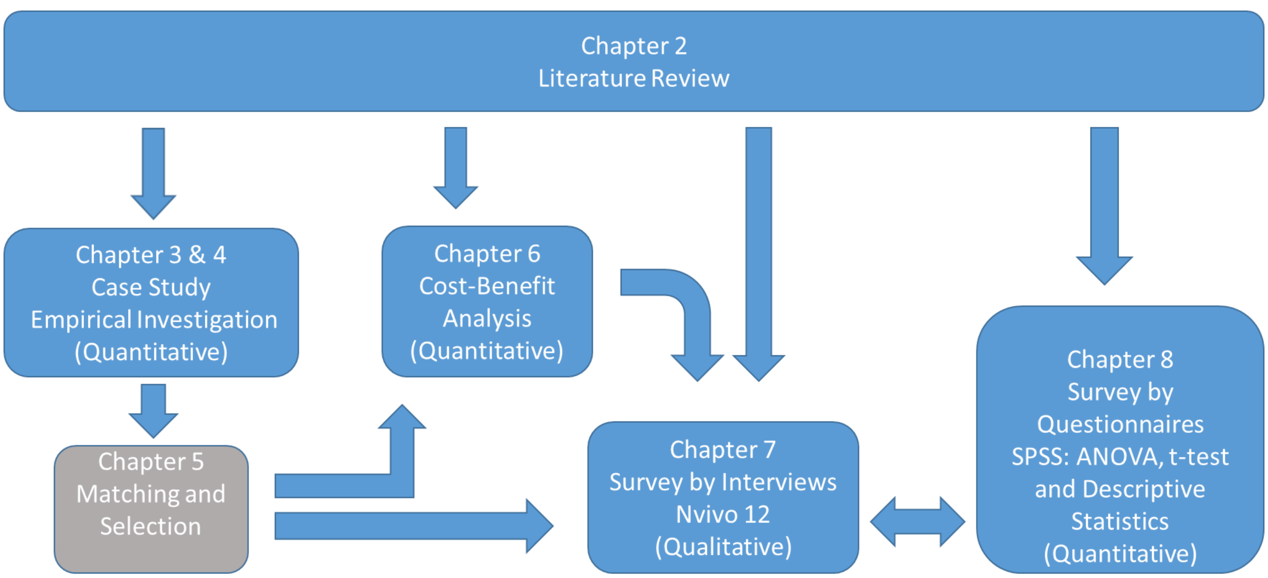

Figure 3.2: The Connections between Methodologies of Different Chapters

3.2. Research Methodology Overview

This research has adopted a "Case Study" framework (Yin, 2003), using the "Mixed Method Approach" by combining two methodological approaches: quantitative and qualitative methods. The mixed method approach has many advantages in that it combines the strengths of both qualitative and quantitative research and is ideally suited to address the complexity of social reality, and provide a better understanding of the research subject. Moreover, it helps to better understand, explain, or build on the results from quantitative and qualitative approaches.

According to Creswell (2003), who identified the Mixed Method Approach types, this research uses the "Sequential Exploratory Design" as the quantitative findings interpret the qualitative data of survey 1. Figure 3.3 summarizes the methodologies and illustrates the relationships between them.

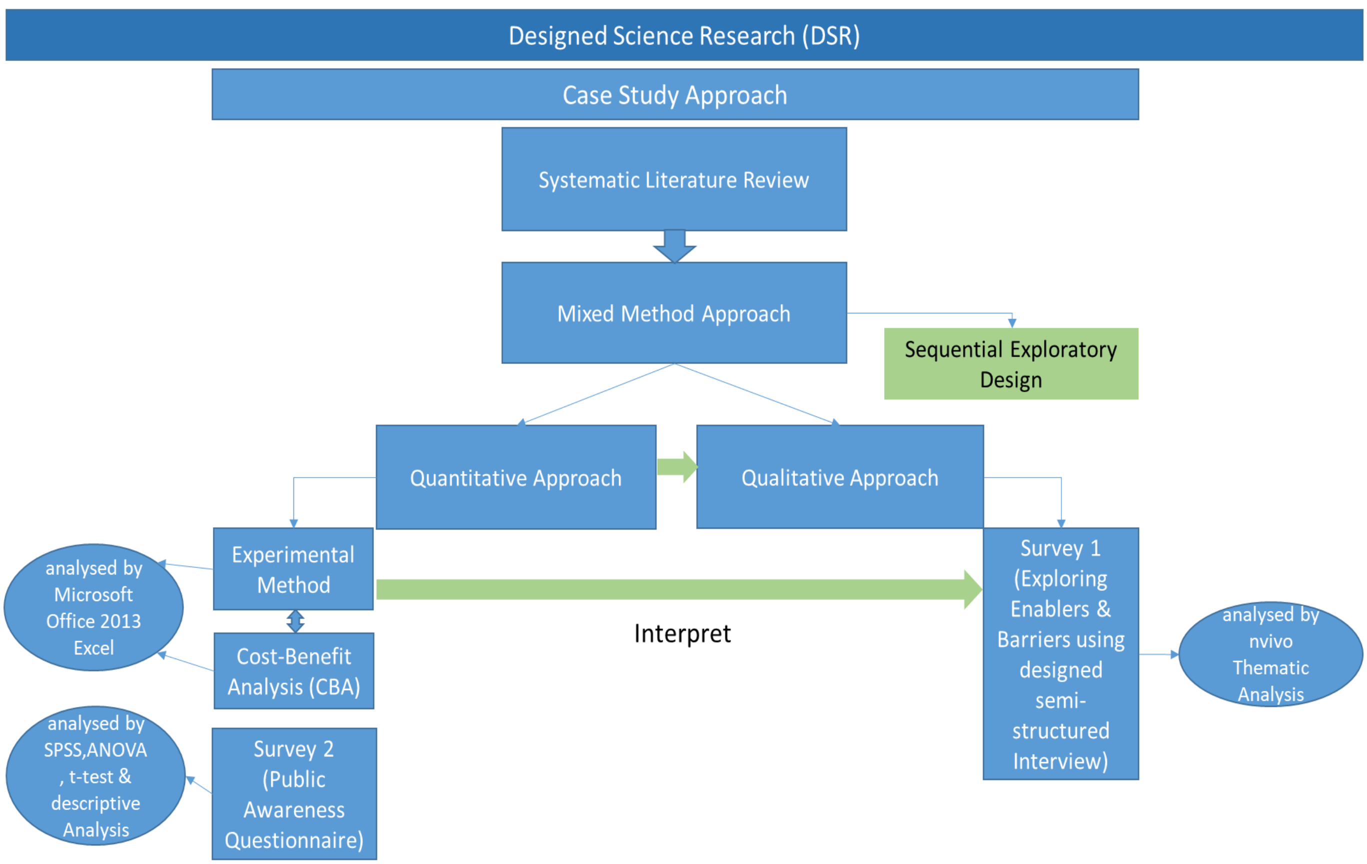

Figure 3.3: A summary of the research methodologies and their interrelation

The research commences with the empirical investigation via an experimental method; interviews and questionnaires in order achieve the research overarching aim and objectives. Crowe et al.

(2011) stated that case study approach is beneficial for its appropriateness in examining a contemporary situation and exploring phenomena where local "real life" context is intrinsically linked with the phenomena. Case study design also allowed using a full suite of data sources to answer the research questions (interviews, participants' observation and document review).

Whilst the literature did not reveal the ideal framework for OHW technology selection using a parameter/technology matrix, the outer framework to do so includes the four main research objectives: OHW characterization (technical criteria), technology feasibility (economic criteria), enablers and barriers to technology adoption, and the public awareness measurement as a key enabler for the successful implementation of waste measurement technologies (social criteria). Moreover, successful implementation of the selected technology options depends on OHW characterization. The selected preferred technologies might be considered (context specific) e.g. the socio-economic factors are unique for the Bahraini context and must be understood to ensure its alignment with the governmental strategy and business unit within the country. Figure 3.4 summarizes the research phases, technology selection criteria and methodology:

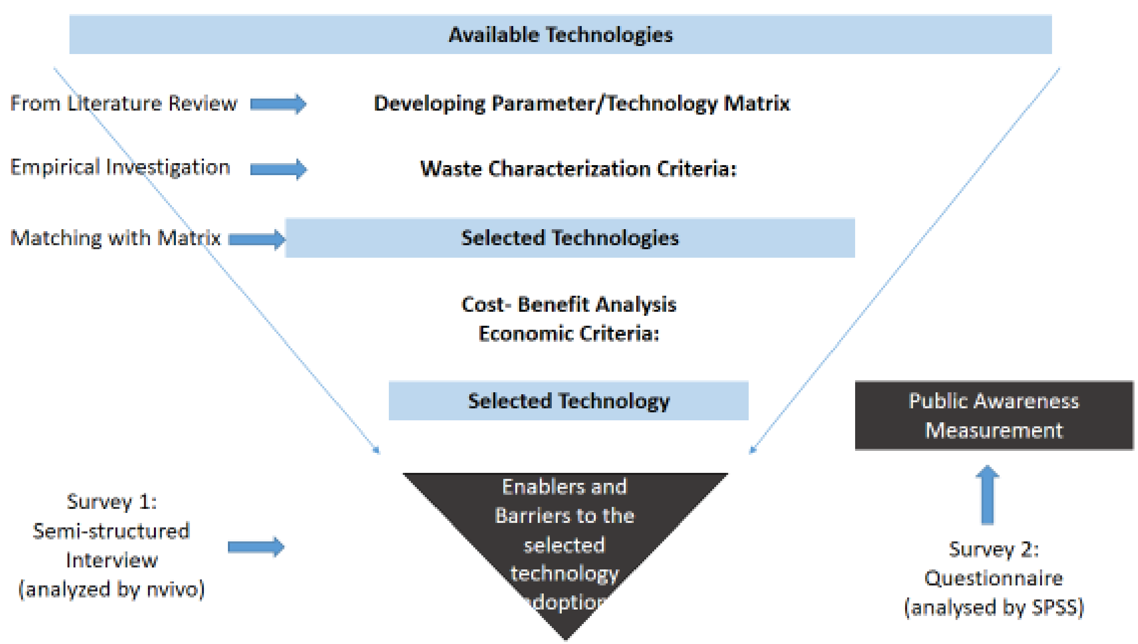

Figure 3.4: The research phases with selection criteria and methodology.

The selection criteria for OHW management technology options were based on the availability of published data, knowledge of physical as well as chemical characteristics of the OHW and conducting designed interviews with experts.

This research may facilitate the development of a new model to select the most preferred technology in order to manage the organic waste for any context. This model depends on waste characterization as the primary technical criteria to select and shortlist the technologies in the first stage, before considering the economic criteria as the secondary criteria for selection by applying cost-benefit analysis (CBA) for Bahraini context to explore the most feasible technologies, and then determining the possible enablers as well as barriers for the chosen technologies using semi-structured interviews with 11 experts. The expert interviews that aim to explore enablers and barriers to technology adoption were analysed using nvivo 12 software for qualitative data analysis. Section 3.6 includes more details about how were experts selected and why nvivo software used for interviews analysis.

In parallel, as public awareness is considered a key enabler of any waste management technology adoption and waste management practice, the same is measured for the Muharraq Governorate population through the conduit of a questionnaire. The questionnaire was designed based on the information provided by literature and theory about public awareness measurement, particularly environmental public awareness. The statements of this questionnaire were divided into 3 main components: knowledge, attitude and behaviour. The results were analysed using SPSS, particularly ANOVA, t-test and descriptive statistics.

3.3 Philosophy of the Research Methodology, Ontology and Epistemology

Vaishnavi, et al. (2004/17) identified the Design Science Research (DSR) as follows:" *Design science research is a "lens" or set of synthetic and analytical techniques and perspectives (complementing positivist, interpretive, and critical perspectives) for performing research in IS and Engineering. Design science research involves two primary activities to improve and understand the behaviour of aspects: (1) the creation of new knowledge through design of novel or innovative artifacts (things or processes) and (2) the analysis of the artifact's use and/or performance with reflection and abstraction.*"

Therefore, this research can be classified as a Design Science Research (DSR) in that it contributes to the design of a new artifact, as shown in section 3.2 in order to select the most preferred OHW management technology for a specific context apart from assessing the selection's economic feasibility, with contribution of both enablers and barriers exploration within the selection process, apart from designing a tool to measure public awareness, which signifies key enablers to succeed in any waste management technology adoption across the country.

Vaishnavi, et al. (2004/17) claimed that DSR cannot be value free because the aim of the researcher is not only to describe the existing world, but also to make contributions to shape it. Therefore, the researcher accepts responsibility even for the unforeseen consequences of the research.

They added that the design science researcher is ontologically involved in the research through multiple contextual situations. Even as the research progresses through more than one circumscription phase (empirical, economic and social), the researcher is challenged with an epistemology of gaining knowledge through the process of construction, acknowledging and accepting that context affects the process. In my research, this engagement was intended to gain a detailed understanding of the techno-socio-economic work-role context so as to select the desirable technologies ideally suited for the Bahraini context.

In order to understand the "Ontology and Epistemology" of this research, it is important to define these terms. According to Checkland (1999) and Dietz, (2006), Ontology can be defined as a reflection of the nature of science or the nature of reality. On the other hand, Epistemology reflects the relationship between an inquirer and the object of inquiry. For example, in the context of design science research, an epistemology of 'knowing through making' describes the relationship between the researcher and object of construction (Vaishnavi et al., 2013).

Table 3.1 presents the guidelines for DSR that are applicable to the different phases of this research.

Table 3.1: Guidelines for DSR (Hevner and Chatterjee, 2010)

GUIDELINE	DESCRIPTION
Design an artefact	Research must produce a viable artefact
Problem relevance	Objective is to develop a technology-based solution to a relevant business problem
Design evaluation	Use well-executed evaluation methods to test utility, quality and efficacy of an artefact
Research contributions	Effective DSR must provide clear and verifiable contributions in the areas of design artefact, design foundations, and/or design methodologies
Research rigour	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artefact
Design as a search process	Utilise available means in the search for an effective artefact and solution to a problem
Communication of research	Effective presentation of DSR to both technology- and management-oriented audiences

Correspondingly, Hevner and Chatterjee (2010) distinguished three research cycles in design science research, as illustrated in figure 3.5. These cycles are: the relevance cycle, the design cycle and the rigour cycle. The research problem and the research environment are explained in the relevance cycle. The rigour cycle uses existing knowledge bases such as theories, methods, design products, design processes, artefacts, experiments and expertise so as to provide a basis for rigorous design research. The design cycle meanwhile includes the research activities and actions.

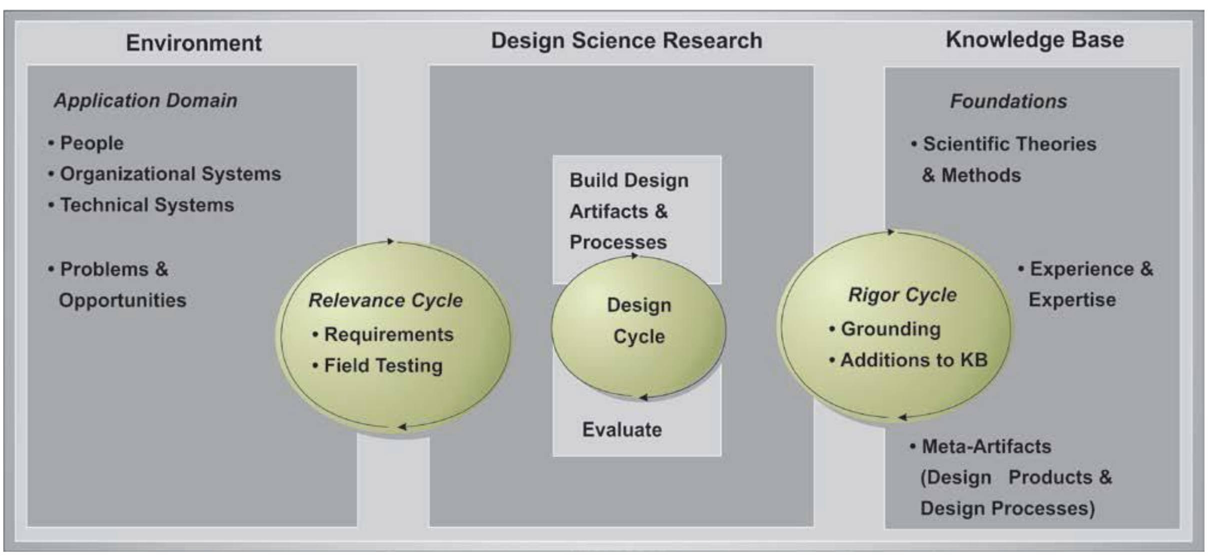

Figure 3.5: Design Research Cycles and Research Relevance and Rigour (Hevner and Chatterjee, 2010)

Furthermore, Vaishnavi, Kuechler and Petter (2004) outlined the five steps of the design research process applied through this research study:

1. Awareness of problem. The awareness phase is characterised by the identification of a problem, a need or an idea wherein design and creation of an artefact, model, construct, method, theory or framework can lead to possible solutions. A research proposal is the outcome of this phase.

2. Suggestion. A solution is suggested in the second step by drawing on relevant existing knowledge or theories. During the suggestion phase, a possible design or solution is suggested.

3. Development. An artefact is developed in the development phase.

4. Evaluation. The artefact is evaluated and tested in the evaluation stage. Quantitative or qualitative evaluation techniques are implemented to measure the performance of an artefact.

5. Conclusion. Here, the results of the design research make a useful contribution to the body of knowledge in the form of an acknowledged, approved, accredited artefact.

Figure 3.6 illustrates the general methodology of design research.

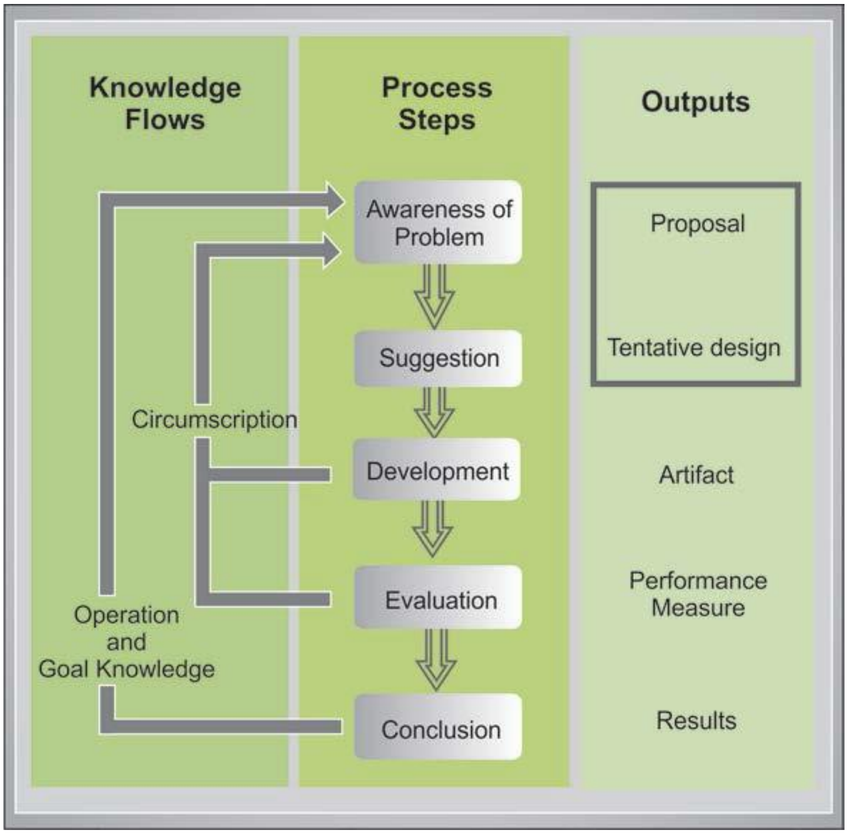

Figure 3.6: General Methodology of Design Research of Vaishnavi and Kuechler (2013)

Whereas Figure 3.7 illustrates the Cognition in the Design Science Research Cycle

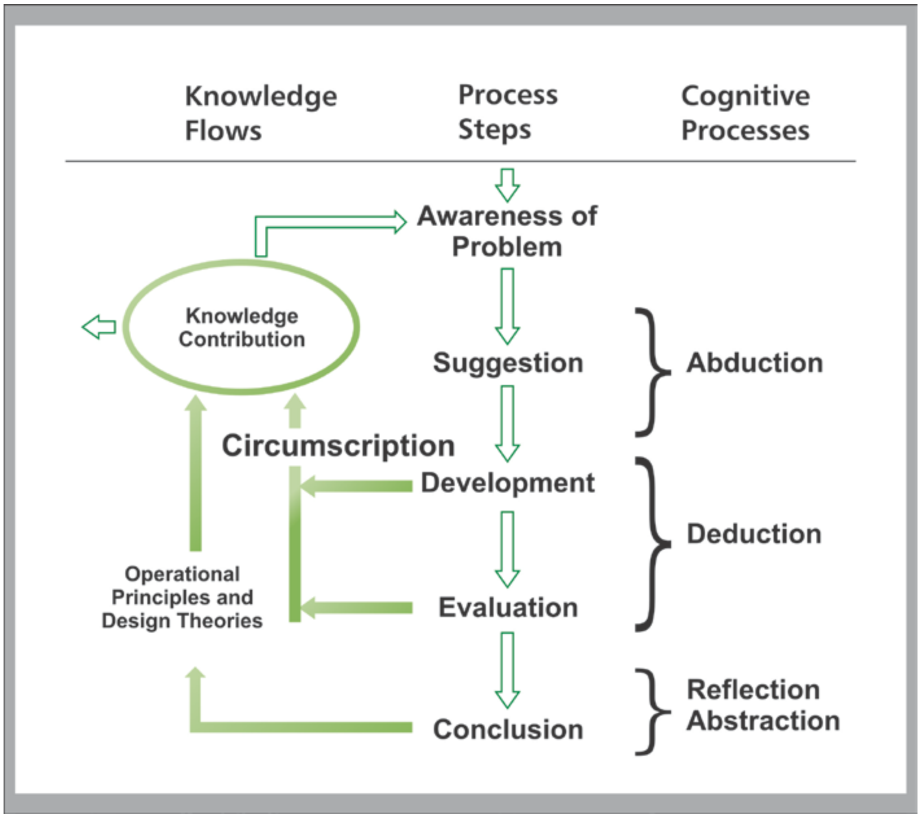

Figure 3.7: Cognition in the Design Science Research Cycle (Vaishnavi et al., 2017)

Furthermore, quantitative and qualitative data can be mixed for the purpose of illustrating a more complete understanding of the phenomenon under investigation (Mertens and Hesse-Biber, 2012). Against this backdrop, the current research will use a mixed method approach, which comprises of multiple methods of quantitative and qualitative approaches. Mertens and Hesse-Biber (2012, p.76), said: "*qualitative methods are for discovery and quantitative methods are for testing causal relationships. He challenges this conceptualization of the roles for quantitative and qualitative data by introducing the concept of Agential causation (A-causation), which rests on the assertion that people act in intentional ways and that researchers can capture the complexity of collective intentionality that leads to the construction of social facts when combined with certain knowledge, skills, and dispositions. However, establishment of A-causation places the role of quantitative experimental methods in the role of description and the qualitative interpretive methods in the role of providing causal explanations because they can answer the ''why'' question. He labels this position as mixed methods interpretivism".* In order to explain the meaning of triangulation, Mertens and Hesse-Biber, (2012, p.5) said*: " its philosophical positioning in the mixed methods community, and strategies for using triangulation in the design of mixed methods studies, analysis and interpretation of data, and making visible subjugated voices. They take provocative positions, suggesting that qualitative, constructivist, and interpretive pathways provide greater potential for research to address the social good than has been possible using mixed methods approaches that are more closely aligned with the postpositivist paradigm".*

This research may also apply the triangulation method that encompasses the use of different qualitative and quantitative methods which complements each other in order to realise the overarching aim of the research. Figure 3.8 explains the research design from a methodological perspective, exhibiting the interrelation between the different methodologies used to attain the overarching aim.

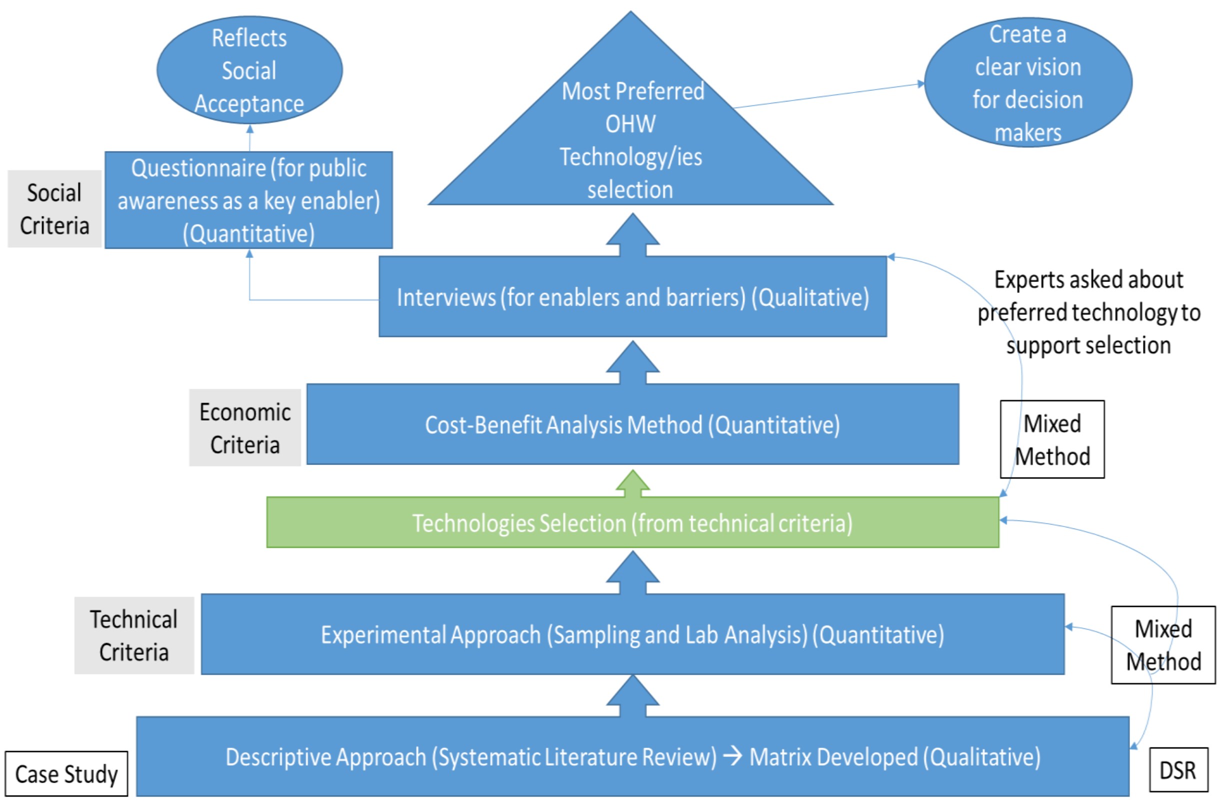

Figure 3.8: Research Design from a Methodological Perspective, showing the Interrelation between the Different Methodologies used to achieve the Overarching Aim

3.4. Empirical Investigation: OHW Characterization

This section illustrates the empirical investigation that catalyses the full OHW characterisation of Muharraq Governorate in order to align with the parameter/technology matrix developed from the literature to accomplish objectives 2 and 3. Notably, the "Experimental Quantitative Approach" is used to accomplish these objectives, as the first objective of the research has already been achieved in Chapter 2 by developing the OHW parameter/technology matrix using a systematic literature review.

A standard approach was used to select the technologies into a comprehensive list before selecting the most preferred technologies based on the OHW chemical characterization so as to short-list them to realize the second objective.

In accordance to the literature review in Chapter 2, the long list of the OHW technologies to be considered for the case study context are as follows:

1. Anaerobic Digestion (AD)
2. Aerobic Digestion (composting)
3. Combustion (Incineration)
4. Gasification
5. Pyrolysis
6. Refused Derived Fuel (RDF)

3.4.1. Organic Household Waste (OHW) Sampling and Lab Analysis

This section describes the first quantitative method used in the current study, which is the empirical investigation for Muharraq Governorates OHW sampling via the experimental quantitative research method. Figure 3.9 illustrates Bahrain Map with the main governorates, including Muharraq (North), the case study area.

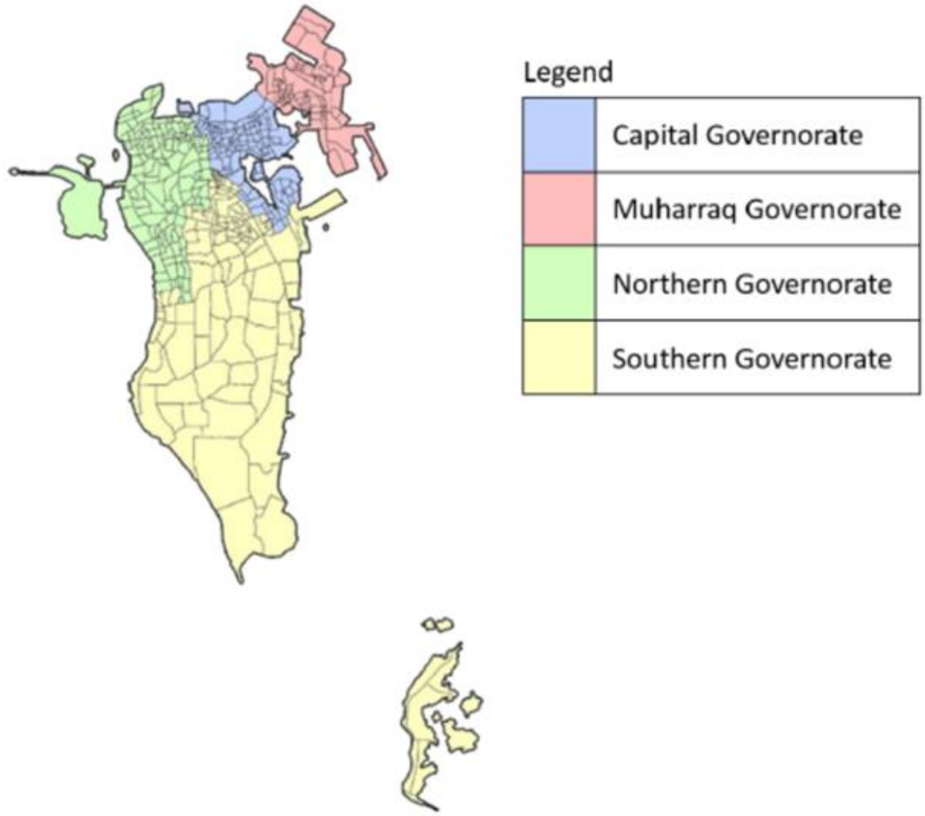

Figure 3.9: Bahrain map with the main governorates including Muharraq (north), the case study area. Source: Central Informatics Organization (CIO), 2017

Aliaga and Gunderson (2002, p.3) described quantitative research as '*Explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics).'*

Furthermore, numerical data are collected in quantitative research; thus, the lab analysis results of the OHW characterization signify the numerical data. Experimental designs were also used, sometimes known as 'the scientific method' due to their popularity in scientific research from where they originated (Mujis, 2011).

a. The Stages of activities conducted during the practical work are as follows:

As the type of waste in Bahrain is mixed, it was essential to sort the collected waste from Muharraq Governorate residential waste in order to segregate the OHW. The methodology for this physical sorting was derived from ASTM D5231-92 (Reapproved 2008); Determination of the Composition of Unprocessed Municipal Solid Waste. The ASTM standard describes the procedures for measuring the composition of MSW whilst defining statistical criteria and provides a formula to determine the minimum number of samples which should be targeted in order to ensure the desired level of precision. In accordance with the requirements of the ASTM standard, the duration of this sorting was five consecutive days between the April 2 and April 6, 2017 and was undertaken at the Askar Landfill in the Southern Governorate. The Askar Landfill was selected as the location since it was the only endpoint waste disposal facility in the country and also because the access to it is provided to the GCCC contractor; it is also currently used for waste disposals on a daily basis. In order to facilitate the physical sorting of waste samples, an area of shaded hard standing situated at the Askar Landfill was used. (Appendix 1)

Muharraq Governorate contains as many as 74 residential blocks, as illustrated in figure 3.10 and 3.11. Further details of demographical distribution within these blocks will be described in Chapter 4. A total of 14 residential blocks were targeted to collect the random samples to be characterized within the lab (Figures 3.12). In order to make sure that the random selected samples are representative of the entire Muharraq governorate, the sampling took place from different income levels: High, middle, and low income residential blocks, as shown in figure 3.12. Additional details pertaining to the case study literature and statistics are found in Chapter 4.

Figure 3.10: Muharraq official Arial map with total residential blocks.

Source: Central Informatics Organization (CIO), 2016.

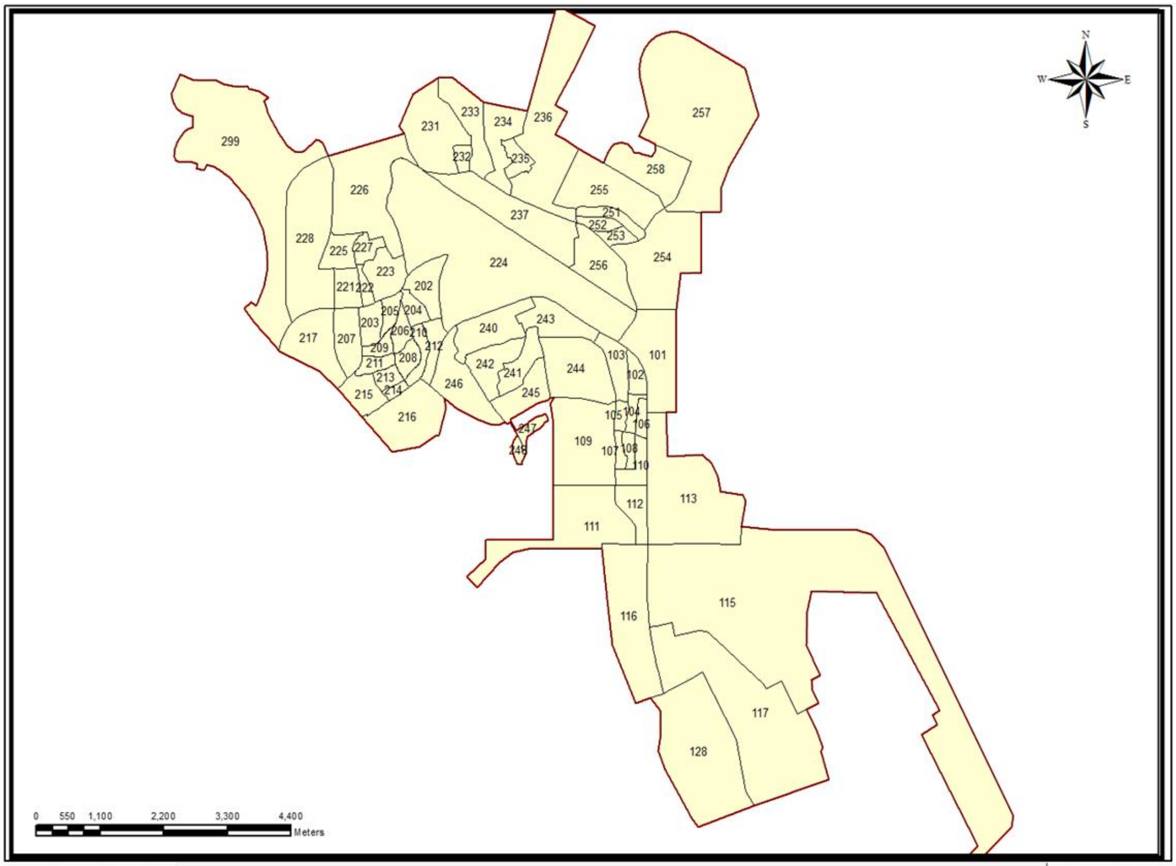

Figure 3.11: Illustration of the total residential block of Muharraq Governorate.

Source: Central Informatics Organization (CIO), 2016.

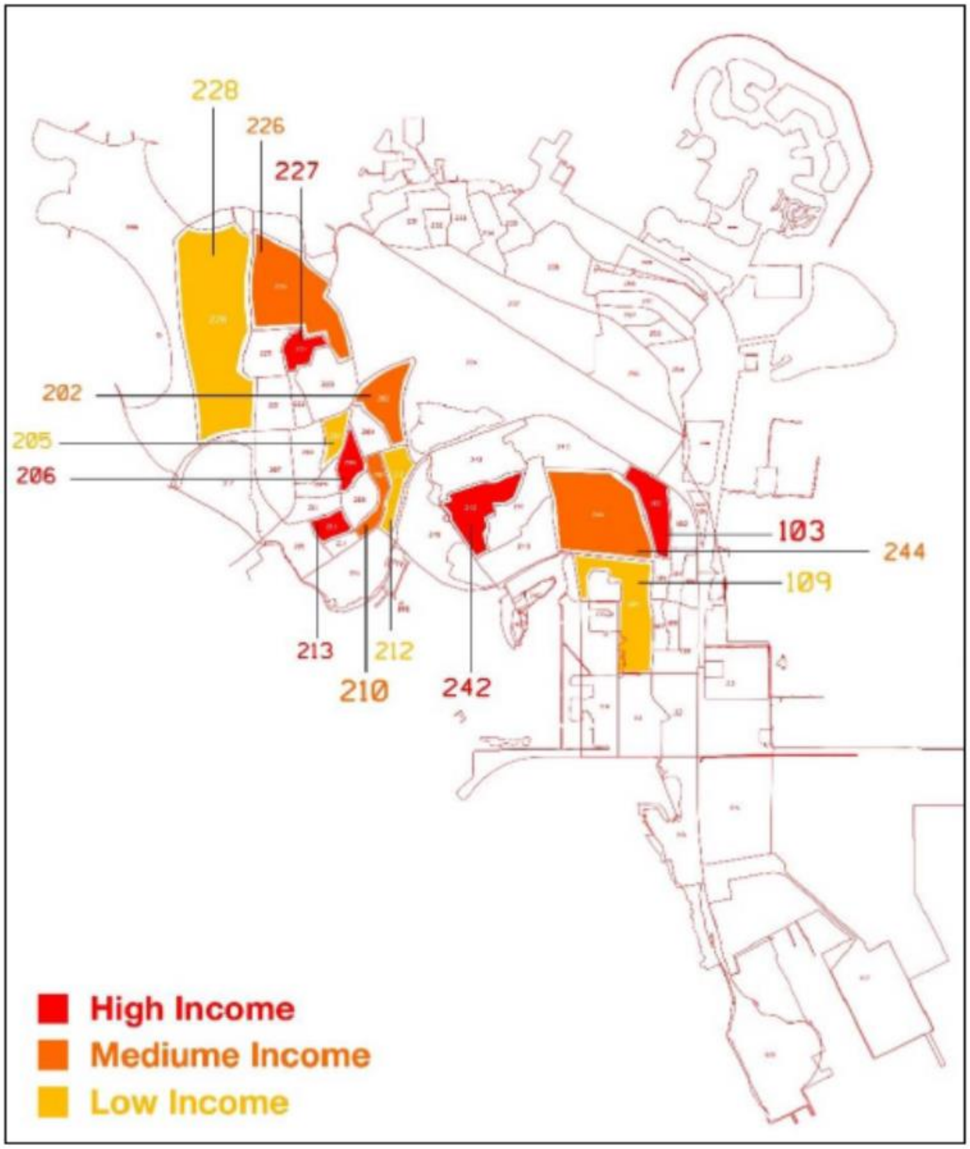

Figure 3.12: Constituents sampled within the Muharraq Governorate

The empirical investigation is inclusive of the following steps:

1. **Preparation:**

   The first step to commence the empirical work is the preparation of the entire investigation process including:

- Obtaining permission after arranging planning meetings with the Ministry of Works, Municipalities and Urban Planning (MWMUP) and the Gulf City Cleaning Company (GCCC), the official private contractor to serve Muharraq Governorate, in addition to the Alhooti Laboratory Analytical Services.

• Set the sampling protocol and collection mechanism within the timeframe

• Site and lab visits for further process organization and arrangements

• Set the samples receiving mechanism by the lab professions for analysis

• Arrange sorting labour with the GCCC

• Lab document preparation (sampling timeline and parameters to be measured in the lab) by coordinating with the lab coordinator and technician.

2. Execution

- Attending Askar landfill
- Supervising waste sampling
- Contribute to supervising OHW screening, sorting and weighing
- Ensuring appropriateness of OHW portion segregation
- Supervising the OHW containers transferring to the lab
- Supervising the OHW samples preparation and storage prior to analysis in the lab
- Final approval on the parameters and the method of testing each parameter
- Continuous communication before and during the sampling and resolving urgent logistics issues
- Receiving the final results reports for the sampling days
- Documentation

3. Parties and partners involved:

- MWMUP
- Askar landfill staff
- GCCC executives
- GCCC labours
- Alhooti Analysis Services lab executive coordinator and technicians

4. Data Manipulation

- Documentation & data entry
- Data tabulation
- Statistical analysis

- Reporting

b. Sampling Procedure Details

After setting all the sampling and analysis procedures, the labour of the Gulf City Cleaning Company (GCCC) commenced sampling by collecting the household waste from the residential area's collection points using their special mixed-waste vehicles. The physical collection was carried out by targeting 14 residential blocks selected from across three income brackets - high, medium and low-income areas in Muharraq Governorate - in order to have the most representative sample for diverse income groups.

A total of 14 containers of 1100 L each were collected by the waste vehicle, which passed through the selected areas, and began collecting the domestic waste. The entire waste was mixed by the vehicle and taken to Askar landfill area, the place where this waste was segregated to obtain the organic household waste fraction to be sent to the lab for analysis.

The physical sorting method was used to determine the composition of mixed household waste whereas a visual assessment method was used to determine the composition of other streams and waste categories, which then helps in segregating the OHW that contains: paper, plastics and food waste.

Waste bulk categories were segregated manually and taken throughout the duration of three-day sampling (April 4, 5, and 6, 2017). OHW bulk density was taken by filling a 240 L bin/sample/day with a material type which was sent to the lab for analysis at the end of each day. The first day of sampling encompassed the low income blocks, the second covered the middle income, whereas the third day was specifically for the high income population in order to ensure a good mixture of all the social levels to obtain the average that could be considered as the official OHW characterization report for Muharraq Governorates. This would then be matched with the developed matrix in order to select the most preferred technologies to manage the OHW.

Since the fasting season (known as Ramadan month) is a special season in Islamic countries wherein all Muslim people fast throughout the day and break their fasting after sunset. This season is socially known by the very high consumption rate of goods and food as compared to normal days due to the preparation for the breaking the fast (known as Iftar), as well as because of the absence of smart purchasing, in addition to the lack of awareness and commitment to ensure compliance with Islamic rules, which leads to the generation of a very high amount of OHW as compared with normal year days. Thus, it was a very interesting point that was added to this research by undertaking the OHW characterization in the Ramadan season to explore whether the differences in waste characteristics as the amount is greater in Ramadan or not.

Therefore, the sampling and analysis steps were repeated for one more day taken in Ramadan (June 2^{nd}, 2017), by selecting random samples one from each income level from the aforementioned residential blocks of Muharraq Governorate in order to represent the whole residential area. Table 3.2 listed the sampling blocks associated with the income level. The colored block number indicates the blocks wherein the sampling was repeated in Ramadan season:

Table 3.2: The sampling residential blocks and their income levels

Sample	Block	Income	Day
1	228	Low	
2	109	Low	Day 1
3	212	Low	
4	205	Low	
5	226	Medium	
6	244	Medium	
7	210	Medium	Day 2
8	202	Medium	
9	110	Medium	
10	227	High	
11	242	High	
12	206	High	Day 3
13	213	High	
14	103	High	

Since the household waste was manually segregated into categories to separate the OHW to be sent to the lab, it signified an addition to the research by including the most recent waste audit results and each waste category percentage. The results and the accompanying comparisons will be presented in Chapter 5. Figure 3.13 illustrates the steps of the empirical phase.

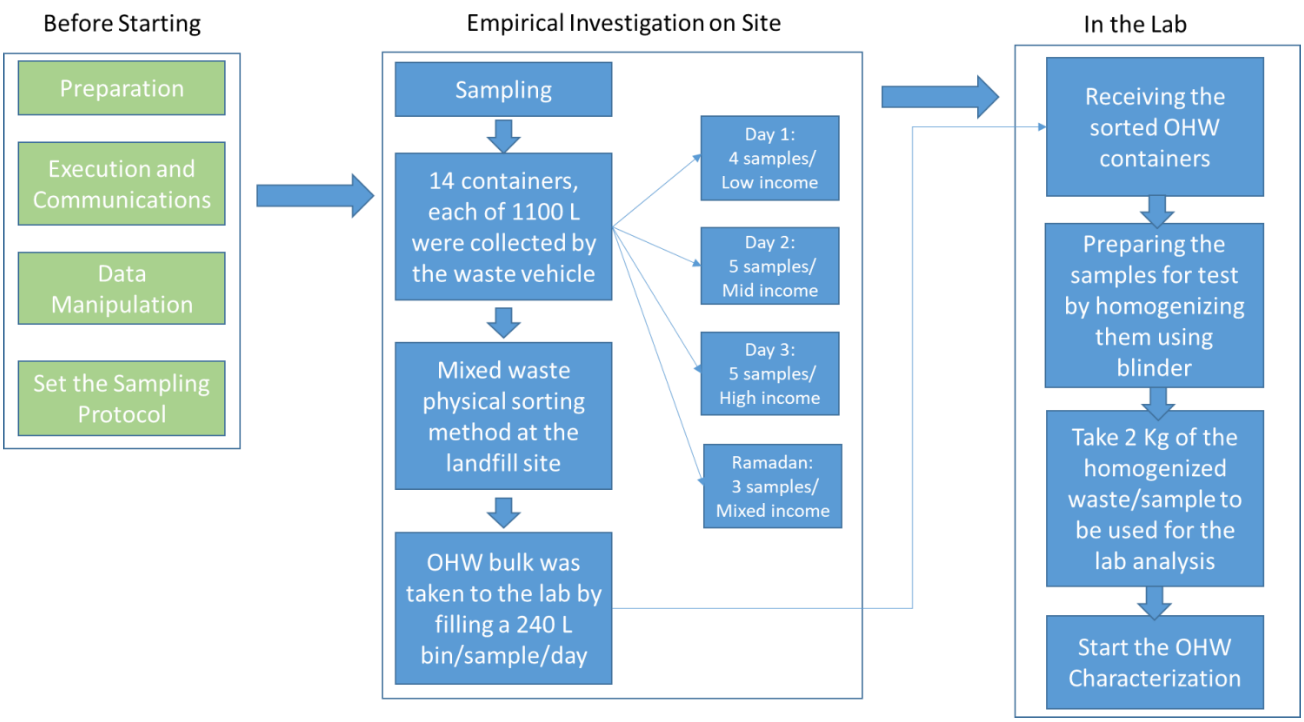

Figure 3.13: The Empirical Phase Steps

The Limitation of the Waste Sampling and Lab Analysis:

Additional days were targeted for the sampling procedure to get as accurate results as possible, but the main impediment against extending the sampling procedure and analysis time was financial constraints. The high cost of the tests used for OHW samples characterization and analysis in the laboratory was a main obstacle as the cost of lab analysis per sample received was US$1000, which also justifies why repeating the analysis for each sample to get more readings for more accuracy was not possible. The high cost of household waste segregation in the landfill, the massive amount of waste, time limitations and the high cost of labour impeded further sampling and analysis. In addition, lab test needs almost 3-5 days to obtain the final results, which depend on the measured parameter, since some tests must be outsourced as they cannot be performed in the same lab, as will be explained later on in this chapter. All of the above represents the main restrictions against repeating the sampling and lab analysis for more than three times in the normal season and one time during the Ramadan season.

c. Sample Preparation, Lab Analysis Tests and Methods

In the lab, the received samples were prepared for analysis by homogenizing the OHW using an electric blender, before immediately commencing the test or storing it by freezing until testing it. Table 3.3 illustrates the process of OHW samples analysis, including the physical features of these received samples, the preparation steps as well as storage:

Table 3.3: Outline of the process of OHW samples analysis, including the physical features of the received samples, the preparation steps and storage

PROCESS	PHYSICAL FEATURES (Color, Texture)	CONTAINER	WEIGHT (Appropriate)	STORAGE TEMPERATURE	REMARKS
Upon Receiving	-mostly brown (some colored plastic wrappers, etc) -slightly wet	Plastic waste bin	25-30 kg	-	-
Storage	-mostly brown (some colored plastic wrappers, etc) -slightly wet	Plastic bag	10 kg	0°C	-
Sample preparation (during homogenization)	-brown -slightly wet	Plastic bottle	2 kg	-	blender was used to homogenize the sample
Sample (after homogenization)	-brown -slightly wet	Plastic bottle	2 kg	0°C	stored in the freezer
Sample (for analysis)	-brown -slightly wet	Glass beaker	1 kg	-	-
Sample (for analysis, dried)	-brown	Glass beaker	0.2 kg	-	oven-dried at 105°C
Sample (for analysis, ashed)	-dark brown	Glass beaker	100 g	-	ashed in a muffle furnace at 550°C

The methods used to measure each parameter were determined as per the American Standards (American Public Health Association, American Water Works Association, Water Environment Federation, 1999 and USEPA, 2016). The analysis methods used for waste characterization are listed below with a short brief.

1. pH was measured using the USEPA 9045 D method. This method is an electrometric procedure for measuring pH in soils and waste samples. Wastes may be solids, sludge, or non-aqueous liquids. If water is present, it must constitute less than 20 percent of the total volume of the sample.

2. Heavy metals were measured using the USEPA 3050B Method. This method has been written to provide two separate digestion procedures, one for the preparation of sediments, sludge, and soil samples for analysis by flame atomic absorption spectrometry (FLAA) or inductively coupled plasma atomic emission spectrometry (ICP-AES); and one for the preparation of sediments, sludges, and soil samples for analysis of samples by Graphite Furnace AA (GFAA) or inductively coupled plasma mass spectrometry (ICP-MS).

3. USEPA 6010 B Method was also used; it is defined as inductively coupled plasma-atomic emission spectrometry (ICP-AES) which determines trace elements, including metals, in solution. This method is applicable on specific listed elements (appendix). Meanwhile all samples of organic wastes, soils, sludges, sediments, and other solid wastes necessitate digestion prior to analysis. Groundwater samples that have been pre-filtered and acidified will not need acid digestion. Samples which are not digested must either use an internal standard or be matrix matched with the standards.

4. Oil and Grease were measured using the USEPA 9071 method, which may be used to quantify low concentrations of oil and grease in the soil, sediments, sludges as well as other solid materials amenable to chemical drying and solvent extraction with n-hexane. “Oil and grease” is a conventional pollutant under 40 CFR 401.16 and generally denotes substances, including biological lipids and mineral hydrocarbons that

exhibit similar physical characteristics and common solubility within an organic extracting solvent.

5. Moisture is measured using the Oven Drying Method. This test is used to determine the water content of materials by drying a sample to constant mass at a specified temperature. The water content of a given soil is denoted as the ratio, expressed as a percentage of the mass of the pore water to the mass of the solid material (or "solids").

6. Total Organic Carbon (TOC) was measured using the APHA 5310 B method, which is a high-temperature combustion method. The organic carbon in water and wastewater is composed of a gamut of organic compounds in various oxidation states. Some of these carbon compounds can be oxidized further by biological or chemical processes; the biochemical oxygen demand (BOD), assimilable organic carbon (AOC), and chemical oxygen demand (COD) methods may be used to characterize these fractions. Total organic carbon (TOC) is a more convenient and direct expression of total organic content than BOD, AOC, or COD, although it does not provide the same kind of information.

7. Total Nitrogen (N) was measured using the APHA 4500 N-C method, which is the Standard Method: 4500-N (Org) C: Organic Nitrogen/Semi-Micro-Kjeldahl. "Kjeldahl nitrogen" is the sum of organic nitrogen and ammonia nitrogen.

8. Chemical oxygen demand (COD) is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. Notably, the quantity of oxidant consumed is expressed in terms of its oxygen equivalence and was measured using APHA 5220 D “Closed Reflux, Colorimetric Method”.

9. The biochemical oxygen demand (BOD) determination is an empirical test wherein standardized laboratory procedures determine the relative oxygen requirements of wastewaters, effluents, and polluted waters. Dissolved oxygen is measured initially and

after incubation, while the BOD is computed from the difference between initial and final DO.

10. ASTM D4809 was used to determine the calorific value (CV) through the measurement of the LHV and the HHV of the samples. It is referred to as the Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method).

11. Sulphur (S) was measured using ASTM D 4294 method, which is defined as Standard Test Method for Sulphur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry.

12. Total phosphorus (P) was measured using the Spectrophotometry - a method to measure the amount of light a chemical substance absorbs by measuring the intensity of light as a beam of light passing through the sample solution. The basic principle is that each compound absorbs or transmits light over a certain range of wavelength. Accordingly, this measurement can be used to measure the amount of a known chemical substance.

13. Ash content was determined using the Ignition method. Ash refers to the inorganic residue after either ignition or complete oxidation of organic matter in a food sample.
14. Total Ammonia Nitrogen (TAN) was measured using the Distillation method. It is a process that separates pure liquid from a mixture of liquids. It works when the liquids have different boiling points.

The results will be presented in Chapter 5. The next section is allocated for the methodology used to examine the economic feasibility of the OHW technologies (economic criteria) which will accomplish objective 4 and be presented in Chapter 6:

3.5. Economic Feasibility of the OHW Management Technology Options

In order to support the decision of technology selection in Bahrain, cost-benefit analysis (CBA) approach for the shortlisted technologies based on the empirical phase was conducted.

CBA is an analytical tool that allows decision makers to evaluate potential outcomes and select suitable technologies in order to achieve these outcomes. Decision makers require a framework which structures information in a manner that makes the complexity more tractable; thus the CBA can advance this process.

CBA provides a means for systematically comparing the value of outcomes with the value of resources achieving the desired outcomes. It measures the economic efficiency of the proposed technology or project.

For the application of CBA, inputs may be divided into parameter values and cost values. Parameters include the discount rate, the future rates of economic growth, the future rates of inflation and the estimations about the future rates of technological change. On the other hand, cost values include monetary values for marketed goods, monetary values for non-marketed directly used goods, monetary values for non-marketed passively used goods, and goods for which monetary values cannot be measured.

One of the limitations of CBA is that the computation of components of costs/benefits is intuitively obvious, but there are other components for which intuition fails to suggest methods of measurement. Therefore, some basic principles are needed to serve as a guide.

Hochman et al. (2015) evaluated four available waste treatment technologies: direct combustion, landfilling, composting, and anaerobic digestion in New Jersey- USA using the CBA method. Since the economic criterion is a priority worldwide among governments, this research took the economic feasibility into consideration as the second main criteria for technology selection. Furthermore, Moutavtchi et al. (2008) showed that CBA is useful for decision making in MSW management because it can be utilized as an efficient tool for information support for implementation of waste management technologies.

In conclusion, the CBA is considered to be a powerful tool for comparing costs with benefits of different technologies in the waste management sector. It allows users to compare a variety of variables and provides a monetary value to the comparison. For this reason, we found that CBA would help us realize our research objective and support the decision making process for OHW management technology selection. The analysis can be found in greater detail in Chapter 6.

In order to calculate the costs of each technology, extensive communication took place between local and regional technology suppliers, project managers of big companies in Bahrain, experts and professionals in waste management, technology and economic sectors. These interactions aimed to collect the data of all costs required by each technology, including direct costs (Consultant Fees, ESIA and Permits, Equipment, Engineering Design and Building costs), and indirect costs (Land Lease Agreement, Loan Repayments, Electricity, Water, Labour of Maintenance, Insurance, Labour of Operations, and Transportation costs). The benefit was estimated for each technology based on its marketable end product- it is shown as (Sales). The cost of the current practice of waste disposal in the landfill was collected from the MWMUP. In addition, Microsoft Office Excel 10 spread sheet was used to conduct the CBA in this research. All the details can be found in Chapter 6.

3.6. Exploring Enablers and Barriers to the Selected Technology Adoption in Bahrain

3.6.1 Overview

As stated in Chapter 2, the descriptive systematic literature review resulted in descriptions of perceived barriers and enablers to waste technology adoption, which makes a hypothesis of the existence of these barriers in the Bahraini context. Therefore, in order to explore and highlight the barriers as well as enablers to the adoption of OHW management technology in Bahrain, a semi-structured interview survey was used for the explanatory investigation. The efficacy of the data collection method has been demonstrated in several studies to explore the barriers to technology adoption in many sectors (Atkin et al., 2017; Al-Senaidi et al., 2009; Jesson et al.; 2014, Ezeah C; Luken and Rompaey, 2008; Macdonald et al., 2017).

Furthermore, Mujis (2011) reported that the most popular quantitative research design in social sciences is survey research due to its flexibility and hence, can appear in a variety of forms to collect the data using either standard questionnaire forms or semi-structured interviews that are administered by telephone or face to face, by postal pencil-and-paper questionnaires or increasingly, using web-based and e-mail forms. As quoted from Mujis (2011), "*Survey research is well suited to descriptive studies, or where researchers want to look at relationships between variables occurring in particular real-life contexts. In survey research, in particular, the temptation is to specify a very extensive research design which attempts to capture the full complexity of the world. Often, it will not be possible to collect data on all the variables we might* *want to include because of financial and time constraints, and we may have to settle for a sample that is a bit smaller than we would have liked. Where this is the case, the key is to select those variables that we think are most likely to affect our outcomes*. " (pp. 31-32)

Mujis, (2011) clarified that in order to design a survey study, the research objectives should be clearly defined, formulate hypotheses, define what information is needed, decide what our population is, design research instruments accordingly, and collect the data.

3.6.2 Designing the Interview

"The expert interview as a method of qualitative empirical research, designed to explore expert knowledge, has been developed considerably since the early 1990s. Expert interviews are simply just "information gathering meetings" used primarily for collecting facts and knowledge." (Bogner et al., 2009, p. 17); they added that "*in scientific research an individual is addressed as an expert because the researcher assumes that she or he has knowledge, which she or he may not necessarily possess alone, but which is not accessible to anybody in the field of action under study. It is this advantage of knowledge which the expert interview is designed to discover, and it is an exclusive realm of knowledge which is highly potential because and in as far as it is linked with the power of defining the situation.*" (Bogner et al., 2009, p.18)

The designed interview used to interview the experts in the field of waste management and technology in order to explore the enablers and barriers to the adoption of OHW technology in Bahrain, specifically semi-structured interview. According to Given, L (2008), a semi-structured interview can be defined as *"a qualitative data collection strategy in which the researcher asks informants a series of predetermined but open ended- questions"*. The semi-structured interview is a commonly used methodology by many studies (O'Leary et al., 2017; Santos, 2016; Bischoff, 2008; Wells et al., 2013; Najibullah et al., 2013).

The semi-structured interview used in this research included a mixture of open-ended questions which allowed the respondents to formulate their own answers. Interviews targeted 11 experts as the study focus group. The interview was oral, and main questions were designed in Microsoft Office Word 2013; they comprised of general specific questions for each technology. The interview was undertaken in Arabic and/or English. The duration of most interviews was an hour and a half, but some lasted two hours and one of them lasted 30 minutes.

A combination of open and closed-ended questions was used in the survey to highlight the requirements for the enablers and barriers to OHWM technology adoption. The interview questions can be found in the Appendix.

3.6.3 Bias in an Interview

Interviewer bias is mitigated by trying to avoid influencing interviewees through comments, tone or non-verbal behaviour on the part of the interviewer. Questions were addressed as neutrally as possible, and the interviewer was conscious to avoid any body language which might have communicated their preferences to the interviewee. Care was also taken not to interrupt the interviewee, which could have otherwise directed them to a preferred answer (Bugawa, 2016).

The use of interviews entails both advantages and disadvantages, as Oates (2006) described:

3.6.4 Advantages of Interviews

1. This technique enables the researcher to have more details about the concepts under investigation.

2. Interviews do not necessitate any other tools as they are largely dependent on the researcher's skill.

3. It can be used to comfortably gather information since the interviewer can control the interview to obtain more details from the interviewees.

Interview is better than questionnaire in some cases since it gives participants the chance to explain their opinion in a detailed manner rather than limiting them in writing. (Bugawa, 2016)

3.6.5 Disadvantages of Interviews

1. It needs time and effort on the part of the researcher to transcribe the interview and choose a suitable analysis.

2. The voice tone and texture of the researcher might influence the participant to answer differently which may prompt them to provide the answer needed by the interviewer. This also will affect the reliability of the interview if there is no consistency in the answers given by interviewees.

3. The participant might feel uncomfortable when they are recorded by tape recorder or video recorder; this may affect the replies of the interviewees.

4. The interviewers need skills and knowledge on the topics under investigation since more elaboration may be needed from the researcher to the interviewees.

5. It is limited to a small sample; therefore this technique cannot be used to make generalizations about the population. (Bugawa, 2016)

3.6.6 Ethical Considerations

Ethical approval for this research was obtained from the Biomedical and Scientific Research Ethics Sub-Committee (BSREC) from the University of Warwick (Appendix 4).

Experts to be interviewed were given a verbal introduction about the purpose of the interviews, in addition to a written consent form to be signed prior to the interview. Some experts preferred an oral consent for confidential purposes. This step indicated the general area of interest without disclosing the research hypotheses to reduce the effect of interviewee bias. The information sheet informed that participation was entirely voluntary and participants could withdraw from the interview at any time. This ensured that the participants did not suffer from any unnecessary distress. Experts were informed about the duration of the interview, so they were not subject to additional time pressures. They were also informed that the data would be kept confidential and that the identity of the participants would be kept anonymous, in order to answer the questions transparently. All these considerations ensured the protection of the individuals' rights, and also allowed the experts to feel comfortable while sharing their personal opinion and experiences to ensure data integrity.

3.6.7 The Interview Protocol

The experts were selected based on their high level of expertise in the field of waste management, energy, technology and project management in Bahrain. The selected experts are the most recognized in the field of waste management locally and regionally who are known for their publications, academic contribution and conferences participation.

The selected experts and interviews details are described in Chapter 7: Table 7.1

The criteria for selecting the experts is that they must be experts in the field, and have good experience and knowledge about the waste management technology adoption, in order to explore the possible enablers and barriers to the technology adoption in Bahrain.

The interviewed experts were selected from different authorities, governmental and non-governmental. They included Arabian Gulf University (AGU), MWMUP, GCCC, Supreme council of Environment (SCE), private contractors and international technology supplier companies' representatives, who were interviewed in their working places to ensure that they felt relaxed when answering the questions. Participants were encouraged to talk beyond the outlined topics and discuss what they thought was important.

A total of 11 interviews were carried out between April and May 2018, each of which lasted between 30 and 80 minutes. The survey consisted of 11 main questions falling into the following main categories: the most preferred technology for Bahrain from their point of view, general enablers and barriers to any new technology adoption in Bahrain, enablers and barriers to each of AD, Incineration, Composting, Gasification, Pyrolysis and RDF adoption in Bahrain, as well as suggestions to overcome these barriers.

Face-to-face interviews were undertaken by the researcher in most instances; when this failed, which was the case with two experts, a telephone interview was carried out in the first case whereas the second one was done via email. One of the international experts requested to send him the interview questions by email since he is located abroad and face-to-face interview was not possible, so he answered them completely and resent them via email within three days.

The interview always began with an overview of the purpose of the research and survey in particular. Anonymity was highlighted and consent was obtained from each expert. These interviews were written by taking notes using a paper and a pen. After finishing the interview, the researcher reviewed the answers and instantly requested more clarification if any point was missed. The full interviews were written at the same day of each interview to ensure that the data was conserved and no point was missed. The interview questions and the total of 11 complete interviews, are found in Appendix 5.

3.6.8 Interview Data Analysis Method

As stated by Alhojailan, (2012), qualitative data collection usually depends on interpretation, which means that the data requires several explanations due to the collection of huge amounts of qualitative evidence. Additionally, there is no distinction between data collection and its analysis (Cassell and Symon 1994). Cohen et al. (2011), cited in Alhojailan, (2012), said that data analysis in qualitative research is distinguished by, "*Merging of analysis and interpretation and often by* *the merging of data collection with data analysis*" (p.537) (Cohen et al., 2011 cited in Alhojailan, 2012).

Moreover, some researchers utilize programming for preparing and instructing the data, while others prefer to use traditional manual methods. In some instances, it may be better to use manual analysis rather than computer based methods, e.g. nvivo. (Alhojailan, 2012)

Furthermore, Alhojailan, (2012) added that software is usefully able to analyse qualitative data in terms of gathering all the evidence and subsequently organising it into similar themes or ideas. In this regard, he claimed that using software for analysing qualitative data is valuable for enhancing the rigors of the analytical steps. In addition, the software allows the researcher to analyse the data at a more specific level.

Sometimes, however, software is less helpful. Welsh (2002) cited in Alhojailan, (2012), argued that software might not prove as helpful as one may expect. He said, "*In term of addressing issues of validity and reliability in thematic ideas that emerge during the data analysis process and this is due to the fluid and creative way in which these themes emerge.*" (p. unknown)

Therefore, the collected data were analysed using the qualitative data analysis method using thematic analysis software NVivo, which is considered as one of the most commonly used methods of qualitative analysis by several studies (Walsh, M., 2003, Ozkan, B.C., 2004, Ishak, N. Bakar, A., 2012 and Wells et al., 2013). This thematic analysis involves making sense of what the interview participants are saying, including: What main points are they making? What surprising perspectives do they have? How do their ideas differ? And what are the points of commonality? (McNiff, 2016)

Thematic analysts create their codes by defining what they see in the data and codes emerge even as the data are scrutinized. Hence, coding is a fluid process wherein codes may be modified or altered as ideas develop. Themes that integrate sets of codes are then defined by the researchers and illustrated in the report results below along with examples. (Wells et al., 2013)

More details in addition to the full results of the analysis are provided in Chapter 7.

3.7 Measuring the Public Awareness toward Household Waste Management in Muharraq Governorate

3.7.1 Overview

This section covers the methodology used to accomplish objective 6 of this research study, which is to measure public awareness toward the household waste management via its components: knowledge, attitude, and behaviour, and find any significant correlation between the variables and public awareness components. This section represents the second survey in this research study, which is achieved via a designed questionnaire as the study instrument.

As public awareness represents a key enabler to the adoption of technology, it was necessary to combine qualitative and quantitative methods to support the decision making tree tool which was built in this research in addition to the empirical waste characterization criteria as well as the economic criteria applied via cost benefit analysis; the social surveys provide a sustainable picture of the selection tool which might be developed in this thesis in order to select the most preferred technology adoption relevant to Muharraq Governorate.

3.7.2 Ethical Considerations

Ethical approval for the study was obtained from the Biomedical and Scientific Research Ethics Sub-Committee (BSREC) from the University of Warwick.

3.7.3 Methodology and Study Instrument Design

A self-administered questionnaire was used to assess the publics' knowledge, attitude, and behaviour towards domestic waste management.

The study instrument (questionnaire) is divided into two main parts: personal profile or background question to obtain demographic characteristics of the surveyed population, such as age, gender, occupation, education, place of residence, etc. (IUCN, 2010); and survey questions, that consist of 38 statements distributed into three divisions. These include "Knowledge" (perception) that aims to measure the knowledge about household waste management and related issues encompassing 10 statements, "Attitude" that aims to measure the attitude as well as trends in household waste management via 16 statements, and "Behaviour" or the practices towards household waste via 12 statements.

Survey instrument consists of multiple choice or closed-end questions to determine feelings or opinions towards certain issues by allowing the respondents to choose an answer from a list of 5 alternative answers, as well as to gauge the intensity of the respondent's feelings towards an issue (IUCN, 2010).

The Likert Scale was used to answer the questionnaire's questions using three types of the scale alternatives: for knowledge, "totally true, true, not sure, not true, and not true at all" scale was used; for attitude: "strongly agree, agree, not sure, disagree, and strongly disagree" was used; while for behaviour, the following scale was used: "always, sometimes, not sure, rarely, never"

"Totally true" for the knowledge statements mean that the respondent knows this information very well. In the attitude statements, "strongly agree" mean that they are highly aware and willing to participate and cooperate. For behaviour or practice statements, "always" means that the respondent is always practicing this activity which reflects the high level of awareness and means that they have the knowledge and attitude which leads to the practice stage (the highest level of awareness)

Meanwhile "true" means that the respondent does not have completely perception about this point, but knows something about it in parallel, "agree" means that the respondent has the attitude, albeit of a lower level, while in practice statements, "sometimes" means that the respondent sometimes practices this activity.

"Not sure" is a little negative response, which means that the respondent is unsure about the information, about their attitude, and whether they are practicing or willing to practice this activity.

"Not true" means that the respondent doesn't have the stated information; "disagree" means they lack the attitude and that they are "rarely" practicing this activity.

Finally, "not true at all" reflects a very negative response of the respondent implying that they do not know much about it or are against what is being stated; "strongly disagree" reflects the respondent's strong disagreement about the attitude statement, whereas "never" means they are not practicing the stated behaviour at all.

The statements were carefully selected based on previous studies' questionnaires from the literature review and conversations with many experts within the fields, including national environmental activists, and municipality staff, newspapers and official governmental social media reports, which contribute to enriching the researcher's personal experience in this aspect in a way that reflects the needs of the Bahraini society.

The personal profile contains 10 dependent variables that might be related to the level of public awareness among Muharraq Governorate's population. These variables are: age, gender, educational level, marital status, nationality, location, and number of family members, type of residence, monthly income and occupation.

The questionnaire primarily was assessed by seven experts from different disciplines, including social studies, environmental studies and engineering, and technology management from the Arabian Gulf University (college of graduate studies).

The questionnaire assessment scale includes: statement suitability and compatibility to the study aim, the statement's contextual spelling and structure, notes per statement, and other suggestions for improvement. This process lasted two weeks from March 15th- 30th 2018.

Thus, after taking all the comments of experts into consideration and modifying the weakness as required, questionnaire was finally upgraded to its final version, and was given –for the last time- to the experts to assess it; the final experts' personal assessment results demonstrated that the questionnaire obtained more than 90 percent level of experts satisfaction and thus, ready for distribution. The survey was designed in Microsoft Office Word 2013 to be answered as hardcopies only.

3.7.4 Bias in Questionnaire

In order to minimize the effects of response bias, participants were not informed about the research hypotheses and were only given an indication about the subject of study. In the questionnaire, themes were addressed using multiple questions to try and establish consistency whilst reducing the impact of bias arising from individual questions. It is difficult to eliminate bias in all questions. However, the questions were phrased as clearly and concisely as possible without the use of jargons or theoretical concepts. Wherever possible, questions were grounded in the real-life experiences of participants rather than being abstract (Bugawa, 2016).

There are certain advantages and disadvantages of using questionnaires, as Oates (2006) cited in Bugawa, (2016) described:

3.7.5 Advantages of Questionnaire

1. Does not cost time and money for the researcher.

2. Questions with Likert-scales or closed questions enable the researcher to analyse and the participant to answer the questions.

3. There are different ways of sending the questionnaire: telephone, emails and by post. Though in this research, these questionnaires were sent by hand-to-hand as hardcopies.

3.7.6 Disadvantages of Questionnaire

1. The limited options for the respondents, such as closed questions, might be biased and restrict their answers.

2. The researcher does not have the opportunity to discuss the questions with the participant so as to find correct answers.

3. The researcher cannot provide a detailed explanation to the participant.

4."Self-administered" questionnaires are difficult for participants with difficulties in learning.

3.7.7 Validity and Reliability of the Tool

a. Validity:

Face validity: For establishing facial validity, the final form of the tool was shown to seven experts (university professors) to seek their responses regarding content, format and language of the tool. All the experts were satisfied with the language and format of the questionnaire to ensure the scale’s face validity.

Content Validity: At the stage of questionnaire planning, 38 statements were used to measure the level of awareness toward household waste management. Experts reviewed all the 38 items, which means that the final form of the tool evenly represented the contents. Hence, it can be said on logical basis that the tool has adequate content validity.

b. Reliability:

Reliability of the tool was determined using the test- retest method. The same tool was administered to a group of 40 participants (family members, neighbours, and friends) twice at an interval of one week, and the two sets of scores were correlated to obtain a correlation coefficient, which was the index of reliability. The pilot study is described in details below:

3.7.8 The Pilot Study

According to IUCN, (2010), the selected survey firm should conduct a pre-test (pilot study) of the questionnaire. The pre-test is the last step in questionnaire design with the aim of testing the questionnaire with a small number of people before conducting the actual fieldwork. This exercise should be conducted among the survey target group of public. This stage of research will enable the researcher to determine the strength as well as weaknesses of the survey questionnaire about its reliability and validity; this process must be completed before actually fielding it. Moreover, such a procedure will also reveal unanticipated problems with question wording, format, instructions to skip questions, and thus make sure that respondents understand the questions and providing useful answers. (IUCN, 2010)

The firm should pretest the questionnaire with at least 30 representatives, and should be conducted in languages that will be used for the actual fieldwork, which is the national language. (IUCN, 2010)

Therefore, the language of the questionnaire is Arabic, since it is the national language of the country. However, it was translated in to English language in order to attach them both in this thesis.

The pilot study aims to measure the questionnaire’s stability and reliability. Based on what was stated in IUCN (2010), the questionnaire was given to about 40 randomly selected people.

The questionnaires were then collected to be analysed using IBM SPSS Statistics Version 23 (2015) software to identify the points of weakness. The same groups were given the same questionnaire to answer after one week, to measure the stability and reliability by repeating.

Pearson Correlation Coefficient was calculated using SPSS, which is a measure of the strength of a linear association between two variables and is denoted by r. It indicates how far away all these data points are to this line of best fit and can accommodate a range of values from +1 to -1. When r is found to be greater than 0, it means that both variables are moving in the same direction. When r is +1, it signifies that both variables are being compared to have a perfect positive relationship; when one variable moves higher or lower, the other variable moves in the same direction with the same magnitude. The closer the value of r is to +1, the stronger the linear relationship (Nickolas, 2017 and Laerd Statistics).

Accordingly, Pearson correlation found to be equal 0.94, which is close to +1, indicates that the two variables being compared (the total answers of 40 people before and their answers after one week) have a perfect positive relationship with high similarities; this means a high level of stability and reliability of the questionnaire as designed study instrument. The result is shown below in table 3.4.

Table 3.4: Result of pilot study for reliability: the Pearson Correlation Coefficient

		Total 1	Total 2
Total1	Pearson Correlation	1	.945**
	Sig. (2-tailed)		.000
	N	40	40
Total 2	Pearson Correlation	.945**	1
	Sig. (2-tailed)	.000	
	N	40	40

**. Correlation is significant at the 0.01 level (2-tailed).

Therefore, this score gives the green light to commence the main survey in order to measure public awareness using this valid, stable and reliable questionnaire.

The main survey will consider 40 participants of the pilot study since there were no changes to apply on the questionnaire, except some minor spelling modifications.

For further confirmation, in order to measure the consistency of the statements as groups in the questionnaire, one more factor was considered. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. It is considered as a measure of scale reliability. A "high" value for alpha does not imply that the measure is uni-dimensional. The alpha coefficient for 38 questionnaire statements was calculated using SPSS and it was found to be equal to 0.813, which indicates that the questionnaire statements have relatively high internal consistency. Notably, a reliability coefficient of 0.70 or higher is considered "acceptable" in most social science research situations, according to idre statistics professional website: https://stats.idre.ucla.edu/spss/faq/what-does-cronbachs-alpha-mean/) The result is shown in Table 3.5.

Table 3.5: Cronbach's alpha to measure the internal consistency of the questionnaire

Reliability Statistics

Cronbach's Alpha	**Number of Items**
0.813	38

3.7.9 Sampling Protocol

This survey focused on conducting representative samples of the adult population (18-years and above) living in Muharraq Governorate. After approval, the questionnaire is ready to be distributed in the designated public places (neighbourhood, family members, friends, school staff, and health centre staff).

Selection of the households within the Governorate to survey was random, but it also relied upon the respondents' willingness to participate.

The questionnaire was undertaken in Arabic Language since it targets people who speak the national language.

About 300 people answered the questionnaire.

In this study, the stratified random sampling technique was used.

In the first page of the questionnaire, participants were given a brief outline of the purpose of the research as well as an indication of the expected time it would take to complete the questionnaire (15 minutes or less). They were explicitly asked not to disclose their names in completing the questionnaire in order to ensure anonymity. They were asked to be as honest as possible but were also informed that they could decide not to continue with answering questions at any time. This was intended to ensure the integrity of the data as well as protect their rights (Bugawa, 2016).

The researcher informed the participants of neighbourhood, relatives and friends of oral consent prior to distributing the questionnaires, starting from the researcher's contacts list which was already provided personally to the researcher via direct phone calls or face-to-face. Accordingly, relatives and friends were informed in their working places personally and distributed/recollected the questionnaires. The researcher and relatives (distributors) met with the public via face-to-face to distribute the questionnaires in public areas, and immediately gave it back to the researcher. The participants will be informed by the researcher or distributor that their participation is voluntary, but their involvement would go a long way in contributing to life enhancement in Bahrain.

The questionnaires were stored in a highly secured place within the researcher's home office, and/or in the researcher's laptop locked by a password so that no one could access it except the researcher.

The residential houses of the researcher's neighbourhood started receiving the questionnaires as a hard copy. Neighbours and friend's families contributed to this study after they were informed orally about it and seeking their consent to fill the questionnaire. Relatives and friends were asked to take part in distributing the questionnaires among people they may know and also recollect them personally; in their working places, they specified a person (the secretary) to centralize the recollection at the end of the working day, who gave it back directly to the researcher.

The distribution and recollection lasted from April 10^{th}- April 30^{th} 2018 in order to cover 300 participants from eight different Governorates villages. The participants were given time form one day to one week in order to fill the questionnaire and return it to the researcher directly or to distributor who gave it back to the researcher. The complete survey protocol and other related ethical documents are found in the Appendix. The questionnaire in both languages can also be found in Appendix 7.

3.7.10 Analysis of the Questionnaires Data

SPSS statistical program (IBM, 2013) was mainly used to analyse the questionnaire data, including ANOVA (analysis of variance) and t-test which were used to undertake statistical analyses to highlight significant statistical relationships between variables. Descriptive statistics by frequency was also used to determine the percentage of respondents who agreed and strongly agreed or disagreed/strongly disagreed with some statements of high importance for the Bahraini society e.g. percentage of people who supported the establishment of an incinerator to treat their waste. Chapter 8 contains the results (Appendix 8).

Figure 3.13 summarises the two surveys procedures of this research.

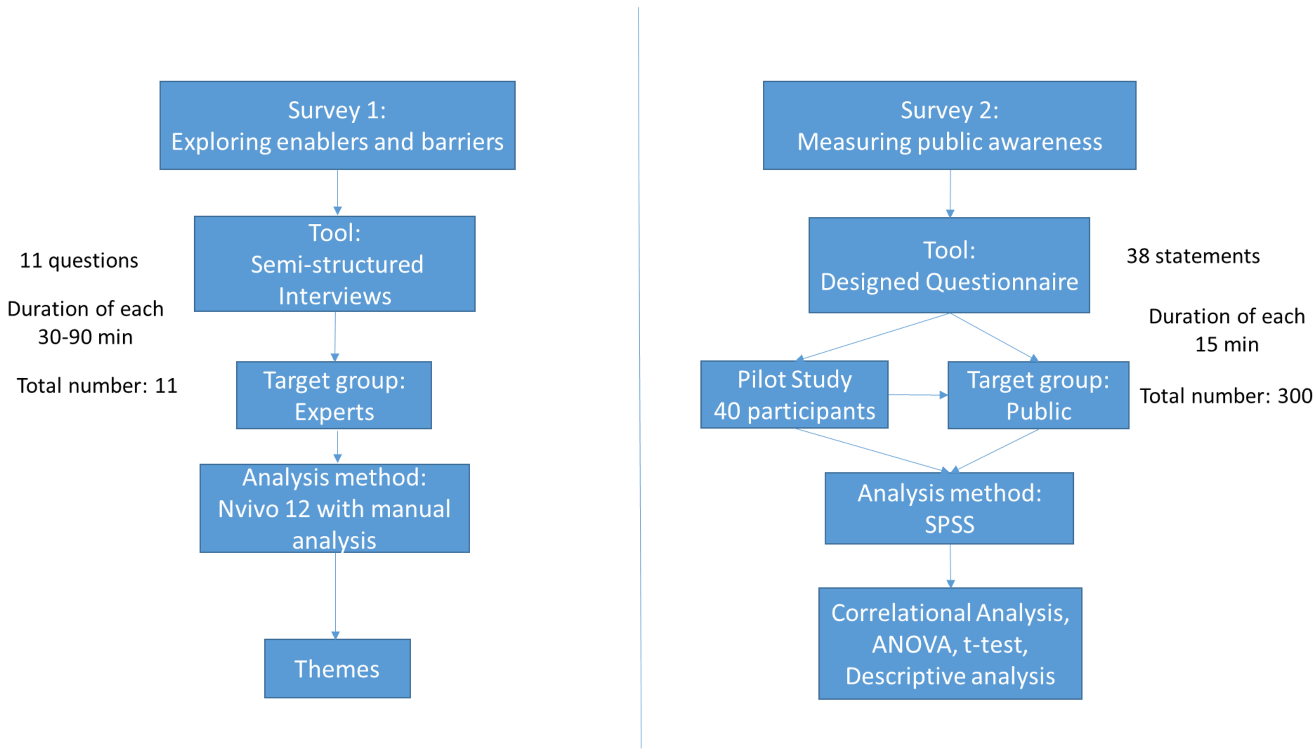

Figure 3.14: A Summary of the Two Procedures of the Survey

CHAPTER 4: The Case Study: Muharraq Governorate, Kingdom of Bahrain

4.1 Chapter Overview

This chapter contains detailed information about the Kingdom of Bahrain and in particular, the case study area of Muharraq Governorate. This chapter complements the literature review presented in Chapter 2, but is specific to the Kingdom of Bahrain. The research requires knowledge of the geographical information of Bahrain, information on the rates of municipal solid waste production along with its official statistics, the existing method of managing municipal waste and organic waste specifically in the country, and other information related to Bahrain which is necessary for this research. Furthermore, it is important to emphasize the existing methane estimation in the landfill and shed light on the legislation, policies and international agreements that the Kingdom of Bahrain is signed on and committed to. This chapter's information is necessary to interpret and discuss the results which will be presented in the subsequent chapters to achieve the general conclusion of this research.

4.2 About Bahrain

Bahrain is an archipelago that consists of 33 islands. It is located on eastern coastline of Saudi Arabia within the Arabian Gulf, West Asian Region. The total area of Bahrain is 665 km^2 (257 sq mi), but the area increased to 765 km^2 (295 sq mi) owing to land reclamation. Bahrain is characterized by arid, very humid and hot summers and slightly cold winters. Oil and natural gas are the primary natural resources in Bahrain. Only three mains islands are currently inhabited, namely the islands of Manama, Muharraq, and Sitra (MWMUP, 2015). Bahrain's location and map is shown in figure 4.1 and 4.2, respectively.

Figure 4.1: The Kingdom of Bahrain Location

Source: https://geomasterglobal.wordpress.com

Figure 4.2: Bahrain Map

Source: https://geomasterglobal.wordpress.com

According to the official census for 2017 issued by the Central Informatics Organization (CIO), the population of the Kingdom of Bahrain stood at 1.418 million. It is expected to reach 1.592 million in 2020 and 2.128 million in 2030, up from 621,000 in 1999. The population growth rate is 7.4 percent on average.

In the Kingdom of Bahrain, most of the land areas do not exceed 5 meters above mean sea level; where all of its large urban centres are situated, nearly all of its population and infrastructures are located in the coastal lowlands. This makes the threats of rising sea levels real and imminent. Thus, it is imperative for the central government, local authorities, and other stakeholders to initiate appropriate adaptation policies to enhance the nation's ability to deal with the potential ramifications of climate change (PCPMREW, 2005).

The climate of Bahrain is an arid type; the mean annual rainfall is small (70.8mm) and irregular. There are two main climatic periods - from June to September and from December to March - separated by two transitional periods (April/May and October/November). Bahrain is characterized by extremely hot summers and mild winters. The temperature is usually high with an average of 17^{o}C for the winter months (Dec-Feb), as well as an average of 38^{o}C in summer months (Jun-Aug), respectively. The mean monthly relative humidity is usually high, reaching 67 percent, with a daily mean maxima ranging from 78percent to 88percent. http://www.bahrainweather.gov.bh/web/guest/climate

The Kingdom of Bahrain possesses a prosperous economy with a high standard of living. However, with its small area, high population density, and limited natural resources, the country has great concerns over the future of its sustainable development. Bahrain is striving hard to diversify its economy and manage its natural resources effectively. Furthermore, being an island state, its climate change poses serious threats to the existence of the country due to risks posed by rising sea levels (Al-Sabbagh, 2012 and PCPMREW, 2009).

4.3 Municipal Solid Waste Management in Bahrain

One of the key strategies under Bahrain vision 2030 is to improve the principles of sustainability, competitiveness and fairness so as to ensure that every Bahraini has the resources to live a safe and secure life (Bahrain vision 2030, 2007). This vision also affirms that *“Bahrain will continue to be home to a rich and ancient culture and a sustainable natural environment.”* According to this strategy, numerous initiatives will be taken to support and protect its environmental concerns. One of these initiatives is "*directing investments to technologies that reduce carbon emissions, minimize pollution and promote the sourcing of more sustainable energy.”* The strategy also signifies the sustainability of water and air emission. (Bahrain vision 2030, 2007)

Bahrain is considered to be one of the highest per capita municipal solid waste generators. Despite being the smallest nation in the region, Bahrain produces largest amount of waste per person among GCC countries. Solid waste management is considered to be a highly challenging task for Bahrain’s policy-makers, urban planners and municipalities due to rising population, burgeoning growth rate of waste generation, limited availability of land and scarce waste disposal sites (Zafar, 2016).

Bahrain, like other developing countries, is confronted with increasing quantities of MSW, declining landfill capacity, rising public objection to the current handling practices, concerns about the risks associated with municipal waste management, and growing environmental problems (Alansari, 2012).

Furthermore, the Kingdom of Bahrain possess a high population growth rate, rapid industrialization, unorganized SWM sector, poor public awareness and limited land resources. Against this backdrop, the Bahraini government is aiming to improve waste management scenario by launching recycling initiatives and waste-to-energy projects. (Zafar, 2016)

Recently, the Waste Atlas (2015) compiled and published statistics for the GCC countries relevant to MSW as well as other associated indicators for the year 2015. According to these statistics, Bahrain has the highest generation per capita (2.48 kg/d/p).

Very limited literature about Bahrain Waste Management is available. The only published papers about Bahrain’s waste and its management is listed in table 4.1 below, which means that this research signifies a good contribution to the existing knowledge and advances the literature related to Bahraini waste.

Table 4.1: The Available Published Literature about Bahrain Waste Management (Salman, 2016)

Title	Author/editor/contributor	Publish year
Domestic Waste and Methods to Benefit from it. State of Bahrain: Al Qubs Publishing (in Arabic).	Al Madani I and Abu Shosha M	1992
Bahrain's Initial Communications to the United Nations Framework Convention on Climate Change. Volume I: Main Summary Report	Kingdom of Bahrain. General Commission for the Protection of Marine Resources, Environment & Wildlife. Eng. Zahwa M Al Kuwari	March , 2005
Bahrain National Assessment Report on Implementation of The Mauritius Strategy (Msi) of The Barbados Programme of Action (BPOA)	The Public Commission for Protection of Marine Resources, the Environment and Wildlife The Kingdom of Bahrain	November, 2009
Bahrain's Second National Communication Under the United Nations Framework Convention on Climate Change Kingdom of Bahrain Public Commission for the Protection of Marine Resources, Environment and Wildlife. Bahrain's Second National Communication Under the United Nations Framework Convention on Climate Change	Dr. Bill Dougherty, Dr. Mahmoud Abdalla Medany, Dr. Sabah Saleh Al jenaid, Dr. Mohd Sulaiman Abido, Dr. Hamida Mohamed Klai, Professor Waleed K Al-Zubari, Prof. Ibrahim Abdel Gelil, Dr. Randah Hamadeh, Professor Waheeb Essa Alnaser	January, 2012
Municipal solid waste Management Systems in the Kingdom of Bahrain	Mohammed Saleh Al. Ansari	April, 2012
Resource Management Performance In Bahrain: A Systematic Analysis of Municipal Waste Management, Secondary Material Flows and Organizational Aspects	Maram K Al Sabbagh, Costas A Velis, David C Wilson and Christopher R Cheeseman	May, 2012

Al-Ansari (2012) argued that waste management has been acknowledged as one of Bahrain's greatest challenges due to its impending effects regarded as being detrimental to the country. The data gathered within the past thirty years have all revealed significant increases on waste quantity generated in the country in addition to the categories of residential, commercial, institutional, construction and demolition, municipal services, public areas, treatment plant sites, industrial, and agricultural wastes. Furthermore, he found that the main factor which exacerbates the problem of managing the increasing waste accumulation in the country and finding sustainable systems of waste management is the limited land area, which is characterised by Bahrain's small geographical space (Al-Ansari, 2012).

This gives a clarification about the current status of the MSWM process in the Kingdom of Bahrain whilst exhibiting opportunities toward the betterment of investment in Zero-Waste and green technologies so as to realize the concept of sustainability in Bahrain's Society. (Al-Ansari, 2012)

According to the Eco-waste (2018), governments and municipalities in the GCC countries including Bahrain, are developing zero-waste strategies to minimise the amount of solid waste dispatched to landfills or dumpsites. These strategies include plans of developing waste-to-energy (WTE) facilities, incinerating waste and providing energy to supplement a country's electricity needs and diversify its energy mix.

4.4 Current Municipal Solid Waste Management Approached in Bahrain

Waste management in Bahrain is the responsibility of Ministry of Works, Municipalities and Urban (MWMUP), and run through the Waste Disposal Department. Administratively, there is one municipality in each Governorate and each Municipality is responsible for ensuring that waste is collected, streets are clean, and current disposal facilities are operated.

Currently, there are four managerially and financially autonomous municipalities, one in each governorate, which are responsible for the management of public spaces, roads, beaches and the environment at large (Al-Sabbagh, 2012). These four municipalities have an executive responsibility for waste collection under Law No. 3 1975, and are currently, being serviced by two private waste collector contractors. Each contractor serves a group which comprises of 2-3 municipalities; Gulf City Cleaning Company (GCCC) currently serves the Capital (Manama) and Muharraq, whereas Urbacer provides services to the Northern, Southern, and the Central municipalities. Figure 4.3 illustrates the total municipalities of Bahrain.

Figure 4.3: Bahrain Map with all Municipalities Including Muharraq (North), the Case Study Area.

Source: Central Informatics Organization (CIO)

Furthermore, waste is unavoidable in Bahrain; people now produce more waste than ever before. This is further compounded by the lack of suitable disposal sites (landfill), constant enlargement of areas of present landfill, increasing rates of methane and other GHGs generation, as well as lack of environmental awareness, coupled with the lack of environmentally appropriate technologies for waste collection and treatment. The age of affluence, convenience and higher standards of living is also contributing to the accumulation of waste. One of the major problems facing Bahrain is the need for proper disposal of the voluminous solid waste and wastewater generated every year (PCPMREW, 2009).

According to the CIO, (2016), the official population and area as well as the population density of each governorate in Bahrain including Muharraq, the case study area is illustrated in table 4.2 below.

Table 4.2: The population, area and the population density of each governorates in Bahrain including Muharraq in 2016

Governorate	Area (km^2)	Population Estimate (2016)	Population Density per km^2
Capital	68	612,202	9,002
Muharraq	57	256,271	4,495
Northern	175	370,169	2,115
Southern	480	185,084	386
Total	**780**	**1,423,726**	-

Currently, the private contractor is responsible for collecting waste, and transporting/disposing to Askar Municipality Landfill Site from various locations in the country.

Askar landfill for Non-Hazardous waste is situated exactly in the quarry area of the limestone rocks. A big hole with a depth of approximately 10 meters is used for waste disposal/burial. Seven quarries are located in this area. Currently, the third and fourth quarries are being used with a combined capacity of 12 million cubic meters. This landfill site has been operating since February 1986. Prior to this, municipal waste was disposed and buried in Buhair area, located on the west of Sanad, very closed to the urban sprawl and nearby residential areas. Offensive odours and emission of gases, resulting from the decomposition of waste, were common complaints from the inhabitants. This site was closed in September 1987, and the authorities carried a massive transportation operation so as to relocate the residues of the decomposed waste from that area to Askar landfill. Currently, the waste is collected and squeezed using dedicated trucks. The government is currently proposing a plan to extend the landfill area, which is not a sustainable solution given that the MSW volume is rapidly increasing. According to Khalil, (2017), Askar landfill is to reach the end of its operational life by 2016 based on the massive quantities of waste generated and the space consumed each day. However, it continues to operate and receive municipal wastes and started to form a pile. Figure 4.4 illustrates the Askar landfill location and area proposed for landfill extension within Bahrain.

Figure 4.4: Askar landfill location and proposed area for landfill extension

Source: (Khalil, 2017)

According to the MWMUP (2017), the municipal solid waste composition in the Kingdom of Bahrain includes: 1- food waste; 2-garden (yard) and park waste. 3- paper and cardboard; 4-wood; 5- textiles 6- nappies (disposable diapers); 7- rubber leather; 8- plastics; 9- metal; 10- glass (and pottery and china); others (e.g. ash, dirt, dust, soil, electronic waste).

4.5 Household Waste Composition and Organic Household Waste in Bahrain

According to Alsabbagh (2012); the organic fraction (60 percent wt.) is comparable to that in middle- and low-income cities (50–80 percent wt.), although on the basis of gross domestic product (GDP), Bahrain is classified as a high-income country. Since organic waste is considered as the most harmful portion of the MSW content due to its hazardous environmental impact, organic waste management becomes a concern in many of the developing countries with the highest organic portion within their MSW content. Waste composition is considered to be one of the main factors influencing emissions from solid waste treatment, as different types are known to contain varying amounts of degradable organic carbon (DOC), and fossil carbon. Waste composition, commonly known as waste sort, is required to estimate the fraction of various waste materials or items present within a waste stream (Bagchi, 2004).

Thus, most of these countries started to find ways in order to minimize the organic amount in landfills and reduce the harmful effect on the environment.

Organic waste in landfills undergo degradation process, mainly anaerobic digestion, resulting in methane gas production, which is considered to be the most harmful greenhouse gas (GHG) that causes global warming and as a consequence, climate change.

Organic waste (consisting of plastics, papers and food waste) represents the highest composition percentage in Bahraini MSW, according to MWMUP. It reached more than 60 percent in 2017. The most recent waste audit studies held by MWMUP shows that organic waste continues to be one of the biggest components (percentage wise), which will be presented in greater detail in the chapter.

According to the National Waste Audit report by MWMUP (2017), domestic waste is defined as, but not limited to, household waste; it includes green waste, bulky waste and some commercial and selected non-hazardous small scale industrial wastes. The following table identifies the components of the household waste:

Table 4.3: Household Waste Components Official Identification by the MWMUP

Domestic Waste Components	Component Items
Paper and cardboard	Newspaper & magazines, other recyclable paper, corrugated cardboard, thin non-waxy card
Dense plastics	Fizzy drink, water bottle, milk bottles, bleach, cleaners and shampoo bottles
Plastic film and other plastics	Packaging film, carrier bags
Textiles	Reusable clothing, clean bed linen & sheet material including towels, soft toys
Miscellaneous combustibles	Disposable nappies, treated wood, untreated wood
Miscellaneous non-combustibles	Construction & Demolition / DIY waste
Glass	Green, brown, clear and blue glass
Ferrous metal	Cans and aerosols
Non-ferrous metal	Aluminium foil and food trays, cans and aerosols
Food waste	All food waste
Other organics	Garden waste, pet litter
WEEE	All electrical items
Residual	Tissue paper, Diapers, and all other remaining residue

Accordingly, the household waste (or domestic waste) in Bahrain comprises of a mixture of different percentages of the above components (MWMUP, 2017) illustrated in figure 4.5 below. It is evident that the organic household waste including (papers, plastics and food waste and other organics) denotes the majority of the household waste generated in the country (reached 65 percent according to the figure). The nation's annual generation rate of household waste for the last 2 decades, according to MWMUP (2017), is presented in table 4.4 and figure 4.6 below. It can be clearly observed that the waste volume has almost doubled.

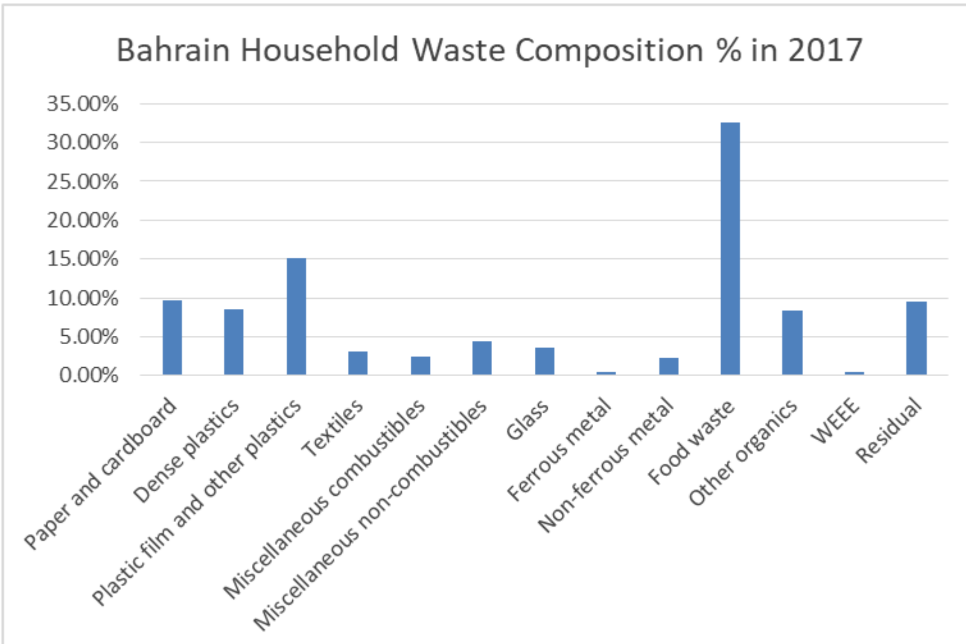

Figure 4.5: Bahrain Household Waste Composition Average Percentages in 2017

Source: Data from (MWMUP, 2017), Figure created by the researcher.

In this research, the OHW considered is the summation of the following composition: paper and cardboard 9.70 percent, dense plastics 8.60 percent, plastic film and other plastics 15.20 percent, food waste 32.60 percent, and other organics 8.10 percent. These compositions represent 74 percent of the total household waste in Bahrain, reaching 434,915 tonne/year in 2017.

Table 4.4: The annual generation rate of the household waste in Bahrain for the last two decades

Domestic Waste	
YEAR	**TONNES**
1997	231627.8
1998	240157.4
1999	233916.3
2000	234187.0
2001	274236.9
2002	279295.3
2003	293111.1
2004	323990.3
2005	306202.9
2006	312983.5
2007	287205.2
2008	380871.2
2009	390177.3
2010	408489.3
2011	407504.4
2012	428730.7
2013	447764.2
2014	451902.1

2015	459527.0
2016	497949.8
2017	587722.8

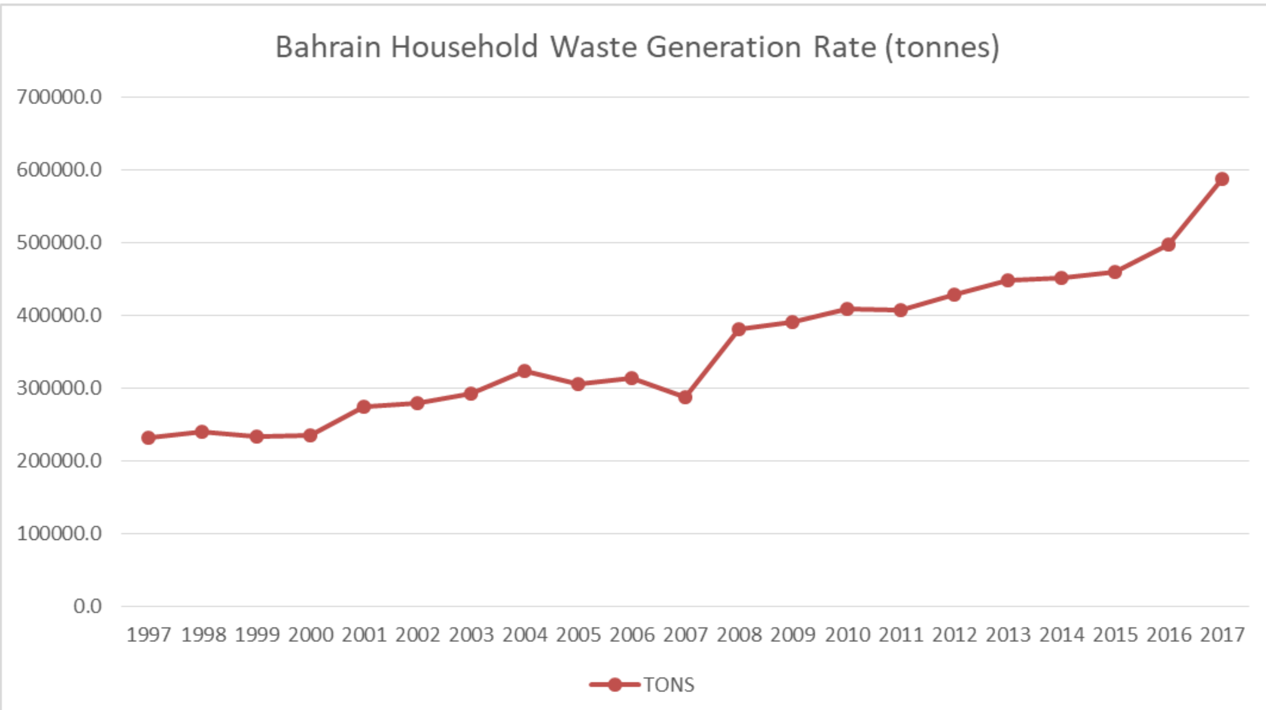

Figure 4.6: The annual generation rate of the household waste in Bahrain for the last two decades

Source: Date from (MWMUP, 2017), (Figure created by the researcher)

Food Waste in Ramadan Season in Bahrain

Scientists opine that CO_2 is a main contributor to climate change, but there is also a religious motivation for people to conserve food, especially during Ramadan. http://tradearabia.com/news/MISC_286102.html

Therefore, Ramadan season is an attractive season to discover differences and make comparisons between the OHW characterization as the percentage of the waste composition held by the

MWMUP in 2017 (Figure 4.7). As mentioned in Chapter 3, the empirical investigation of the OHW characterization was held on two different seasons: the normal year days and in the fasting season of Ramadan.

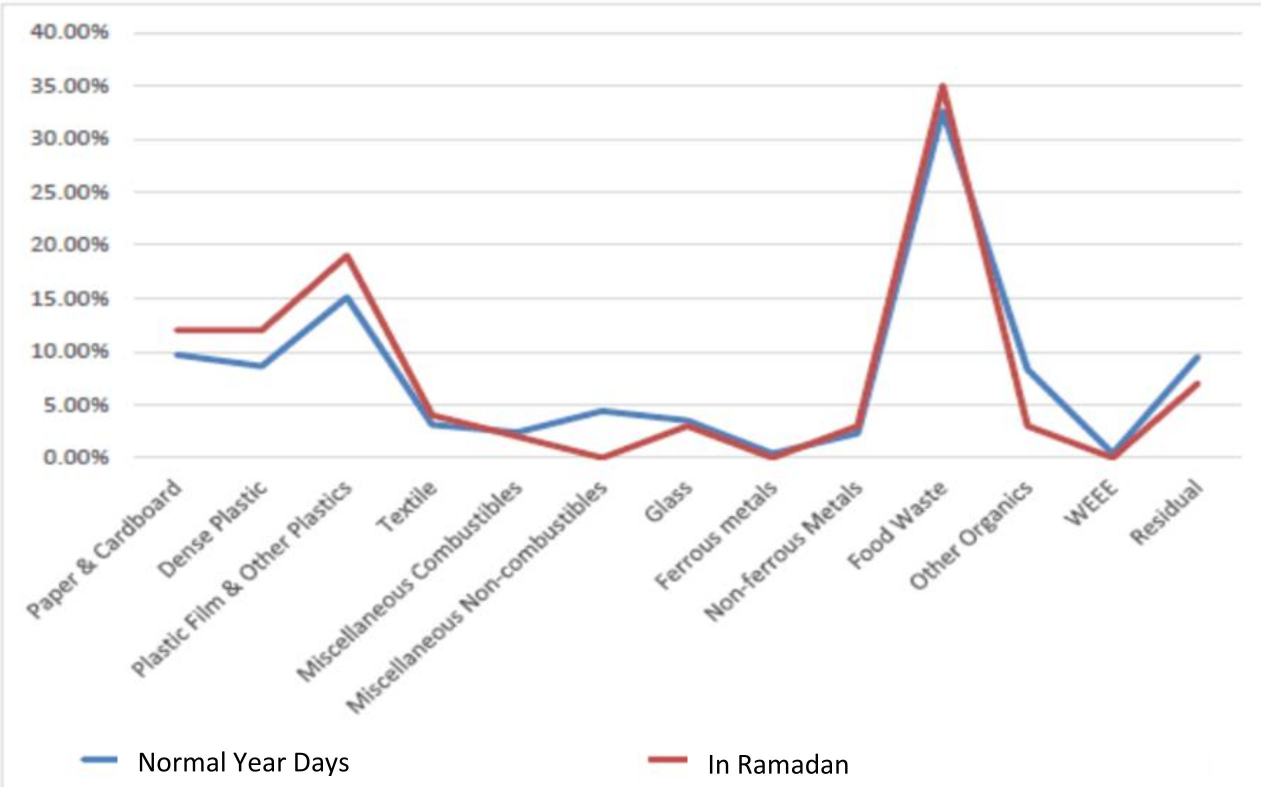

Figure 4.7: Comparison between Bahrain Waste Composition in Normal Year Days and in the Ramadan season.

Source: Date from (MWMUP, 2017), figure created by the researcher.

Food waste and other organics portions (collectively named OHW) represent the highest percentage of the MSW composition, which again supports the findings of literature and prioritizes OHW to be managed properly across Bahrain.

It can be observed from the aforementioned figure that OHW (Paper & Cardboard, Dense Plastics, Plastics and Other Plastics, Food Waste and Other Organics considered in this research) has higher percentage in Ramadan as compared to normal year days but still there is no significant difference between the two seasons which does not show significant variation in the waste composition. The slight difference may reflect the nature and culture of the Bahraini society, which witnesses a higher purchasing rate during Ramadan in order to meet all of the requirements for cooking as well as hospitality of family members. Moreover, it reflects that most of people are not committed to Islamic religious rules, which calls for saving and discourages wastage of food and other resources. Ironically, the exact opposite is happening and the amount of organic waste is much higher in Ramadan as compared to non-Ramadan season. This research adds further findings about Ramadan OHW in Bahrain by characterizing it and comparing the characteristics between the two seasons - which adds a new dimension to this study.

4.6 Muharraq Governorate

Muharraq is the third largest Governorate in Bahrain, and is situated on Muharraq Island. Apart from having a great historical significance, the Bahrain International Airport is also located in the Governorate. Muharraq Island is the third largest island among all islands in Bahrain, following Bahrain Island and Hawar Island. It includes several towns and villages, including Al Muharraq, Arad, Dair, Busaiteen, Hidd, Halaat, Galali, and Samaheej. In 2017, the total area of Muharraq Governorate reached 64.8 Km^2, and the population had increased to 298,517 (Information eGovernment Authority, 2018).

In 2016, the percentage of Muharraq domestic waste contribution reached almost 22 percent of the entire country's domestic waste, as shown in figure 4.8 below: (note that all of the statistical figures found in this chapter have been developed by the researcher after gathering the required data from official authorities. Since these statistical figures are unavailable, source under the figure means that only the original data is provided by the mentioned source)

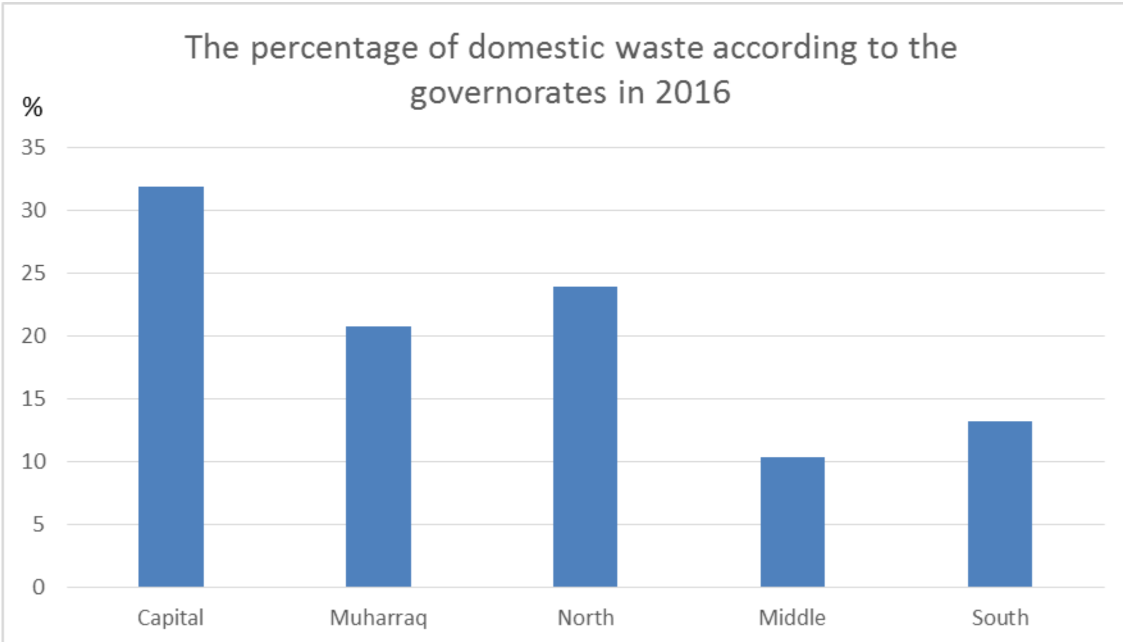

Figure 4.8: The Percentage of Muharraq Governorate's Domestic Waste as Compared to the other Governorates

Source: Data from (MWMUP, 2016), figure created by the researcher

The total annual domestic waste generation rate in Muharraq is illustrated in figure 4.9

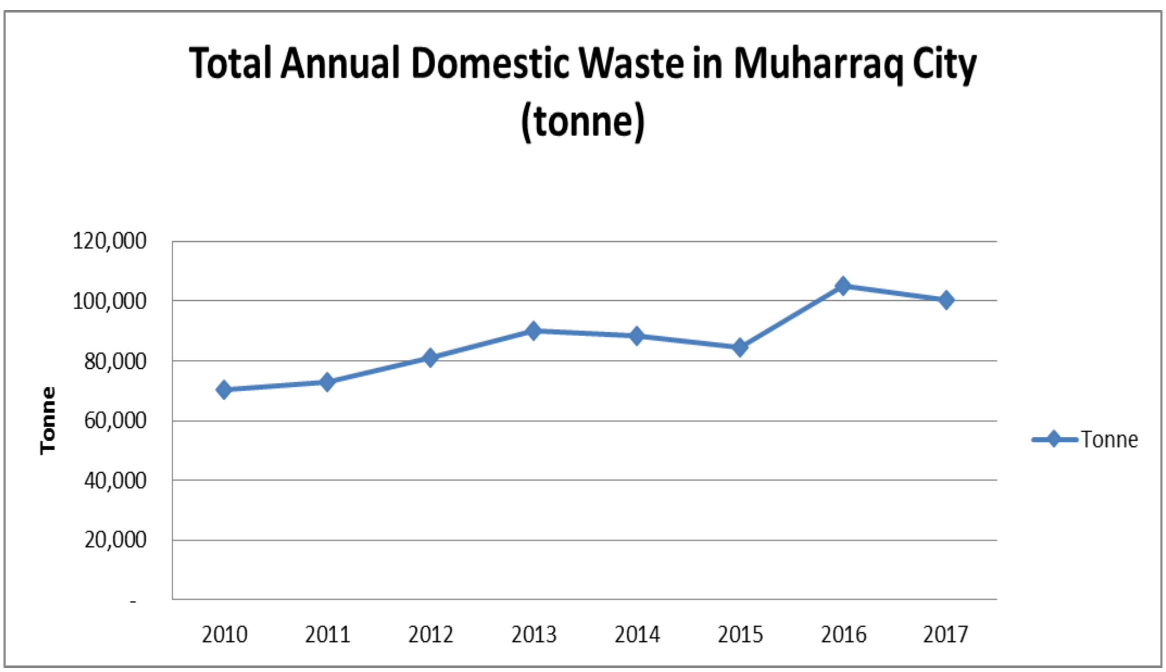

Figure 4.9: The total annual domestic waste generation rate in Muharraq Governorate

Source: Data from (MWMUP, 2016), figure created by the researcher

In 2017, the household waste in Muharraq touched 57 percent of the total MSW, with generation rate reaching 280 tonne/day, in addition to an annual generation rate of 102,547 tonne/year, as shown by Figure 4.10 (MWMUP, 2017).

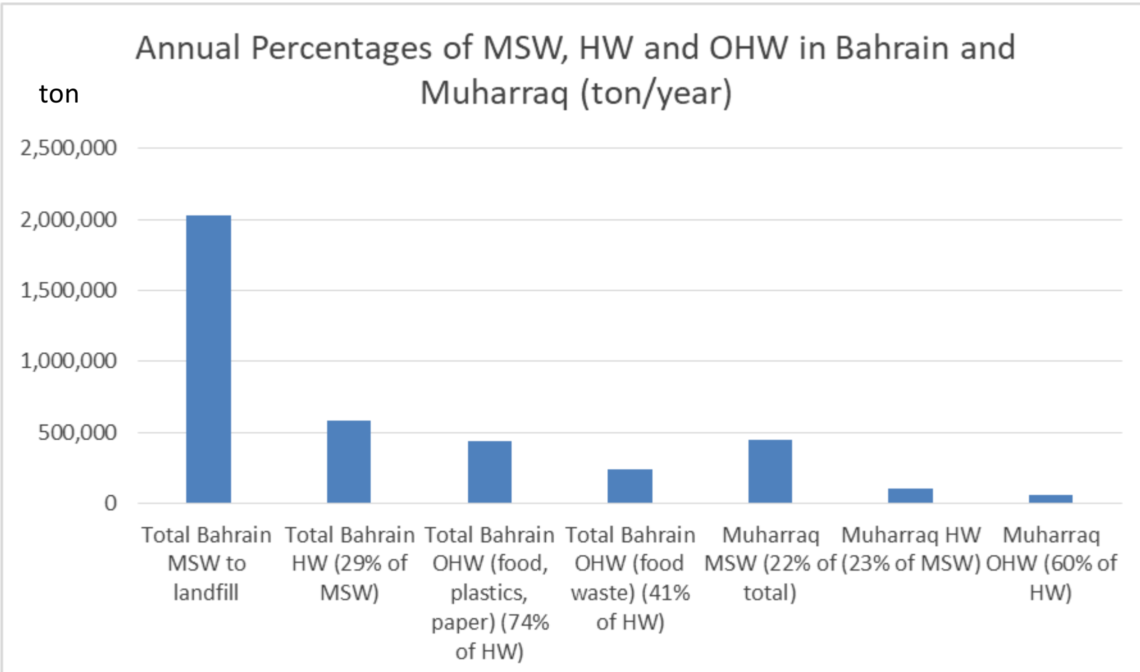

Figure 4.10: Estimated annual percentages of MSW, HW and OHW in Bahrain and Muharraq Governorate

Source: (MWMUP, 2017), figure created by the researcher

The annual waste rate is shown in tonne/capita/year in figure 4.11 for Muharraq Governorate; it is considered as one of the highest generation rates globally. On the other hand, Figure 4.12 shows the daily generation rate in kg/capita.

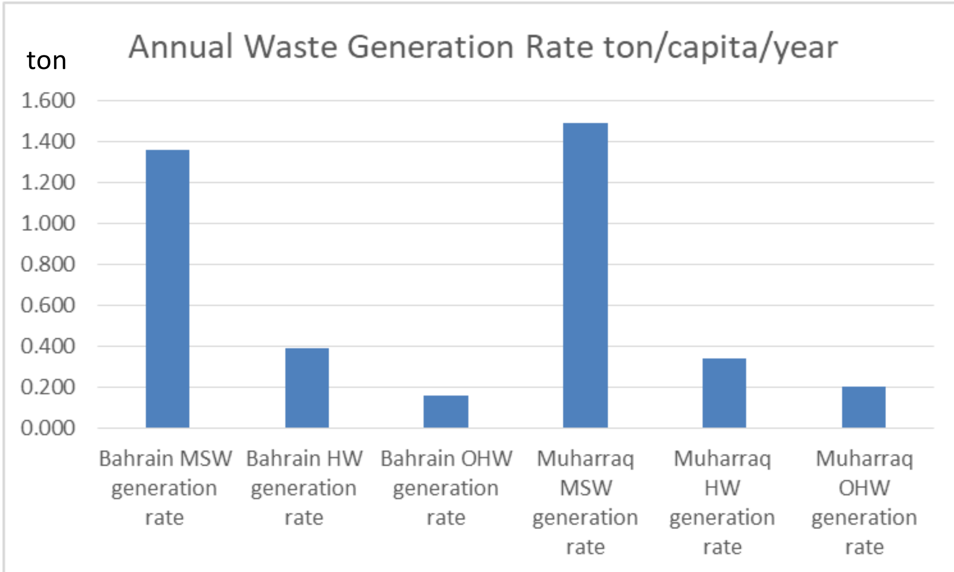

Figure 4.11: Annual Waste Generation Rate in tonne/capita/year

In order to make a comparison of Bahrain MSW generation rate and waste composition with various cities globally, Figure 4.12 illustrates the composition of MSW per capita (kg/capita/year) in several cities globally, according to (Mutz et al., 2017)

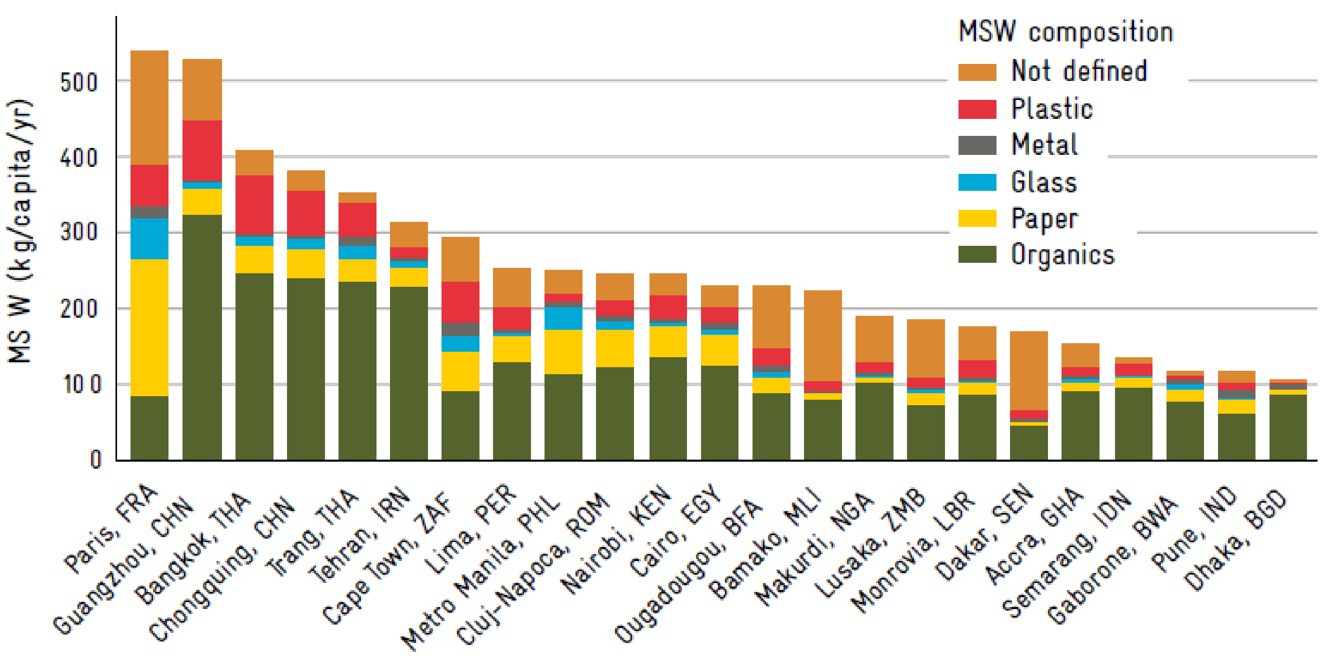

Figure 4.12: Composition of MSW per Capita (kg/capita/yr) in various Cities of the World

Source: (Mutz et al, 2017)

Figure 4.12 illustrates that the MSW generation rate is 1200 kg/capita/year while in Paris, it is only around 530 kg/capita/year; it is even lower in other cities. This indicates that the MSW generation rate is high in a very small country like Bahrain, which reflects the necessity of finding an urgent solution to manage this waste in a sustainable manner rather than dumping it in the landfill, which already exceeds its expected life time.

Mutz et al. (2017) argued that in most developing countries, organic waste with high moisture content is the most relevant fraction that ends up as a formal waste stream and necessitates treatment. In developing countries, mixed municipal solid waste is intrinsically different from that in industrial countries and entails specific characteristics in every city. This diversity must be considered in the course of any technology assessment. Figure 4.14 illustrates the MSW composition in the Muharraq Governorate.

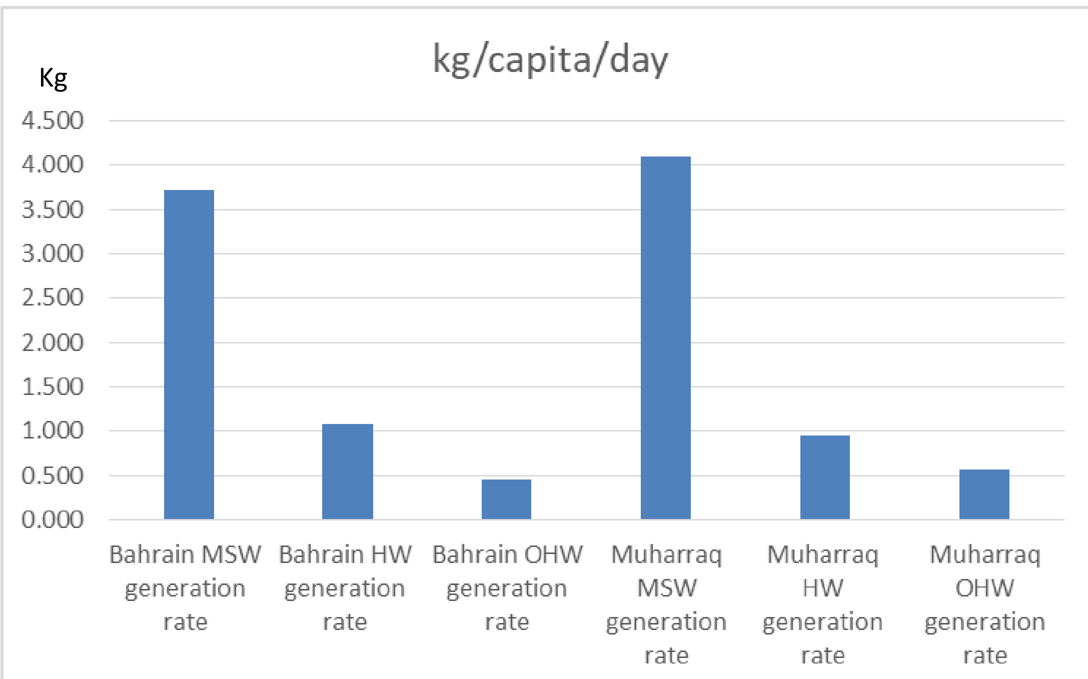

Figure 4.13: Daily Waste Generation Rate in kg/capita/day

When sorting the OHW to be characterized in the lab in order to accomplish this research objective, Muharraq domestic waste composition was identified in cooperation with the MWMUP and GCCC (2017). Organics represents the majority of the HW, as shown below:

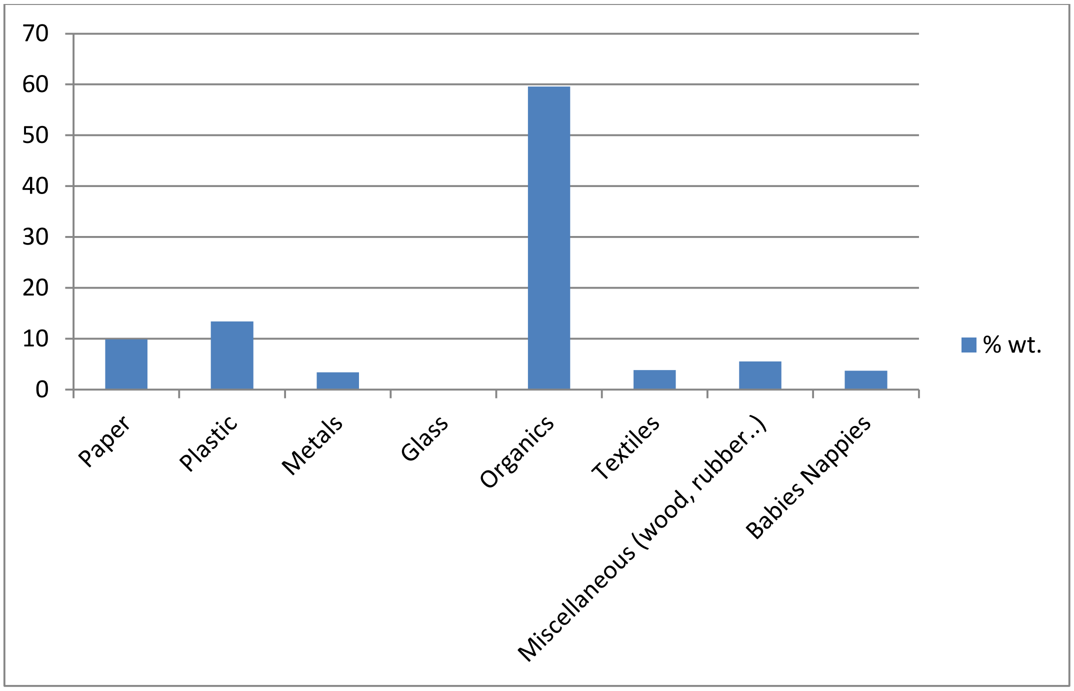

Figure 4.14: Muharraq Household Waste Composition 2017

Table 4.5 summarises the statistical data shown in the figures above.

Table 4.5: Summary of the above statistical data of Bahrain and Muharraq waste

Bahrain and Muharraq Waste Statistics (2017)			
	ton/year	kg/day	ton/day
Total Bahrain MSW to landfill	2,026,631	5552414	5552.4
Total Bahrain HW (29% of MSW)	587,723	1610200	1610.2
Total Bahrain OHW (41% of HW)	240,966	660181	660.2
Muharraq MSW (22% of total)	445,859	1221532	1221.5
Muharraq HW (23% of MSW)	102,547	280951	281.0
Muharraq OHW (60% of HW)	61,529	168571	168.6
Population	**People**		
Bahrain Population (2017)	1,492,584		
Muharraq Population (2017) (20%)	298,517		
Generation Rate	**kg/capita/day**	**ton/capita/year**	
Bahrain MSW generation rate	3.720	1.358	
Bahrain HW generation rate	1.079	0.394	
Bahrain OHW generation rate	0.442	0.161	
Muharraq MSW generation rate	4.092	1.494	
Muharraq HW generation rate	0.941	0.344	
Muharraq OHW generation rate	0.565	0.206	

According to the table above, the Kingdom of Bahrain produces 1610 tonnes/day of household waste of which 660 tonnes a day is accounted for by OHW while the Muharraq Governorate generates 280 tonnes/day of household waste, including 168 tonnes/day of OHW.

The next section will illustrate the methane emission estimation resulting from the OHW being dumped into the landfill.

4.7 Methane Emission Estimation

According to the US-EPA (2007) cited in Salman, (2016), landfills contributes to approximately 34 percent of all man-made methane released to the atmosphere. Emissions from Canadian landfills account for 20 percent of national methane emissions (http://www.ec.gc.ca/gdd-mw/default.asp?lang=En&n=6f92 e701-1). In a landfill, methane emission from organic matters depends on many factors, including the composition of decomposing materials and the time of residency. For example, Eleazer et al. (1997) showed that 94 percent of grass and 84 percent of food waste was decomposable in a landfill, as compared to only 28-29 percent of leaf mass and branches. The rapidly degradable wastes, like grass or food waste, generally start generating methane within a few days or weeks, which can be lost if they are not captured by a collection system.

Unlike other GHGs, methane is a major component of natural gas, and can be captured and converted into useful clean energy, which can improve air quality and enhance economic growth. The realization of the adverse effect of GHGs led the international community to endorse the Convention of the United Nations' Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas (GHG) emissions, which came in effect in 1994. The USEPA (2016) estimated that the global total man-made CH4 emissions stood at 282.6 million tonnes in 2000, 36.7 million tonnes (or 13 percent) of which were attributed to landfill emissions (2002). Based on the same data but under different assumptions, Themelis and Ulloa (2007), however, reported that the global generation of CH_4 from landfilled MSW was in the order of 54 million tonnes of methane.

According to Salman (2016), Methane emission can be measured using three different equations and therefore gave three different estimates for Bahraini landfill methane emissions.

Table 4.6: Three equations that can be used to estimate Bahraini methane emission

Equation number	Modeling equation	Annual CH4 emission Kg/yr	per capita methane emission kg/d	Details/reference
1	CH_4 Emissions (kg/yr.) = (MSWT • MSWF • MCF • DOC • DOCF • F • 16/12-R) • (1-OX)	32,776.62	0.06	IPCC
2	CH_4 Emissions (Units) = CH_4 generated * (1 – oxidation factor)	101,761.8	0.20	Climate Leaders GHG Inventory Protocol, 2004
3	CH4 Emissions (tonnes)=Total MSW*0.147	69,953.9	0.147	Themelis and Ulloa (2007)

When converting the OHW from the landfill by making use of OHW management technologies, methane emission will be reduced to very minimum levels, which represents an environmental benefit for technologies adoption. This will be discussed in greater detail in Chapter 6 in the cost-benefit analysis.

The net heating energy of methane obtained from EIA report is (35,846 KJ/m^3). (Hotchman et al., 2015)

Considering the above annual methane emissions, according to Hotchman, (2015) the power that can be generated from the landfill methane uses the following equation:

Gross energy generated (P), measured in kJ/yr:

$P = VCH4, yr * 35{,}846 * 0.75$

Where VCH_4, yr refers to the volume of methane generated from combined waste in an entire year.

We assume that the efficiency of the internal combustion engine (θe) is 35 percent. Accordingly, the final electricity generation (kWh) can be expressed as following:

$Electricity = P * 0.35 * (1/3600)$.

Therefore, for the three estimated methane emission values illustrated in table 4.5 above, the estimated Gross energy generated is 8812 GJ/yr, 2736 GJ/yr and 1881GJ/yr respectively.

In order to count the final electricity generation in (kWh), we can further use the equation of the aforementioned electricity; thus, the results are as follows: 85,671 kWh, 265,980 kWh, and 182, 843 kWh, respectively. For this reason, recovering methane from the landfill might be a feasible option in case the landfill continues to receive waste over the next few years, something that is not assured by the government since the landfill exceeds its duration this year.

The calorific value (CV) is considered to be an important parameter of the OHW, which was measured empirically in this research, owing to the possibility for its usage as the estimation of power that can be generated from this waste, as will be demonstrated later.

4.8 Legislation, Policies and International Agreements

Bahrain is among the signatories of the United Nations Framework Convention on Climate Change (UNFCCC). As part of the on-going effort to combat challenges posed by climate changes, the Kyoto protocol was introduced back in 1997. This protocol is an international agreement that is linked to the UNFCCC and commits its parties by internationally setting binding emission reduction targets. A newly negotiated agreement (Paris Agreement) was introduced in 2016. The Paris Agreement is a global framework to promote resilience and low carbon development growth under two major global objectives: (1) stabilization of GHGs concentrations in atmosphere at a level that allows ecosystems to adapt to climate change naturally; and (2) limit GHG emissions until 2050 so that the average global warming remains below 2°C until 2100. A major change adopted by the Paris Agreement is that there is no more division between developed countries with mitigation obligations and developing ones without; hence, almost all nations of the world have contributed to this cause (UNFCCC, 2016).

On the other hand, international concerns over methane generation have led to the establishment of the Global Methane Initiative (GMI) in 2004 (https://www.globalmethane.org/index.aspx). Effort of this initiative includes methane abatement, recovery, and use by *"focusing on the five main methane emission sources: agriculture, coal mines, municipal solid waste, oil and gas systems, and wastewater."*

Moreover, Bahrain has signed a number of International Agreements and is committed in order to reduce GHG emissions accordingly.

In 1999, the GCC countries collectively published a Common System of Waste Management. It encompassed all tasks related to waste (definitions, waste and hazardous waste definitions, waste producers terms and conditions, waste transportation terms and conditions, owner as well as operator terms of waste management facilities, procedures, privacies, and obligation). This document formed the basis for MSW management across GCC countries. For this reason, waste management in Bahrain is governed by the following legislations:

• Law No. 3 for 1975 with Respect to Public Health, Ministry of Health, State of Bahrain.

• Resolution No. (3) Of the Year 2006 with respect to the Management of Hazardous Materials.

• Law No. 3 is mostly concerned with public health and sanitation Section 6 of this law meanwhile includes clauses on the Collection and Disposal of Garbage (Waste). Waste is deemed the responsibility of Executive Authority, which in this case accounts for five Municipal Authorities in Bahrain. Waste collection services are sub-contracted to private enterprise companies in the company.

• Resolution No (3) is concerned with the proper isolation, transport and safe disposal of all hazardous waste material. The Resolution defines hazardous waste as any solid, semi-solid or liquid matter containing gaseous waste or a group of compounds of waste that may lead to a hazard or potential hazard to public health, environment as well as wildlife due to their quantity, concentration, physical chemical or biological properties when they are not managed in an environmentally proper manner.

a. National Legislation:

According to the SCE, the environmental legislative system in the Kingdom of Bahrain is among the most advanced in the region. Indeed, the Kingdom seeks to strengthen its efforts to protect the environment and natural resources through devising the necessary legislative guarantees so as to ensure the optimum use of those resources and promote development that does not cause harm to the environment or the health of citizens. Moreover, the kingdom takes into account the global trends in preventing and treating major environmental problems.

b. International Environmental Agreements:

The Kingdom of Bahrain has ratified many regional and international agreements, conventions and protocols related to protecting the environment and achieving sustainable development, according to the official Supreme Council of Environment (SCE) website accessed on June 01 2018. As many as 41 international environment agreements were signed between 1969 and 2018. The most related ones to Waste Management and its implications are as follows:

1- Royal Decree 75 of 2016 on ratifying the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) 2016:

The agreement aims to strengthen the global response to the threat of climate change by holding the increase in global average temperature well below 2 degrees Celsius above pre-industrial levels as well as the increased ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development.

The Paris Agreement was adopted in COP21 on December 12, 2015 in Paris and established clear aims for climate action with respect to mitigation and adaptation, grounded in sustainable development. It came into effect on November 04 2016.The Paris Agreements sets a long term goal to keep increasing global average temperature to below 2°C, with global emissions to peak as soon as possible. The Paris Agreement also established a global goal on adaptation in order to strengthen resilience and reduce vulnerability to climate change. In order to attain these ambitious goals, financial flows, new technology framework and enhanced capacity building framework will be put in place. Under the Agreement, each Party is required to submit Nationally Determined Contributions at the end of every five years that it intends to achieve.

2- Kyoto Protocol to the United Nations Framework Convention on Climate Change Decree 45/2005: It is an international environmental treaty negotiated at the Earth Summit that aims to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

3- Stockholm Convention on Persistent Organic Pollutants Law 39/2005: This convention aims to transform the Rio Declaration on Environment and Development into an approach that aims to protect human health as well as the environment from persistent organic pollutants.

4- Regional Protocol on the Control of Marine Trans-boundary Movements and Disposal of Hazardous Wastes and Other Wastes Decree 26/2001 highlights the importance of cooperation and effective coordination at the regional level in order to control the maritime transport of hazardous waste along with other wastes and restrict the import of wastes from non-contracting countries.

5- United Nations Framework Convention on Climate Change Decree 7/1994: The UNFCCC objective is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

6- Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and Their Disposal, and its amendment Decree-Law 11/1992 and Law 8/2005: it is an international treaty that was designed to reduce the movements of hazardous waste between nations, and specifically to prevent the transfer of hazardous waste from developed into less developed countries (LDCs)

Bahrain's Green House Gas Emissions:

The effects of climate change are complex and include increased average temperatures, rising sea levels, changes in rainfall, and more frequent extreme weather events. While climate change poses a serious risk to the Kingdom, the total net national emissions in the year 2000 was 22,374 CO_2e, which contributed a relatively small amount of global emissions at less than 0.1 percent. Approximately 77 percent are associated with the combustion of fossil fuels or the release of fugitive emissions from oil and gas operations. Industrial processes accounted for about 11 percent of all GHG emissions, followed by the waste sector, which accounted for about 12 percent of total emissions.

Bahrain's Vulnerability to Climate Change:

Bahrain is an archipelago of low-laying islands in addition to numerous islets, shoals and patches of reefs that are situated off the central southern coast of the Arabian Gulf. Bahrain falls in the subtropical region within the desert belt.

As a small island, Bahrain is particularly vulnerable to the threats of climate change, especially when considering the rising sea levels. Increased sea level will lead to potentially major impacts on the population and the country's economy. As cited in the Kingdom of Bahrain's Second

National Communication Report to the UNFCCC, Bahrain faces the prospect of severe land loss in the long and near term. This is of particular importance, considering the intensive pressure from pollution, urbanization and high population density concentrated along coastal zones. Over the last four decades, rapid population growth and urbanization, coupled with the expansion of irrigated agriculture and industrialization, have led to very high water demand and rising vulnerability of water supply. With rising sea levels, additional pressure will be placed on already stressed groundwater resources due to seawater intrusion into groundwater. Climate change is also understood to pose a potentially significant threat to public health through increased exposures to thermal extremes, changing disease vector dynamics, an increased incidence of food-related and waterborne infections likely to be experienced throughout the Bahraini population, with the elderly, patients with pre-existing medical conditions, and children likely among those that are hit the hardest.

Climate change impacts on biodiversity can also affect fish-stock levels, coral reefs, mangroves, date plantations, and migratory birds. In the case of marine life, Bahrain has sixteen different marine habitats. Of these, six entail a strong consensus exists within Bahrain scientific community to be considered as priority systems for any subsequent climate change adaptation, namely algae beds, coral reefs, seagrass beds, oyster beds, mangrove forests, mudflats, and salt marshes/coastal dunes.

Based on a personnel communication with Mr. Bob Doig, the waste management advisor at MWAUP, the official landfill at Askar is soon coming to the end of its expected practical life and Bahrain needs to reduce the dependency on landfill. In addition, a new National Strategy Plan will be developed by a French consultant firm (BFTPI). This plan will be premised on practical considerations that are relevant to the Bahraini scene.

CHAPTER 5: Results and Discussion

5.1 Overview

This Chapter explores the empirical investigation results apart from representing the developed matrix based on literature review. It contains five main sections: overview being the first one. The second section describes the development of parameter/technology matrix from the literature review of Chapter 2. Third section provides the results of the empirical investigation of Muharraq Governorate OHW characterization and lab analysis whilst comparing the result of the average of a normal day's investigation along with Ramadan season, whereas the fourth section contains the selection of the most preferred technologies based on the OHW characterization results and shortlisting them by matching with the developed matrix. The fifth section entails the discussion of the findings.

5.2 Section 1: Developing the Parameter/Technology Matrix from the Literature Review

In order to develop the Parameter/Technology Matrix that might represent an important reference to select the optimum technology premised on waste characterization, Chapter 2 showed that almost all of the existing references related to the waste characterization/technologies and their interrelation were carefully reviewed. Most of the reviewed references were mainly about the waste characterization and parameters in relation to waste management technologies. Moreover, the data search also includes the optimum feedstock for every specific technology. A total of four matrices existed in the literature for very limited parameters concerning waste management technologies and they were general to MSW management and not specific to the OHW. These parameters include both qualitative and quantitative data along with other criteria for technology selection without focusing on waste characterization parameters e.g. waste volume, cost, land requirement, etc. (Mutz et al., 2017; Asian Development Bank, 2011; Sharma et al., 2018, and selection criteria matrix by unknown author found on: http://cpcb.nic.in/cpcbold/upload/Latest/Latest_125_SW_treatment_Technologies.pdf)

As a reminder of some parts of the literature reviewed in Chapter 2, the available literature that were used to relate the parameters to each technology are mentioned below to begin developing the Matrix:

5.2.1 Optimal Operating Conditions Required by Anaerobic Digestion (AD)

1. **Carbon/Nitrogen (C:N):** The ideal carbon to nitrogen (C:N) ratio for anaerobic digestion ranges from approximately 20:1 to 30:1 (EPA, 2014 and Wang et al., 2014). Low C:N means high ammonia which inhibits AD. (Wang 2014). Carbon/nitrogen (C/N) ratio and biodegradability are the main factors. Failure in AD may refer to low pH, insufficient alkalinity, ammonia inhibition, and the accumulation of volatile fatty acids (VFAs) and the digesters (Heo et al., 2004). The hydrogen production ability of the anaerobic microflora (dominated by Clostridium Pasteurianum) in the sewage sludge relied upon the influent C/N-ratio. (Lin, C.Y. and Lay, C.H., 2004). The relative abundance of carbon and nitrogen is an essential parameter of microbial growth and should be in the range of 16-25 for anaerobic digesters (Mutz et al., 2017), with the optimum range being between 20 and 30. A higher ratio is an indication of higher N consumption by methanogens and leads to lower gas production. Lower ratio cause ammonia accumulation and pH is raised to 8.5, which is toxic to methanogenic bacteria. In order to achieve an optimum ratio, waste can be mixed with sewage or animal manure (Monnet, 2003)

   Another study showed that an increase in C/N ratio of food waste resulted in better pH stability and enhanced methanogenic activities.

   Similarly, a study showed that substrate with low C/N ratio is most likely to result in the production of high amount of total ammonia nitrogen (TAN) and volatile fatty acids (VFAs). These substances are important intermediate products produced during the anaerobic digestion. Increased concentrations of VFAs and TAN could hinder methanogenic activities. Gradual accumulation of these intermediates could lead to total failure of the anaerobic digestion (AD) process. http://www.ijimt.org/papers/497-H1008.pdf

2. **TAN:** TAN and FA depend on organic N and C:N. the optimum TAN is 200mg/L. It was found that experimental Total Ammonia Nitrogen (TAN) concentrations that cause a 50 percent reduction in methane production range from 1,700 to 14,000 mg/L. Similarly, higher TAN content inhibit rapid acidification and AD. (Fisgativa, et al., 2016).
3. **VFA:** Must be <4000 mg/L. (Fisgativa, et al., 2016)

4. **Moisture:** McKendry, (2002) stated that the optimum moisture content for AD is 80-90 percent, while Harnadekel et al. (2015) mentioned that it is 70-80percent. The total moisture content of any solid waste is one of the most significant variables affecting the energy content of the material (Roberts and San, 2015). In the matrix developed in this research, the range that will be considered is 70-90 percent.

5. **pH:** It was found that the optimum pH for AD is 6.8-8.2 (Cio, 2012; Hobson and Shaw 1976; Wang et al., 2014). Low pH can inhibit acidogenesis bacteria, and pH below 6.4 can be toxic to the methane forming bacteria, with the optimum range for methanogenesis being pH 6.6-7.2, and the optimum range for all being 6.4-7.2. (Monnet, 2003). For this reason, the considered range will be 6.4-8.2.

6. **COD, BOD and VS:** Food has a high biodegredable potential with high Volatile solids (VS) and chemical oxygen demand (COD), which makes it suitable for AD (Fisgativa, et al, 2016).

   The recovery of biogas as well as a reduction of chemical oxygen demand (COD) in organic waste and waste stabilization is the main advantages of AD. (Reungsang, 2012 stated that optimum COD for AD is 18,000mg/kg.

   -VS represents the organic matter in the sample measured as solid content minus the ash content. High VS content is suitable to AD (Monnet, 2003). For AD, optimum COD (mg/kg) > 282000 mg/kg (Tanimu et al 2014). The biodegradable COD concentration meanwhile is approximately 238,000 kg/m^3 (Baawain et al., 2017) The COD values were classified as young (>10,000 mg/L) as per Foo and Hameed (2009). The BOD/COD ratio reflects the degree of biodegradation within the landfill and provides information on the age of a landfill. The lower the BOD/COD ratio (less than 0.2), the higher the concentration of non-biodegradable organic compounds, which lead to biological degradation (Zarkovic et al., 2011). The BOD/COD ratio ranged from 0.4 to 0.5; thus, the landfill leachates are young (Foo and Hameed, 2009).

7. **Heavy metals:** >80ppm, high heavy metals are rates that limit AD. There is a need to add sulfate in order to remove toxicity. (Alseadi et al., 2013; Speec, 1985; Anderson et al.,

1982). Heavy metals: Cd and Cu need to be below 150 mg/lL, Ni below 500mg/L. Thermophilic requires minerals more than mesophilic since they are different in behaviour in that thermophillic are more active than mesophilic. While Ni is the most important among all (Uemura 2010 and speec, 1985). Cu, Pb, Cr and Zn are inhibitors to AD. The average concentrations of Selenium, Barium, Manganese, Cobalt, Arsenic and Boron must have very low concentrations.

8. **FA, lipid (oil and grease):** High fatty acids inhibit thermophilic bacteria, but not mesophillic.
9. **VFA** (inside the digester) <4000 mg/L (Fisgativa, et al, 2016)
10. **Sulphur:** <50mg/L (Fisgativa, et al, 2016)
11. **Ash** affects the cost of the technology, which must be low. (Fisgativa, et al., 2016)
12. **Alkalinity** >100mg/L (Fisgativa, et al., 2016)
13. **Calorific Value** is 5000-6000 kcal/m3 (Abdel-Shafy, 2014). Calorific value 7-25 MJ/kg-800-1000kcal/kg suitable for AD
14. The higher material recovery achieved with the technology was associated with greater transfer of nutrients (N and P), carbon (total and biogenic) also in addition to heavy metals (except Pb) to the produced biomass (Naroznova et al., 2016).

5.2.2 Optimal Operating Conditions Required by Composting

1. **Moisture:** 50-60percent (Bobeck, 2010) 34-65 percent (Ohio state university). High moisture is suitable.
2. **C:N:** 25-35, optimal is 30:1. (Bobeck 2010) C:N ratios of above 40:1 tend to compost slowly and the mixture may not achieve sufficient temperatures to support thermophilic organisms. (SEPA, 2015)
3. **pH:** 5.5-8 (Bobeck, 2010), 6-8.5 (SEPA,2015)
4. **Calorific value (CV)** 7-10 MJ/kg- 800-1000kcal/kg suitable
5. **TAN:** high
6. **Oil and grease:** very low
7. **Heavy metals**: low heavy metal required

- **Cd** 0.7-1.5
- **Cr & Cu** 100-150 mg/L
- **Hg** 0.5-1
- **Ni** 50-75mg/L
- **Pb** 100-150
- **Zn** 200-400

8. **C:P** 100:1 for windrow composting, as reported by Brinton (2000).

5.2.3 Optimal Operating Conditions Required by Incineration

1. **Moisture:** The moisture content of the feedstock should be low (<45 percent) and pre-drying may be necessary in some cases.
(https://advancedbiofuelsusa.info/wpcontent/uploads/2010/05/8_gasification_pyrolysis_combustionRevised.pdf)
In addition, Komilis et al. (2014) concluded that substrates with moisture content up to 60percent wb can maintain self-sustained combustion as long as their organic matter contents are greater than 40 percent wb (or 75 percent db).
2. **TOC** >25percent
3. **Fixed carbon** <15percent
4. **Calorific Value (CV):** CV >1600kcal/kg (high) (Mutuz et al., 2017). In order to ensure autothermic combustion of the waste, LCV should not be below 7 MJ/kg on average over a year (for comparison: The LCV of 1 kg fuel oil is about 40 MJ/kg). World Bank-recommended value (Rand et al., 2000) suggests that the LHV wb of MSW should be 7 MJ/kg on average, and must never fall below 6 MJ/kg for use in thermochemical conversion processes. (Robert and Hla, 2015)
5. **pH** is not applicable
6. **Ash:** must be <60 percent
7. **VFA:** low
8. **Volatile matter (OM) or (VS)** >40 percent

5.2.4 Optimal Operating Conditions Required by Gasification

1. Gasification is more sensitive to feedstock CV than incineration due to the requirement to produce a homogenous syngas. This leads to producing lower net efficiency/higher parasitic loads with wetter and lower CV material. Therefore gasification usually requires pre-treatment, for example through a dirty MRF. Gasification plants can be modular in design allowing for capacity to be added when needed.
2. Besides, emissions, such as heavy metals and dioxins, are also compared to conventional incineration to verify the environmental feasibility of gasification. (Dong at al 2016)
3. IEA Bioenergy has argued that the main properties of biomass that influence the gasification process are: High moisture content (hydrophilic). • Low bulk density, high porosity. • Fibrous nature (low friability). • Chemical composition: high volatile content, low fixed carbon. • Lower C and higher O content than coal ◊ lower heating value. • Low N, S, and Cl content. • Lower ash content than coal, with lower melting point and very aggressive in molten state. • Higher content in alkaline metals (Na, K) than coal. The high alkali contents in the feedstock, like sodium and potassium, cause slagging and fouling problems in gasification equipment, thus they must be low.
4. Optimal moisture content for gasification is: 10-15percent wt. The appropriate MSW moisture content is found to be lower than 20–25percent. (Dong et al., 2016).
5. High volatile content, low fixed carbon content, low ash content, and very low heavy metals content.

5.2.4 Optimal Operating Conditions Required by Pyrolysis

1. Pyrolysis is highly sensitive to the CV of the feedstock waste. (Dong et al., 2016)
2. The appropriate MSW moisture content for pyrolysis is lower than 20–25percent.
3. Heavy metals content is important. (Dong at al., 2016)
4. The typical temperature range for combustion and gasification is 800 to 1200 degrees; it is 350 to 600 degrees for pyrolysis. Emissions are also lower as nitrogen and sulphur oxides are created only at higher temperatures.
5. Moisture, volatile matter, fixed carbon, ash, elemental C, H, N, S, O, and higher heating value (HHV) data are all important parameters for pyrolysis (Reddy and Vinu, 2018; Lievens et al., 2009)

5.2.6 Optimal Operating Conditions Required by Refused Derived Fuel (RDF)

1. A calorific value of RDF of about 10 - 15 MJ/kg is desirable for economically sound operation (Mutz et al., 2017).
2. The moisture ranged from 15 to 25 percent, while another source mentioned 10-35 percent is acceptable for RDF.
3. The ash content is from 10 to 22 percent. Another source specified the range of ash content suitable for RDF o be 15-20 percent. (https://www.netl.doe.gov/Filepercent20Library/Research/Coal/energy percent20systems/gasification/gasifipedia/production-refuse-derived-fuel-chapter12.pdf accessed in January, 2018)
4. The reduction of moisture content increases the CV of waste and makes it a more profitable product. (Mutz et al, 2017).
5. pH ranges from 6.8-8.5.
6. TOC is 51 percent
7. Sulphur 0.06 percent
8. Total N is 1.6 percent
9. Heavy metals: Cr 100 mg/kg, Cu 300 mg/kg, Ni 40 mg/kg, Pb 200 mg/kg, Zn 500 mg/kg
10. The highest the OM percent fraction, the less thermal efficiency attained from RDF.

5.2.7 Parameter/ Technology Matrix

Accordingly, all the available properties limits that influence each technology were gathered in a matrix; hence, the parameter/ technology matrix was developed, which realized the first objective of this research as follows:

Table 5.1: The Parameter/Technology Matrix

Matrix	OHW Management Technology Options					
Parameter	Physical Conversion	Thermochemical Conversion			Biological Conversion	
	RDF	Combustion	Pyrolysis	Gasification	Anaerobic Digestion	Composting
Moisture percent	10- 35percent	<45percent (As minimum as possible)	<20- 25 percent	<10-15percent	70-90percent	34-85percent (55percent optimum)
C:N	30	NA*	20- 30	20- 30	16-30	20-40 (25-30 optimum)
pH	6.5-8.5	NA	6.5- 8.5	NA	6.4-8.5	5.5-8.5 (7-7.5 optimum)
OM percent (VS)	Low	>40percent	Low	Low	High	>30percent
COD	NA	NA	NA	NA	10,000-280,000 mg/kg	NA
BOD	NA	NA	NA	NA	Low	NA
BOD/COD	NA	NA	NA	NA	0.2-0.5	NA
Ash percent	15-20percent	<60percent	Low	Low	Low	High
Ammonia	NA	NA	NA	Low	<200mg/kg	NA
TAN	NA	NA	NA	Low	200-1700mg/kg	High >400mg/L
Cd	NA	Low	Low	Low	<150 mg/kg	0.7-1.5mg/kg
Cr	100mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/mg
Cu	300 mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/mg

Hg	Low	Low	Low		<150 mg/kg	0.5-1mg/kg
Ni	40 mg/kg	Low	Low	Low	<500 mg/kg	50-75mg/L
Pb	200 mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/kg
Zn	500 mg/kg	Low	Low	Low	<500 mg/kg	200-400mg/kg
VFA	NA	Low	Low	Low	500-3,000mg/kg	NA
Sulphur	0.06percent	Low	Low	Low	<50 mg/kg	5000 mg/kg (0.5percent)
Calorific Value (CV)	Minimum of 10 – 15 MJ/kg, Higher is better	> 8MJ/kg Higher is better	> 8 MJ/kg	> 8 MJ/kg	7-10 MJ/kg	7-10 MJ/kg
TOC	51 percent	>25percent	>25percent	>25percent	High	High
Total N	1.6percent	NA	Low	Low	Low	Low 1percent
Oil and Grease	NM**	NM	NM	NM	Low	Very Low

*NA means not applicable, or there is no reference that mentions this parameter in relation to the designated technology.

NM** means not mentioned in any reference in the literature review.

Since the parameter/technology matrix was developed from the literature review that accomplished the research study's first objective, the next section would present the empirical investigation results in order to match it with this matrix and select suitable technologies based on the waste characterization criteria.

5.3 Empirical Investigation Results of the OHW Characterization

As stated in Chapter 3, the empirical investigation was achieved by sampling from 14 residential blocks in the Muharraq Governorate representing the three income levels in the country: high income, mid income and low income areas. The sampling, followed by sending the samples to the lab for analysis during the course of three days to get their average, had to be comparable to the sample taken in Ramadan season. The full results of the OHW Characterization of Muharraq

Governorate are shown in table 5.2, which realizes the second objective of this research. (Appendix 2)

Table 5.2: Results of the Empirical Investigation for OHW Characterization of Muharraq Governorate Including the test Methods Used

PARAMETER	UNIT	DAY 1	DAY 2	DAY 3	AVERAGE	RAMADAN
pH (1:2.5 water extract)		4.8	5.1	4.5	4.8	4.7
Ash Content @ 750 C		5.50	5.40	3.50	4.80	1.40
Organic Matter @ 550 C		93.50	92.70	96.10	94.10	83.10
Oil & Grease		7.30	3.60	7.80	6.23	9.30
Total Phosphorous (P)	%	0.13	0.07	0.21	0.14	0.62
Sulphur		0.11	0.13	0.11	0.12	0.06
Moisture		76.70	66.20	74.80	72.57	73.50
Carbonate		0.60	0.90	0.60	0.70	0.60
Cadmium (CD)		<0.01	<0.01	<0.01	<0.01	<0.01
Chromium (Cr)		<0.01	<0.01	<0.01	<0.01	3.30
Lead (Pb)		<0.5	<0.5	<0.5	<0.5	<0.5
Copper (Cu)		15	17	17	16	5
Nickel (Ni)		4.60	1.60	3.30	3.17	2.80
Zinc (Zn)		89.00	113.0	104.0	102.0	26.0
Mercury (Hg)	mg/kg	<0.2	<0.2	<0.2	<0.2	<0.2
Total Organic Carbon (TOC)		45,720	64,480	45,520	51,907	43,760
Total Ammonial Nitrogen (TAN)		1,070	935	1,612	1,206	469
Total Nitrogen (N)		6,156	3,117	7,900	5,724	3,840
Ammonium Salts		1,380	1,206	2,079	1,555	605
Chemical Oxygen Demand (COD)		117,000	154,000	134,000	135,000	183,000
Biological Oxygen Demand (BOD)		29,250	38,500	34,840	34,197	29,280
C:N		7	21	6	9	11
Gross Calorific Value (HHV)	MJ/Kg	21.2	19.1	15.2	18.5	16.9
	KCal/Kg	5,062	4,560	3,638	4,420	4,206
Net Calorific Value (LHV)	MJ/Kg	19.1	17.2	13.7	16.7	15.2
	KCal/Kg	4,560	4,108	3,277	3,982	3,789

These results will be interpreted after matching them with the matrix developed in section 5.2, as well as the selection of the most suitable management technologies based on the OHW characteristics presented in the aforementioned table.

The parameters grouped according to the measuring unit used, as well as a comparison between the average of the normal days and Ramadan results is illustrated in the figures below:

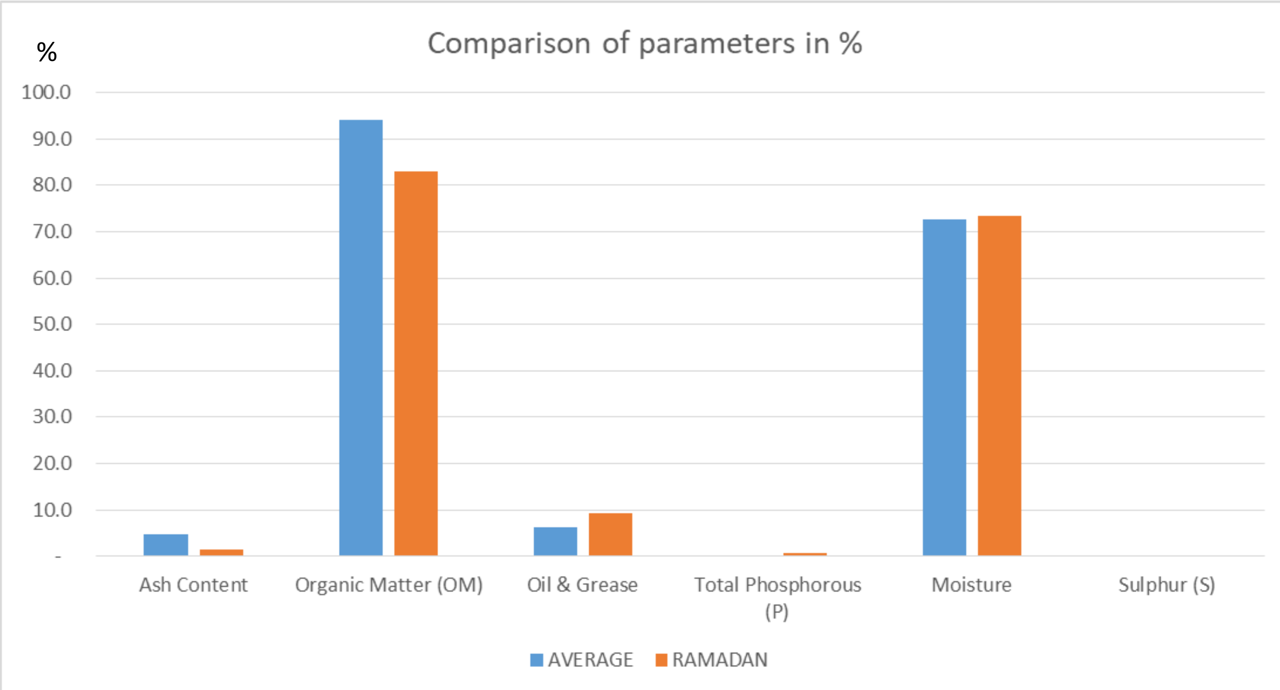

Figure 5.1: A Comparison between the Average of Normal Days and Ramadan for some Parameters using Percent unit

According to figure 5.1 above, it is obvious that in totality, the results do not exhibit a major difference between the two seasons, barring in organic matter that was higher in the normal days (94.1 percent) than Ramadan (83.1 percent), as well as the oil and grease, which is oppositely higher in Ramadan (9.3 percent) as compared to normal days (6.2 percent).

The consumption pattern of goods in Ramadan apart from the unique nature of fasting month in that people are consuming more oil in preparing traditional cuisines, and the lower consumption of fruits and vegetables in the form of salads or sweets, which is known to impact the organic household waste content, shows slight differences regarding the OM and oil and grease contents.

Figure 5.2 shows the comparison between the average of the normal days and Ramadan month regarding the parameters using the unit mg/kg:

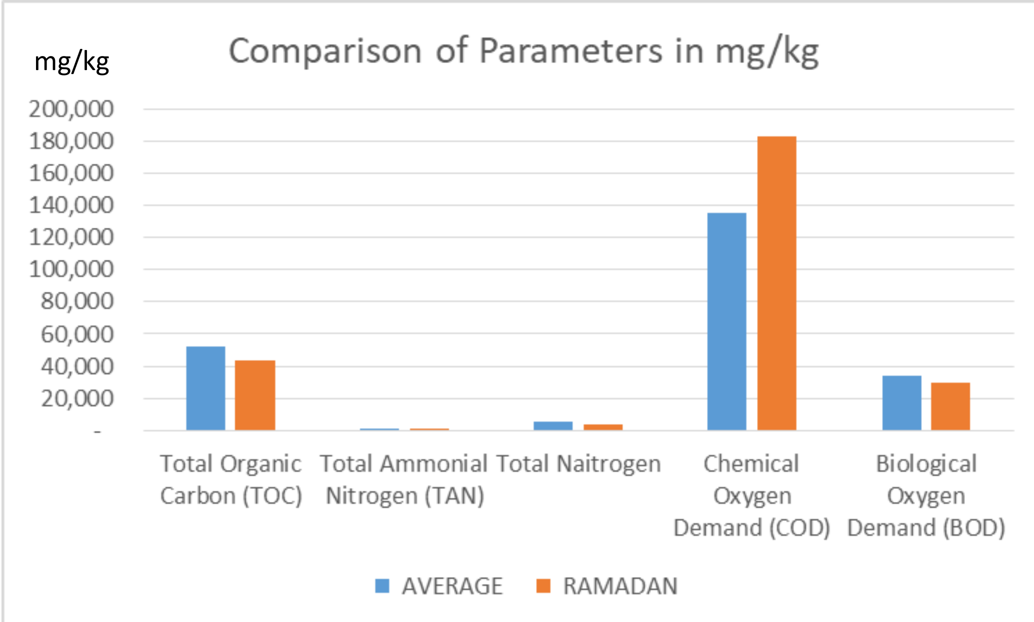

Figure 5.2: Comparison between the Average of the Normal Days and Ramadan regarding the Parameters in mg/kg

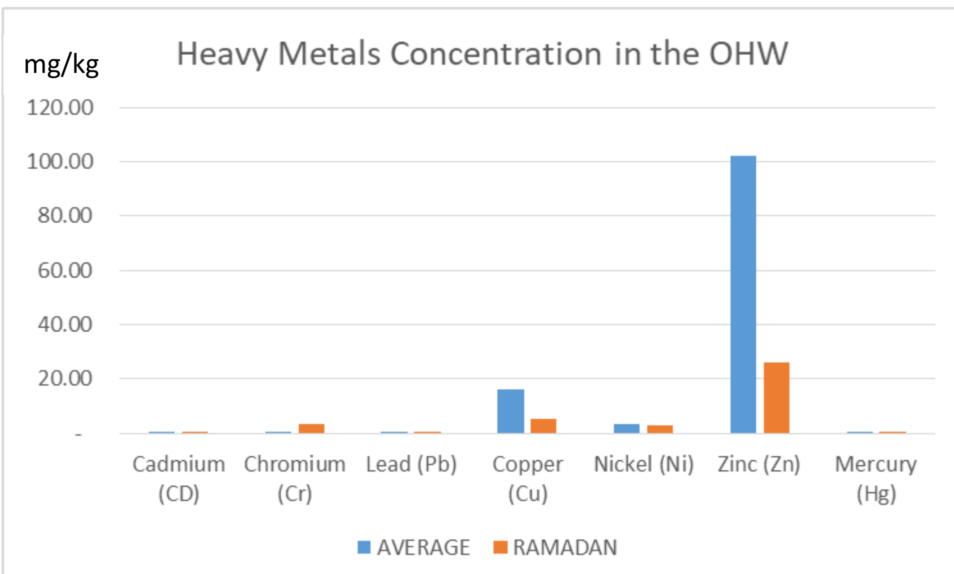

Figure 5.3: Comparison of Heavy Metals Concentration in the OHW in the Average of Normal Days and in Ramadan

As shown in figure 5.3 above, the heavy metals were all low and showed no differences, except for Copper (Cu) which was found to be higher in the normal days (16 mg/kg) as compared to Ramadan (5.3 mg/kg), and Zinc (Zn) which was 102 mg/kg compared to Ramadan (26 mg/kg). It was observed that there are higher heavy metals content (but still considered low and within the safe range according to EIA (2009). This can be justified again by the nature of the fasting month that is characterized by different consumption pattern in that the public trend goes toward purchasing more food and other groceries in Ramadan. However, since people are fasting, they follow different ways in preparing special food that focus on meat, chicken and vegetables, but no seafood during this season.

The TOC is higher during the normal days since people do not fast and consume lots of organic carbon sources throughout the day to produce waste with a high TOC. Nitrogen is higher in normal days for the same reason in that people are eating three times a day compared to just once in Ramadan, which will definitely reflect on the OHW composition and therefore, characteristics.

The COD is higher in Ramadan as compared to the normal days. Since Chemical Oxygen Demand or COD is a measurement of the oxygen required to oxidize soluble and particulate organic matter in water, Chemical Oxygen Demand is an important water quality parameter. Higher COD levels mean a greater amount of oxidizable organic material in the sample, which will then reduce dissolved oxygen (DO) levels. A reduction in DO can lead to anaerobic conditions. https://realtechwater.com/parameters/chemical-oxygen-demand/

More details will be illustrated after matching results and selecting the suitable technologies.

The following figure shows the calorific value in the two seasons:

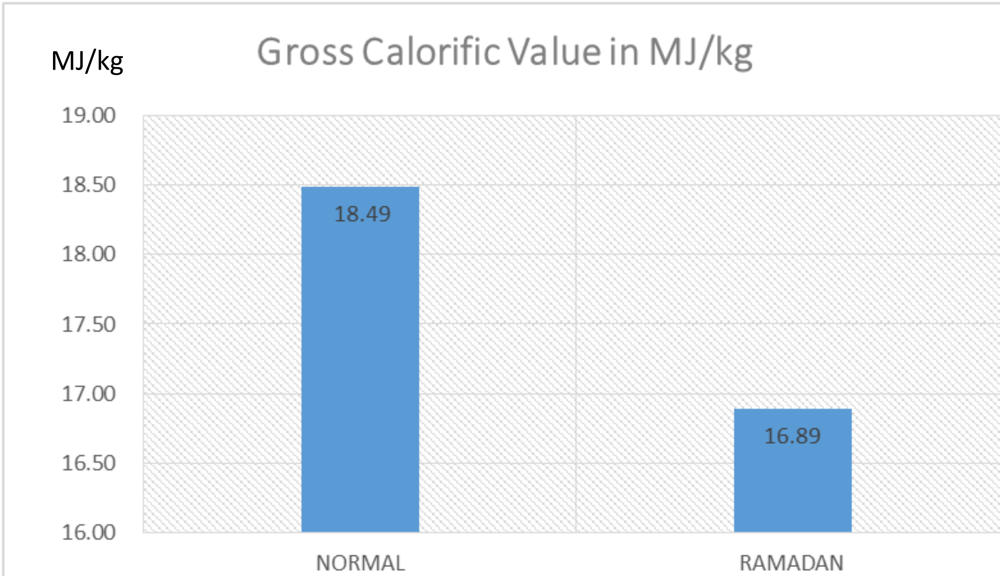

Figure 5.4: Comparison between the Normal Day's Average and Ramadan regarding the Gross Calorific Value (CV) in MJ/kg

The OHW of normal days is shown to have a higher gross calorific value than Ramadan; that is, it reached 18.5MJ/kg, which was slightly lower in Ramadan with a value of 16.9MJ/kg.

An overview of calorific value of selected fuels is listed in Table 5.3 below for making comparisons with our result. The table demonstrates that the OHW of Muharraq Governorate is comparable to the RDF in Germany:

Table 5.3: An Overview of Calorific Value of selected Fuels

Fuel	Calorific Value (MJ/kg)
Natural gas	36-50
Diesel	46
Black coal, various types	29-32.7
Lignite briquettes	21
Refuse derived fuel, in Germany	13-23
Wood	15
Crude lignite	10
Residual waste, unsorted, in Austria	8-12
Residual waste, unsorted, in China	3.5-5

Source: (World Energy Council, 2016)

The pH was measured during the two seasons, but the results don't show significant differences between the two seasons. The OHW was acidic (pH<7) in both seasons. The results are presented in figure 5.5 below:

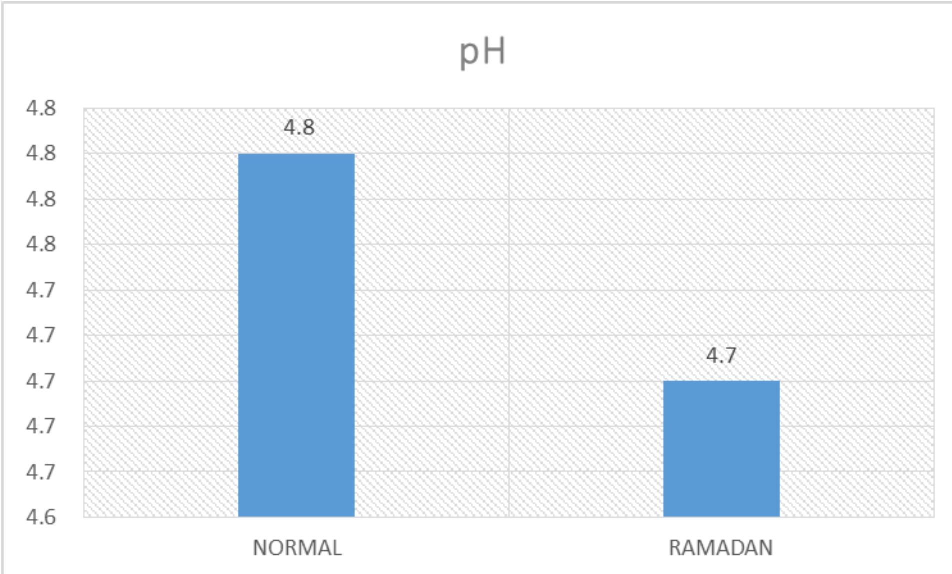

Figure 5.5: The pH result in the Normal Day's Average and in Ramadan

As an overall observation and conclusion for the comparison of the OHW characteristics between two seasons in Bahrain in Muharraq Governorate, no significant differences were found between the normal days and Ramadan season in terms of the OHW characterization, except very slight differences in some heavy metals content and OM, which is still not considered significant and will impact the selection of the most suitable technology selection based on the OHW characterization as evidenced in the next section.

5.4 The Selection of the Most Preferred Technology/ies by Matching

In the previous sections, the parameter/technology matrix was developed, and the empirical investigation results of the OHW characterization of Muharraq Governorate are found. Therefore, the remaining step to select the most preferred technology based on the OHW characterization criteria is to match the results with the developed matrix, which will be illustrated in the matching matrix below. This section accomplishes the third objective of this research study, which is to select and shortlist the preferred technologies as per the developed OHW parameter/technology matrix.

5.4.1 How to Use the OHW Technology Selection Matrix

For each of the twenty two parameters listed in the developed matrix above, the decision maker should assess their local OHW characteristics in accordance with the suitability of the six technologies. The potential suitability of the six technologies is illustrated by a different colour for each of the horizontally given OHW characteristic and parameter:

Green: The technology is most probably suitable

Yellow: Some pre-treatment of the OHW may be necessitated for successful planning and implementation of the technology.

Red: The technology is not suitable

Grey: the parameter is not applicable (NA) or not mentioned in the literature (NM)

The application of the matrix allows users to build a first assessment of OHWM technology options by examining the suitability of the OHW characteristics with regard to the technologies in order to use them in the near future. It gives an overview of the pre-treatment that requires fulfilment for the targeted OHW for adoption of each technology as a first step. This is followed by a comprehensive evaluation by exploring the economic feasibility of all the selected technology options, as well as by exploring the enablers and barriers to the adoption of each of the selected technologies in the Bahraini context, which will be shown in greater detail in the following chapters. Table 5.4 shows the OHWM technology selection matrix with the empirical results in both seasons. The selection was based on the normal average season readings since it is the most dominant season in the year and there was no significant difference between the two seasons.

Table 5.4: The OHWM Technology Selection Matrix

Matrix	OHW Management Technology Options						Empirical Results (Normal Average)
Parameter	Physical Conversion	Thermochemical Conversion			Biological Conversion		
	RDF	Incineration	Pyrolysis	Gasification	Anaerobic Digestion	Composting	
Moisture	10- 35 percent	<45 percent (As minimum as possible)	<20- 25 percent	<10-15 percent	70-90percent	34-85 percent (55percent optimum)	73 percent
C:N	30	20- 30	20- 30	20- 30	16-30	20-40 (25-35 Optimum)	9
pH	6.5- 8.5	6.5- 8.5	6.5- 8.5	6.5- 8.5	6.4- 8.5	5.5- 8.5 (7-7.5 optimum)	4.8
OM (VS)	Low	>40percent	>40percent	>40percent	High	>30percent	94 percent
COD	NA	NA	NA	NA	10,000-280,000 mg/kg	10,000-280,000 mg/kg	135,000 mg/kg
BOD	NA	NA	NA	NA	Low	Low	34,197 mg/kg
BOD/COD	NA	NA	NA	NA	0.2-0.5	0.2-0.5	0.25
Ash	<60 percent (10- 22 percent optimum)	<60percent	Low	Low	Low	High	4.8 percent
Ammonia	NA	NA	NA	NA	<200mg/kg	<200mg/kg	1,555 mg/kg
TAN	NA	NA	NA	NA	200-1700mg/kg	High >400mg/L	1,206 mg/kg
Cd	100 mg/kg	Low	Low	Low	<150 mg/kg	0.7-1.5mg/kg	<0.01 mg/kg
Cr	100 mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/mg	<0.01 mg/kg

Cu	300 mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/mg	16 mg/kg
Hg	200 mg/kg	Low	Low	Low	<150 mg/kg	0.5-1mg/kg	<0.2 mg/kg
Ni	40 mg/kg	Low	Low	Low	<500 mg/kg	50-75mg/L	3.17 mg/kg
Pb	200 mg/kg	Low	Low	Low	<150 mg/kg	100-150mg/kg	<0.5 mg/kg
Zn	500 mg/kg	Low	Low	Low	<500 mg/kg	200-400mg/kg	102 mg/kg
Sulphur	0.06percent	Low	Low	Low	<50 mg/kg	5000 mg/kg (0.5percent)	0.12 mg/kg
Calorific Value (CV)	Minimum of 10 – 15 MJ/kg, higher is better	> 8MJ/kg Higher is better	> 8 MJ/kg	> 8 MJ/kg	7-25 MJ/kg	7-10 MJ/kg	18.5 MJ/kg
TOC	51 percent	>25 percent	>25 percent	>25 percent	High	High	51,907 mg/kg
Total N	1.6 percent	Low	Low	Low	Low	Low	5,724 mg/kg
Oil and Grease	NM	NM	NM	NM	Low	Very Low	6.23 percent

5.4.2 Discussion of the Results

1. The OHW characterization shows that the pH is low (pH = 4.8), which is lower than that required by all the technology options; thus, a pre-treatment is required to adjust this parameter by increasing it to the level required by the desired technology. It was thus highlighted in yellow colour.

2. The results show that the moisture content is around 73 percent, due to the high content of the wet food waste. This percentage is considered very high for the thermochemical conversion technologies and RDF, which means that the pre-treatment of the OHW is required in the form of drying before using these technologies (shown in yellow), whereas it lies in the optimum range for the biological conversion technologies including AD and composting (shown in green)

3. The C:N ratio was found to be 9, which is considered very low for any technology. The low ratio is an indication of high nitrogen (N) content in the OHW, possibly due to the high consumption of meat products and the diet of Bahraini people which contains more meat sources than vegetables since the majority of the OHW was food waste. Thus, to treat this waste by any technology, a pre-treatment is required to increase the carbon content of the OHW before increasing the ratio to the suitable limit (shown in yellow in the matrix) e.g. by adding food processing residues, such as potato waste with a C:N ratio of 28:1, or crop residues, such as oat straw with a C:N ratio of 48:1.

4. The organic matter (OM) content is very high (94 percent) in the OHW, which makes it suitable to all technologies (shown in green) except RDF, which need a low OM percentage as per the the literature that the highest the OM fraction, the less thermal efficiency attained from RDF (shown in red).

5. The COD, BOD and the COD/BOD ratio are essential to only the bioconversion technologies and not applicable to others (shown in grey). These parameters were in the suitable range for both AD and composting (shown in green).

6. The ash content of the OHW found to be equal 4.8 percent, which is considered very low. This percentage is suitable for all the thermochemical conversion technologies in addition to the AD (shown in green). The RDF needs a specific range of ash content but it is still applicable, while composting requires a high ash content, which makes this percentage unsuitable to it (shown in red)

7. The ammonia content of the OHW was suitable for the bioconversion technologies (shown in green) and not applicable to the thermochemical conversion nor for RDF (shown in grey)

8. Similarly, the total ammonial nitrogen (TAN) was suitable for the bioconversion technologies (shown in green) without being applicable on the thermochemical conversion or for RDF (shown in grey)

9. All of the heavy metals including Cd, Cr, Cu, Hg, Ni, Pb and Zn are in very low concentration level, which is a good indication that the OHW can be treated by all of the technologies with no harmful effects in this regard (all shown in green).

10. Similarly, the sulphur content (S) is considered very low, thus all of the thermochemical conversion, RDF and biochemical conversion technologies are suitable for it (shown in green).

11. The Calorific Value (CV) is found to be high (18.5 MJ/kg), which makes it an excellent feedstock for the thermochemical conversion for energy recovery as well as for the RDF and AD (shown in green), whereas this value is considered higher than the suitable range shown in the literature for composting but still it will not affect the technology operation and can be considered applicable (shown in green).

12. Since the C:N ratio was a fraction of the total organic carbon (TOC) over the total nitrogen (N) and it was low, the TOC required by all technologies is higher than found; thus, pre-treatment is needed to adjust the carbon to the required limit (shown in yellow)

13. The total nitrogen is in the suitable range for all technologies (shown in green)

14. The oil and grease content of OHW was found to be low, which suits the bioconversion technologies (shown in green), while no accurate data was available regarding the thermochemical and RDF in terms of this parameter (shown as NM in grey).

Therefore, after assessing a total of twenty two parameters, we have an overview of the suitability of each of the technologies for the OHW characteristics. As an orientation, the number of red, yellow, green and grey fields for each technology were calculated and illustrated in table 5.5 below to be interpreted for the most preferred technology selection:

Table 5.5: The number of the coloured fields for each technology in the selection matrix

	RDF	Incineration	Pyrolysis	Gasification	AD	Composting
Green	11	12	12	12	19	18
Yellow	4	4	4	4	3	3
Red	1	0	0	0	0	1
Grey	6	6	6	6	0	0

From the table above, it can be seen that grey fields mean 'not applicable', which means that the mentioned parameter can be at any value regardless of how much it was, so they can be added to the green fields and increase the applicability of all OHW technology options as shown in table 5.6 below:

Table 5.6: The preference of the technologies based on the coloured fields

	RDF	Incineration	Pyrolysis	Gasification	AD	Composting
Green	17	18	18	18	19	18
Yellow	4	4	4	4	3	3
Red	1	0	0	0	0	1
Total	22	22	22	22	22	22

Based on table 5.5, it is clear that AD has the highest green fields, which reflects the high suitability of the OHW to this technology. Moreover, the yellow fields number is one of the lowest values among all, which reflects that the OHW needs a pre-treatment to adjust three parameters only (pH, TOC and therefore the C: N). Since the thermochemical conversion technologies have the same numbers of green fields that collectively represent the second highest after the AD (highlighted in green), the incineration, pyrolysis and gasification will occupy the second place in the list. Subsequently, the preference of the technology will be based on selecting a technology with less pre-treatment required (less yellow) which is composting which shares the same pre-treatment requirement as by AD - in this case to be in the third place, and then with one red field. RDF fall at the end of the list with the least green fields, one of the highest yellow fields (more pre-treatment required), as well as one unsuitable parameters, which cannot be fixed with pre-treatment (requires low OM percent to ensure high efficiency).

Since the AD had the highest green fields and lowest yellow ones, it will discussed in greater details with regard to the pre-treatment of OHW that might be needed to adopt the technology in Bahrain. Referring to the literature, Tanimu et al. (2014) argued that food waste mixture at low carbon to nitrogen (C/N) ratio (e.g. 17) needed to combine with fruits and vegetable wastes in order to increase its C/N ratio to 26 and 30 before anaerobic digestion (AD).

In order to recognize the effect of the C:N on the biogas yield in AD, Zhang et al. (2017) showed that biogas methane yield obtained during the digestion increased from 0.352L/g VS to a maximum yield of 0.679 L/g VS at C/N ratio of 17 and 30, respectively. A maximum food waste treatment efficiency of 85 percent was obtained at C/N ratio 30. Generally, an increase in C/N ratio through co-digestion resulted in a more stable pH and better methanogenic activity in the wake of enhanced buffering effect of the digestion medium.

In addition, Zhang et al. (2017) claimed that one of the methods used by researchers to avoid excessive production of ammonia during AD is to increase the C/N ratio of feedstock. This can be done by co-digesting with other waste feedstock that is high in biodegradable carbon to improve the performance of AD. Co-digestion of chicken waste or cattle slurry with fruits and vegetable wastes is another example of improving the C/N ratio, which obtained a yield improvement of over 60 percent when fish waste was co-digested with sisal pulp. The benefits of increasing C/N ratio through co-digestion with complementary feedstock include: higher biogas yield and feed loading rate along with a reduction of potentially toxic ammonia concentration. The purpose of this batch AD study was to investigate the effect of increasing the C/N ratio of the available food waste (C/N=17) through co-digestion with meat, fruits and vegetable wastes. (Zhang et al., 2017)

Moreover, food waste (FW) is an attractive feedstock for AD because of its high methane production potential. Other potential waste that locally would be suitable for AD are sewage and crops. However, AD of FW often entails some drawbacks e.g. a suboptimal carbon to nitrogen (C/N) ratio, lack of certain nutrients and a low pH. In order to overcome the deficiencies of mono-digestion, anaerobic co-digestion - the simultaneous AD of FW with other organic wastes, was developed so as to improve the operational stability and economic viability of AD plants. A common example is to co-digest FW with animal manure since co-digestion not only provides a robust buffering capacity to the AD systems; the nutrient profile is also favourably altered. On the basis of total solids (TS) content, AD can be categorized into wet AD (TS < 15 percent) and high-solids AD (15 percent < TS < 40 percent). High solids AD are preferable for reactor design by leading to a much smaller requirement for reactor volume. However, the higher moisture content of wet AD promotes the growth of methanogens and enhances mass transfer between substrate particles and microorganisms during methanogenesis (Zhang et al., 2017).

Referring back to the investigation results, the moisture content of OHW is 73 percent. This indicates that OHW has sufficient moisture content for anaerobic digestion. The OM percent content is 94 percent, which indicates that OHW is rich in organic solid content and can be converted into biogas during anaerobic digestion. The carbon to nitrogen (C/N) ratio of the initial OHW was about 9-11.

During anaerobic digestion, it was found that the microbial population makes use of about 25 to 30 times carbon faster than nitrogen. Therefore, waste material, which is high in easily biodegradable carbon, can be mixed with waste material low in nitrogen or vice versa in order to attain the desired carbon to nitrogen ratio (C/N) of 30. Substrate with low C/N ratio may lead to the production of high amount of total ammonia nitrogen (TAN) and volatile fatty acids (VFAs). These important intermediate products are produced during the anaerobic digestion. Gradual accumulation of these intermediates could result in the absolute failure of the anaerobic digestion (AD) process (Tanimu et al, 2014).

Meanwhile an official consultant in Bahrain initially did not recommend AD to be included in the long-list of waste treatment options in the country due to the high cost and complexity as well as it is considered a new technology for the region and not yet tested in the GCC countries.. However, as it is an increasingly popular technology that is able to produce “green power”, it has been included. Notably, AD is suitable for the treatment of food waste only, and Bahrain does not separate food waste. It may be possible to investigate co-treatment of sewage sludge and food waste to increase C:N ratio, but as sewage sludge is not managed currently at Askar Landfill, this aspect is not considered further in this report.

An essential step is required to enable AD adoption, which is the source segregation of waste to improve biogas production (Asian Development Bank, 2011); this will be discussed in greater detail in Chapter 7. Grinding of waste might be needed as a pre-treatment. High moisture was found to be suitable. High Calorific value 7-25 MJ/kg is suitable for AD (18.5MJ/kg in our case). Carbon deficiency (low C:N ratio) can be fixed by adding wood chips, dry leaves, or sawdust. Meanwhile the biodegradable COD concentration is approximately 238,000 kg/m3 (Baawain et al., 2017). The COD values were classified as young (>10,000 mg/L), according to Foo and Hameed (2009).

A study held by Sun et al. (2015) explored the impact of high moisture on the thermochemical conversion technologies, especially the incineration. They stated that due to the high moisture content of the feedstock, moisture evaporation consumes a vast amount of heat, and evaporation takes up most of the combustion time (about 2/3 of the whole combustion process). They added that the entire bed combustion process reduces greatly with an increase in MSW moisture content. Thus, it is necessary to dry the feedstock prior to incineration or any thermochemical process in order to increase the efficiency and save energy as well as cost.

Moreover, the BOD/COD ratio reflects the degree of biodegradation in the landfill and gives important information about the age of a landfill. The lower the BOD/COD ratio (less than 0.2) - the higher the concentration of non-biodegradable organic compounds. This causes difficulty in biological degradation (Žarković et al., 2011). The BOD/COD ratios ranged from 0.4 to 0.5, and hence, the landfill leachates are young (Foo and Hameed, 2009).

In Muharraq OHW, the BOD/COD ratio is 0.25, so we can say that it lies within the range of the presence of biodegradation of organic waste.

Characterization of substrates used for anaerobic digestion was studied by Awe et al. (2017). Food waste was collected from the student's restaurants, China Agricultural University, and characterized for some parameters similar to our study as a comparison; the results were as follows:

Table 5.7: Characterization of substrates used for anaerobic digestion in China study

	(FW)
Ph	5.85
TS (%)	14.3
VS (%)	13.1
%VS (of TS)	91.90
Ash content (%)	8.01
NH_4^+-N (mg/L)	166
TCOD (mg/L)	154,250
CODs (mg/L)	39,083
SCOD/TCOD	0.25
C (%)	51.12
N (%)	2.74
O (%)	30.41
H (%)	7.2
S (%)	0.52
C/N	18.68
Carbohydrate (g-glucose/L)	26.51
Lipids (g/L)	51.1

Regarding composting as an option, a study found that composting of chicken litter (with an initial C/N ratio of 14-15) without the addition of bulking agents can lead to N losses of as much as 58 percent of the initial N (Fuchs and Cuijpers, 2016).

Furthermore, a low protein diet will result in lower total N contents of the manure, and higher amounts of organic N. Not all OW are suitable for AD, wood and lignocellulosic containing which are not suitable for AD, but for composting and combustion with energy recovery. The best practice for AD digestible materials is Separation at Source.

However, the energy content of organic feedstock for an anaerobic digester does have an impact on the energy content of the biogas yield. Higher energy content feedstock can increase the quality of the biogas (Mutz et al., 2017).

As a comparison, AD is considered more environmentally friendly than composting, besides the suitability of materials and feasibility of technology. (Al Seadi et al., 2013)

Similar to AD, source segregation program can improve the quality of composting end product. In case source segregation is not done properly, it is recommended to use vegetable market waste and wet organic waste from hotels and restaurants (West Asian Bank, 2011). Low heavy metal is required and high moisture is suitable, which are all available in the OHW of Muharraq Governorate. Calorific value 7-10 MJ/kg- 800-1000kcal/kg is suitable, but the results show that higher CV may affect the composting process. Moreover, carbon deficiency (low C:N ratio) can be fixed by adding wood chips, dry leaves, or sawdust.

In order to facilitate the waste segregation, Baawain et al. (2017) argued that the use of color-coded containers for designated waste types must be advertised to promote recycling behaviours. Furthermore, he claimed that owing to the high percentage of organic materials, (>43 percent) the MSWs of Muscat is found to be suitable for compost production. Thus, in addition to recycling, composting can be used as one of the solutions to bring down the amount of disposing.

Iqbal et al. (2010) highlighted the chemical properties of food waste used for composting as follows:

Table 5.8: Chemical properties of food waste used for composting

Chemical properties of food wastes used for composting

Parameters	*Concentration*
pH	7.53
C:N	35.74
Potassium (%)	0.2
Phosphate (%)	0.12
Moisture (%)	78 -84

Since the LCV of 1 kg fuel oil is about 40 MJ/kg, it was agreed that the LCV of unsorted MSW is often below this threshold in developing countries due to a dominant organic content with high moisture in addition to a significant level of inert waste fractions such as ash, or sand in our case.

The results of Oman MSW characterization by (Baauwain et al., 2017) showed the total energy content of MSW in Oman is 15.2 MJ/kg to 23.7 MJ/kg. In comparison, the total energy content in Muharraq OHW is 18.5 MJ/kg, which falls in the range of Oman waste energy content.

The high CV in Muharraq Governorates OHW is attributed to the fact that samples consist of some kitchen paper wastes, paper tissues, food wastes, some yard wastes and plastics that represent the OHW composition.

Komilis et al. (2014) concluded that, substrates with moisture content up to 60 percent wb can maintain self-sustained combustion as long as their organic matter contents are greater than 40 percent wb (or 75 percent db).

Since Muharraq OHW has a high moisture content and a high calorific value in addition to high OM content, combustion seems to be a suitable option for this kind of waste after being pre-treated by drying e.g. solar drying (which may have no cost but still needs a large amount of space); this option can be included to the suggested OHW management technology options list.

Moreover, the theoretically calculated calorific value of the OFMSW is 6021 kcal/kg, which is higher when compared to our results which show that the gross CV of the OHW equals 4420 KJ/kg, thereby making it a good option for energy recovery by thermochemical conversion technologies in general.

It was argued that food wastes had the highest S content among all materials. Meat, in particular, had the highest S content (0.79 percent). In Muharraq, S content was 0.1 percent (very low and safe for incineration with very low SOx emissions expected)

In a comparable study held in Australia by Robert and Hla (2015), moisture content was reported to have a significant role: energy content of food waste was found to be reasonably high on a dry basis but was very low when moisture content was included in reporting lower heating values. A similar relationship was observed for garden wastes owing to their high moisture content. The energy content of plastics categories are found to be the highest due to their high carbon and hydrogen content, low ash content, and low moisture content. Higher heating value for paper categories was found to be the lowest owing to their low carbon content and high ash content. The energy content (LHV) of the entire MSW sample used in the Australian study was 7.9 MJ/kg. This is relatively high when compared with LHV of typical MSW from a range of different countries, e.g. 6 MJ/kg [Taiwan, (Chang et al., 2007)], 4.8 MJ/kg [India, (Kumar and Goel, 2009)], 2.85–6.71 MJ/kg [China, (Liu et al., 2006)] and [Algeria, 4.3 MJ/kg (Guermoud et al., 2009)]. It is also above the World Bank-recommended value (Rand et al., 2000), which opines that the LHV of MSW should be on average of 7 MJ/kg, and never go down below 6 MJ/kg for use in thermochemical conversion processes. However, it is found to be lower when compared with the average lower heating values of MSW reported from Japan (8.2–9.0 MJ/kg, (Tsukahara, 2012), Korea (8.16–11.92 MJ/kg, (Ryu and Shin, 2013), UK (9.22 MJ/kg, (Parfitt and Bridgwater, 2008) and USA (9.2 ± 0.96 MJ/kg, (Chin and Franconeri, 1980 cited in (Robert and Hla, 2015). In Muharraq Governorate, the LHV of the OHW is found to be 16.7 MJ/kg, which is higher than all of above countries.

Furthermore, Shi et al., (2015) pointed out that the average LHV of residential and at the City of Red Deer were 26.27 MJ/ kg. According to the reported data (The City of Red Deer Website, 2013), the City of Red Deer’s population stood at 97,109 in the 2013 census, and its average generation rate of residential MSW was 180 kg/cap/yr. Thus, the annual amount of residential MSW generated was about 17,479,620 kg. While Muharraq population was 298,517 in 2017 and the average generation rate of MSW is 1.494 tonne/capita/year, and the annual amount of MSW generated was 445,859 tonne/year.

According to Baawain et al, (2017), a “waste-to-energy” program was recommended due to the high-energy content of the MSWs (>15,000 kJ/kg) in Muscat city, which is consistent with our results. Therefore, incineration with heat recovery is considered to be the best economical method of waste management compared to plain incineration and landfill (similarly, in Bahrain, landfill needs a large area). Incineration saves a lot of money on transport of waste to landfills and also lowers carbon emissions released during the transportation process apart from reducing the waste volume. Moreover, designing of incinerators is being constantly evolved to increase efficiencies and reduce dioxin production. (Baawain et al., 2017)

Moreover, an official consultant in Bahrain recommended Incineration for inclusion in the long-list for a number of waste streams.

Dong et al. (2016) argued that gasification is more sensitive to feedstock CV than incineration due to the requirement to produce a homogenous syngas. This leads to producing lower net efficiency/higher parasitic loads with wetter and lower CV material. For this reason, gasification usually requires pre-treatment, for example through a dirty MRF.

In addition, Kumar et al., (2009) stated that although combustion of biomass is the most direct and technically easiest process, the overall efficacy of generating heat from biomass energy is low. Gasification offers a number of advantages over combustion. It can use low-value feedstock and convert them not only into electricity, but also into transportation fuels. In the foreseeable future, it will serve as a major technology component for complementing the energy needs of the world. Use of advanced technologies like fuel cells and gas turbines with the syngas generated from gasification leads to increased efficiency.

Kumar et al., (2009) added that biomass also has low sulphur content, which results in lower SOx emission. However, the high alkali contents in biomass, such as sodium and potassium, cause slagging and fouling problems in gasification equipment. Thus, drying is needed to obtain a desired range of water content for the gasification processes. Drying is an energy intensive process which may decrease the overall energy efficiency of the process.

Biomass gasification is a promising technology to displace the use of fossil fuels and reduce CO_2 emission. Among other alternative energy conversion pathways, it is advantageous owing to its flexibility to use a wide range of feedstock, as well as to produce energy and a wide range of fuels and chemicals. (Kumar et al., 2009)

The pyrolysis process is highly complex (Lievens et al., 2009). Combustion, pyrolysis and gasification have many similarities and the manufactured products can be the same, but in a different ratio. When choosing the most suitable mechanism for energy production, the desired final products and end uses must be considered. For example, if the end use is for transportation fuels, power and heat or electricity generation. And whether the desired final product is gas, char, oils or only heat, is to be considered. (Siirala, 2013)

Pyrolysis is highly sensitive to the CV of the feedstock waste, which is why pre-treatment would definitely be required with a known feedstock.

According to the official consultant working for the Bahrain government, *"pyrolysis is not recommended for inclusion in the long-list as the scale is too small for the tonnages required for Bahrain and pyrolysis is not yet proven for mixed waste streams."*

Mutz et al., (2017) stated that pyrolysis is not recommended for either mixed municipal waste, or for an environment wherein robust and proven technologies are needed. Pyrolysis or gasification cannot be considered easy to handle stand-alone technologies but need to be a component of the overall waste management system. Operation requires good understanding of the composition of incoming waste and process knowledge. According to past experiences, trouble free operation of a pyrolysis plant requires highly skilled technicians. It must be assumed that environmental legislation does not deal with the application of pyrolysis and gasification in most developing countries as combustion (or WtE) technology. This renders the entire process of impact assessment and operation licensing quite complicated and time consuming (Mutz et al., 2017). These barriers to technologies adoption will be explored via a survey (using a semi-structured interview with experts) in Chapter 7.

Furthermore, since the calorific values > 8 MJ/kg, it is indicative of the fact that all thermal technologies are suitable options for WtE projects. (Mutz et al, 2017)

In terms of the RDF, the reduced moisture content increases the CV of the waste and makes it more profitable. The production of electricity from the combustion of the RDF can lead to approximately 25-30 percent of the energy embodied within the RDF being converted into electricity, and a quantity of ash being produced, which will be approximately 15 percent of the waste that necessitates further treatment or disposal (Johary et al., 2014 and Mutz et al., 2017).

A calorific value of RDF of about 10 - 15 MJ/kg is known to be suitable for economically sound operation (Mutz et al., 2017).

The main findings of the parameter results were highlighted and discussed based on the above literature. As a conclusion of this section, it appears that the most suitable technologies premised on Bahraini OHW represented by Muharraq Governorate are listed on the basis of most suitable without pretreatment and suitable with pretreatment as follows:

1. Anaerobic Digestion (AD)
2. Thermochemical conversion technologies:
    a. Incineration
    b. Gasification
    c. Pyrolysis
3. Composting
4. RDF

Since all of the above technologies are applicable in some ways, it is important to consider the economic criteria to select the most preferred technology for Muharraq Governorate. The economic criteria conducted in the form of an economic cost-benefit analysis for each technology endeavours to explore the economic feasibility of each technology option so as to assess the technology options and refine the selection. The cost-benefit analysis of all of the listed technologies is found in Chapter 6.

Three of six objectives of this research were accomplished at the end of this chapter, whereas the remaining three related to economic feasibility, exploring enablers and barriers to technologies adoption and measuring public awareness will be covered in Chapters 7, 8 and 9, respectively.

CHAPTER 6: Economic Feasibility Study: Cost- Benefit Analysis

6.1 Overview:

This chapter emphasizes the economic criteria that were followed to assess the feasibility of OHW management technology options in the Muharraq Governorate, after the primary selection of the applicable technologies based on the waste characterization technical criteria. In this chapter, the economic criteria represented by the cost-benefit analysis (CBA) were applied to each of the following technologies: Anaerobic Digestion (AD), Incineration, Gasification, Pyrolysis, Composting, and Refused Derived Fuel (RDF). This chapter will realise the fourth objective: *"To assess the economic feasibility of the selected technologies using cost-benefit analysis*." The cost-benefit analysis (CBA) is part of the quantitative approach used in this study and considered to be an approved decision-making tool used to *"choose between alternative solutions in a way that the chosen alternative is the most cost-effective within the context of budgetary and political considerations"* according to http://www.urenio.org/newventuretools/cba/ as described previously in chapter 3. Furthermore, the goal of this study is to deliver support for decision-making on the investment in Bahrain's OHW management technology.

6.2 Current Cost of the MSWM Service in Bahrain

In order to conduct a CBA of all the OHWM technological options, it is first necessary to highlight the current status and cost of the MSWM service sector in Bahrain, which is considered the baseline case. After applying each project case, it is also important to consider other cost and benefits accompanying each technology; the comparison between them will inform whether or not the technology is feasible.

According to the MWMUP, 2018, the municipal solid waste management service sector currently spends about 17 million BHD (45.05 million USD) per annum on MSWM; however, they get nothing in return. Each proposed technology will be useful as instead of spending money, they will get the revenue back in the form of useful energy as electricity, digestate (fertilizer), oil and ash, and compost as both marketable and profitable end products.

Table 6.1 shows the total annual budget of 45.05 million USD allocated for the MSWM as overall cost with no return. This cost includes the cost of labour, containers, and offices, overhead and total annual gate fees, as well as the total dumping cost, which includes the collection, transportation, and cleaning cost. The benefits obtained by stopping the dumping of organic household waste (OHW) by discontinuing the OHW dumping will encompass the saving of dumping cost and gate fees that touches 32.3 million USD as direct saving, representing 71.8 percent of the total annual cost. It is assumed that the rest 12.65 USD is an allocated fixed cost of labour, containers and segregation activities required by the ministry in order to cooperate in implementing the OHW technology projects.

Table 6.1: Current MSWM Cost in Bahrain

Description	Millions (BHD)	Millions (USD)
Overall Cost / Year	17	45.05
Labour		
Containers		
Offices		
Overhead		
Dumping cost / Year		
Gate fees		

Description	Millions (BHD)	Millions (USD)
Dumping / Year	**11.0**	**29.2**
Gate fees	**1.2**	**3.2**
Total Dumping Cost	**12.2**	**32.3**

The dumping cost is of the total Bahraini MSW to the landfill which is 2,026,631 tonne/year; this means that the cost of dumping each tonne of MSW in Bahrain is 15.94 USD. The MSW includes 434,915 tonne/year total Bahraini OHW in which 61,529 tonne/year is from Muharraq Governorate. Therefore, the cost of Muharraq OHW dumping was calculated based on the total cost and found to be equal to 981,539 USD/year. This cost will be considered in this research under scenario 2 per technology as a direct saving option of stopping the dumping of Muharraq OHW by implementing any technology option in, in addition to each technology benefits. The description of the costs stated above is illustrated in Table 6.2.

Table 6.2: Description of Dumping Cost for Bahrain and Muharraq Governorate

Description	Ton / Yr
Total Bahrain MSW to landfill	2,026,631
% From total Bahrain OHW from Dumping Cost	11.9%
Total Bahrain OHW from Dumping Cost (Million USD)	3.844
% From Muharraq OHW From Dumping Cost	3.0%
Muharraq OHW From Dumping Cost (Million USD)	0.982

6.3 Financial Aspect of OHWM Technologies Projects

Waste management technologies projects require high investments for the treatment process as well as for the mitigation of operational risks. Operation and maintenance (O&M) costs for waste management plants are known to be higher than for sanitary landfills, especially the waste-to-energy technologies. Moreover, the key for any functioning MSWM system is the availability of a secure and permanent financing. Thus, the municipality needs to ensure that financial requirements can be met (Mutz et al., 2017).

In order to obtain the total cost of the six different OHW technologies considered in this research, communication was established with the technologies' suppliers companies represented by their project managers and economic experts who are directly involved in the establishment of these projects regionally and worldwide, and have wide-ranging experience about the expenditure of each technology. The names of these suppliers and contractors were kept anonymous as per their request. The literature (Mutz et al. 2017) was also used to estimate the capital cost, and O & M cost per ton of waste for WtE technologies. On the other hand, the estimation of sales, which represent the benefit of each technology based on the international market prices of the end products were provided by the project manager of these technologies. According to Stein and Tobiasen (2004), a project is considered small-scale if the capacity is typically less than 50,000 tonne/year. Since the capacity of Muharraq OHW is 61,529 tonne/year, the proposed projects considered for the CBA in this chapter pertain to mid-scale.

6.4 Cost-Benefit Analysis (CBA)

In order to commence the CBA for each technology, the considered project life time in this research is 15 years. Data of the technologies in this section is based on the cost estimated from waste management technologies plants in developing countries ($/tonne) in Germany (Mutz et al., 2017). Further Investigations done by the researcher through communications with experts of supplier companies in the industrial sector. Each technology has a fixed direct cost (capital cost), which includes the cost of: Consultant Fees, Environmental and Social Impact Assessment (ESIA) and Permits, Equipment, Engineering Design and Building. This cost is paid at the first year of the project. Next, the indirect costs that need monthly payment (Operation and Maintenance cost) include: Land Lease Agreement, Loan Repayments, Electricity, Water, Labour of Maintenance, Insurance, Labour of Operations and Transportation. The benefit of each technology is realized through two different ways: by sales estimated depending on the type of technology and product market price; and through the savings realized by stopping the dumping in the landfill, as mentioned previously. It is important to mention that this section conduct the CBA of each technology in two scenarios. Scenario one is the CBA without considering the benefits earned from the discontinuing of the dumping of waste in the landfill which is expressed by the current cost spent in the waste collection and dumping activities, while the second scenario takes into consideration the benefit earned from discontinuing of the dumping activity (Appendix 3). Hochman et al. (2015) evaluated four available waste treatment technologies: direct combustion, landfilling, composting, and anaerobic digestion in New Jersey- USA using the CBA method. Since the economic criterion is a priority worldwide among governments, this research took the economic feasibility into consideration as the second main criteria for technology selection. Furthermore, Moutavtchi et al. (2008) showed that CBA is useful for decision making in MSW management because it can be utilized as an efficient tool for information support for implementation of waste management technologies.

Therefore, the CBA of OHWM technologies for Muharraq Governorate are presented below:

6.4.1 Anaerobic Digestion (AD)

Anaerobic digestion is a biochemical processes that produces clean energy in the form of biogas. It is considered to be a natural biological process which biochemically degrades the organic waste in a controlled, oxygen-free environment, resulting in the production of bio fuels; it is a reliable technology for the treatment of wet, organic waste. Thus, it is necessary to predict the biogas yield and to perform cost analysis in order to investigate whether the waste conversion into biogas and digestate is financially feasible (Khan and Kaneesamkandi, 2013). Biogas is a mixture of different gases that can be converted into thermal and/or electrical energy. The flammable gas methane (CH_4) is the main energy carrier in biogas and its content ranges between 50 – 75 percent, depending on feedstock and operational conditions. The heating value of biogas is about two thirds that of natural gas (5.5 to 7.5 KWh/m^3) in the wake of its lower methane content (Mutz et al., 2017).

In a comparable study held in the Kingdom of Saudi Arabia (KSA) by Khan and Kaneesamkandi (2013), biogas yield of an average value of 450 m^3/tonne organic waste was approved based on experimental based literature. For this reason, the approximate biogas yield from organic waste generated in the KSA found to be 3420.50 million m^3 per annum (Table 6.3), from which one tonne OW can generate about 398 KWh. However, the Official Information Portal on Anaerobic Digestion in the UK (http://www.biogas-info.co.uk/about/faqs/) outlined that digesting 1 tonne of food waste can generate about 300 KWh of energy, considering the electricity cost by EWA of 0.02 USD/KWh. Since the KSA is a Gulf country and shares many similarities with Bahrain in terms of lifestyle, culture, etc., the value considered to estimate the electricity generated from the biogas yield is 398 KWh/tonne OW and therefore, was used as a reference in this study, as illustrated in Table 6.3, which outlines the comparison and benefit from electricity sales in USD:

Table 6.3: Biogas yield and electricity sales estimation for Bahrain and Muharraq OHW based on Saudi study by Khan and Kaneesamkandi, 2013

Description	ton / year	Biogas Yield m^3	Biogas m^3/ton	KWh/ton	Total Energy Output (KWh)	Electricity Cost USD/KWh (Domestic)	Benefit $
Saudi OW	7,600,000	3,420,000,000	450	398.5	3,028,812,800	0.03	179,911,480
Total Bahrain OHW	240,966	108,434,700	450	398.5	96,031,698	0.02	2,544,840
Muharraq OHW	61,529	27,687,844	450	398.5	24,520,847	0.02	649,802

From the above table, it is obvious that the AD Plant is expected to generate 24.5 GWh/year, with annual revenues of $649,802 from electricity sales. Note that the total OHW in Bahrain is 74 percent of the HW which is 434,915 tonne/year, including: paper and cardboard, plastic film and other plastics, food waste and other organics. Food waste and other organics were only considered for biogas yield estimation since plastics are not suitable for AD. Thus the total Bahraini OHW that consists of food waste and other organics are 240,966 tonne/year, as shown in the table above, excluding plastics. However, most of the food waste and other organics in Muharraq OHW reached 61,529 tonne/year; therefore, the following table presents the total cost and benefit of a mid-scale AD plant of a capacity that can accommodate the entire OHW produced by Muharraq Governorate annually (Capacity = 70,000 tons/year) .

Cost estimates of an anaerobic digestion plant in developing countries was mentioned by Mutz et al (2017) who showed that the capital cost of AD is 18$/ton in average. While he stated that the O & M cost is 14.5$/ton. Accordingly, the total Capital cost and the total O & M cost were calculated based on these prices for an AD of 70,000 ton/year Capacity for Muharraq Governorate and shown in the CBA of an AD Plant Table below.

Anaerobic Digestion Community Website claimed that the AD plant is designed for treating the organic fraction of source-segregated MSW and not mixed waste. Thus, source-segregation practice is essential in order to succeed the operation of the AD plant.

Mutz et al. (2017) argued that the revenues of AD depend largely on the quality of the feedstock. He added that contamination with inorganic substances increases separating costs and diminishes the potential benefits derived from process residues, which could be used as fertilizer in agriculture. Furthermore, Mutz et al. (2017) claimed that the direct use of biogas requires minimum additional investments in that biogas can be upgraded to bio-methane, or converted to heat and power with further investments (Mutz et al., 2017).

In terms of benefits, it was estimated that the produced biogas from Muharraq OHW will lead to electrcity generation of 24.5 GWh which worth 649,802$ which will be earned annually (Table 6.4). Perez Garcia (2014) highlighted that the cost of fertilizer produced by the AD was estimated to be 140 USD/tonne. This cost can be considered as one scenario (scenario 1.1) to calculate the CBA considering market existence, as well as a high cost of fertiliser. While in reality, the current known cost of the fertiliser does not exceed 6 USD/ton in the market according to experts. This can be re-calculated in a second scenario (scenario 1.2) for AD to calculate CBA. It was found from the literature that 1 tonne of organic waste results in 0.2 tonne of fertilizer by AD. Based on this factor, estimation was held to calculate the total fertilizer produced from 61,529 tonne/year OHW. Therefore, the estimated amount of fertilizer that can be produced by AD of Muharraq OHW was around 12,306 tonne/year. Table 6.4 represents the full CBA of AD for Muharraq Governorate under its first scenario considering the high cost of the fertiliser (140 USD/ton):

Table 6.4: The Cost-Benefit Analysis (Scenario 1.1) of AD Plant for Muharraq Governorate Considering High Market Cost of Fertiliser (140 USD/ton)

Anaerobic Digestion (AD) Scenario 1.1	
Description	**USD**
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	**1,260,000**
Total O&M Cost/Year	**1,015,000**
Benefit/year	
Electricity	**649,802**
Fertiliser	**1,722,840**
Total Benefit/year	**2,372,642**
Net Profit / Year	**1,357,642**

Based on the table above, the capital cost is a fixed cost which is paid during the first year of the project, whereas the operation and maintenance cost (O&M cost) represents the cash out flow, which is the annual cost considered in calculating the net profit. The benefit is expressed as sales revenues from the digestate that can then be used as fertilizer to enhance the soil in agriculture. Since the net profit number is positive and is high, it can be inferred that the AD project itself is primarily considered to be a viable solution to manage the OHW in Muharraq Governorate, after calculating the Net Present Value (NPV) that must also be positive.

The NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of an investment or project. It measures the excess or shortfall of cash flows, in present value terms, once financing charges are met (ElQuliti, 2016). In addition, the Internal Rate of Return (IRR) is defined as the interest rate at which the net present value of costs (negative cash flows) equals the net present value of the benefits (positive cash flows). An investment is considered acceptable if its IRR is greater than an established minimum acceptable rate of return or cost of capital (ElQuliti, 2016). Furthermore, the Payback Period (PBP) indicates the amount of time it takes for a Capital Budgeting project to recover its initial cost. In capital budgeting, payback period denotes the period of time required for the return on an investment to "repay" the sum of the original investment. To calculate it, the Payback period = Investment required / Net annual cash inflow (ElQuliti, 2016).

Considering the discount rate 10 percent, the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback Period (PBP) were calculated by the researcher for the AD Plant project based on the CBA shown in table 6.4, and presented in table 6.5 below.

Table 6.5: Cash Flow (1.1) with NPV, IRR and PBP of the AD Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(1,260,000)
1	1,357,642
2	1,357,642
3	1,357,642
4	1,357,642
5	1,357,642
6	1,357,642
7	1,357,642
8	1,357,642
9	1,357,642
10	1,357,642
11	1,357,642
12	1,357,642
13	1,357,642
14	1,357,642
15	1,357,642

DISCOUNT RATE	10%
NPV	9,066,333
IRR	108%
PBP	0.93

The cash flow suggests that the AD is a viable project, since the NPV is positive and worth around 9 M USD, with a high internal rate of return (IRR) that reached 108%, and a payback period of less than 1 year, which indicated the viability of the project. In the other hand, the second scenario was conducted by considering the saving earned by discontinuing of the current waste dumping as additional revenue, the annual net profit was recalculated and the results were as follows:

Table 6.6: Cost-Benefit Analysis (2.1) of AD Plant for Muharraq Governorate Considering the Saving Earned by Discontinuing Waste Dumping

Anaerobic Digestion (AD) Scenario 2.1	
Description	**USD**
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	**1,260,000**
Total O&M Cost/ Year	**1,015,000**
Benefit/Year	
Fertiliser	**1,722,840**
Electricity	**649,802**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**3,354,181**
Net Profit / Year	**2,339,181**

Moreover, the cash flow including NPV, IRR and PBP were recalculated and the results are presented in table 6.7.

Table 6.7: Cash Flow (2.1) with NPV, IRR and PBP of the AD Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(1,260,000)
1	2,339,181
2	2,339,181
3	2,339,181
4	2,339,181
5	2,339,181
6	2,339,181
7	2,339,181
8	2,339,181
9	2,339,181
10	2,339,181
11	2,339,181
12	2,339,181
13	2,339,181
14	2,339,181
15	2,339,181

DISCOUNT RATE	10%
NPV	16,531,997
IRR	186%
PBP	0.54

Based on the above table, it is obvious that the NPV is become higher in the second scenario due to the additional revenue earned (around 16 million USD), and that the IRR has touched 186 percent; the project will payback capital cost in around six years which is considered to be a very good economic indicator. As a result, based on the cost benefit analysis above, the AD is considered to be a feasible, viable and profitable solution to manage the OHW in Muharraq Governorate regardless of whether the government invests in it or the private sector expressed by the second or the first scenarios respectively under the fertiliser cost of 140USD/ton.

In addition to the suitability of the OHW of Muharraq Governorate to the AD as seen in Chapter 5 after adjusting pH and C:N ratio, the cost-benefit analysis supports this selection and gives an additional economic evidence to recommend the AD technology to the nation's decision makers to manage the OHW of Muharraq Governorate, which can then be embedded into the national legal and policy frameworks. However, AD is receiving increasing attention as a possible option of energy recovery from waste in the urban context. However, the operation of biogas plants from heterogeneous MSW poses a major challenge in terms of operational, safety and financial requirements. As a consequence, there are very few successful examples of biogas from MSW in developing countries (Mutz et al., 2017) due to some specific barriers which will be explored via a survey for the Bahraini context in Chapter 7.

In contrast, considering the current low market cost (6 USD/ton) of the fertiliser under the second scenario for AD (scenario 1.2), the CBA can be re-calculated and the results are shown in Table 6.8 below:

Table 6.8: The Cost-Benefit Analysis (Scenario 1.2) of AD Plant for Muharraq Governorate Considering Current Low Market Cost of Fertiliser (6 USD/ton)

Anaerobic Digestion (AD) Scenario 1.2	
Description	**USD**
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	**1,260,000**
Total O&M Cost/Year	**1,015,000**
Benefit/year	
Electricity	**649,802**
Fertiliser	**73,835**
Total Benefit/year	**723,637**
Net Profit / Year	**(291,363)**

From the table above, it is obvious that the annual net profit is negative and reflects a non-profitable project considering the current cost of fertiliser under the first scenario. The NPV was calculated and presented in table 6.9 below, which indicated a non-viable nor feasible project.

Table 6.9: Cash Flow (1.2) with NPV, IRR and PBP of the AD Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(1,260,000)
1	(291,363)
2	(291,363)
3	(291,363)
4	(291,363)
5	(291,363)
6	(291,363)
7	(291,363)
8	(291,363)
9	(291,363)
10	(291,363)
11	(291,363)
12	(291,363)
13	(291,363)
14	(291,363)
15	(291,363)

DISCOUNT RATE	10%
NPV	(3,476,130)

While under the second scenario of considering the saving earned from discontinuing of the waste dumping in the landfill, the project will be feasible and profitable as shown in Table 6.10 below:

Table 6.10: Cost-Benefit Analysis (2.2) of AD Plant for Muharraq Governorate Considering the Saving Earned by Discontinuing Waste Dumping (fertiliser cost 6USD/ton)

Anaerobic Digestion (AD) Scenario 2.2	
Description	**USD**
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	**1,260,000**
Total O&M Cost/ Year	**1,015,000**
Benefit/Year	
Fertiliser	**73,835**
Electricity	**649,802**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**1,705,176**
Net Profit / Year	**690,176**

Moreover, the cash flow including NPV, IRR and PBP were recalculated and the results are presented in table 6.11.

Table 6.11: Cash Flow (2.2) with NPV, IRR and PBP of the AD Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(1,260,000)
1	690,176
2	690,176
3	690,176
4	690,176
5	690,176
6	690,176
7	690,176
8	690,176
9	690,176
10	690,176
11	690,176
12	690,176
13	690,176
14	690,176
15	690,176

DISCOUNT RATE	10%
NPV	3,989,534
IRR	55%
PBP	1.83

The cash flow suggests that the AD is a viable project, since the NPV is positive and worth around 4 M USD, with a high internal rate of return (IRR) that reached 55%, and a payback period of less than 2 years, which indicated the viability of the project under the second scenario at the current fertiliser cost (6USD/ton).

Based on the above table, it is obvious that the NPV is become higher in the second scenario due to the additional revenue earned, and the project will payback capital cost in around 2 years which is considered to be a very good economic indicator. As a result, based on the cost benefit analysis above, the AD is considered to be a feasible, viable and profitable solution to manage the OHW in Muharraq Governorate under the current market cost of fertiliser (6USD/ton) only if the government invests in it and discontinue the dumping activities expressed by the second scenario (2.2), but not under the scenario (2.1).

Environmental Aspects

According to Mutz et al. (2017) and Lee et al. (2017), the conversion of organic waste to biogas is associated with a number of environmental benefits. Biogas from organic waste reduces the emission of greenhouse gases into the atmosphere (Mutz et al., 2017) resulting from organic waste dumping (Lee et al., 2017)

Dumping of 61,529 tonne/year of OHW in the landfill results in 2215.03 tonne CH_4/year based on the Intergovernmental Panel on Climate Change (IPCC) method to estimate methane emission from dumped waste: 1kg organic waste produces 0.036 kg CH_4) (Siddiqui and Paranjpe, 2016). Therefore, the AD and the other technologies projects contribute to GHG emission reduction since the landfill methane has a global warming potential of approximately 21 times higher than that of CO_2. (Mutz et al., 2017)

Releasing 1 kg of CH_4 into the atmosphere is about equivalent to releasing 25 kg of CO_2 (http://climatechangeconnection.org/emissions/co2-equivalents/)

Thus, 55,375.7 tonne/year of CO_2e can be reduced by discontinuing OHW dumping into the landfill after implementing the OHWM technology project, assuming the existing OHW generation rate in Muharraq Governorate.

Since the Clean Development Mechanism (CDM) allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, these CERs can be traded and sold, and used by industrialized countries as part of their emission reduction targets under the Kyoto Protocol which was adopted in 1997 (UNFCCC website http://cdm.unfccc.int/about/index.html).

This might represent an opportunity for the Bahraini government to benefit from the CDM since Bahrain is a signatory on Kyoto protocol in 2006, as stated in Chapter 4. Further study is recommended to find out if each project is eligible to be registered as a CDM project and satisfies the criteria set by Kyoto Protocol. If so, there will be additional revenue from the sales of the CERs which will increase the profitability of each project.

6.4.2 Incineration

Incineration refers to the burning of waste within a specific facility in a controlled process. Incinerator necessitates a major capital investment and must be supported by long term financial planning and sufficient resources to be able to secure continuous operation and maintenance of the plant (Mutz et al., 2017).

As explained in the previous sub-section, the same procedure was followed to achieve the CBA for an OHW incinerator project for Muharraq Governorate. According to the Waste to Energy International Website, the biggest problem encounters development of waste-to-energy facilities is the price.

The capital cost was estimated using the cost stated by Mutz et al. (2017) for an Incineration Project in developing countries. Assuming that the capital cost is 44.7 $/ton, the total capital cost of an incinerator of 70,000 tons/year of Muharraq Governorate is $3,129,000. The cost includes the combustion system with the steam generator, and the costs of construction and the costs of regulation and control equipment. This estimate was done assuming basic technical set-up of a single furnace line). Since capital costs are very dependent on world steel price indices and on various local factors, the estimate is expected to be within +/- 20% accuracy (Rodríguez, 2011)

The annual O&M cost was calculated based on the average stated by Mutz et al (2017) (27.5$/ton), therefore total estimated O & M cost was calculated and found to be equal 1,925,000 $/year.

Considering the discount rate 10 percent per year for the investment, with the expected life span of the facility being 15 years. The revenues from energy sales are predicated on the domestic price for electricity (0.02$/kWh), the efficiency of the plant (40%) and the CV of the waste (Mutz et al., 2017). The calculation of the electricity generated from incineration technology in this section was determined considering the CV of Muharraq OHW empirically investigated in Chapter 5, which is 18.5 MJ/kg.

At incineration plants, energy and valuable materials in the ash residues after combustion could also potentially be recovered (Tang, 2012, Sakai and Hiraoka, 2000). Accordingly, ash has a market value which provides additional revenues to the project. Ash from WTE facilities should be used to make bricks in cement factories (Ranjith, 2012); since there is no cement factory in Bahrain (no market for ash), ash can be exported. The direct saving by discontinuing waste dumping was considered as for AD, and will be illustrated in the CBA table (2). The CBA of a proposed OHW Incinerator for Muharraq Governorate is illustrated in Table 6.12 below.

Table 6.12: Cost-Benefit Analysis (1) of a Proposed OHW Incinerator in Muharraq Governorate

Incineration Scenario 1	
Description	**USD**
Capital cost $/ton	44.7
O & M Cost $/ton	27.5
Total Capital Cost	**3,129,000**
Total O&M Cost/ year	**1,925,000**
Benefit/year	
Electricity	1,011,800
Ash	6,000
Total Benefit/year	**1,017,800**
Net Profit / Year	**(907,200)**

Fixed costs are associated with the capital investment during the first year of the proposed incinerator (Tang, 2012), while the O&M cost are paid on a yearly basis.

From the table above, it is obvious that the annual net profit is negative and reflects a non-profitable project. The total KWh of Muharraq Governorate OHW with a calorific value of 18.5MJ/kg was estimated and found to be 5.14 MWh/tonne (3.6MJ = 1KWh). Therefore, if the efficiency was 100 percent, the combustion of 61,529 tonne/year OHW leads to a total of 316.2 GWh/year. WtE plants can produce heat and power simultaneously using a CHP unit that raises the overall efficiency to up to 40 percent. This percentage was considered in this research study as it is the highest using a state-of-art incineration technology. In this context, the heat generated during electricity production is captured and utilised (World Energy Council, 2016). As a result, the net energy production will be 126.5 GWh/year (Table 6.13). Considering the cost of 1KWh in Bahrain as per Electricity and Water Authority (EWA) which is 0.02 USD/KWh, the total revenues of electricity sales of 126.5 GWh/year was found to be 1,011,800 USD/year.

Table 6.13: Energy Yield by Muharraq OHW Incineration Based on the Process efficiency

Description	MJ/kg	KWh	GWh
Calorific Value of Muharraq OHW	18.5	5.1	0.0
Estimated total kWh from OHW from Muharraq/day		866,288.2	0.9
Estimated total kWh from OHW from Muharraq/year (100%)			316.2
Estimated total kWh from OHW from Muharraq/year (40%)			126.5

While the fly ash is the second end product that can be used in concrete and cement plants, the revenues earned from ash was estimated based on the annual fly ash produced from Muharraq OHW, according to the project manager, who estimated it as 120 tonne/year, whereas the cost of 1 tonne fly ash was 50 USD; thus, the total revenue from fly ash was 6000 USD/year.

Based on the official data (EWA, 2016), there are five main power plants in Bahrain that are generating a total of 17069 GWh/year. These power plants and their generation capacities are listed in Table 6.14 below:

Table 6.14: List of power plants in Bahrain with their power generation capacities

Total Bahrain Electricity Generation in Power Plants (2016)	GWh
Sitra	869
Riffa	981
Al-Hidd	5,808
Al-Ezzel	3,659
Al-Dur	5,769
Outer link	-17
Total	**17069**

Al-Hidd power generation is serving the Muharraq Governorate area. Therefore, the contribution percentage of the OHW of Muharraq Governorate using incineration technology in the national power generation was calculated as follows:

- Estimated annual percent Muharraq OHW contribution to Bahrain total power generation: 0.74 percent
- Estimated annual percent Muharraq OHW contribution to Al-Hidd power generation: 2.18 percent

The World Energy Council (2016) claimed that incineration of MSW continues to offer the most desirable economic conditions in the market, and is therefore the preferred option in most markets.

In order to decide whether incineration is an economically feasible technology, the Net Present Value (NPV), IRR, and PBP as a ramification of CBA are presented in Table 6.15.

Table 6.15: Cash Flow (1) with NPV, IRR and PBP of the Incineration Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(3,129,000)
1	(907,200)
2	(907,200)
3	(907,200)
4	(907,200)
5	(907,200)
6	(907,200)
7	(907,200)
8	(907,200)
9	(907,200)
10	(907,200)
11	(907,200)
12	(907,200)
13	(907,200)
14	(907,200)
15	(907,200)

DISCOUNT RATE	10%
NPV	(10,029,235)
IRR	NA
PBP	NA

Based on the table above, it is obvious that the NPV is negative thus the IRR and PBP are not applicable, which is considered a losing project. Based on the aforementioned CBA, it can be concluded that the OHW Incineration is considered neither feasible nor viable solution to manage the OHW in Muharraq Governorate. Whereas by considering the saving earned from discontinuing OHW dumping, the net profit and NPV will increase, and therefore the project will become viable and profitable. Table 6.16 illustrated the CBA in scenario 2, the conversion of the profitability from negative to positive is shown clearly with considering the revenues earned from discontinuing of waste dumping by the government.

Table 6.16: Cost-Benefit Analysis (2) of a Proposed OHW Incinerator in Muharraq Governorate Considering the Saving Earned by Discontinuing Waste Dumping

Incineration Scenario 2	
Description	**USD**
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	**1,260,000**
Total O&M Cost/ year	**1,015,000**
Benefit/year	
Electricity	1,722,840
Ash	6,000
Direct saving by discontinuing waste dumping	981,539
Total benefit/year	**2,710,379**
Net Profit / Year	**1,695,379**

The Cash Flow (2) with NPV, IRR and PBP of the Incinerator Plant Project for Muharraq Governorate are shown in table 6.17:

Table 6.17: Cash Flow (2) with NPV, IRR and PBP of the Incinerator Project for Muharraq Governorate

YEAR	CASH FLOW
0	(1,260,000)
1	1,695,379
2	1,695,379
3	1,695,379
4	1,695,379
5	1,695,379
6	1,695,379
7	1,695,379
8	1,695,379
9	1,695,379
10	1,695,379
11	1,695,379
12	1,695,379
13	1,695,379
14	1,695,379
15	1,695,379

DISCOUNT RATE	10%
NPV	11,635,187
IRR	135%
PBP	0.74

The cash flow indicates that incineration is considered to be a viable project in the Muharraq Governorate, and that the government can earn high benefits by investing in this project.

As compared to the AD technology CBA, AD still earns higher profits and obtains higher returns on economy; in addition, the payback period is shorter and IRR is higher. However, both technologies are strongly recommended based on the technical and economic criteria, noting that in order to have a viable incineration, the government must invest in this project and discontinue the waste dumping consequently.

6.4.3 Gasification

As described previously in Chapter 2, solid waste gasification is the partial oxidation of waste fuel in the presence of an oxidant of lower amount than that which is required for the incineration. The produced gas is called syngas, which can be used for various applications after cleaning. Once the syngas gas is cleaned, it can be used to generate high quality fuels, chemicals or synthetic natural gas (SNG); it can also be used in a more efficient gas turbines and/or internal combustion engines or be burned in a conventional burner connected to a boiler and steam turbine (World Energy Council, 2016). Mutz et al., (2017) claimed that in order to establish a gasification plant in developing countries, the capital cost is 46.4 $/ton. He argued that this price is based on a German technology cost. Accordingly, the Capital cost for a Gasification Plant of a capacity of 70,000 ton/year is $3,248,000. While O&M cost was estimated to be 40.6$/ton, with a total of 2,842,000$/year.

However, the CBA was conducted for a mid- scale Gasification plant with a capacity of 70,000 tons/year; the results are shown in the below table:

Table 6.18: Cost-Benefit Analysis (1) of a Proposed OHW Gasification Plant in Muharraq Governorate

Gasification Scenario 1	
Description	**USD**
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	**3,248,000**
Total O&M Cost/Year	**2,842,000**
Benefit/year	
Electricity	**2,759,482**
Total Benefit/year	**2,759,482**
Net Profit / Year	**(82,518)**

Based on the above table, it is obvious that the capital cost of Gasification is higher when compared to previous technologies, and the benefit accrues from electricity sales, considering the fact that the most state-of-art-technology with a high efficiency is also high.

According to the Global Syngas Technology Council (GSTC), conventional waste-to-energy plants that use mass-burn incineration can convert one tonne of MSW to about 550 kilowatt-hours of electricity. With gasification technology, one tonne of MSW can be used to produce up to 1,000 kilowatt-hours of electricity, a much more efficient and cleaner way to utilize this source of energy.

Since OHW of Muharraq Governorate has higher Calorific Value, it was found that one tonne of OHW using mass-burn incineration technology as discussed previously produces 2056 KWh considering 40 percent efficiency, gasification will lead to produce 3737 KWh/tonne accordingly. Therefore, total electricity that can be produced using Gasification considering 100 percent efficiency is 230 GWh/year. According to the U.S Department of Energy official website, an integrated gasification combined cycle (IGCC) power plant can have a plant efficiency of greater than 43 percent depending on the gasification and heat recovery technologies employed as well as the degree of plant integration with other processes, like air separation, for example. They claimed that when coupled with other advanced technologies under development, such as hydrogen turbines and solid oxide fuel cells, a gasification power plant can have efficiencies as high as 60 percent, which is considered to be a very substantial gain over conventional technologies like incineration. Thus, the electricity generation rate from Muharraq Governorate's OHW using Gasification technology is 138 GWh/year.

Higher efficiency means higher sales, considering the national domestic electricity cost by EWA which is 0.02 USD/kWh, with the estimated sales from electricity found as 2,759,482 USD.

Accordingly, in order to explore whether Gasification is considered a feasible solution for Muharraq Governorate, the NPV, IRR and the PBP were calculated considering the cash-flow in 15 years, as displayed in Table 6.19 below.

Table 6.19: Cash Flow (1) with NPV, IRR and PBP of the Gasification Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(3,248,000)
1	(82,518)
2	(82,518)
3	(82,518)
4	(82,518)
5	(82,518)
6	(82,518)
7	(82,518)
8	(82,518)
9	(82,518)
10	(82,518)
11	(82,518)
12	(82,518)
13	(82,518)
14	(82,518)
15	(82,518)

DISCOUNT RATE	10%
NPV	(3,875,635)
IRR	NA
PBP	NA

From the table above, NPV is negative which reflects a non-feasible project. Similar to incineration, the project will be profitable by considering the savings obtained from discontinuing the waste dumping, and the CBA was repeated; the results are shown in Table 6.20.

Table 6.20: Cost-Benefit Analysis (2) of a Proposed OHW Gasification Plant in Muharraq Governorate Considering the Saving Earned by Discontinuing of Waste Dumping

Gasification Scenario 2	
Description	**USD**
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	**3,248,000**
Total O&M Cost/ Year	**2,842,000**
Benefit/Year	
Electricity	**2,759,482**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**3,741,021**
Net Profit / Year	**899,021**

While the new NPV, IRR, and PBP are presented in Table 6.21

Table 6.21: Cash Flow (2) with NPV, IRR and PBP of the Gasification Plant Project for Muharraq Governorate

YEAR	CASH FLOW
0	(3,248,000)
1	899,021
2	899,021
3	899,021
4	899,021
5	899,021
6	899,021
7	899,021
8	899,021
9	899,021
10	899,021
11	899,021
12	899,021
13	899,021
14	899,021
15	899,021

DISCOUNT RATE	10%
NPV	3,590,028
IRR	27%
PBP	3.61

As a normal result, the NPV becomes much higher with a longer PBP which reaches more than 3 years and a half. IRR is just 27% which is lower than AD and incineration. When the government invests in this project and takes it as an alternative to the current waste dumping practices, it will be a viable solution, otherwise it is not viable.

In conclusion, considering the ideal conditions for project adoption in the country, AD occupied the first place as a most feasible solution to manage OHW in the Muharraq Governorate based on the economic criteria. Incineration and Gasification are not feasible if not considering the saving earned from discontinuing waste dumping. When considering it, Incineration became the second preferable solution due to the high NPV, high IRR and short PBP. It is highly important to mention that this chapter discusses the economic feasibility of technologies considering the estimation of costs and benefits from the literature as well as from experts, which does not reflect the actual reality without considering the enablers and barriers of each technology adoption in Bahrain.

Despite the economic feasibility and viability in scenario 2, it is confirmed worldwide that there are many challenges accompanying gasification technology adoption in developing countries and in Europe (World Energy Council, 2016). Mutz et al. (2017) stated that gasification of high calorific waste fractions can offer, in combination with power plants and industrial furnaces, an alternative technical solution; he added that it is mainly used for selecting high calorific waste and waste fuels. Moreover, Mutz et al. (2017) argued that this technical approach represents a possible choice within an already fully organized waste management system and not as an independent facility. As primarily concluded in Chapter 5, the high CV of the OHW in Muharraq Governorate renders gasification a suitable solution in addition to its economic feasibility under the second scenario. Enablers and barriers to gasification adoption in Bahrain have been explored in Chapter 7, and the results will complement the previous chapters to form the final recommendation of each technology since the social criteria consideration is essential and complementary for the decision making process.

6.4.4 Pyrolysis

As described in Chapter 2, Pyrolysis refers to the thermochemical decomposition of organic matter into non-condensable gases, condensable liquids, and a solid residual co-product, bio-char or charcoal in the absence of oxygen. The CBA of pyrolysis for Muharraq Governorate was conducted to produce marketable products are oil (bio-oil) according to the project manager. Bio-oil is a renewable liquid fuel which can be used for the production of chemicals and liquid fuels. Bio-oils have been successfully tested in engines, turbines, and boilers, and upgraded to high-quality hydrocarbon fuels (Czernik and Bridgwater, 2004, Yang et al., 2018).

Mutz et al. (2017) claimed that the capital cost and O & M cost of Pyrolysis can be considered the same as that of Gasification so the average of the stated capital cost per ton was considered in this section (46.4$/ton and (40.6$/ton). Furthermore, Mutz et al (2017) argued that due to high operation and maintenance costs, the economics of both gasification and pyrolysis can only be considered as acceptable if the process products have a good market value. He added that this depends to a great extent on market conditions and the need for an end consumer (e.g. cement plant) to be in close proximity to the Pyrolysis plant. However, Bahrain has no market for the pyrolysis end products towing to the lack of cement plants; thus, the only revenue estimated in this study resulted from the export of the resulted bio-oil.

The following table includes the overall cost, benefit and the annual net profit for a medium-scale pyrolysis plant in Muharraq Governorate that end up with bio-oil production.

Table 6.22: Cost-Benefit Analysis (1) of a Proposed OHW Pyrolysis Plant in Muharraq Governorate

Pyrolysis Scenario 1	
Description	**USD**
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	**3,248,000**
Total O&M Cost/Year	**2,842,000**
Benefit/year	
Bio-Oil	**837,312**
Total Benefit/year	**837,312**
Net Profit / Year	**(2,004,688)**

It is clear from the above table that the capital cost is very high and the annual net profit is negative, which reflects the non-profitability of the pyrolysis project.

The maximum yield of bio-gas from pyrolysis was estimated to be 45 percent of dry MSW feed (Islam et al., 2010). Based on this calculation ((total annual OHW (wet)- 73 percent moisture) * 45 percent), the estimated bio-oil from dry OHW of Muharraq Governorate which was anticipated to be 7476 tonne/year (7476000 Liter bio oil/year). Popoola et al. (2015) claimed that the selling price of one litter of bio-oil equals 0.112 USD. Cole Hill Associates (2004) argued that at the current international price of fuel oil of 0.86 USD per gallon, the equivalent cost of bio-oil would be 0.47 USD per gallon (which means 0.124 USD/L). Accordingly, the total revenue from bio-oil was 837,312 USD/year.

In order to decide whether pyrolysis is a viable solution for Muharraq Governorate, the cash flow was conducted for a period of 15 years and the NPV, IRR and PBP were calculated; the results are shown in table 6.23 below:

Table 6.23: Cash Flow (1) with NPV, IRR and PBP of the Pyrolysis Project for Muharraq Governorate

YEAR	CASH FLOW
0	(3,248,000)
1	(2,004,688)
2	(2,004,688)
3	(2,004,688)
4	(2,004,688)
5	(2,004,688)
6	(2,004,688)
7	(2,004,688)
8	(2,004,688)
9	(2,004,688)
10	(2,004,688)
11	(2,004,688)
12	(2,004,688)
13	(2,004,688)
14	(2,004,688)
15	(2,004,688)

DISCOUNT RATE	10%
NPV	(18,495,816)
IRR	NA
PBP	NA

Since the capital cost is very high (more than 3 million USD), and the annual net profit of pyrolysis is low, the NPV had a negative value (by approximately 18.5 million USD), which indicates that the project is economically unfeasible and denotes a big loss to the economy of the country.

Mutz et al. (2017) argued that when compared to all other WtE technologies, pyrolysis and gasification are the most expensive technologies. In this research study, pyrolysis had a high cost and lowest benefit with the absence of the market. However, other barriers to pyrolysis adoption will be illustrated in Chapter 7.

In order to illuminate the effect of adding the savings obtained by discontinuing current waste dumping in scenario 2, the net profit was re-calculated with NPV, IRR and PBP.

Table 6.24: Cost-Benefit Analysis (2) of a Proposed OHW Pyrolysis Plant in Muharraq Governorate

Pyrolysis Scenario 2	
Description	**USD**
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	**3,248,000**
Total O&M Cost/ Year	**2,842,000**
Benefit/Year	
Bio-Oil	**837,312**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**1,818,851**
Net Profit / Year	**(1,023,149)**

From the table above, the Pyrolysis project in still unprofitable by adding the savings earned by discontinuing waste dumping. Moreover, NPV was recalculated over a period of 15 years with PBP and IRR, as presented in table 6.25.

Table 6.25: Cash Flow (2) with NPV, IRR and PBP of the Pyrolysis Project for Muharraq Governorate

YEAR	CASH FLOW
0	(3,248,000)
1	(1,023,149)
2	(1,023,149)
3	(1,023,149)
4	(1,023,149)
5	(1,023,149)
6	(1,023,149)
7	(1,023,149)
8	(1,023,149)
9	(1,023,149)
10	(1,023,149)
11	(1,023,149)
12	(1,023,149)
13	(1,023,149)
14	(1,023,149)
15	(1,023,149)

DISCOUNT RATE	10%
NPV	(11,030,153)
IRR	NA
PBP	NA

Therefore, from economic perspective, Pyrolysis cannot be considered a viable solution to manage OHW in the Muharraq Governorate under all scenarios. Notably, economic viability is not a strong enough reason to select the most suitable technology for the Muharraq Governorate. Other factors might be explored through the social survey, which mainly aims to explore enablers and barriers to technology adoption, which will be examined in Chapter 7.

6.4.5 Refused-Derived Fuel (RDF)

As seen in Chapter 2, RDF is a final form of waste after a suitable sequence of operations, composed of primary and secondary shredding, grading, wind sifting and screening, magnetic and eddy-current separation that aim to obtain the high calorific value storable fuel which can then be used in direct combustion, gasification and pyrolysis (Buekens, 2013). Furthermore, refuse derived fuel (RDF) production is designed to divert combustible fractions from municipal solid wastes

(MSW) in order to produce fuel and be used as substitution or supplementary energy (Nithikul, 2007). As concluded in Chapter 5, RDF is the last technology in the list of preferred and suitable technology based on OHW characterization owing to high moisture, high organic matter (OW) attributed to the high organic fraction, and the low ash content required by the technology. Nevertheless, the CBA of establishment of a MRF plant that can produce RDF from the OHW waste for Muharraq Governorate was conducted; the total capital cost was determined based on the average cost estimated by Mutz et al. (2017) for a co-processing plant (RDF) in developing countries, which is 20.3$/ton, while the O & M cost is 17.4$/ton. While the average per tonne revenue earned from the RDF produced is $3.48. Total Cost and Benefits are shown in table 6.26 below:

Table 6.26: Cost-Benefit Analysis (1) of a Proposed OHW Co-processing for RDF Plant in Muharraq Governorate

RDF Scenario 1	
Description	**USD**
Capital cost $/ton	20.3
O & M Cost $/ton	17.4
Total Capital Cost	**1,421,000**
Total O&M Cost/Year	**1,218,000**
Benefit/year	
RDF	**243,600**
Total Benefit/year	**243,600**
Net Profit / Year	**(974,400)**

From the table above, it is noted that the capital cost is the lowest when compared to the previous technologies (AD, Incineration, Gasification and Pyrolysis). Hence, it is considered a sort of pre-processing that aims to prepare OHW for thermal conversion technologies to be used in specific industries e.g. cement plants. Initial investments primarily include pre-processing to generate a homogenous mixed RDF, introduction of conveyer belts as well as new technical functions to enable input of RDF into the combustion process (Mutz et al., 2017). The profit was calculated based on the RDF price (3.48$/ton), considering the annual capacity of 70,000 tonne.

The cash flow was conducted to test the feasibility of this project for the Muharraq Governorate; the NPV, IRR and PBP were calculated and presented in the table below:

Table 6.27: Cash Flow (1) with NPV, IRR and PBP of the Co-processing Plant for RDF in Muharraq Governorate

YEAR	CASH FLOW
0	(1,421,000)
1	(974,400)
2	(974,400)
3	(974,400)
4	(974,400)
5	(974,400)
6	(974,400)
7	(974,400)
8	(974,400)
9	(974,400)
10	(974,400)
11	(974,400)
12	(974,400)
13	(974,400)
14	(974,400)
15	(974,400)

DISCOUNT RATE	10%
NPV	(8,832,364)
IRR	NA
PBP	NA

Consequently, the RDF project is unfeasible under the first scenario, since the NPV is negative. By adding the saving earned from discontinuing waste dumping under the second scenario, the CBA becomes as follows:

Table 6.28: Cost-Benefit Analysis (2) of a proposed OHW MRF for RDF Plant in Muharraq Governorate considering savings from Discontinuing Waste Dumping:

RDF Scenario 2	
Description	**USD**
Capital cost $/ton	20.3
O & M Cost $/ton	17.4
Total Capital Cost	**1,421,000**
Total O&M Cost/ Year	**1,218,000**
Benefit/Year	
Bio-Oil	**243,600**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**1,225,139**
Net Profit / Year	**7,139**

The annual net profit increased consequently, and the NPV, IRR and PBP were re-calculated. As a result, the NPV was found to be negative, despite the annual profitability of the project. The cash flow is presented in table 6.29 below:

Table 6.29: Cash flow (2) with NPV, IRR and PBP of the MRF for RDF in Muharraq Governorate

YEAR	CASH FLOW
0	(1,421,000)
1	7,139
2	7,139
3	7,139
4	7,139
5	7,139
6	7,139
7	7,139
8	7,139
9	7,139
10	7,139
11	7,139
12	7,139
13	7,139
14	7,139
15	7,139

DISCOUNT RATE	10%
NPV	(1,366,700)
IRR	NA
PBP	NA

In addition to the unfeasibility of the Co-processing for RDF Plant, the purpose of using RDF technology must be remembered. Calorific Value (CV) is an indicator of the market value of RDF (Caracol, 2016). Moreover, Dianda et al. (2018) claimed that RDF can be used to substitute coal in the main burning process and calcinations of cement industry.

Since RDF technology is a kind of waste pre-processing that aims to maximize the calorific value to be within the suitable range for combustion (mainly 10-23 MJ/Kg) to be used in cement plants. The absence of market of RDF and cement plants utilizing RDF makes this technology not suitable for Bahrain. Although, the estimated calorific value of the resulting RDF was almost the same as Muharraq OHW, which already has a high gross calorific value (18.5MJ/Kg) and was measured empirically earlier in this research; it is almost ready for combustion, which makes this technology not necessary and not useful for Muharraq OHW. Consequently, the project RDF technology is not viable. This is in addition to the existence of other barriers that will be explored further in Chapter 7.

6.4.6 Composting

Composting is the last technology considered for economic feasibility in this chapter. According to Jovičić et al. (2009), composting is one of the most acceptable options for the processing of organic waste, and entails the aerobic biological decomposition of organic materials to produce a stable humus-like product. The construction of in-vessel composting plant was considered for the CBA in this research. The technology used for composting involves the following three phases: (1) preparation of the feedstock (also known as "pre-processing"), 2) the compost process itself, and (3) the grading as well as upgrading of the final product (or "post-processing"). The steps involved in the preparation of the feedstock generally include some type of size reduction and segregation of unwanted materials (Jovičić et al., 2009). Hoornweg et al. (1999) claimed that composting rarely generates profits on its own. However, when viewed as a component of an integrated solid waste management program, composting can provide economic benefits on a much larger scale.

However, the selected solution for composting plant which was considered in the CBA uses composting technology to the close space in the bunker, with forced ventilation material through the bottom of bunkers, coupled with constant monitoring of the process with the appropriate equipment (Jovičić et al., 2009). One tonne of mixed waste is known to give 60 - 70 Kg of compost (Annepu, 2016). Accordingly, 61,529 tonne OHW results in 3999.3 tonne compost annually, considering the average of 65 kg to compost produced per tonne OHW. Lasoff M. (2000) specified that the selling price of compost is 50 USD, which was considered in the CBA. According to Hochman et al. (2015), the capital cost of composting is 13.6$/ton, while the O & M cost reached 45$/ton. Table 6.30 represents the CBA of a proposed OHW Composting Plant in Muharraq Governorate

Table 6.30: Cost-Benefit Analysis (1) of a proposed OHW Composting Plant in Muharraq Governorate

Composting Scenario 1	
Description	**USD**
Capital cost $/ton	13.6
O & M Cost $/ton	45.0
Total Capital Cost	**952,000**
Total O&M Cost/Year	**3,150,000**
Benefit/year	
Compost	**199,969**
Total Benefit/year	**199,969**
Net Profit / Year	**(2,950,031)**

As compared to previous technologies, the capital cost and the annual O&M cost of the Composting Plant were found to be high due to the inclusive of the segregation of the mixed waste, whereas the benefits derived from compost sales are still low, which leads to an annual loss reflected by the negative net profit value. Furthermore, the project is not viable due to a negative NPV. The cash flow with NPV, IRR and PBP were calculated and presented in Table 6.31

Table 6.31: Cash Flow (1) with NPV, IRR and PBP of the Composting Plant in Muharraq Governorate

YEAR	CASH FLOW
0	(952,000)
1	(2,950,031)
2	(2,950,031)
3	(2,950,031)
4	(2,950,031)
5	(2,950,031)
6	(2,950,031)
7	(2,950,031)
8	(2,950,031)
9	(2,950,031)
10	(2,950,031)
11	(2,950,031)
12	(2,950,031)
13	(2,950,031)
14	(2,950,031)
15	(2,950,031)

DISCOUNT RATE	10%
NPV	(23,390,168)
IRR	NA
PBP	NA

Despite adding the saving earned from discontinuing waste dumping by the government, the net profit is still negative, as illustrated in Table 6.32.

Table 6.32: Cost-Benefit Analysis (2) of a Proposed OHW Composting Plant in Muharraq Governorate Considering Savings from discontinuing Waste Dumping:

Composting Scenario 2	
Description	**USD**
Capital cost $/ton	13.6
O & M Cost $/ton	45.0
Total Capital Cost	**952,000**
Total O&M Cost/ Year	**3,150,000**
Benefit/Year	
Compost	**199,969**
Direct saving by discontinuing waste dumping	**981,539**
Total Benefit/year	**1,181,508**
Net Profit / Year	**(1,968,492)**

Whereas the cash flow below in table 6.28 denotes the loss of the composting plant with a negative NPV in a period of 15 years, which indicates that composting is not a viable solution to manage the OHW in Muharraq Governorate.

Table 6.33: Cash Flow (2) with NPV, IRR and PBP of a Proposed OHW Composting Plant in Muharraq Governorate Considering Savings from discontinuing Waste Dumping:

YEAR	CASH FLOW
0	(952,000)
1	(1,968,492)
2	(1,968,492)
3	(1,968,492)
4	(1,968,492)
5	(1,968,492)
6	(1,968,492)
7	(1,968,492)
8	(1,968,492)
9	(1,968,492)
10	(1,968,492)
11	(1,968,492)
12	(1,968,492)
13	(1,968,492)
14	(1,968,492)
15	(1,968,492)

DISCOUNT RATE	10%
NPV	(15,924,505)
IRR	NA
PBP	NA

Due to the high cost and low benefits, Composting is considered not feasible solution to manage OHW in Muharraq Governorate. Furthermore, composting is accompanied by other barriers in addition to having some enablers to its adoption in Bahrain, which shall be explored in Chapter 7.

6.5 Conclusion

As a conclusion, the CBA gave a further evidence to select the most preferred technology for Muharraq Governorate. A comparison between all technologies for their NPV for viability in scenario 1 and scenario 2 is summarized in figure 6.1.

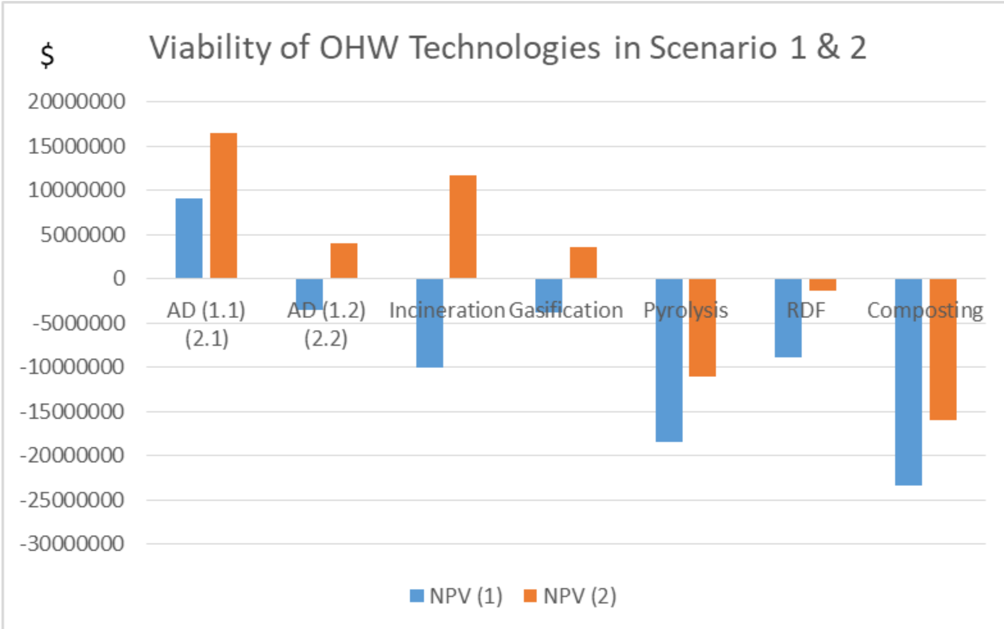

Figure 6.1: Viability of OHW Technologies in Scenario 1 and Scenario 2

It is obvious that under the first scenario, all technologies except AD (fertiliser cost 140USD/ton) were not feasible, while AD (fertiliser cost 6USD/ton), Incineration and Gasification became feasible after considering the savings accrued after discontinuing the current waste dumping practices. This indicates that to enable them, they must be established through a governmental investment in order to be viable. A comparison of cost and benefit between different technologies in scenario 1 and 2 are shown in figure 6.2 and 6.3 respectively.

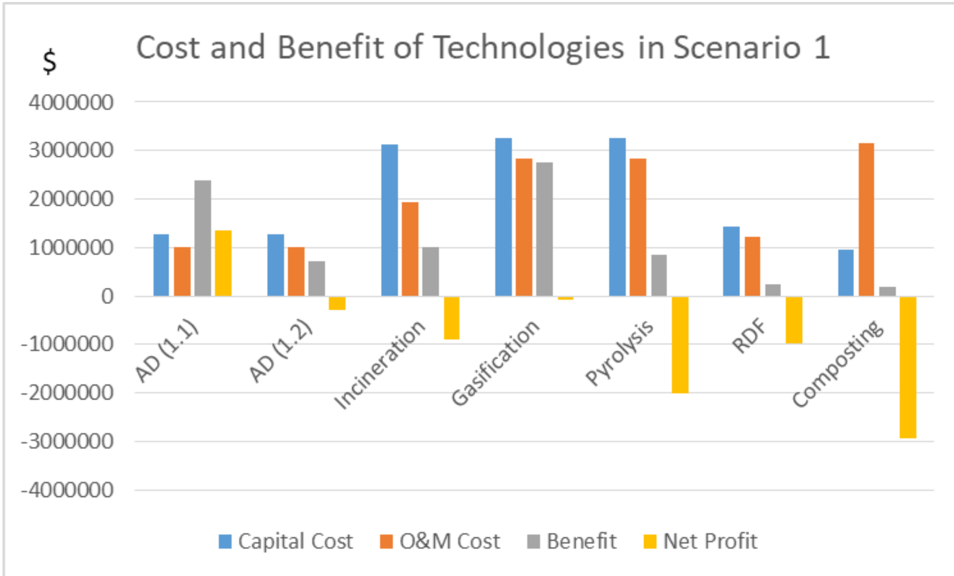

Figure 6.2: Comparison between Technologies in Cost and Benefit in the First Scenario

While figure 6.3 illustrated the cost and benefit of technologies in scenario 2:

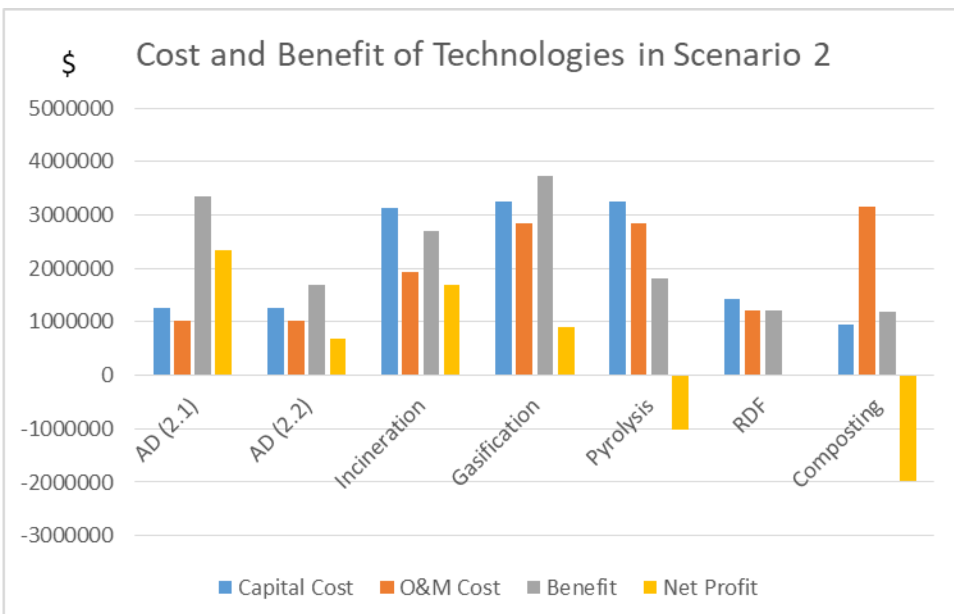

Figure 6.3: Comparison between Technologies in Cost and Benefit in the Second Scenario

As an overall conclusion, it is evident from the above figures that AD (considering fertiliser cost at 140USD/ton) is the most and only viable technology under both scenarios, due to its high benefits compared to its cost. Incineration and Gasification in addition to AD (considering fertiliser cost at 6USD/ton) are not viable in the first scenario while they converted to viability in the second scenario. RDF is not viable as well as there is no market for it in Bahrain. And finally, Composting has the lowest capital cost, but also has the highest operation and maintenance cost due to the mixed waste (and a large land in case of widrow composting) and the need of an intensive maintenance to ensure a high quality of the end product. Despite that, the compost sales is very low and lead the technology to loss (figure 6.3 and 6.4). Due to the highest resulting net profit from the sales of end products compared to the total cost, it was concluded that AD was the most profitable and viable technology in order to manage OHW of Muharraq Governorate amongst all other technologies under both scenarios referring to the NPV figures under the two scenarios in case considering the fertiliser cost at 140USD/ton and not at 6USD/ton (figure 6.2).

Accordingly, the technologies can be ranked from most to least economically feasible premised on the economic criteria signified by the CBA as follows:

1. Anaerobic Digestion (AD)
2. Incineration
3. Gasification
4. Pyrolysis
5. Composting
6. RDF

These results can be compared with the first technology ranking list resulting from the technology selection matrix based on the OHW characterization as a technical criterion to refine the selection listed in Table 6.34:

Table 6.34: The ranking of the most preferred technologies for Muharraq Governorate based on the technical criteria and the economic criteria

Rank	Technical Criteria (OHW Characterization)	Economic Criteria (Cost-Benefit Analysis)
1	Anaerobic Digestion (AD)	Anaerobic Digestion (AD)
2	Incineration	Incineration
3	Gasification	Gasification
4	Pyrolysis	Pyrolysis
5	Composting	Composting

6	RDF	RDF

As observed from the table above, the ranking of most preferred technologies to least came exactly identical to the list ranked based on the waste characterisation criteria. Considering the high fertiliser cost (140USD/ton), AD occupied the first place in technical and economic selection criteria, respectively; it is the only technology that takes an advanced position amongst all technologies, considering both criteria. While AD at the current low cost of fertiliser (6 USD/ton) found to be not feasible under the first scenario, and thus Incineration might have the preference over it economically, however, it will still be viable if the government invest in it. Incineration came second according to the technical criteria, and if the government invest in it, it will be the second preferred and viable solution for Muharraq OHW management. Similarly, Gasification came in the third place when considering the technical and economic criteria. However, incineration can be considered as a viable option in the future since it is suitable by both criteria under the second scenario with higher revenues than Gasification, while composting and pyrolysis are neither technically suitable nor economically feasible, and might be out of consideration as a recommendation for decision makers. Regarding the RDF, based on all of the given information discussed above, it was found to be a useless technology due to the high calorific value of OHW in Muharraq Governorate; hence, it will not add any value. Moreover, the absence of RDF end product market in Bahrain (e.g. Cement Plant) makes the viability of the RDF Plant unachievable and will cause loss to the project. At the end of this chapter, the fourth objective of this research was realized. The next chapter (Chapter 7) aims to explore the enablers and barriers to all technologies' adoption in Bahrain by conducting semi-structured interviews survey with the experts in order to realize the fifth objective of the research, as well as to refine the technology selection by conducting the social criteria (exploring enablers as well as barriers to technology adoption), which leads to the recommendation of the most satisfying (technically, economically and socially) solution.

CHAPTER 7: Exploring Enablers and Barriers to Technology Adoption in Bahrain

7.1 Overview

In order to explore the enablers and barriers to the adoption of each of the OHWM technologies for Muharraq Governorate and Bahrain in general, qualitative methodology, particularly semi-structured interviews with experts, was used to achieve this objective. This methodology is commonly used in literature for similar purposes (O'Leary et al., 2017, Santos, 2016, Bischoff, 2008, Wells et al., 2013, Najibullah et al., 2013), as discussed previously in Chapter 3.

This chapter contains a full analysis of the interview survey outcomes that were conducted to explore the enablers and barriers of the following technologies adoption in Bahrain: AD, incineration, composting, RDF, gasification and pyrolysis. This step is necessary to refine the selection of the most preferred technology based on the social criteria that will complement the previous recommended technologies selected in Chapters 5 and 6 on the basis of technical and economic criteria, respectively. The fifth objective of the research will be fulfilled at the end of this chapter and a complete picture of the expected circumstances related to any OHWM technology adoption in Bahrain will be clarified. Furthermore, the enablers and barriers will be classified as the main themes or categories based on the type of the enabler or barrier, given that they will be ranked at the end of the chapter based on the most effective and common theme in Bahraini society which could affect the adoption of technology.

7.2 Qualitative Findings of Study

As described in Chapter 3, data were collected through in-depth interviews with experts (n=11). The interpretation and description of these research findings were divided into predominant themes, followed by sub-themes or topics. The identification of these topics is based on the research objectives, which are related to the research background as well as to a literature review described in Chapter 2. The themes are illustrated using quotes from the experts. Table 7.1 illustrate the experts' codes, date of the interview, duration and language used through the course of the interview:

Table 7.1: Experts Codes, Description, Date of the interview, Duration and Language used

Expert Code	Description	Date of the Interview	Duration	Language
1	President. Academic professor and researcher in waste management, Al-Areen Resort	9th April, 2018	8:00- 9:30 am	Arabic
2	Head, Waste Management Directorate, SCE	10th April, 2018	8:45- 10:00 am	English
3	Head, Waste Management Department, MWMUP	10th April, 2018	12:00-2:00 pm	English
4	Head at Gulf Cleaning Company GCCC	11th April, 2018	1:30pm- 3:00pm	Arabic
5	Academic professor and researcher in waste management and urban planning, AGU	12th April, 2018	9:00-10:30	Arabic & English
6	Assistant professor, researcher in environmental management & natural resources, Texas A & M University	12th April, 2018	2:00-3:00pm	Arabic & English
7	Assistant professor, Researcher in WtE technologies, University of Loughborough	19th April, 2018	1:30-2:00pm	English
8	Superintendent, project manager, Bahrain Aluminum Company ALBA	23rd April, 2018	12:30-2:00pm	English
9	CEO, OAK WtE technology supplying Company	26th April, 2018	12:30pm-1:45pm	English
10	Environmental Specialist, researcher in waste management, Bahrain petroleum company BAPCO	28th April, 2018	5:00-6:00pm	Arabic
11	Bio-energy consultant, waste management expert in the Gulf region, researcher in ECO-MENA Organization	29th April, 2018	4:00-5:00pm	English

The data obtained from in-depth interviews were thematically analysed using QSR NVivo 12 software, which was followed by a content analysis to confirm the main themes. Thematic analysis was conducted to extract the main themes; subsequently, content analysis was made to confirm the findings of the thematic analysis.

Thematic analysis is a widely used foundational method of analysis in the realm of qualitative research, which is undertaken in a sequential order (Buetow, 2010). It analyses, interprets and reports different themes within the overarching theme of qualitative data, which allows for flexibility in the researcher's choice of theoretical framework (Braun and Clarke, 2006). In content analysis, categories are formed and their frequencies are calculated on the basis of the number of times each category is used in a text or an image. Therefore, content analysis is considered as a partial quantitative technique. Thematic analysis is similar to content analysis, but it focuses more on the qualitative aspects whilst analysing the material (Helene, 2012).

Thematic analysis was performed as per the following procedure. The researcher became acquainted with the data by reading and re-reading the interview quotes of the participants to understand the main contents. After getting familiar with the data contents, the researcher generated initial codes by reducing the data and assigning labels to create categories to pave the way for further analysis. Each code was then interpreted to understand the core meaning (Bauer and Gaskell, 2000). Similar codes were combined under one dominant theme, keeping the exact meaning of themes being developed into consideration (Helene, 2012).

These themes were reviewed to ascertain that the themes supported the data and the theoretical aspect under investigation. The researcher closely observed the data to identify the missing contents which could be coded under the developed themes (Joffe and Haarhoff, 2002). After reviewing the themes, suitable names were assigned to each theme. Themes were then defined individually with the help of related topics, which gave a sense about the meaning and interesting features of that theme (Miles, Huberman et al, 1994).

Following thematic analysis, content analysis was conducted to make replicable and valid interpretations from written or oral collected data, within the context in which it was obtained (Johnson and LaMontagne, 1993). The process of content analysis was tedious and required the researcher to go over and over the data in order to ensure that a thorough analysis was done.

Thematic and content analysis are based on the data of in depth interviews transcribed from the experts. The interview was conducted using protocol containing open ended questions based on the conceptual model, as shown in figure 7.1.

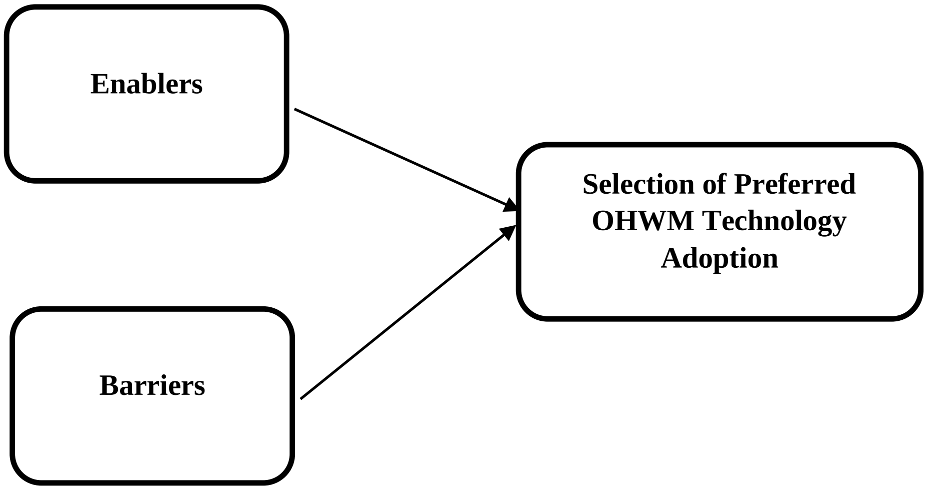

Figure 7.1: Conceptual Model

This study collected data through 11 interviews from experts whose names, occupation and places of work were kept anonymous for ethical reasons, as described previously in Chapter 3.

Nvivo 12 software was used for the purpose of data analysis following the approach of:

1- Inserting data files in Nvivo 12 software
2- Classification of respondents
3- Transcription of interviews
4- Data coding, finding themes, and developing nodes
5- Exploring hierarchal chart using queries

7.3 Data Coding and Identification of Themes

Data coding has been done and parent nodes has been formed as Enablers and Barriers, whereas child nodes are the technologies: AD, Incineration, RDF, Gasification & Pyrolysis, and Composting. All the experts agreed that Gasification and Pyrolysis have the same enablers and barriers to their adoption; thus, they were put together in one child node. Meanwhile child nodes inside each technology representing the main classification of enablers and barriers of this particular technology are as follows: social, economic, technological, managerial, political and environmental (Appendix 6). Coding was then done into each node, as shown in Table 7.2. The two main ‘Parent Nodes’ and their ‘Child Nodes’ extracted from the interviews data are presented as follows:

Parent Nodes:

1. **Enablers**

   Child Node:

   a. **AD**

      Child Nodes:

      - Technical
      - Social
      - Managerial
      - Political
      - Economic
      - Environmental

   b. **Incineration**

      Child Node:

      - Technical
      - Social
      - Managerial
      - Political
      - Economic
      - Environmental

   c. **RDF**

      Child Node:

      - Technical

- Social
- Managerial
- Political
- Economic
- Environmental

d. Gasification & Pyrolysis

Child Node:

- Technical
- Social
- Managerial
- Political
- Economical
- Environmental

e. Composting

Child Node:

- Technical
- Social
- Managerial
- Political
- Economical
- Environmental

Parent Nodes

2. Barriers

Child Node:

a. AD

Child Node:

- Technical

- Social
- Managerial
- Political
- Economic
- Environmental

b. Incineration

Child Node:

- Technical
- Social
- Managerial
- Political
- Economic
- Environmental

c. RDF

Child Node:

- Technical
- Social
- Managerial
- Political
- Economic
- Environmental

d. Gasification & Pyrolysis

Child Node:

- Technical
- Social
- Managerial
- Political
- Economic

- Environmental

e. Composting

Child Node:

- Technical
- Social
- Managerial
- Political
- Economic
- Environmental

Table 7.2 illustrates the number of codes (referred as sub-themes or topics) as well as the number of references that indicates the count of the number of subthemes or topics within each interview that may have been coded to any node by each expert, which will be explained in the next section.

Table 7.2: The number of codes and references per expert

Name	Codes	References
Exp.1	37	58
Exp.2	38	74
Exp.3	39	89
Exp.4	32	80
Exp.5	24	32
Exp.6	15	18
Exp.7	25	37
Exp.8	15	18
Exp.9	11	12
Exp.10	22	29

Exp.11	19	26

7.3.1 Identification of General Enablers and Barriers

In order to investigate the enablers and barriers to the OHWM technologies' adoption in the kingdom of Bahrain, six themes were developed from the theoretical framework and the questions. The analysis of interview transcripts revealed codes about the general enablers and barriers to any technology adoption in the country in addition to those specified to each technology. These themes were described as follows:

- Technical
- Social
- Political
- Managerial
- Economic
- Environmental

These themes were considered and applied to each particular technology as they were mentioned by experts.

Table 7.3 specifies the subthemes to have emerged within each theme for the general enablers to technology adoption in Bahrain, according to the experts.

Table 7.3: The subthemes emerged within each theme for general enablers to technology adoption in Bahrain

Technical	enforce segregation at source provide supportive infrastructure deploy recycling
Social	raising public awareness, including awareness of smart purchasing

	improve education and curriculum enforce public participation and communication
Political	governmental support with supportive policies establish governmental Sustainable Energy Unit (SEU) centralize responsibility effective legislations
Managerial	needs private sector participation needs a national waste management strategy National Capacity building
Environmental	the government supports safe technologies
Economic	no financial barrier in the GCC countries technology availability in the market

Moreover, all experts mentioned the general barriers to technology adoption in Bahrain, as delineated in table 7.4:

Table 7.4: The subthemes emerged within each theme from experts for the general barriers to technology adoption in Bahrain

Technical	absence of waste segregation at source lack of land availability Lack of locally-available technologies Inadequate management infrastructure
Social	social acceptance and cultural

	lack of public awareness and participation public attitude
Political	recruiting un-qualified people in decision making positions fragmented regulations and legislations political stability lack of governmental support to initiatives from the private sector and NGOs complexity of the approval procedure government's lack of confidence in national capabilities energy is not a priority for the government
Managerial	absence of a national waste management strategy absence of privatization lack of capacity building paucity of trained manpower deficiencies in waste management legislations poor planning scarcity of accurate and reliable background data and information
Economic	high cost lack of incentives to investment cost effectiveness lack of investment fuel cost is subsidized lack of market of the end products

	no structured tariff Insufficient funds

Theme 1: Technical

Segregation at source

All experts agreed that waste segregation at source is essential to enable and succeed in any waste technology adoption in Bahrain. Expert 4 claimed that: *"segregation at source is considered a key factor to succeed any technology adoption, though one challenge is the availability of space inside homes to segregate waste at source since the containers number might not be less than 3…"* This indicates that most houses in Bahrain are small in size and may not be designed properly to accommodate more than one waste container, which represents a barrier to segregation at source, and in effect, an impediment to successful technology adoption. Metson and Bennett (2015) investigated that organic matter separation from solid waste and recyclables is essential to divert food and yard waste from landfills, and treat organic matter appropriately, which supports our results. Furthermore, Expert 4 mentioned scavengers and absence of penalties as the main barriers to segregation at source as an internal issue; he said: "*scavengers are looking for aluminium cans, plastics and cardboards. The absence of penalties makes them "steal" the segregated items from any current segregation trial points to sell them since the plastic market price is affordable (30BD/tonne)…"*

Therefore, it is essential to formulate deterrent penalties in order to prevent the theft of segregated wastes by scavengers and commence segregation at source successfully.

Infrastructure

Expert 5 mentioned that: "*availability of supportive infrastructure is an important enabler to any technology adoption…"*

Availability of land

Expert 4 said: "lack of land availability for the project is a barrier since the sea reclamation to provide land in Bahrain has a very high cost…" Therefore, the availability of land represents an important enabler that may specify the technology's suitability for adoption.

Availability of technology

Lack of locally-available technology represents an important barrier to technology adoption, according to the experts. Lack of technologies adopted in the area makes it difficult to adopt new technologies in the country, which is a barrier to any technology adoption, according to Expert 11. Expert 5 said: "*The society is very low in technology management…*" which reflects the immature availability of expertise with regard to new technology adoption.

Theme 2: Social

Public awareness

Moreover, all experts mentioned that public awareness represents a key enabler to any waste management technology adoption in Bahrain. Metson and Bennett (2015) argued that the lack of knowledge about management of waste in general represents major barriers to waste management. Expert 2 illustrated the role of education at an early stage in improving public awareness, which will contribute in preparing the floor for technology acceptance, he claimed: "*public awareness must start at very early stage in life by improving children school curriculum to raise public awareness in order to prepare the ground to transform the community to be smart enough to accept and cooperate with regard of any technology adoption in the future*". In addition, Expert 4 stressed upon the importance of smart purchasing habits in lowering waste generation that reflects a high awareness toward waste management. He said: "*raising public awareness for source segregation at first is an important issue. In addition to awareness of smart purchasing that helps in decreasing waste generation. We can't ignore the importance of communicating with people and understand their needs to be listened to…*"

Expert 7 agreed and mentioned the role of education in raising public awareness; he claimed that:" *increasing public awareness is a priority to start with in order to have a good waste management strategy because the power to make a change in the society starts with the education, people must be aware enough…*". Expert 8 said:" *public awareness is an important enabler in order to prepare the society for advance technologies.*"

Culture

Besides the importance of public awareness as a key enabler, as agreed by all experts, Expert 3 focused on cultural barrier as a main barrier against any waste management technology adoption in Bahrain. He argued that" "*cultural barrier is the main barrier to technology adoption in Bahrain…*" since background, customs, traditions and even religious reasons may prevent them from accepting some reusing and recycling practices as essential practices to succeed any technology adoption in the country. Metson and Bennett (2015) stated that the public culture plays an important role in the success of any management practice e.g. separate organic waste collection and composting. It was found that the concerns over organic waste bins being smelly and attracting flies, maggots, and rodents are widespread, exacerbating the challenge of changing existing habits of not segregating organic from non-organic waste. The lack of information and knowledge about waste separation and composting also impedes the adoption of the waste management plan.

Public attitude and acceptance

Public acceptance and attitude are the reflection of public awareness in the society. If a society is aware enough, acceptance of technology will be easy and the public will cooperate; consequently, their attitude and behaviour will be positive to succeed in the technology adoption. *Expert 5 mentioned that: "sometime the technology is feasible but it is not socially accepted so it cannot be adopted successfully…"*

Theme 3: Political

Expert 1 and 6 described political barrier as the most important player in the waste management sector in Bahrain. Expert 1 claimed that: "*politics represent the main barrier in Bahrain against waste management improvement and will be for any technology adoption*…" When asked about the main general barriers to technology adoption: Expert 2 said, "*it is all about politics…*" Therefore, the following subthemes were explored under political barrier based on the experts' interviews:

Lack of governmental support

As a barrier, lack of governmental support to initiatives from the private sector and NGOs was mentioned by Expert 4 who said: "*there are many initiatives from the private sector and NGOs* *that are not supported by the government*". In addition, complex procedures required by government to approve any initiative that aims to improve waste segregation and recycling practices as well as awareness among people is a barrier as he claimed*: "the complexity of the procedure in order to approve it makes it not possible…*"

Lack of strategy, policies, regulations and legislations

All experts agreed that the absence of a national waste management strategy represents a main barrier to improvement and will definitely adversely affect OHWM technology adoption in the country. Expert 4 said: "*all technologies need supportive policies to work properly, beside the governmental support*…" Expert 2 claimed that Bahrain needs to plan an Integrated Waste Management System to start any further waste management technology in the future. This is a reflection of the urgent need for a clear strategy, plan, or system that can formulate and coordinate waste management sector in the country.

Expert 3 described the existing regulations as fragmented, which represent another barrier to technology adoption within the country, as he claimed: *"the fragmented regulations and legislations here in Bahrain, makes the government to concentrate on hazardous waste management and general environmental issues and neglect the MSW management*…" Moreover, Expert 9 said: "*there are no regulations for tariff for renewable energy projects in Bahrain, and in general the lack of effective regulations is an important obstacle to waste management technologies adoption…*"

Moreover, Expert 11 thought that the focus by the government must be on reducing, reusing and recycling initiatives: "*Bahrain requires a waste management sustainable development agenda regarding minimization of generated waste, reuse and recycling as a main priority*." He added: "*poor planning and lack of waste management legislation are barriers in addition to the absence of strategic waste management plans…"*

As a positive initiative from the government, which might be considered an enabler according to Expert 9, "*the government has recently established the new Sustainable Energy Unit (SEU) which belongs to the Ministry of Electricity and Water Affairs (EWA), and it may improve the regulations in this regard*…"

Expert 2 believed that "*current legislations and regulations support any practice that is safe and feasible and possible based on its nature and assessment for Bahraini context*."

Political stability

Expert 3 mentioned political stability as a key player that could affect investment in waste management; therefore it represented a barrier against technology adoption. *He claimed:* "*Political stability affects the investment…"* Since Bahrain has been undergoing political instability since 2011, experts thought that it may affect investment in the country, including investing in WM projects.

Centralization of responsibility

All experts agreed that the efforts of waste management in Bahrain must be centralized under one umbrella. In this regard, Expert 6 said, "*the absence of interlink between the whole system parties represents a barrier since it is a nexus, so efforts must be integrated and complementary…"* Furthermore, Expert 10 said, "*there are several bodies responsible for waste management in the country, from government, private sector, NGOs…etc. who are responsible for each part of waste. This leads to weakness of waste management process in the country*." Expert 3 agreed and said*: "it is important to create a Waste Management Directorate which is a kind of centralization of the waste management responsibilities. The government concentrate on the hazardous waste and general environmental issues and there is no focus on the MSW management at all. There is no central authority which is totally responsible to manage waste sector which makes it out of proper control and coordination…*"

Recruitment Policy

Government's lack of confidence in national capabilities was frequently confirmed by many experts. Expert 6 claimed that, *"the government depends on foreign experts who miss the perception of the nature of our countries and ignore the national expertise in many situations…".* Furthermore, Expert 1 said: *"the decision makers are listening and recruiting people representatives in the municipality councils who are not well qualified and their knowledge is very limited to specific areas but still they gave themselves the right to say wrong information and they are listened to by the government. The government is recruiting the wrong people and making decisions based on this, it's all about political considerations…"* whereas Expert 4 claimed *"the* *main barrier in Bahrain is that there are many unqualified persons in the decision making positions, which makes an obstacle against improvement…"*

Theme 4: Managerial

Shortage of capacity building

Many experts believed that the shortage of capacity building was an important barrier to the adoption of waste management technologies in Bahrain. Expert 11 claimed that *"shortage of skilled manpower and deficiencies in technical and operational decision-making are important barriers to technology adoption…"* Expert 8 agreed and said "*well trained manpower is required including expertise to operate them…*" In addition, Expert 6 believed that there is no capacity building in Bahrain, which represents a barrier to any technology adoption in the future.

Privatization

Many experts believed that the waste management sector in Bahrain must be managed by the private sector and not directly by the government, in order to create more opportunities for improvement and open competitiveness to investment which then leads to create innovative solutions in the waste management sector, create job opportunities that leads to lower unemployment in Bahrain, as well as better quality of life and reputation. Furthermore, privatization may lead to the lower cost of disposal to the government, as Expert 1 said*: "to privatize the final disposal will minimize the cost…*" Expert 2 agreed: "*private sector is better to manage the waste sector…"*

Availability of supportive information

It is important to provide information in support of the application of technologies by the government. Experts agreed that the lack of related data and information about waste generation rate, volume, distribution per area, sufficient and full statistics on waste, etc… are important in order to have a full view of the waste generation in the country. In this regard, Expert 11 said*: "scarcity of reliable data and accurate information on the solid waste status in Bahrain is another barrier to technology adoption*…"

Theme 5: Environmental

Environmental impacts

Environmental barrier was mentioned directly only by Expert 2 who said, "*The government supports any technology that doesn't have environmental impacts and harmful effects on human health and environment."*, while other experts mentioned the environment as an important enabler indirectly within their answers on the other questions of the interview which is an indication of the high importance of this theme for OHWM technology adoption in the country.

Theme 6: Economic

Fuel cost subsidy and oil dependency

Another techno-economic barrier was clarified by Expert 8 who claimed, "*Bahrain is an oil country, which means that there is no need for a new energy resource practically, and the fuel cost is subsidized by the government which means the availability of fuel in low cost. This represents a barrier against the waste-to- energy projects initiatives in the country, because getting energy is not a priority for the government…"*

He added: "*These projects might be attractive for the government by changing the point of attraction, when the priority from the project was to reduce the waste volume, get rid of odours, and have a safe disposal then these technologies might be more attractive…"*

Expert 9 added that the government subsidizes fuel cost and electricity, which is why they are available at a low cost, thus representing a barrier to the waste-to-energy technologies deployment. Therefore, the motivation for the government to adopt waste management technologies is not to have a new source of energy, since the fossil fuel is available in quantities that can secure the next generations, especially after the recent discovery of the largest oil well in Bahrain history, although the government may find it more attractive to use motivation such as enhancing the scene and getting rid of environmental impacts accompanying waste dumping.

Lack of incentives to investment

Many experts agreed that the lack of incentives to investment in waste management technologies was considered to be a barrier to their adoption. According to Expert 8 *"the lack of the incentives to the investment in these projects represents another barrier, so these projects never get green light…"*

Expert 2 said in this regard, *"incentives are needed to attract investment in this sector in Bahrain since the lack of incentives to attract private investment is a barrier to improve waste sector and adopt new technologies in Bahrain…"*

Furthermore, Expert 3 added, *"Lack of investment represent a major barrier to technology adoption in Bahrain. It needs to encourage investment in waste recycling and waste management projects…"*

Meanwhile Expert 9 believed that *"there are no incentives to the green technologies including the renewable energy projects in Bahrain, and they are not economically desirable. In addition to the lack of structured tariff with low tariff proposals for government and no incentives…"*

Moreover, Expert 10 opined, "*the budget designated for the waste management is very low, this will lower the investment in this sector and makes it not attractive to investors…"*

Economic feasibility

Undoubtedly, economic feasibility of the waste management technology project assumes significance. Almost all experts mentioned that the high capital and operations/maintenance cost of a technology represents a major barrier to its adoption, especially if the benefits are unable to recover the cost; therefore, the project will not be economically feasible. Expert 9 claimed that economic aspect is the most important barrier in the country: "all technologies *need feasibility study and all goes back to the economy…"* Expert 10 added*:" these projects are not* economically *feasible, and not cost effective…"* Meanwhile Expert 8 believed that "*the waste management technologies are not economically feasible nor attractive…"*Finally, expert 1 claimed that: "*the waste management is costly to the government…"*

Lack of market of end products

According to the experts, it is very important for the end products to have a market. The lack of the market of the technology end products represents a barrier to technology adoption. Expert 11 said: *"insufficient funds and insufficient demand for recycled products in the local market are important barriers to adoption…*" Analogously, Expert 10 said, "*there is no market for the end products of these technologies in Bahrain…*" which makes it difficult to sell the end products locally and depend on international demand.

Discussion

Mutz et al. (2017) stated that WtE technologies can improve waste management in the fast-growing cities of developing and emerging countries but added that its application is complex and must consider, amongst others, the following barriers:

1. Lower calorific value in MSW than in industrialized countries owing to the high moisture (high organic content) and mineral content in waste (e.g. ash, construction and demolition waste);
2. Substantial seasonal change in waste composition (i.e. changing consumption patterns during festival seasons, seasonal crops);
3. Limited practice of waste segregation at source, a precondition for anaerobic digestion;
4. Weak business and operation models;
5. Lack of knowledge on operating and maintaining WtE plants;
6. High investment and operating costs which cannot be recovered by existing waste fees and generated additional income from energy sales alone;
7. Neglecting livelihood issues for marginalized persons and informal sector workers based on the availability of recyclables in the waste;
8. Lack of monitoring and weak enforcement of environmental standards, leading to public health issues.

These barriers are the same of Bahraini context since the lack of waste separation at source coupled with the lack of information and public awareness represented by people perception, attitude and behaviour may play stymie the successful adoption of OHW management technology. This hypothesis therefore was tested in this Chapter through experts' interviews.

Summary

At the end of this section, the general enablers and barriers to OHWM technologies adoption were explored. As explained above, general barriers to technology adoption are more than enablers, which underpins the need to have a governmental clear plan in order to enable any waste management technology adoption in Bahrain. The lack of evidence based studies that resulted in listing the main enablers and barriers to waste technologies adoption in the GCC countries contribute to the much-needed knowledge in this area that can enable researchers and decision makers in these countries to reach a successful technology adoption in future apart from helping them overcome the barriers. To that end, Figure 7.2 illustrates the themes and sub-themes shown above.

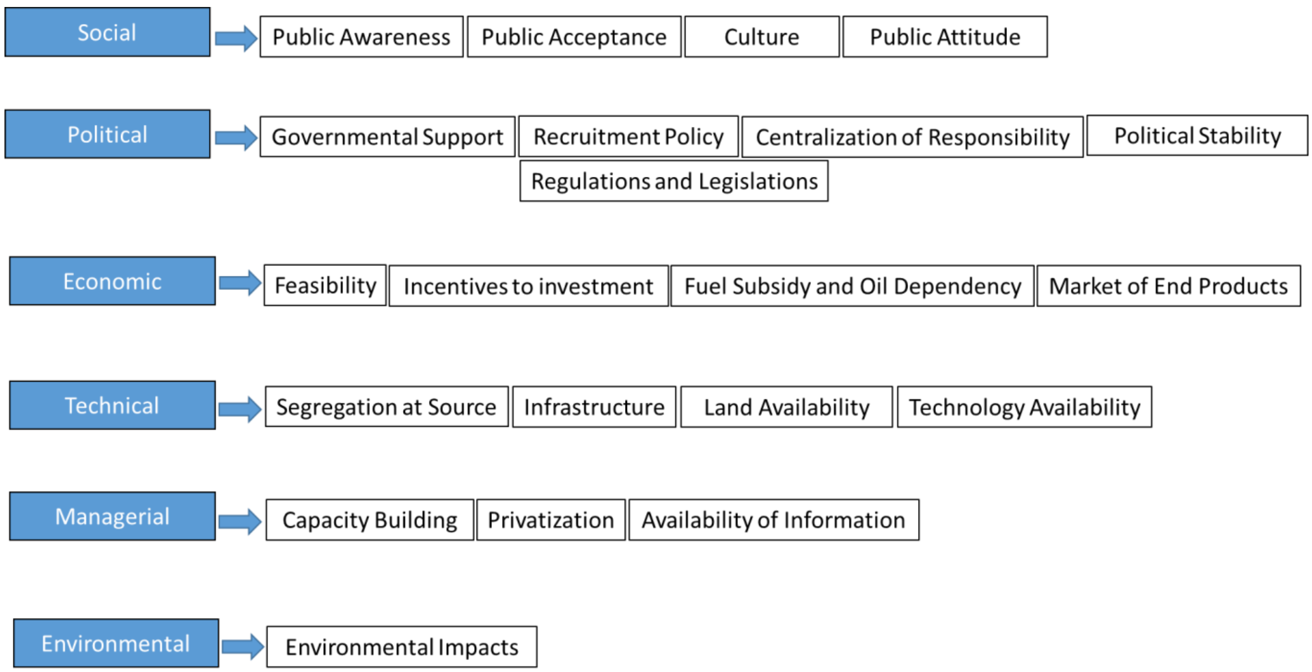

Figure 7.2: Themes and sub-themes from experts representing general enablers and barriers to technology adoption in Bahrain

7.3.2 Identification of Enablers and Barriers to AD adoption

In addition to the general enablers and barriers to technology adoption in Bahrain, experts were asked about the enablers and barriers to anaerobic digestion (AD) technology adoption in Bahrain. Table 7.5 highlighted the subthemes to have emerged within each theme for enablers to technology adoption in Bahrain.

Table 7.5: The subthemes emerged within each theme from experts for enablers to AD technology adoption in Bahrain

Environmental	Emissions are low Safer and cleaner technology to environment compared to thermochemical conversion technologies.

The only AD enabler theme mentioned directly by experts was that of the environmental theme. The other themes were not mentioned as enablers, but as barriers, as shown in table 7.6. Since there is a need to identify barriers and overcome them to enable a technology, the focus will be on the barriers, as was evident during the in-depth interviews with experts. Accordingly, all experts mentioned barriers to AD technology adoption in the country, as delineated in table 7.6:

Table 7.6: The subthemes emerged within each theme from experts for the barriers to AD technology adoption in Bahrain

Technical	need harvesting time low efficiency lack of source segregation complexity lack of infrastructure lack of locally-available technologies end products with unknown quality
Social	moral barrier lack of public awareness cultural barrier low social experience in technology management
Political	lack of governmental support to complicated projects lack of governmental policies and strategy
Managerial	needs labour to segregate need highly skilled and trained manpower
Environmental	environmental impacts risk

	negatively affects air quality
Economic	expensive with high cost economically unfeasible end product has no market in Bahrain needs incentives not economically attractive

Theme 1: Technical

Harvesting time and Efficiency

The quotes Expert 9 sum up this sub-theme: "*AD has a disadvantage, it needs a long harvesting time that reaches up to 21 days, so it depends totally on the microbial activity, which makes it a sensitive situation and you cannot guarantee a consistent level of end products and efficiency…"* Therefore, it is clear that long harvesting time as well as the totally dependence on microbial activity, which leads to instability in the products generation rate and amounts will definitely affect the process efficiency, quality and marketability of end products. Expert 9 added, "*This makes the AD more complex and needs more maintenance since each tonne will lead to only 50 percent of by-product that reflects the low efficiency…*" Expert 11 agreed: *"it is a biological process that totally relies on the initial input of waste material...*" which again reflects the sensitivity of the process in that it is totally dependent on the quality of feedstock as well as microbial activity.

Lack of segregation at source

All experts agreed that segregation of waste at source is highly important to apply AD technology efficiently, and the absence of waste segregation at source makes AD not applicable in large scale. Expert 1 said: "*AD needs segregated waste and waste in Bahrain is mixed, so pre-treatment might be needed which makes it a difficult solution…"* Furthermore, Expert 2 said*, "there is no source segregation in Bahrain, and the mixed waste is not suitable for AD…"* Expert 3 added that unsorted waste may damage the digester that operates the process and lead to failure: "*lack of source* *segregation is a main barrier to AD since it is very sensitive for example high content of fibres may cause clogging up the digester and lead to failure in the whole process…*" while Experts 4, 5, 10 and 11 agreed that the waste segregation at source is highly necessary to enable AD technology adoption.

Complexity

Many experts agreed that AD is considered to be a complex technology in the Bahraini society, and opine that its complexity represents a barrier against its adoption. Expert 1 said, "*It is a complex technology compared to incineration, complex with regard to its operation and maintenance…"* Moreover, Expert 2 claimed: *"it is highly complicated to be operated in the Gulf area, it is very advance to start with as an alternative to landfill…"* This indicates that the country is not ready to use this technology as a main alternative to landfill due its underlying complexity and hence, there is a need to prepare the society first, which will be discussed in the social theme later. In addition, Expert 5 said, "*it is complicated for Bahrain…*"

Technology locally-availability

Expert 1 stated: "*AD is not very common in the GCC countries*…" which makes it a weak alternative to decision makers who are always looking for tested technologies in the region. Expert 2 concurred, "*it is a new technology in the region…"* For this reason, it is unlikely to be chosen as an attractive option to manage the OHW in Bahrain. Expert 11 stated, *"Lack of locally-available technologies*" is a barrier to AD technology adoption.

Lack of infrastructure

Expert 10 claimed that in order to adopt AD, "an *adequate infrastructure is highly required…"* and the dearth of infrastructure needed by all the AD process stages makes it difficult to apply. Infrastructure means the suitable buildings, facilities and the overall setup required in order to operate the technology. Expert 2 observed, *"The lack of infrastructure is a barrier to AD adoption*…" Expert 10 supported the views of other experts: "AD *need infrastructure which does not exist*…"

Theme 2: Social

Moral barrier

Expert 2 mentioned that: *"moral barrier against the succession of AD technology adoption in the country is important..."* since people's morals toward environmental issues might not be mature enough which –at the end - reflects their level of environmental public awareness and in effect, lead to high or low level of cooperation with regard waste source segregation in order to adopt AD successfully.

Lack of public awareness

Lack of public awareness is the most frequently mentioned theme as a barrier to all technologies both generally and specifically, which underpins its importance. Expert 3 said in this regard: "*public awareness needs improvement toward separation and recycling to enable AD…*" Besides, Expert 11 mentioned that lack of public awareness is a main barrier in the successful adoption of AD technology in the Bahraini society.

Culture

Expert 3 stated "*cultural barrier is important*…"In order to shift the society to a more careful society towards waste management, there is a need to work culturally and improve public awareness, as most experts argued.

Society experience

Expert 5 claimed that *"the society is very low in technology management experience…"*

Theme 3: Political

Governmental support

Since AD was described as a 'complicated' technology by all experts, Expert 2 argued that:" *governmental support usually goes to simple and guaranteed technologies but doesn't go to complicated projects…"* which makes AD unfit for support of government which is an important barrier to AD adoption in Bahrain.

Governmental policy and strategy

Expert 10 said:" there is no policy for segregation", while Expert 11 highlighted:" lack of governmental strategy "represent an important barrier to AD adoption.

Theme 4: Managerial

Labour for Segregation

Since the type of waste is mixed in Bahrain, and in order to adopt AD, additional labour must be provided in order to segregate waste since there is no mandatory waste source-segregation policy in Bahrain. Expert 3 mentions: *"at first it needs labour to segregate…"* that may add to the cost.

Highly skilled and trained manpower

In order to operate an AD plant, Expert 1 said, *"It needs highly skilled and trained manpower".* This makes the need to design special training programs by experts as well as professionals for capacity building in the country that may add the cost.

Theme 5: Environmental

Air Quality

Under this theme, Expert 5 said: **"***Bahrain has a serious problem of air quality, AD may not be a good option and it will worsen the problem…"*

Environmental impacts risk

As Expert 5 said*: "AD has environmental impacts risk…"* Expert 11 added that *"if waste already contains toxic matter, then the end fertilizer will not be free of toxins which will be harmful to the environment…"*

Theme 6: Economic

Feasibility and High cost

Expert 1 said: *"It has a high cost, beside the pretreatment that is needed, this makes it a very expensive option… so it is economically not a feasible solution…"* Moreover, Expert 5 added *"feedstock needs pre-treatment which has additional cost, AD is very expensive and will not work, so there are economic burdens and financial loss, it is not feasible…"*

Expert 3 remarked: *"the high tipping fee of the AD project makes it not economically attractive e.g. the current cost of waste dumping is less than 1 BD/ton, then it may jump to 50BD/tonne which is a very big change…"*

Financial support

Expert 2 observed: *"the lack of financial support beside the high operation and maintenance cost all make it a difficult option to implement…"*

Market availability of end products

Expert 1 stated that: *"the end product of the AD has no market in Bahrain, the evidence is that the methane is a combined gas already produced from the oil wells, and they just let it go and it is already available for free! So why we spend a high cost to produce an existing gas which has no attention nor value here?!..."*

He believed that recovering combined methane is a priority over spending huge budgets to establish a *"methane production plant".* Nevertheless, going back to the expert who said*: "changing the point of attraction"* to attract investment is a good way of solving the problems associated with the waste sector in Bahrain, since the priority is to get rid of waste in a sustainable way; AD in this case aims to treat and waste to begin with and then recover energy.

Expert 2 continued: *"there is no market for these end products in Bahrain*…" he referred to the digestate and power generated by AD.

Expert 3 concurred: *"the feedstock need to be clean enough or their will be no market for the low quality end product. However, there is no market for the digestate and fertiliser…"*

Incentives to investment

Expert 2 added: "it needs incentives…" to investment in AD.

Expert 3 argued *"it needs little investment in this, and the lack of investment represent a major barrier to AD technology adoption in Bahrain as it is for other technologies."*

General Discussion and Summary

At the end of this sub-section, enablers and barriers to AD technology adoption in Bahrain were explored. It was concluded that barriers against AD adoption in Bahrain surpasses enablers, which indicates that in order to enable its adoption, all of the above barriers must be overcome. This requires lots of efforts on the part of the government to improve the situation and enable technology adoption. In addition to the above mentioned barriers, the results of waste characterisation mentioned in Chapter 5, showed that some parameters (C:N) and (pH) need to be raised in order to meet the optimal range to an AD operation. Sam et al, (2017) claimed that AD systems need constant monitoring and management because they must be maintained at an optimum temperature and pH level for the proper digestion of farm manures to avoid the risk of explosions, hydrogen sulphide poisoning, and asphyxiation. Moreover, Sam et al, (2017) emphasized the importance of state financial and regulatory incentives on the adoption of AD as one of the main enablers of the technology. Furthermore, Tetra-Tech Inc. through Eastern Research Group (2010) reported that the main barriers to AD adoption in developing countries are economic: investment and high cost barriers: Installation of AD systems is capital intensive, Technological and Managerial barriers: no private sector participation, Informational access for AD technologies is difficult, Convenient availability of other sources of energy reduces incentives to invest in alternative and capital-intensive energy sources like biogas. In addition, the lack of local capacity to conduct operation and maintenance services for AD, with no specific provisions or training. Tetra-Tech Inc. through Eastern Research Group (2010) added that the lack of governmental programs, and limited private sector support to address the financial and technical barriers discussed above, make potential private sector financing wary of focusing investment in AD. Moreover, they claimed that the lack of knowledge and experience with the biological treatment technology prevents investment in these projects.

Accordingly, Barriers can be summarized in the following figure:

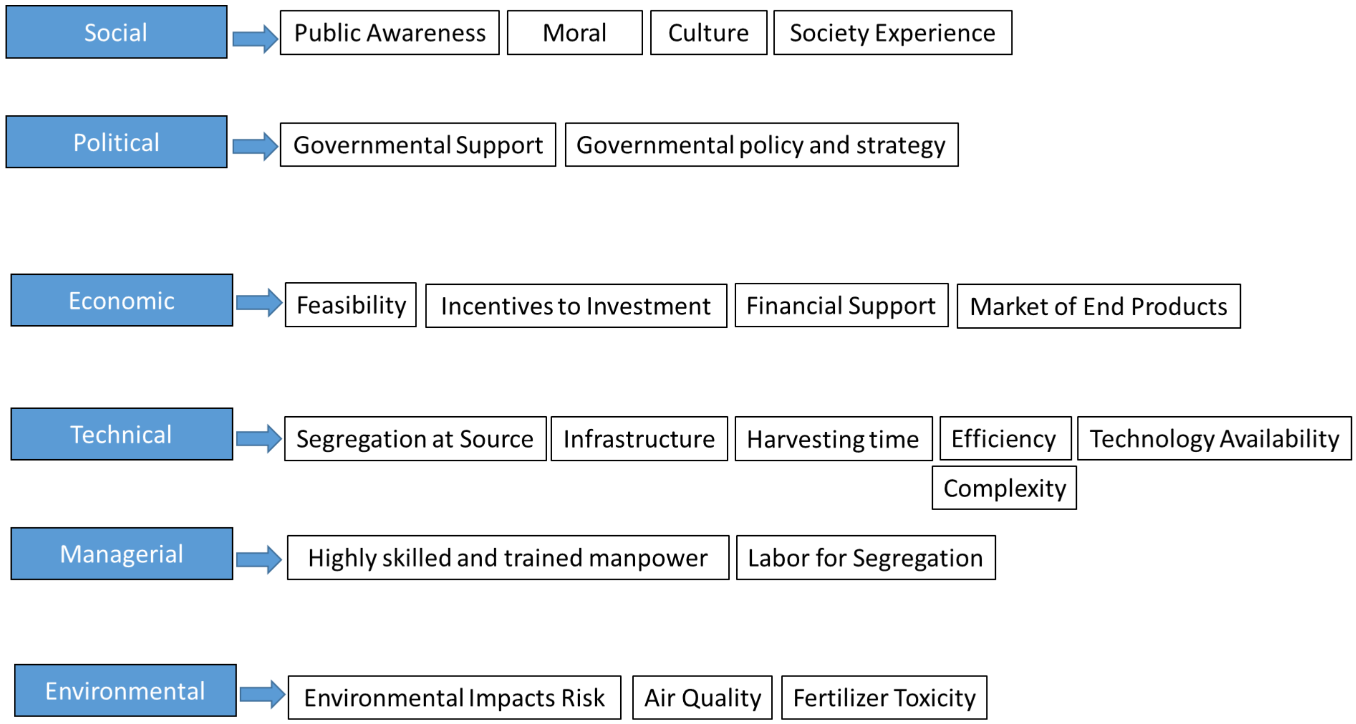

Figure 7.3: Themes and sub-themes from experts representing barriers to AD technology adoption in Bahrain

7.3.3 Identification of Enablers and Barriers to Incineration Adoption

Similarly, experts were asked *"What are the enablers and barriers to incineration technology adoption in Bahrain?"* Various responses were answered as listed in table 7.7 and table 7.8 for enablers and barriers, respectively. Table 7.7 specifies the subthemes that emerged within each theme from experts for the enablers to incineration technology adoption in Bahrain, according to the experts.

Table 7.7: The subthemes emerged within each theme for enablers to incineration technology adoption in Bahrain

Technical	reduce volume to save the limited land produce energy to generate electricity availability of technology proven in the GCC area

	simple, easy and not complicated the resulting ash can be reused
Political	governmental support to investors exists
Managerial	do not need special or highly skilled manpower few workers are needed
Environmental	safe to human and environment (using state-of-the-art technology)
Economic	financial support does exist

In addition to these enablers, all experts spoke about the barriers against incineration adoption in Bahrain, mentioned in table 7.8:

Table 7.8: The subthemes emerged within each theme from experts for barriers to incineration technology adoption in Bahrain

Technical	Waste has a high moisture content land for solar drying might be limited lack of land of safe distance (limited land) absence of segregation at source (mixed waste) low efficiency needs to have the most state-of-the-art technologies
Social	public perception of energy from waste is very negative in Bahrain lack of proper information and educational curriculums incinerator needs social acceptance low public awareness

	need to improve purchasing behaviour the problem with technology transfer, social and religious constrains are important
Political	politics represent a main barriers unqualified persons are recruited in decision making positions policy making lack of integrated waste management strategy It needs strong governmental support to invest
Managerial	needs highly qualified and skilled manpower
Environmental	has environmental negative impacts dioxin and furans emissions cause serious health problems needs air collecting model problem of fly and bottom ash disposal need to clean up gases needs continuous monitoring
Economic	energy is available in low cost and subsidized providing a suitable location is very expensive (sea reclamation) segregation needs additional cost high cost for low benefit it needs finance the electricity price is subsidized not economically feasible for Bahrain

	small budget specified for the waste management in Bahrain high operation cost, high initial cost

Theme 1: Technical

Since incineration has many technical enablers as well as barriers according to the experts, they will be discussed separately as follows:

Enablers:

Waste volume reduction

Expert 1 described this enabler as follows: "*Bahrain has a very limited geographical area, and developmental activities are increasing, so the land will be in high demand and need to reduce waste volume. Incineration is an excellent choice to achieve that…*" Expert 9 concurred*, "It is a way to reduce volume and save land…*"

Energy production

Expert 1 claimed: "*incineration leads to produce energy to generate electricity that may operate the incinerator itself or another utility…*" which -as he thought- represents a sustainable waste-to-energy option in dealing with waste. Expert 3 supported the selection of incineration technology among the waste-to-energy- technologies after combining it with waste separation; he said, "*waste-to-energy is recommended with mechanical separation, mainly incineration…"* On the other hand, Expert 4 said: *"if we were in a non-oil country, this might be a good option to get energy, since currently the biggest oil well in Bahrain history was just discovered and it will secure the next and next generations from energy…"* Hence, the motivation to incineration adoption might be just to bring down the waste volume and provide a sustainable way of waste disposal and not the energy.

Technology availability

When asked about the enablers of incineration, Expert 1 answered: "*Availability of technology, it is already applied and proven in the GCC region…"* Expert 3 added*: "Incineration is a proven solution in the GCC countries, so it is very suitable to be applied in Bahrain…"* However, Expert 4 differed from his counterpart: *"it is not a necessary that if the technology was commonly used* *so it is the best or our country…"* which lowers the importance of technology availability as an effective enabler of incineration in Bahrain.

Simplicity

Expert 1 revealed that: *"it is a simple technology, not complicated, it is very suitable to be applied in Bahrain…"* On the other hand, Expert 7 claimed, *"it is simpler and easier than pyrolysis and gasification…"* In addition, Expert 3 said: *…"beside it is simple compared to other technologies…"*

Reusable ash

Expert 1 claimed*: "the resulted ash can be reused…"* which meant he did not consider it to be a big problem.

Barriers:

High moisture

As previously discussed in Chapter 2, incineration needs a low moisture content of feedstock in order to operate efficiently. As the experts mentioned, high moisture content of OHW may be a barrier to incineration. However, Expert 1 opined: *"the high moisture of OHW is easy to be pre-treated by solar drying…"* since Bahrain has a hot weather.

Land limitation

Despite his defence and strong support to incineration as the most preferable technology in Bahrain, Expert 1 stated *"the land for the solar drying process might be limited…*"

Furthermore, many experts talked about the lack of suitable location for the incinerator with a safe distance from the residential area to avoid any possible environmental impacts that may affect human health. In this regard, Expert 2 believed "*incineration adoption in Bahrain is difficult because Bahrain is small, lands are limited, and so the absence of suitable location is a barrier. It has to have a safe distance from the residence…"*

Lack of segregation at source

Most experts concurred that the lack of segregation at source affects incineration efficiency. Even though experts clarified that segregation at source is not as important as it is for AD technology adoption, it, if not well controlled, may lead to lower efficiency and produce harmful emissions. Thus, Expert 1 opined that the lack of segregation at source might be an enabler to incineration adoption and not a barrier, as Expert 4 believed.

Low efficiency

All experts agreed that if incineration will be the preferred choice, it needs to have the most state-of-the-art technologies for higher efficiency and lower environmental impacts. Expert 7 stated that an important barrier to incineration is its "*low efficiency which do not exceed 15-17percent- it operates on high temperature, and may have problems with hydrogen chloride formation which affects the efficiency of the incinerator*…"

Theme 2: Social

Enablers:

No social enablers were mentioned by any expert. However, the social factor is very important to adopt the incineration including the public awareness and public acceptance of incineration adoption in Bahrain.

Barriers:

Public perception and acceptance

Expert 3 said "*public perception of energy from waste is very negative in Bahrain…"* which may affect their acceptance of incineration technology. He added, *"it needs to improve the public perception of energy from waste…"* He also claimed: *"incinerator needs a social acceptance…"* Meanwhile Expert 4 said, "*Sometime the technology is feasible but it is not socially accepted…"* indicating the importance of social acceptance.

Educational Curriculums

Moreover, Expert 3 thought that the lack of proper information in educational curriculums is an important barrier to incineration adoption in the country, as he claimed: "*incinerator needs a social acceptance…"* which will not be realized without improving educational curriculums, especially at the early stages.

Low public awareness

Low public awareness represents a barrier to all technologies' adoption in the country, including incineration. Almost all experts highlighted this social barrier and described it as a key player or enabler to any technology adoption, including incineration. Expert 10 said, "*People are not aware enough, they might not accept having an incinerator as a main technology to treat their waste*…"

Culture

Expert 3 mentioned culture as an important barrier; he said, *"the problem with technology transfer with people culture, social and religious constrains are important…"*

Purchasing behaviour

Expert 3 stated that: *"to enable incineration, people purchasing behaviour need to be improved…"* which indicates that the current purchasing behaviour characterized by "non-smart" is a barrier.

He added: "*the problem with technology transfer, social and religious constrains are important."*

Theme 3: Political

Experts 1, 3 and 10 mainly talked about the importance of political barrier to incineration adoption in Bahrain. In this regard, Expert 10 claimed that "*political barrier is important…"*

Enablers:

Governmental support to investors

Expert 1 claimed, "*The governmental support to investors exists*" though "*politics represent a main barrier to waste incineration in Bahrain…*" On the other hand, Expert 3 said, "*it needs a strong governmental support to investment…"* which makes it a barrier from this perspective.

Barriers:

Recruitment policy and decision making

Expert 1 argued "*unqualified persons are recruited in the decision making positions which affects the decision making regarding incineration adoption negatively. When the developed countries are applying it and consider it safe, how we can stop against it and try to prove the opposite with no evidence?!..."*

Lack of integrated waste management strategy

Expert 10 said, *"Policy making and integrated waste management strategy adoption are very important…"*

Theme 4: Managerial

Highly skilled manpower

Expert 1 said that incineration *"does not need special or highly skilled manpower..."* and *"few numbers of workers are needed to operate the incinerator*…" as technology enablers. By contrast, Expert 5 claimed, "*it needs high qualified and skilled manpower*…" as a barrier to incineration adoption.

Theme 5: Environmental

At the time of interview, Expert 1 said that incineration is "*safe to human and environment using state-of-the-art technology…"*Expert 4 *meanwhile* said*: "using a very high and advanced technology is proven to be environmentally safe otherwise it has environmental impacts…"* Most of the experts agreed that incineration has negative impacts on the environment. Expert 5 agreed: "*it has environmental cost*…"

Dioxin and furans emissions

Expert 2 claimed that *"the main problem with incineration is the dioxin and furans emissions that cause serious health problems…thus it needs an air collecting model…"* Expert 10 added, "*Hazardous emissions of dioxin and furans might represent a risk to human health and environment…"* Furthermore, Expert 4 added*, "the incineration of unsorted waste with lower controlled combustion caused severe health problems like cancer…"* Accordingly, Expert 3 confirmed that these emissions*: "needs a continuous monitoring…"*

Fly and bottom ash disposal

Expert 2 remarked: "*the fly and bottom ash disposal which may contains heavy metals*…" and cause harm to human health and the environment.

Theme 6: Economic

Energy subsidy

Expert 2 claimed, *"Fuel can be provided in low cost…"so there is no motivation to generate power in high cost.* Expert 4 believed that "t*he cost of natural gas is low as a source of energy in Bahrain, and the electricity price is subsidized by the government, which makes incineration not affordable…"*

Economic feasibility and high cost

Expert 2 added, "*Incineration has high cost for low benefit, high cost to provide suitable land-high operation and maintenance cost, high initial cost, so it is neither economically feasible nor affordable for Bahrain…*" Moreover, Expert 1 said, "*segregation needs additional cost…"* in order to provide a safe location for the project. Expert 2 stated "*to provide a safe place, it might need to reclaim the sea to have a location of a safe distance from the residential area which is an expensive option…"*

Expert 2 added that "*incineration has high operation cost, high initial cost and high maintenance cost*…"

Lack of finance

Although Expert 1 said, *"financial support to the investors exists by the government."* Expert 3 said*: "it needs finance…"*as a barrier. This might be attributed to the strict governmental rules to provide finance, which may not be met by the incineration project due to its environmental impact. Furthermore, Expert 10 highlighted economic driver as a priority in most decision making situations in that "*small budget is specified for the waste management in Bahrain, which may make the decision makers accept a lower quality and less controlled technology just to save money…"* which represents a risk to people's health.

General Discussion and Summary

At the end of this sub-section, enablers and barriers to incineration technology adoption in Bahrain were explored. It was concluded that barriers against incineration adoption in Bahrain exceeds enablers which indicates that in order to pave the way for adoption, all of the above barriers must be overcome, which needs plenty of concerted efforts by the government to improve the situation and enable technology adoption. Bontoux, (1999) stated the barriers to waste incineration adoption are: Environment and health issues (dioxins and furans, heavy metals, CO2, NOx and SOx emissions and global warming), Economic issues (the cost of incineration, commercial competition and Fairness), Social issues (the public image of the incineration and the fear of toxic emissions, social pressure may create difficulties to set up infrastructure). Bontoux (1999) added that however, locally, state-of-the-art facilities have gained public acceptance. Technological issues are also mentioned as the trend towards more pre-treatment of the waste with separation at source may lead to lower the calorific value, thus in Bahrain, in the absence of the source-segregation of waste, it guarantees the high calorific value. And finally he stated that incineration has Management issues.

Accordingly, barriers can be summarised in the following figures:

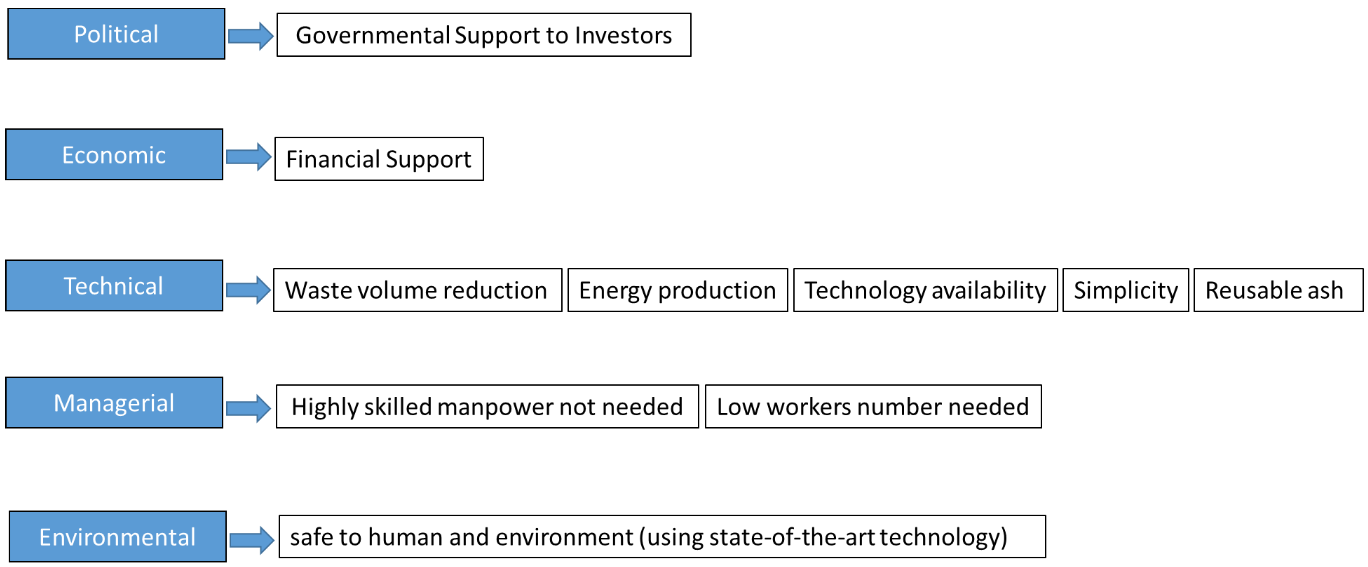

Figure 7.4: Themes and sub-themes from experts representing enablers to incineration technology adoption in Bahrain

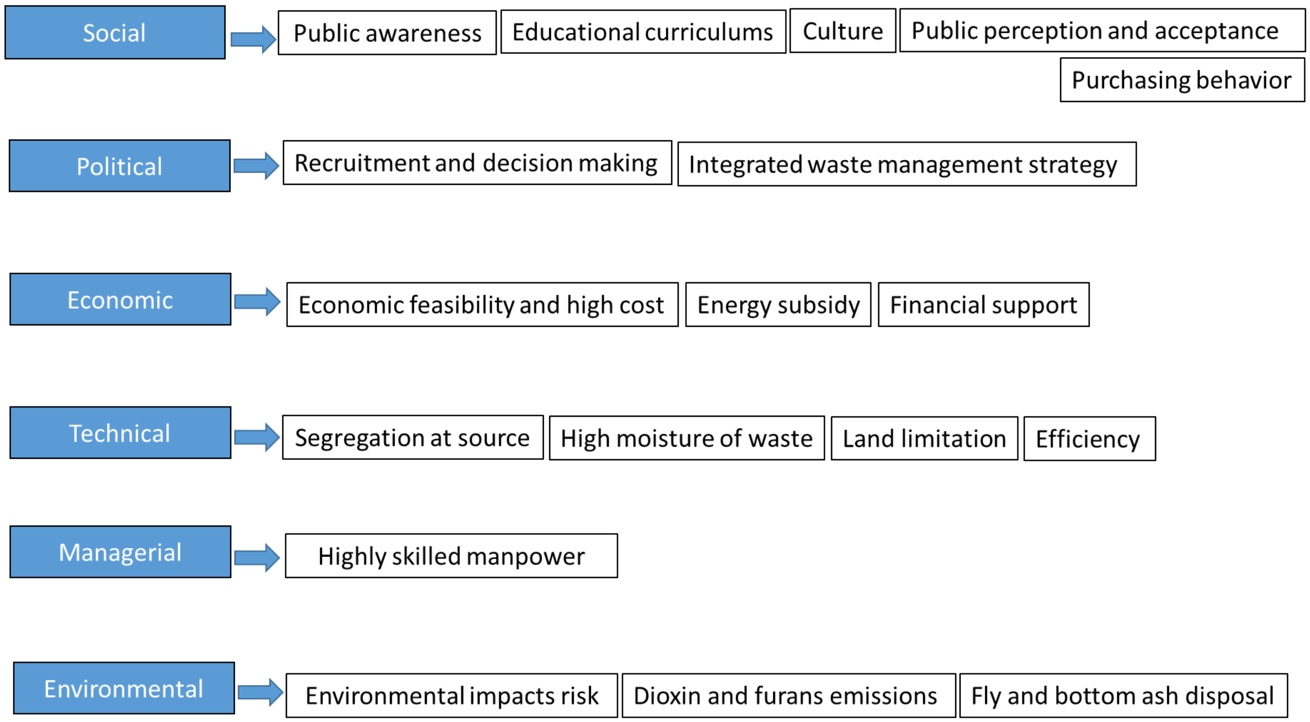

Figure 7.5: Themes and sub-themes from experts representing barriers to incineration technology adoption in Bahrain

7.3.4 Identification of Enablers and Barriers to Gasification and Pyrolysis Adoption

Experts were asked *"What are the enablers and barriers to gasification and pyrolysis technologies adoption in Bahrain?"* To this, all experts agreed that these technologies are not suitable for Bahrain for many reasons, and there are no enablers available to these technologies adoption, as was concluded from their overall responses. Barriers are listed in table 7.9, which specifies the subthemes emerging within each theme from the experts for barriers to gasification as well as pyrolysis adoption in Bahrain, according to the experts.

Table 7.9: The subthemes emerged within each theme for barriers gasification and pyrolysis technologies adoption in Bahrain

Technical	not efficient not commonly used worldwide complicated

	not yet tested in the gulf region not suitable for mixed waste (no segregation)
Social	not enough public awareness need to develop the culture at first
Political	absence of national strategy for waste management need to privatize waste management sector to enable them
Managerial	need very special training programs need very high skilled manpower limited technical experience
Economic	high cost, expensive, not feasible the end products have no market need financing instruction to developers fuel cost subsidy no incentives not economically attractive with high risk of failure

The above themes and subthemes are listed and described in details below.

Theme 1: Technical

Efficiency

Technology availability

Lack of segregation at source

Complexity

Theme 2: Social

Lack of public awareness

Culture

Theme 3: Political

Absence of waste management strategy

Privatization

Theme 4: Managerial

Lack of capacity building

Theme 5: Economic

High cost, unfeasibility

Lack of market of end products

Fuel cost subsidy

Lack of incentives

Expert 1 summed up most of the themes listed above by saying, "*These technologies are NOT suitable for Bahrain, because of the high cost, not common in the world, complicated, need very special training programs and very high skilled manpower, and the end product of them is difficult to be used and has no market. So why to even consider them and go to hard solutions while the easier, more efficient and cheaper are available?!...*"

Expert 2 described the barriers against gasification and pyrolysis adoption in Bahrain as follows *"They are not well recognized or utilized, and not common in the Gulf region, and complicated. Small country cannot test new technology but should go to a sound operation in the gulf area…In addition of the very high cost and it is not tested in the gulf…."*

While Expert 3 said: *"They are unproven in the region, and unable to handle. They are complex technologies and not promoting…"* He added: *"direct combustion is more recommended since it is proven in the gulf region…in addition to the limited technical experience, and the need of high trained labour…"* He cited an example saying*: "risk associated with gasification lead to failure of the project in the UK..."*

Moreover, Expert 4 claimed that: *"Gasification and pyrolysis are not economically attractive, who will invest in them?! Due to the absence of market for the end products, and they are complicated…"*

While Expert 5 stated: "they are good solutions but not feasible, due to the subsidized fuel cost by the government, so there will be no market for the energy produced which is of a high cost, nor for the end products. They are complicated and need highly trained manpower…."

Expert 8 meanwhile argued *"national capacity building is strongly encouraged, public awareness is an important enabler in order to prepare the society for advance technologies*…" He added: *"there are zero incentives…"* which indicated that the lack of incentives to invest in these projects represents a barrier to their adoption as is the case for other WM technologies in Bahrain mentioned previously.

Expert 9 had an important comment about a proposed pyrolysis project for the government concerning Tubli bay in Bahrain, which suffers from sewage and waste water dumping implications. He claimed: "*small-scale project has a direct governmental support for environmental and social reasons, to save the marine life in Tubli bay which was a natural reservation area, enhance the air quality and get rid of odours and enhance the social satisfaction for this area residence…*" which reflects the priority for the government to provide support driven by social and environmental aspects in this area; this will be a positive trend by the government if the project is approved. This confirms Expert 8's view, who said: *"these projects might be attractive for the government by changing the point of attraction, when the priority from the project was to reduce the waste volume, get rid of odours, and have a safe disposal then these technologies might be more attractive …"* However, Expert 3 mentioned: "*there was a project plan to use pyrolysis for Tubli wastewater plant sludge, and it was rejected recently because it was not economically feasible nor successful…*" which again complies with the perspectives of Experts 3 and 4in that it's all about economics in Bahrain. Expert 9 justifies the importance of pyrolysis: "*with pyrolysis we can yield good syngas which is commercialized, bio char and tar which can be sold to construction materials industries, or cement plants..*." Moreover, he claimed: "*the produced syngas can be totally used by the same facility and there will be no need to use the grid fuel. We may need to use the grid energy only to start up the production…"* which will save energy in the case of the project approval.

In addition to the above answers, Expert 10 said, "*They are not recommended at all for Bahrain, they are complex technologies to start with, and there is not enough public awareness to realize the importance of these technologies and therefore cooperate effectively, so we need to build the* *culture at first…"* Emphasizing the importance of a national waste management strategy to enable advanced technologies, Expert 10 noted*: "one of the promising initiatives is that currently the government in collaboration with the private sector are now working to make a national strategy for waste management…"*

Based on the experts' responses, it was observed that the environmental aspect doesn't represent a barrier to these technologies adoption; hence, they are considered safe technologies to human health and environment.

General Discussion and Summary

At the end of this sub-section, barriers to gasification and pyrolysis adoptions in Bahrain were explored. It was concluded that barriers are dominant which indicates that all of the above barriers must be overcome. Gaia, (2017) agreed with our results in that high costs for technical development, repair and maintenance make it unprofitable. Moreover, Gaia, (2017) claimed that high moisture content dramatically reduces process energy efficiency, and varying composition and moisture content of the waste presents challenges to maintaining stable operation, which is the case with Muharraq OHW. Financial barrier lead many gasification projects to fail due to non-viability. Furthermore, Gaia, (2017) argued that gasification has already acquired a negative reputation in the public mind which represent another barrier to its adoption.

Therefore, in order to summarize the barriers to gasification and pyrolysis adoption across Bahrain, refer to figure 7.6 below.

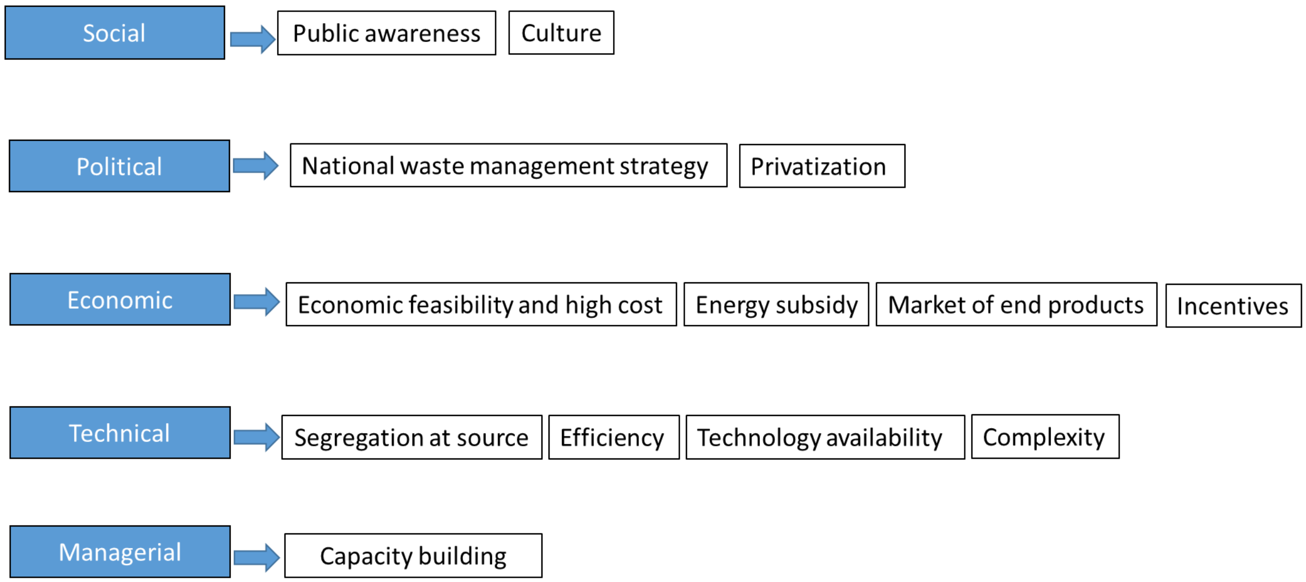

Figure 7.6: Themes and sub-themes from experts representing barriers to gasification and pyrolysis adoption in Bahrain

7.3.5 Identification of Enablers and Barriers to RDF Adoption

Experts were asked: *"What are the enablers and barriers to RDF technology adoption in Bahrain?"* All experts unanimously agreed that this technology is not suitable for Bahrain for a number of reasons. Barriers are listed in table 7.10, which specifies the subthemes emerging within each theme from the experts in terms of barriers to RDF adoption in Bahrain.

Table 7.10: The subthemes emerged within each theme for barriers to RDF technology adoption in Bahrain

Technical	Lack of segregation (mixed waste) very advanced and complicated commonly used in cement plants only need infrastructure not commonly used in the region
Economic	No market for the end product

Theme 1: Technical

Lack of segregation at source

Complexity

Technology availability

Infrastructure

Theme 2: Economic

Lack of market of the end product

Expert 2 mentioned that the barriers to RDF adoption in Bahrain were important, saying: "*Bahrain is far from it. It is very advance and too early to think about. Internationally, it is commonly used in Cement plants only and export it, it is not feasible option. It is complicated, infrastructure needed, not commonly used locally nor regionally, and no market for the end product*…" Expert 3 added: *"there is no market for the RDF in Bahrain beside the lack of the infrastructure…"* while Expert 5 claimed*: "RDF is not feasible and not recommended…"* Expert 4 agreed in that*: "it is not recommended for Bahrain"*. Furthermore, Expert 1 summarized the barriers to RDF in that "*it is a pretreatment to ease the combustion process and to increase its efficiency, but it has a high cost for very little benefits. Since the waste also in Bahrain is mixed, which make the segregation an additional cost, thus for Bahrain no need for this technology, direct incineration is enough and suitable""*

General Discussion and Summary

At the end of this sub-section, barriers RDF adoption in Bahrain were explored. Technical and economic barriers were mentioned by experts in order to describe the barriers to RDF adoption, and all of them concurred that co-processing for RDF is not a recommended technology for Bahrain. Mutz et al, 2017 argued that characteristics of waste and its suitability for co-processing and the type of industry where it is applied are important enablers to RDF adoption. As resulted in Chapter 5, Muharraq OHW characteristics found to be not suitable for this technology. He added that it needs a Cement plant with knowledge and experts for plant operation. Moreover, it needs a segregated high calorific fraction of MSW as a feedstock. Furthermore, Mutz et al, 2017 stated that a legal framework for co-processing is required, since appropriate regulation represents a precondition for applying co-processing in cement kilns successfully. He claimed that the production of RDF costs are affected by the capacity for waste handling, preparation and dosing, emissions control and capital costs, taxes and insurance in addition to infrastructure.

Therefore, figure 7.7 summarizes the barriers to RDF adoption in Bahrain.

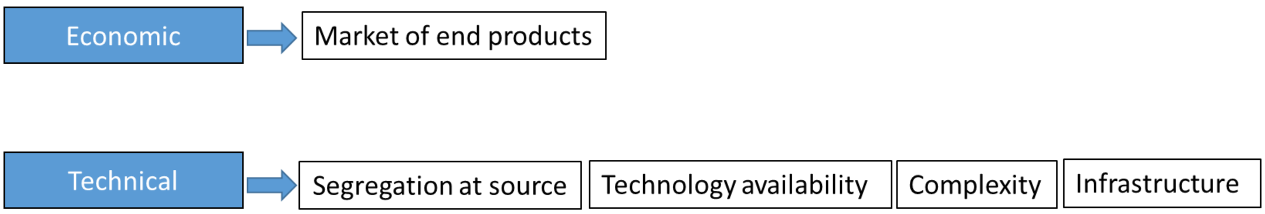

Figure 7.7: Themes and sub-themes from experts signifying barriers to RDF adoption in Bahrain

7.3.6 Identification of Enablers and Barriers to Composting Adoption

Experts were asked about the enablers and barriers to composting technology adoption in Bahrain. Most of them agreed with this option due to its simplicity, availability and cost effectiveness. Table 7.11 highlighted the subthemes emerging within each theme for the enablers to composting technology adoption in Bahrain according to experts.

Table 7.11: The subthemes emerged within each theme from experts for enablers to composting technology adoption in Bahrain

Technical	easy technology commonly used in the region and worldwide simple, not complicated no need for complex equipment does not need energy to operate
Social	well recognized by people ready public acceptance
Political	accepted by the government
Environmental	no harmful environmental impacts
Economic	viable in small scale

	low initial start-up and operation costs marketable end product, can be used locally cheapest option

Meanwhile the subthemes emerging within each theme for barriers to composting technology adoption in Bahrain, as per experts, are listed in table 7.12:

Table 7.12: The subthemes emerged within each theme for barriers to composting technology adoption in Bahrain

Technical	land limitation, needs large space needs continuous aeration absence of waste segregation affects compost quality lack of locally-available technologies biological activity is sensitive to initial inputs
Social	lack of public awareness public perception needs to improve public acceptance public experience and understanding absence of very primary principals among people
Political	absence of a national waste management strategy lack of governmental support
Environmental	needs a safe distance of at least 3 km from residence compost may contains harmful or toxic matter
Economic	absence of market of compost in-vessel composting is expensive lack of investment due to lack of incentives

Theme 1: Technical

Enablers

Simplicity

Technology availability

Barriers

Land limitation

Continuous aeration

Lack of segregation at source

Sensitivity to initial input quality

Land limitation

Theme 2: Social

Enablers

Public awareness

Public acceptance

Barriers

Lack of public awareness

Lack of public perception

Lack of Public acceptance

Theme 3: Political

Enablers

Governmental acceptance

Barriers

Absence of waste management strategy

Lack of governmental support

Governmental monopoly

Theme 4: Environmental

Enablers

Safety

Barriers

Compost contamination

Theme 5: Economic

Enablers

Viability

Low initial and operation costs

Marketable end product

Barriers

Lack of market of compost

High cost of in-vessel composting

Lack of Incentives to investment

Experts talked about the above enablers as well as barriers to composting adoption in Bahrain as follows:

Expert 1 said: "*the advantages of composting are: it has a low cost and it is an easy technology, the only thing that it needs continuous aeration…, almost all countries in the world are using this technology long time ago so it is not new…*" He continued:" *the barriers are: it needs a large area, absence of market, so marketing the end product is another main barrier and problem...*" Furthermore, Expert 2 claimed: "*the main barrier to adopt composting in Bahrain is the marketability for the end product (compost) and the public acceptance…* "*The absence of waste segregation is also a barrier in that it affects the quality of the compost, which may lead to the existence of glasses or plastics in it which makes it in low quality…"* Consequently: *"people will not buy it and will miss the trust in the local product…"* Expert 2 continued: *"the public experience* *and understanding affect this technology adoption, people need to be aware and educated, and their perception needs to be improved…"* In terms of the political and environmental aspect, he stated: *"composting is safe thus it is totally accepted by the SCE due to the lack of harmful environmental impacts…"*

Moreover, Expert 3 summed up the enablers and barriers to adopt composting in Bahrain by saying: "*there is no segregation in Bahrain, and even no market for the compost, so it is not a preferred option…*" He gave the solution to enable it: "*it can be enabled by source segregation, creating market, and give incentives..."*

He continued: "*the main problem in Bahrain is the monopoly of waste sector by the government with the absence of incentives, therefore there is no attraction to investment*…" in addition to the economic barriers, land limitation was another barrier. He believed that "*composting needs land which makes it difficult for Bahrain with the limited space…"* but he supported it by saying*: "this technology is simple and of a very low cost…*" Accordingly, in order to enable it, he suggested: "*composting can be done on the current landfill surface…"*

Expert 3 added: "*the barrier encountered the composting is the low quality of the compost, and there is a big chance to be contaminated with glasses and plastics*…" due to the lack of source segregation. Furthermore, he believed: "*in vessel composting is expensive*…"

While Expert 4 stated: *"composting is considered one of the successful and common ways to manage the OHW, it has low environmental impacts compared to incineration, and it end up with a product which is the compost that can be used locally. An advantage is it is simple technology and it has low initial startup and operation costs. But in the other hand, it needs a large area with a safe distance of at least 3 KM from residences which make it a disadvantage for a small country with a very limited area available…"*

Expert 4 summarized his thoughts about composting as an option for Bahrain by claiming: "*with segregation existence, composting is most recommended in my opinion, and in the absence of segregation, incineration using high tech is recommended*…" Expert 7 agreed and said: "*composting is the most suitable option for restaurants, vegetable and fruit wastes in small scale and this is currently the most suitable option in my opinion for Bahraini society…"*

Expert 5 agreed with Expert 7 in that he did not recommend it as a large –scale project; he said: "*it is feasible, simple, viable, but has land limitation barriers in Bahrain. So if it was adopted on small scale it will be a good option*…" He added: "*it has environmental impacts, the problem with odour…*" and "the end product might be used locally…"

Expert 10 argued: "*compared to AD and incineration, composting is the cheapest and simplest option, and do not need energy to be operated. Beside it has the lowest negative environmental impacts and is considered a safe option to human health*…"

Meanwhile Expert 11 summarized the most suitable technologies in order to manage OHW in Bahrain: "*the best options for treating organic household wastes in Bahrain are composting and anaerobic digestion (AD). Composting and AD are well-proven, widely practiced and eco-friendly organic waste management technologies, and well-suited for household waste in Bahrain which is rich in biodegradable matter…"*

When asked about other barriers, he said: "*we must remember that biological process relies on the initial input of waste material – if this already contains harmful or toxic matter, then we cannot expect to produce a pure, toxin-free fertilizer in the end result. It requires both the industry and consumer to change existing habits in order to achieve a safer outcome…"*

General Discussion and Summary

At the end of this sub-section, enablers and barriers to composting adoptions in Bahrain were explored. All themes were mentioned by experts except managerial under both enablers and barriers to adoption; some experts agreed that composting is a good option to managing OHW in Bahrain albeit on a small-scale, while others thought that it is not suitable due to the reasons mentioned above. Moreover, Viaene et al, 2016 argued that the lack of woody materials, the lack of regulations for composting, and financial and time investments, make it difficult for composting to be profitable on the short term which agrees with our results. Furthermore, the lack of experience and knowledge, besides the quality of compost all represent barriers to composting adoption according to Viaene et al, 2016.

Figures 7.8 and 7.9 illustrate themes and sub-themes from experts that represent enablers and barriers, respectively to composting adoption in Bahrain.

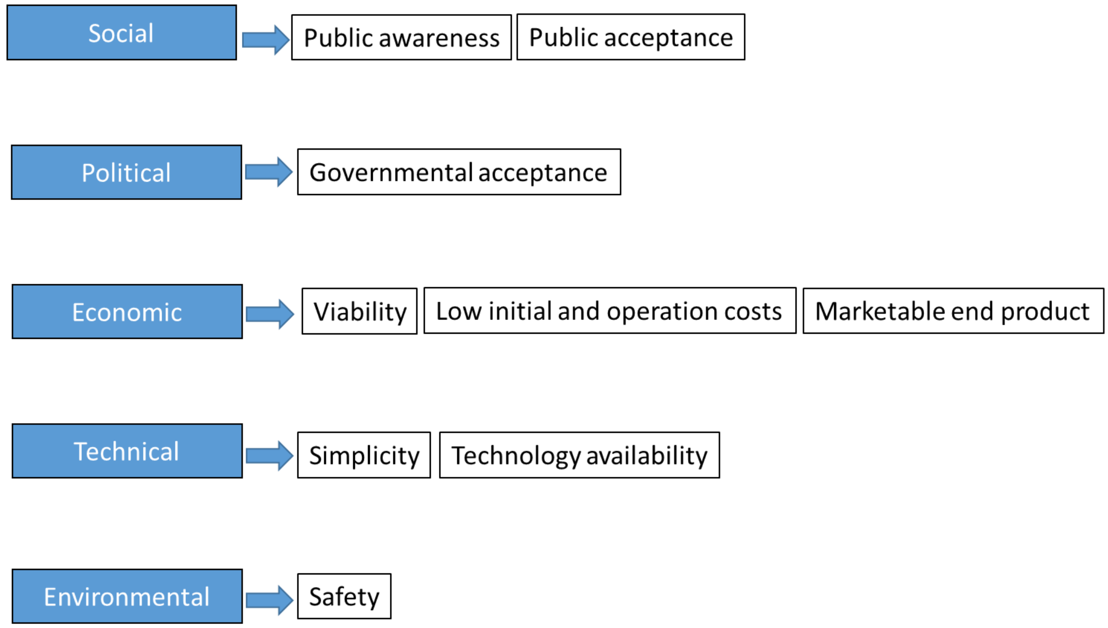

Figure 7.8: Themes and sub-themes from experts representing enablers to composting adoption in Bahrain

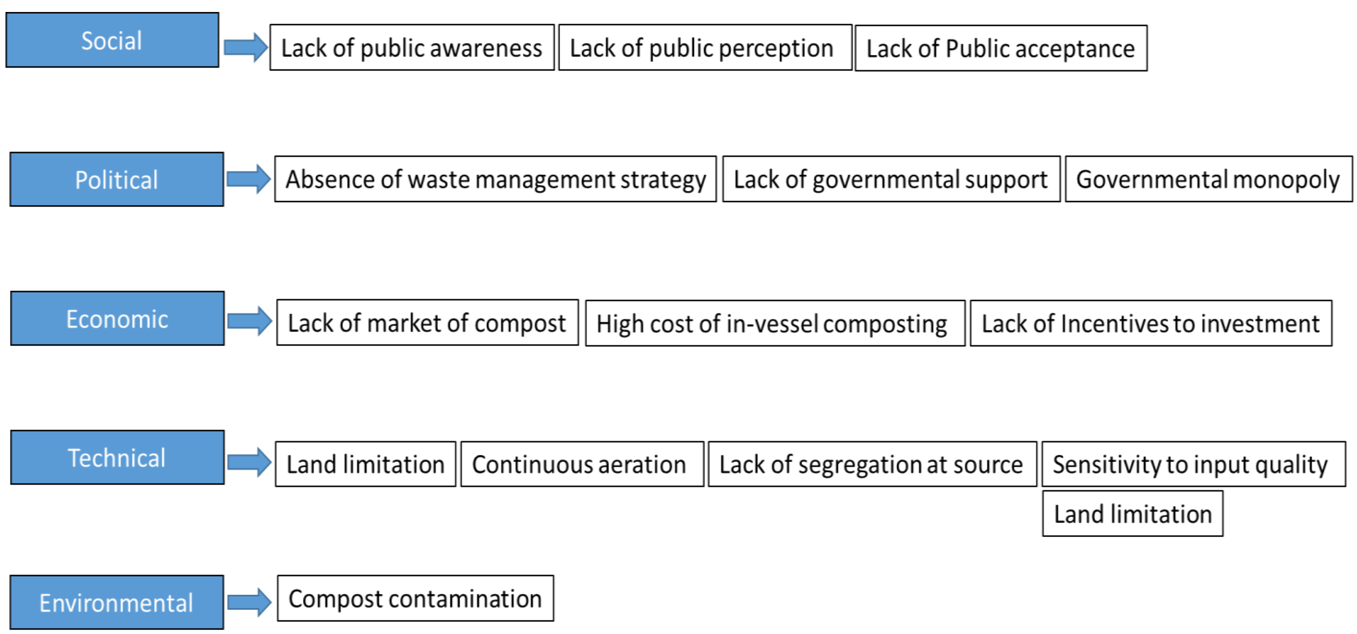

Figure 7.9: Themes and sub-themes from experts representing barriers to composting adoption in Bahrain

Summary:

In order to delineate the most frequent 10 words in the themes and subthemes representing the enablers and barriers of overall technology adoption in Bahrain mentioned in section 7.3 above, Cluster Analysis was used to create a figure using nvivo 12 software; the result is shown in figure 7.10:

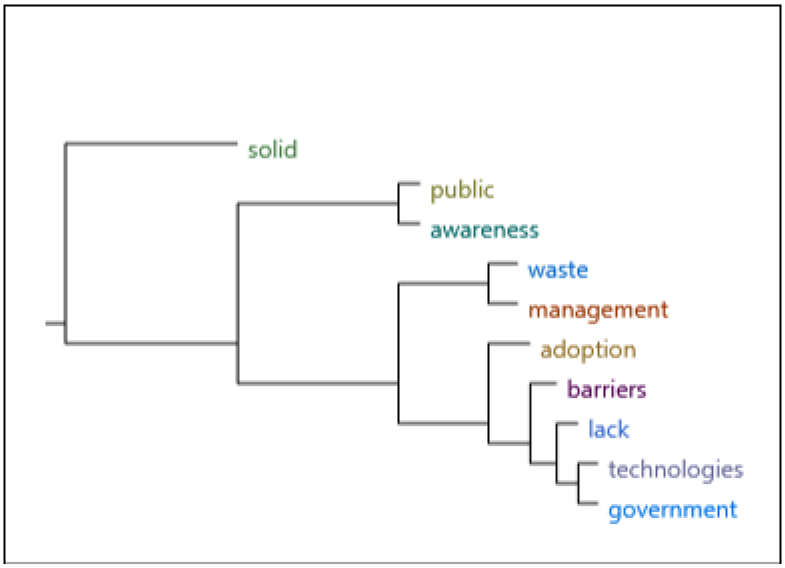

Figure 7.10: Cluster Analysis of 10 most frequent words in the themes and subthemes of enablers and barriers of overall technology adoption in Bahrain

Notably, the only valuable most frequent words are "public" and "awareness" which reflects the importance of the public awareness to enable any technology adoption in the country according to the experts, who all specified it as a main barrier to OHWM technologies adoption in Bahrain. In order to enable any technology adoption, they stressed upon the need to raise public awareness. Accordingly, Chapter 8 is specified to discuss the results of the quantitative survey that was mainly conducted to measure public awareness toward household waste management in the Muharraq Governorate.

7.4 Tree Map Analysis

Tree Map Analysis shows the significance of each scheme of the study. Figures of themes of enablers and barriers of OHWM technology adoption are mentioned below.

The study found out that as illustrated in figure 7.10, each technology has its most critical barriers against its adoption. The biggest spaces in the figure imply that the biggest coefficient value was due to most talked about barrier or enabler. For incineration for example, Environmental, Political and Technical barriers were identified by the experts as the most dominant ranging from most to least, respectively. Gasification and pyrolysis was mostly driven by economic, technical and political barriers. Composting has mostly political and technical barriers, whereas RDF has political and economic barriers. Finally, AD is mostly affected by political and social barriers. The detailed barriers are shown in figure 7.11.

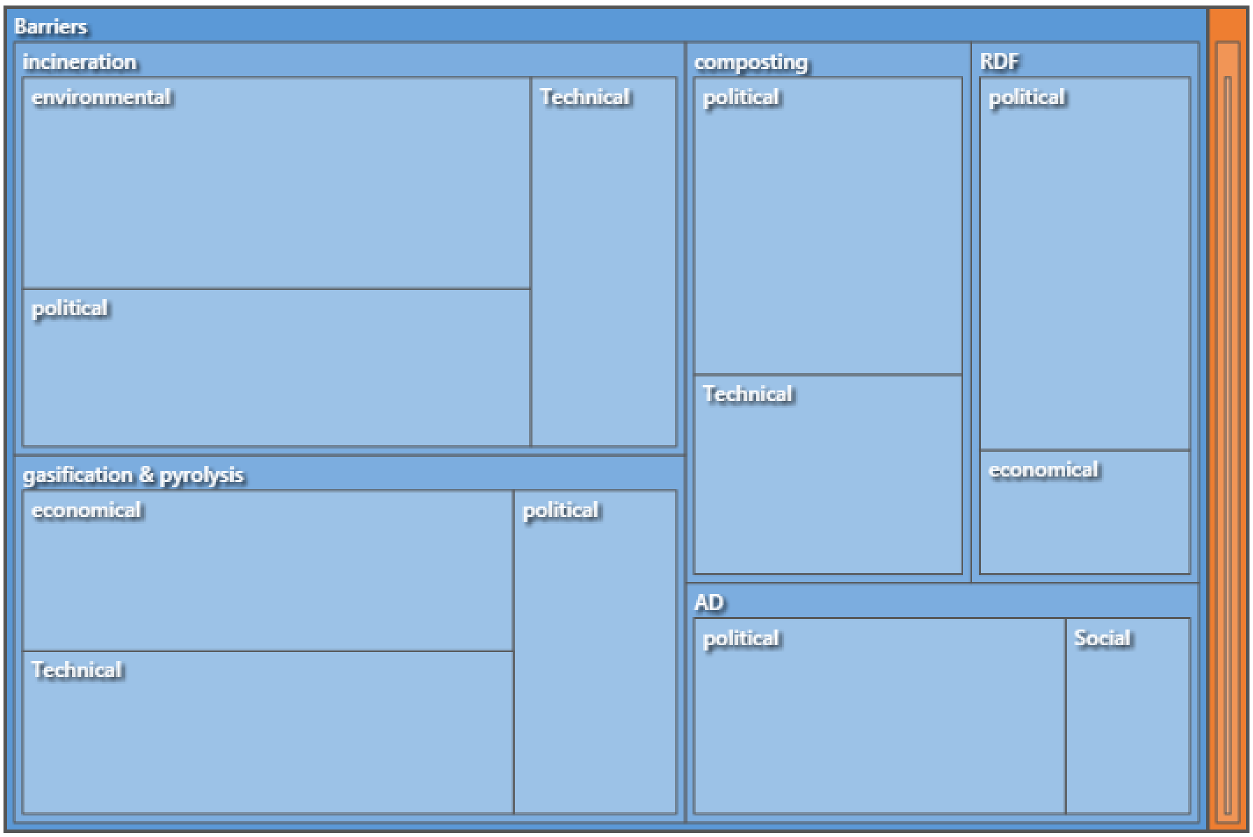

Figure 7.11: Tree Map Analysis (Hierarchal Chart Query) for Barriers

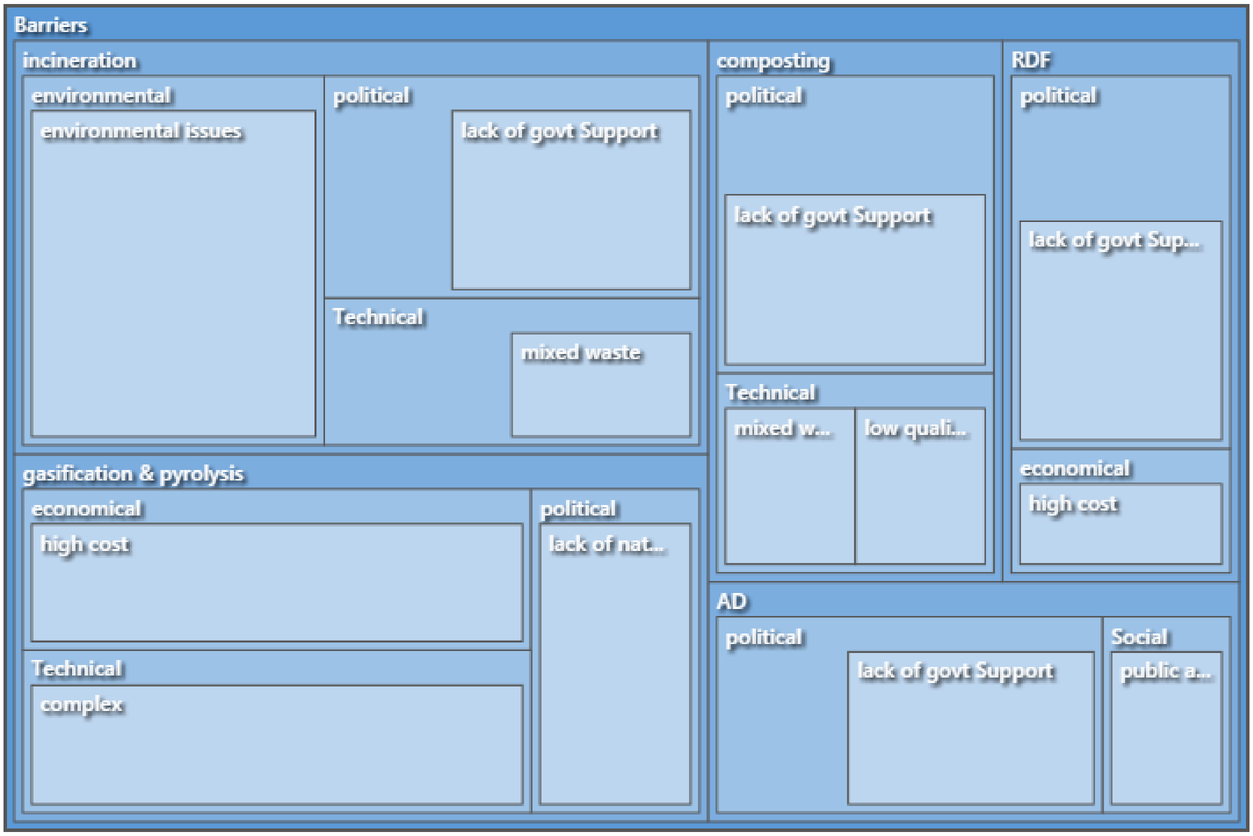

Figure 7.12: Detailed Tree Map Analysis (Hierarchal Chart Query) for Barriers

Most barriers were against incineration which is reflected by the biggest area in the tree map analysis. Similarly, most dominant enablers to technology adoption which were talked about by experts were determined using the Tree Map Analysis; the results are shown in figure 7.13 and 7.14. Importantly, only composting, AD and incineration currently had enablers in Bahrain according to experts, whereas RDF and gasification and pyrolysis do not have those enablers. Moreover, based on figure 7.13 and 7.14, it is apparent that the social enabler represented by public awareness is most effective for both composting and AD, while technical enablers are the most dominant in the country for incineration adoption.

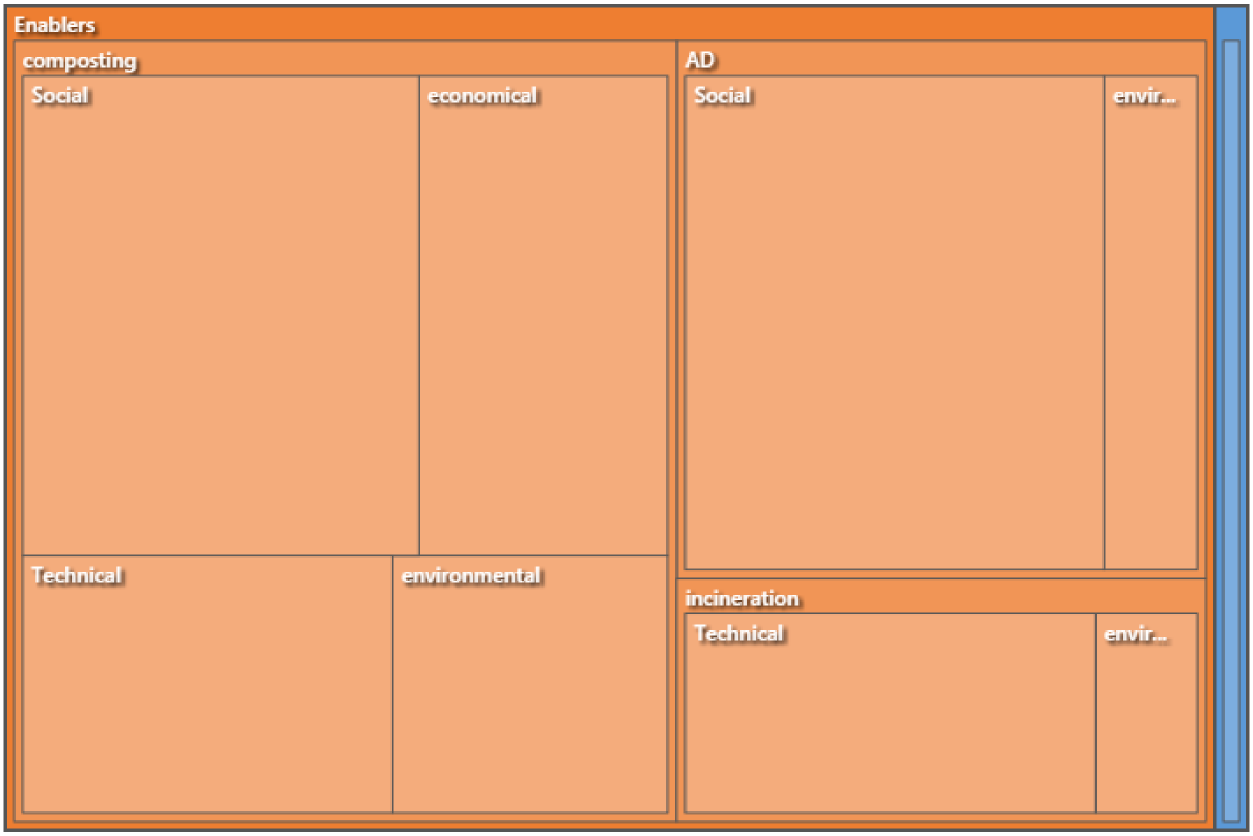

Figure 7.13: Tree Map Analysis (Hierarchal Chart Query) for Enablers

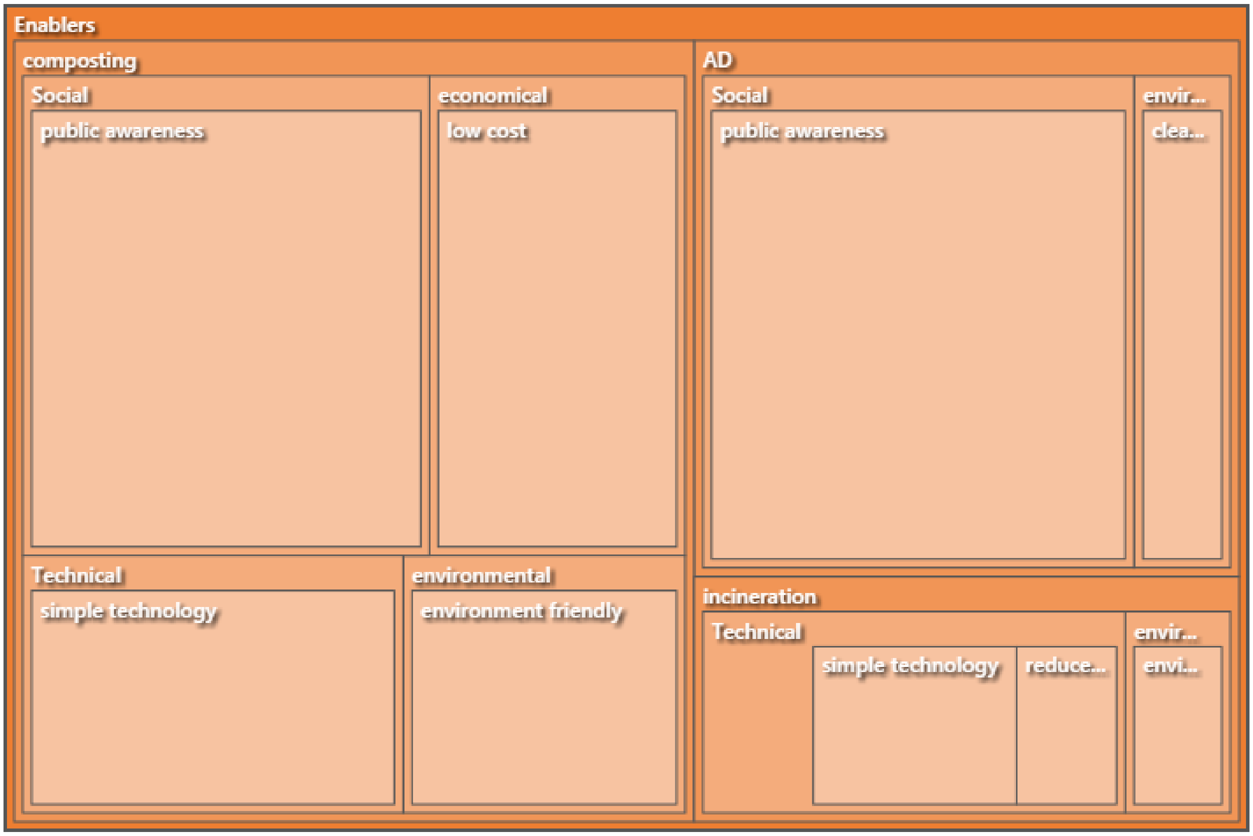

Figure 7.14: Detailed Tree Map Analysis (Hierarchal Chart Query) for Enablers

Despite the above results, social factors emerged as most critical enabler of OHW adoption in Bahrain, according to experts. This social factor is represented by public awareness. People need to be aware enough to cooperate in order to succeed any technology adoption starting from prevention and reduction practices of waste, waste segregation at source, toward commitments to waste management regulations, which contribute to the establishment of a successful waste management strategy in the kingdom of Bahrain. Expert 7 said: "*the efforts must be focused on public awareness to reduce waste generation from source as a main priority by the government, because when you encourage a technology adoption by enabling it, this means that indirectly you are encouraging the waste generation to increase the feedstock availability and prove that the waste generation is a good practice! So producing more waste is better for business and suppliers to have job!*" which is basically not considered a sustainable solution for waste generation. He added: "*The power to make a change in the society starts with the education, people must be aware enough. Economy is a main barrier to the reduction of waste since it encourages the consumption* *and therefore production of more waste, advertising to push people to always buy and gain new products, these are all against good waste management…"*

Furthermore, Expert 10 stated that in order to have a good waste management system in Bahrain, we need: "*to start with the basics and prioritize the ways to manage waste according to the waste management hierarchy which is highly encouraged, and this cannot be achieved without improving public awareness…*"

He added: "*the lack of the sufficient awareness as well as the absence of the very primary principals among people which are prioritized to start with in order to have a successful waste management strategy. These principals are reduce, reuse and recycle, so people are still not aware of them and thus they are not ready for more advanced options*…" the next Chapter highlights the role of public awareness in succeeding the waste management technology adoption with more discussion based literature.

7.5 Summary

In order to compare the enablers as well as barriers to the adoption of all technologies in the country, "Sunburst Analysis" was used by nvivo 12; figure 7.15 shows the result:

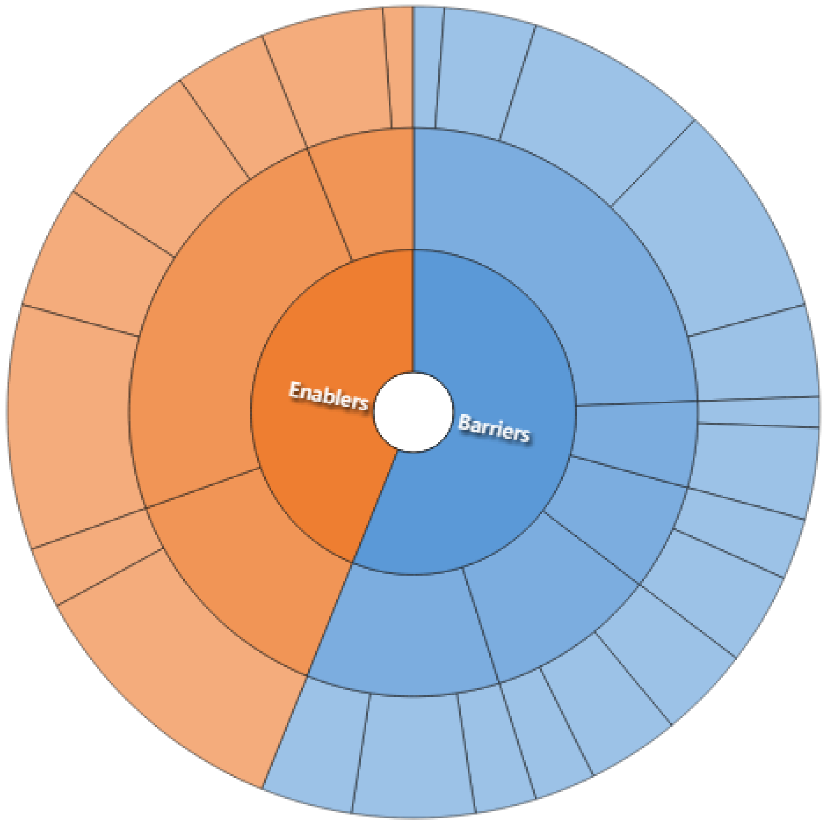

Figure 7.15: Sunburst analysis shows the difference between the overall enablers and barriers to technologies adoption in Bahrain.

General Discussion

Figure 7.15 illustrates that barriers against OHW technologies adoption in Bahrain exceeds the enablers to them. This suggests that in order to enable the adoption, all barriers mentioned in this chapter must be overcome and to that end, it is the responsibility of the government to enable the improvement of the waste management sector in Bahrain, which should begin with deployment of a national waste management strategy that encompasses a plan to raise public awareness encouraging the reduction, reuse and recycling of principal, as a key enabler to succeed in any technology adoption or good practices across the country, starting from reforming education and school curriculum at early stage, to establishing a central authority in order to take responsibility of the waste management in the country.

Zafar (2016) is one of the very few researchers and experts who theoretically discussed the challenges of waste management sector in the GCC area. He agreed with our findings in that GCC waste management sector including Bahrain is currently facing multiple challenges in the form of:

1. Lack of clear and reliable framework by which the solid waste sector is administered from the collection, transformation to disposing or treatment phases

2. The absence of effective and comprehensive legislative frameworks governing the solid waste sector and the inadequate enforcement mechanisms, which are no less important than the legislation themselves

3. Management activities of MSW are considered public services which are directly controlled by governmental institutions. Such management arrangement is considered weak as it lacks market mechanisms, and in cases like these, economic incentives cannot be used to improve and develop the MSW management services

4. Inadequate human and organizational capacities and capabilities

5. The paucity of accurate and reliable background data and information on the status of solid waste such as the rate of generation of different solid waste constituencies, assessment of natural resources and land-use, and transportation needs, scenarios of treatment, and growth scenarios of solid waste linked to several driving forces (Bogner et al, 2007). Needless to say, data and information are crucial elements for developing the MSW management system, including the adequate monitoring of the sector.

6. Inadequate waste strategies/management infrastructure: In most GCC countries, existing waste handling capacities are found to be insufficient. Currently, the recyclable recovery rate is low. Furthermore, in the absence of local recycling facilities, there is no alternative except to dump the recyclable material at Landfills.

7. Waste recycling is expensive: Though recent years have seen an increase in the number of waste recycling facilities, the economics of recycling is still not very favourable. In many cases, recycling waste is more expensive than buying the product.

8. The underdeveloped market for recycled products: Insufficient demand for recycled products within the local market is another reason, which has hampered the growth of the waste recycling industry.

9. Public attitude: Economies in the GCC countries are oil dependent due to the high reserves of fossil fuels. For several decades, alternatives such as solar and wind were not considered and oil was the only feasible option. Recently and due to drop in oil prices, more consideration is being given to renewable sources. Similarly, waste was mainly landfilled as it was an easier choice; yet, due to a known complication associated with such treatment, more suitable measures were considered. Therefore, there is a need for an effective comprehensive "education and awareness" program in regard to these two issues (Zafar, 2016). Almost all of the above challenges were concluded through this study.

Moreover, this study agreed with UNEP (2017) who found that waste management in Bahrain is hindered by the following factors:

1. Low level of Commitment: there is a disconnect between the high-level policy makers and the lower entities responsible for waste management that hinders commitment to the implementation of a sustainable waste management policy and the provision of necessary resources.
2. Weakness in Governance: at Entity level - uncoordinated governance and conflict of interest due to regulatory, operational, duplication and overlapping of responsibilities.
3. The scarcity of data: entity managers lacking data management, effective controls and monitoring systems, tools, and resources to do the job. The data requested for this report from the entities indicated a significant lack of detail, consistency, and systems for control, monitoring and recording, and poor and inconsistent historical records.

Furthermore, WtE technologies can improve waste management in fast-growing cities of developing and emerging countries but its application is complex and must consider, amongst others, the following specific circumstances:

» Lower calorific value in MSW as compared to industrialized countries due to the high moisture (high organic content) and mineral content in waste (e.g. ash, construction, and demolition waste);

» Substantial seasonal change in waste composition (i.e. changing consumption pattern during festival seasons, seasonal crops);

» Limited practice of waste segregation at source, which is a precondition for anaerobic digestion;
» Weak business and operation models;
» Lack of knowledge on how to operate and maintain WtE plants;
» High investment and operating costs which cannot be recovered by existing waste fees and generated additional income from energy sales alone;
» Neglecting livelihood issues for marginalized persons and informal sector workers who are dependent on the availability of recyclables in the waste;
» Lack of monitoring and weak enforcement of environmental standards, leading to public health issues.

Mutz et al. (2017) agreed with the result of the CBA presented in Chapter 6, who argued that high initial investment costs tend to be a major barrier to developing MSWI projects in developing countries. Attempts are being made to bring low-cost MSWI projects to the market with a basic technical standard for low-income countries; however, there is limited experience with these solutions and it remains to be seen if these plants can successfully meet the necessary technical and emissions standards in the long term.

Moreover, Mutz et al. (2017) claimed that the operation of highly complex MSWM technologies requires well developed technical and management skills. It is much more complex than the operation of a sanitary landfill. Only managers, engineers and technicians with proven capabilities and experiences should be assigned key functions. If these qualifications are not available locally, international experts must be contracted on a long-term basis and capacity building program needs to be launched. Thus, it can be concluded that the lack of the well-trained manpower represents the main barrier to incineration technology adoption.

Environmental legislation in most developing and emerging countries do not explicitly deal with the application of MSW incineration technology. This makes the entire process of impact assessment and operation licensing more complicated and time-consuming. However, with the unavailability of comprehensive and legally binding standards, these should first be developed and follow the application of internationally recognized standards. An example of orientation can be the European waste incineration directive (Industrial Emissions Directive). It also needs good capacity for monitoring and enforcement within public institutions (Mutz et al., 2017).

Therefore, Survey 1 was conducted and explored the enablers and barriers to OHWM technologies adoption in Bahrain for the first time using a qualitative approach.

Figure 7.16 and 7.17 show the matrix coding query results, emphasizing public awareness within enablers and barriers, according to the experts. As a comparison, Expert 4 talked mostly about public awareness as an enabler, while Experts 1 and 5 talked about it the least. Meanwhile Experts 2, 6 and 11 mostly talked about public awareness as a barrier to technological adoption in the country.

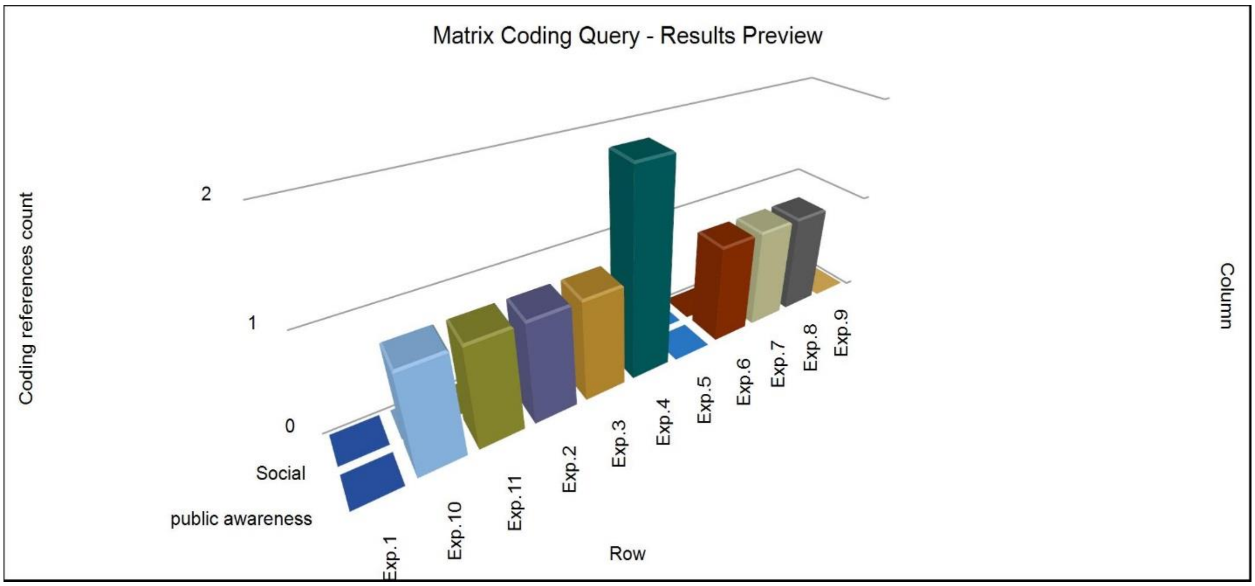

Figure 7.16: Matrix coding query result by experts emphasizing public awareness within enablers

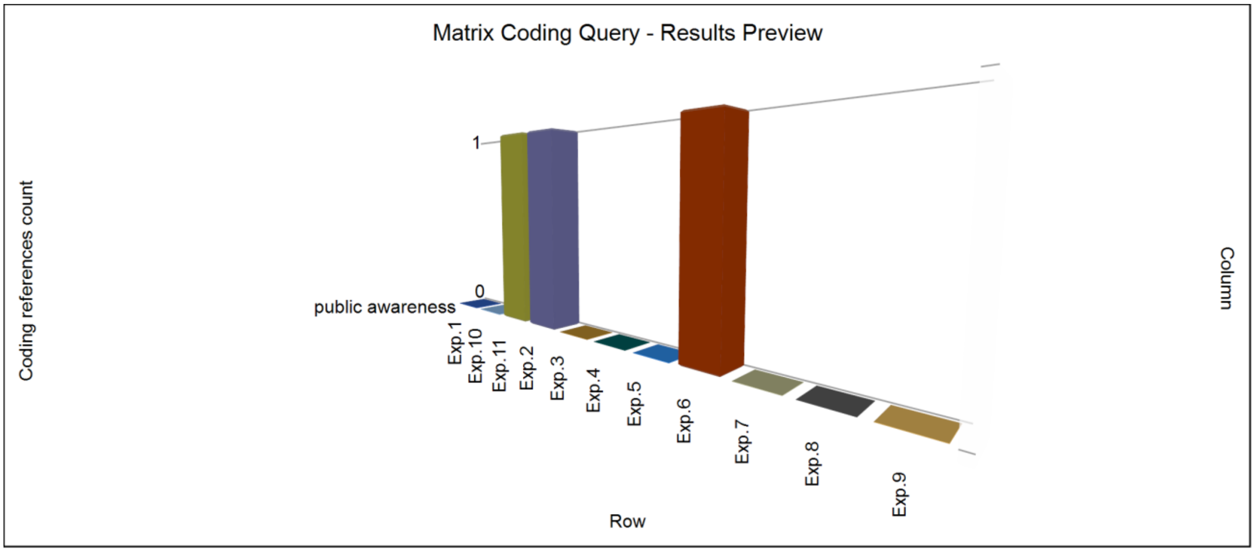

Figure 7.17: Matrix coding query result by experts emphasizing public awareness within barriers

Conclusion and Recommendations from the Experts:

1. Expert 1: Incineration is the most preferred option, with reforming policies; generate a national strategy for waste management and improving public awareness.
2. Expert 2: Composting in small-scale currently is the most preferred. The priority is for preparing the ground using simple options and gradually goes to more complicated options. Improving public awareness, with planning a national strategy is strongly recommended.
3. Expert 3: Incineration is mostly preferred due to the mixed nature of waste. To enable AD and composting, segregation policy is needed to start with. However, public awareness improvement is also a priority in the meantime.
4. Expert 4: Incineration is mostly recommended with governmental support and supportive policies. Composting is suitable with source segregation by raising public awareness.
5. Expert 5: There is no single technology that is considered optimum in his opinion. It is subjected to social acceptance, political, economic and financial resources. Hence, Bahrain needs to start with simple technologies to manage its waste, like composting on a small scale. However, the priority is to reduce waste volume to save land and improve public

awareness in order to reduce, reuse and recycle, in addition to extending the landfill life span using innovative solutions, which may create jobs and conserve environment.

6. Expert 6: The priority is to formulate a national waste management strategy with reforming policies, as well as to improve public awareness on environmental issues. Incineration with high control standards is the most suitable solution for mixed waste in Bahrain.
7. Expert 7: AD is considered to be the best technology to treat the OHW if a source segregation plan was deployed, with the need to improve public awareness. Under the current situation, composting is the most suitable option for restaurants, vegetable and fruit wastes on a small scale; this is currently the most suitable option in my opinion for the Bahraini society.
8. Expert 8: Recommends focusing on reusing, recycling and recovering as the best way to manage waste in Bahrain. However, he did not recommend any specific technology. Improving public awareness is important to start with.
9. Expert 9: AD is one of the considered solutions but cannot be considered as a good option unless it begins by overcoming its barriers.
10. Expert 10: Composting is the most appropriate technology for the Bahraini society due to the absence of public awareness to reduce, reuse and recycle, so that people are still not ready for more advanced options. In order to enable any technology adoption it needs to begin with public awareness to prepare the society.
11. Expert 11: The best options for treating organic household wastes in Bahrain are composting and anaerobic digestion (AD). To enable them, source segregation must be applied, public awareness need to improve and national waste management strategy must be deployed as a starting point.

As a conclusion, in order to manage OHW in Bahrain:

- 4 experts recommended **incineration** under the current situation
- 3 experts recommended **composting in small-scale.**
- 3 experts recommended **AD** after enabling
- 2 experts recommended **composting in large-scale** after enabling

Figure 7.18 summarizes the outcome of interviews with the most recommended technologies as well as their most effective enablers according to the experts:

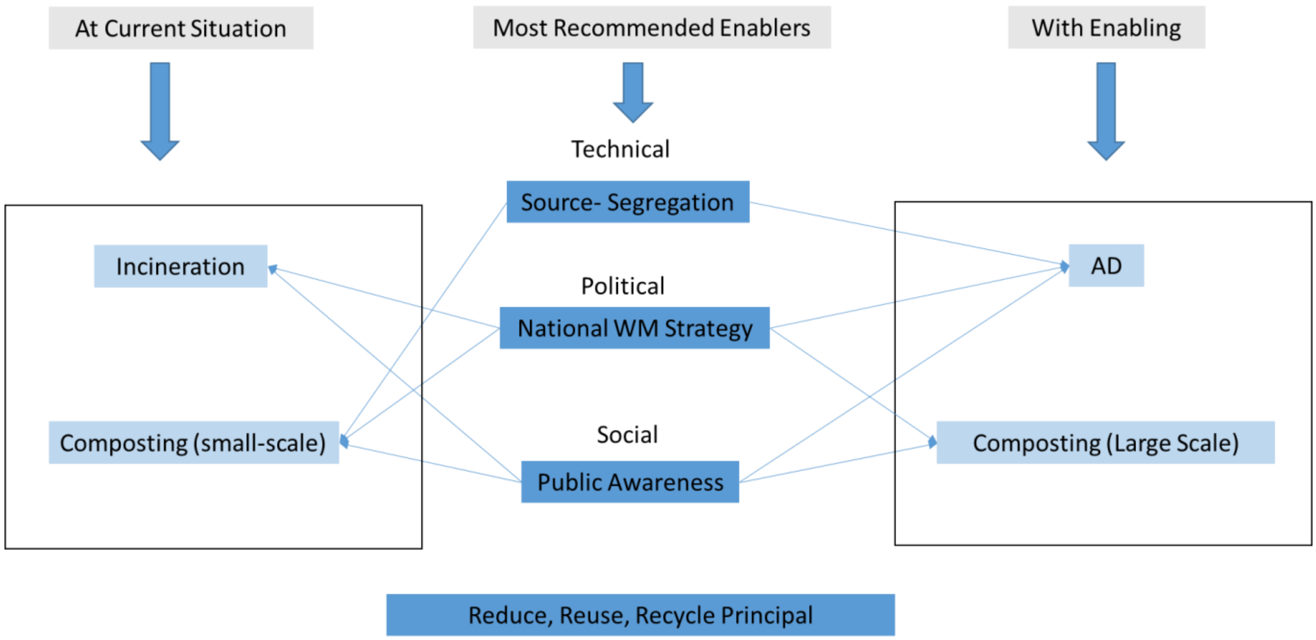

Figure 7.18: Most recommended technologies and their most effective enablers according to the experts

At the end of this chapter, the fifth objective of the research was achieved in that the enablers and barriers to technologies adoption in Bahrain were explored and classified.

At this point, integration of the chosen technologies based on waste characterization (technical criteria), cost-benefit analysis (economic criteria), as well as the enablers and barriers to technologies adoption (social criteria) can be achieved and lead to the final selection of the most preferred technologies for managing OHW in Muharraq Governorate (Table 7.13)

Table 7.13: Comparison of the most preferred technologies based on the technical, economic, and social criteria, as resulted by this research:

Rank	Technical Criteria (OHW Characterization)	Economic Criteria (Cost-Benefit Analysis)	Social Criteria (Enablers and Barriers)
1	**Anaerobic Digestion(AD)**	**Anaerobic Digestion (AD)**	**Incineration**
2	**Incineration**	**Incineration**	**Anaerobic Digestion (AD)**
3	Gasification	Gasification	Composting (small-scale)
4	Pyrolysis	Pyrolysis	Composting (large-scale)
5	Composting	Composting	-
6	RDF	RDF	-

Based on the table above, anaerobic digestion (AD) was found to be the most preferred, suitable and viable technology based on the three criteria. Thus, in order to enable AD adoption, all of the enablers to AD mentioned in this chapter must be activated which can be projected as a good solution to manage OHW in Muharraq Governorate. Incineration has the second preference after AD, since it is suitable for mixed waste and has fewer barriers than AD adoption in the country, as well as its economic feasibility and viability under the second scenario (if the government discontinue the waste dumping in the landfill activities). Despite the feasibility of gasification under the second scenario, it has many socio-cultural, technical, political and managerial barriers that impede its adoption in the country, as mentioned earlier in this chapter. Composting has the least barriers among all technologies, but is still not deemed as a feasible technology based on its characterization and economic viability. RDF, gasification and pyrolysis were not considered by experts and totally excluded from the possibility of adoption in Bahrain.

7.6 Framework Derived from Qualitative Findings

Qualitative findings did illuminate the importance of social factor and public awareness as a critical enabler to OHW management technology adoption. Chapter 2 contained the literature related to public awareness. In order to validate the qualitative findings, a quantitative survey which aims to measure public awareness in the Muharraq Governorate was conducted, which will be mentioned in the next chapter (Chapter 8). Figure 7.18 summarizes Chapter 8 framework as an introduction.

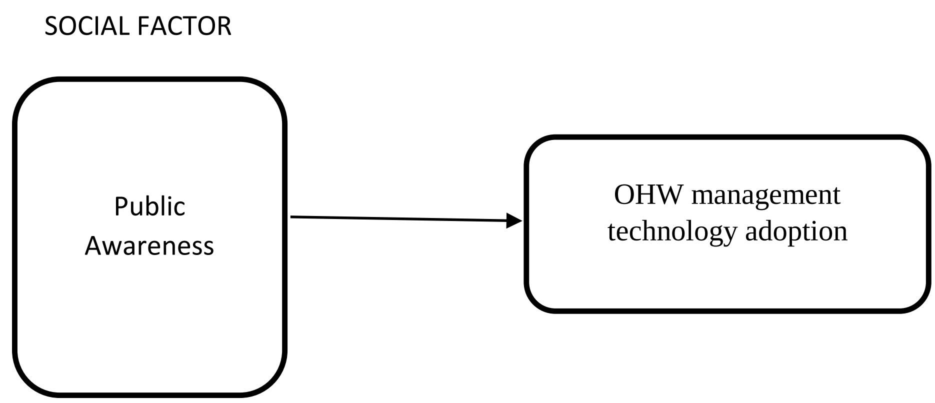

Figure 7.19: Chapter 8 Framework

Chapter 8: Measuring Public Awareness toward Household Waste Management in Muharraq Governorate

8.1 Introduction

As pointed out in Chapter 3 and 7, public awareness signifies the starting point for the fundamental ingredient of a resource-efficient society (Abe and Didham, 2013), something that directly impacts the process of waste management as well as technology adoption. In addition, it is also deemed as the foundation of public capacity that helps the public carry out such steps to succeed in waste management practices across Bahrain (Abe and Didham, 2013) including technology adoption.

This chapter describes and extrapolates the data collected from the questionnaire in Survey 2. More specifically, this work builds on the methodology as well as results from the survey's design and implementation mentioned in Chapter 3 by procuring data using a refined version of the survey (Appendix 7).

The survey aimed at gauging public awareness about household waste management in the Muharraq Governorate and exploring if there are any correlations between educational level, gender, occupation and age and area of living with the level of public awareness as well as its three components. To reiterate, the three main components of public awareness are: knowledge, attitude and behaviour of the people in Muharraq Governorate.

Furthermore, this chapter undertakes an explanation of the missing value analysis and demographics analysis. To that end, confirmatory factor analysis (CFA) was undertaken for each item of the questionnaire using the AMOS 22. In addition, in order to verify the hypotheses, t- test and ANOVA test were performed. The findings are then interpreted by an appropriate use of facts and figures.

8.2 Pilot Testing Results

The pilot testing was performed to validate the reliability of the survey. As mentioned in Chapter 3, data were collected from 40 respondents and preliminary analysis was performed. As part of this preliminary analysis, reliability analysis and confirmatory factor analysis were also performed. The reliability coefficient of 0.70 or higher is deemed "acceptable" in the majority of social science research scenarios. As shown in Chapter 3, the overall reliability coefficient was found to be above

0.7, which indicates the questionnaire is indeed reliable. In addition, the factor loading was measured per item; the results showed many items of knowledge, attitude and behaviour with factor loadings of less than 0.50. The results of pilot testing are available in Table 8.1, 8.2 and 8.3.

Table 8.1: Pilot testing results of knowledge about household waste management and related issues

Dimensions of Awareness	Question Items	Estimate	α
Knowledge about household waste management and related issues	I know where domestic waste is taken daily and how it is disposed of	.433	.700
	I understand the environmental and health damage caused by dumping household waste	.300	
	Sorting waste components by type at home (glass, plastic, food, paper, etc.) is paramount to take advantage of it	.320	
	I know the fine of throwing of waste in areas other than their designated places	.310	
	I know who is responsible for collecting and disposing of household waste	.400	
	Burning household waste in a modern and safe facility is a very effective way of lowering its size and taking advantage of it	.710	

Dimensions of Awareness	Question Items	Estimate	α
	I know the meaning of waste recycling	.740	
	Household waste can be used as a source of energy	.032	
	Some food waste can be converted into compost	.650	
	I know what environmentally friendly products mean	.401	

Table 8.2: Pilot testing results of Attitude toward the waste management

Dimensions of Awareness	Question Items	Estimate	α
Attitude about household waste management and related issues	I am ready to separate waste in separate containers by type in case the municipalities asked me to do so	.544	.700
	I am satisfied with how domestic waste collection is currently collected.	.300	
	I am satisfied with how domestic waste is currently disposed	.333	
	Responsibility of waste management is a fundamental partnership between every individual in society as well as relevant institutions	.710	

Dimensions of Awareness	Question Items	Estimate	α
	I am throwing fines on dumping waste in areas other than the designated ones	.205	
	I am willing to pay extra fees in exchange for the municipality to distribute colored containers for the purpose of sorting household waste	.230	
	Curricula should be used at all levels to promulgate environmental awareness concerning the significance of household waste management within the community	.500	
	Media and social communication should be leveraged to spread environmental awareness about household waste management in the community	.361	
	I think giving rewards and incentives to people for recycling some of their household waste helps reduce them	.202	
	I am ready to cooperate with municipalities regarding the implementation of a national plan for the management of household waste	.344	
	I prefer buying environmentally friendly goods on other goods if available	.452	
	Disposal of waste in environmentally friendly ways contributes to highlighting	.441	

Dimensions of Awareness	Question Items	Estimate	α
	the beautiful image of the country and revitalizing tourism		
	I think that the containers currently used to collect waste outside the houses are feasible	.050	
	I think it is necessary to provide residents and citizens with information pertaining to household waste and the proportion of each type	.800	
	The contribution of community members to voluntary clean-up campaigns is civilized	.400	
	The issue of household waste management assumes significance for me	.360	

Table 8.3: Pilot testing results of behaviour of waste management

Dimensions of Awareness	Question Items	Estimate	α
Action and Behaviour of household waste	I am keen to watch documentaries on environmental issues	.600	.800
	I am careful to guide others to throw the waste in the allocated places only and not the street	.100	

management and related issues	I am currently separating household waste components into special containers or bags at home (food, plastic, glass, paper, ...)	.700	
	I use some of my food waste to feed animals or fish	.400	
	I use some food waste by turning it into fertilizer for agriculture	.800	
	I reuse some household waste components (empty plastic cans, bottles, etc.) in useful things	.421	
	When I go on a trip to parks and other public places, I make it a point to remove all the waste before leaving the place and put it in the allocated containers	-.024	
	Be sure to attend and participate in environmental-related events (seminars, workshops, courses, lectures ...)	.634	
	I encourage others to reuse some of the household waste components to take advantage of them	.715	
	I buy environmentally friendly products (such as reusable water bottles instead of plastic containers)	.700	
	Make sure to remove the waste bags from my house daily at a specific time	.371	
	I put the waste bags inside the containers and not outside when taking them out of the house	.193	

The tables above highlighted that the Cronbach's alpha α (reliability indicator) of each group of components of public awareness was found to be higher than 0.7 (α = 0.8), which indicates that the questionnaire is reliable, making it ready to be distributed for the main study.

8.3 Missing Value Analysis

After the data collection, the entire data was entered in SPSS. There were partial non-responses in the survey data. Before performing the final analysis, the missing value analysis had to be undertaken as well. Missing value analysis is very important because there are multiple statistical analyses which could not be performed on the data with missing values (Mander and Clayton, 2007). For the imputation of missing values, the researcher used the series mean method that is recommended by many research scholars (Troyanskaya et al., 2001).

8.4 Demographics Analysis

The survey consisted of three hundred respondents. The demographics analysis of these respondents is very helpful in studying the characteristics of the sample. The frequency analysis was performed to analyse the respondents' gender, age, education and marital status.

Respondents' demographics results:

The results indicated that among the 300 respondents (n= 300), n= 65 (21.7%) belonged to age group of 18-20 years, n= 50 (16.7%) were 21-30 years, n= 86 (28.7%) were in 31-40 age group, n= 67 (22.3%) were aged from 41-50 years, n= 26 (8.7%) respondents belonged to the age groups of 51-60 years and remaining n= 6 (2.0%) respondents were more than 60 years old.

In terms of gender classification, the researcher found that most of the participants were female respondents (68.7%) as compared to their male counterparts (31.3%). Table 8.4 illustrated the classification of Age, Gender, Education and Marital Status of the respondents.

Table 8.4: Age, Gender, Education and Marital Status Classification

Variable	Group	Frequency	Percent	Cumulative Percent
Age	18-20	65	21.7	21.7
	21-30	50	16.7	38.3

	31-40	86	28.7	67.0
	41-50	67	22.3	89.3
	51-60	26	8.7	98.0
	61 and above	6	2.0	100.0
Gender	Male	94	31.3	31.3
	Female	206	68.7	100.0
Education	Intermediate School and Below	15	5.0	5.0
	Secondary School	94	31.3	36.3
	Undergraduate Degree	164	54.7	91.0
	Higher Education	27	9.0	100.0
Marital Status	Single	95	31.7	31.7
	Married	192	64.0	95.7
	Others	13	4.3	100.0
Total		300	100	100

The results indicated that in education classification, the majority of respondents had undergraduate degree (54.7%), whereas n= 94 (31.3%) participants had attended secondary school; n= 27 (9%) had higher education whereas n= 15 (5.0%) respondents belonged to the intermediate and below group.

In marital status classification, the majority of respondents were married (64%) and the rest were 31.7% (n= 95) single; 13 were included in others' group.

The data were collected from the respondents of different nationalities. Twenty-nine (9.7%) respondents were residence whereas there were 271 (90.3%) respondents Bahraini citizens. In residential area classification, majority of respondents were found to belong to the area of Hidd (21%) Arad (18%), Busaiteen (18.7%); the rest belonged to Halat (1%), Samaheej (6%) and others (7%).

In terms of job categories, it was found that 16.7% (n= 50) respondents were teachers and 17.3% (n= 52) were students. Other details of respondents' occupation are available in Table 8.5.

Table 8.5: The Nationality, Residential Area, and Job category of the respondents

Variable	Group	Frequency	Percent	Cumulative Percent
Nationality	Bahraini	271	90.3	90.3
	Residence	29	9.7	100.0
Residential Area	Hidd	63	21.0	21.0
	Qalali	42	14.0	35.0
	Arad	54	18.0	53.0
	Busaiteen	56	18.7	71.7
	Dair	24	8.0	79.7
	Samaheej	6	2.0	81.7
	Muharraq	45	15.0	96.7
	Halat	3	1.0	97.7
	Others	7	2.3	100.0
Job Category	Head, President, GM.	8	2.7	4.4
	Engineer	8	2.7	8.7
	Teacher	50	16.7	36.1

Health Specialists	8	2.7	40.4
Employee (Secretary, Clerk etc.)	21	7.0	51.9
Bankers	2	0.7	53.0
Retired	11	3.7	59.0
Housewife	14	4.7	68.9
Business Owner	4	1.3	97.3
Student	52	17.3	99.5
Defence Force	4	1.3	99.7
Others	1	0.3	100.0
Missing	117	39	
Total	300	100.0	

Furthermore, the other characteristics of respondents were also studied, such as their income level, the number of family members and their home types. According to the data, majority of the respondents had an income of 301-900 BD (42.7%, n= 128). The lowest income of the respondents (5.3%, n= 16) was 300 BD and below, whereas the highest income (17.3%, n= 52) was more than 1500 BD. The details of the income level and home type are also mentioned in Table 8.6.

Table 8.6: Income level, family number and Home type details of the respondents

Variable	Group	Frequency	Percent	Cumulative Percent
Income	300 BD and below	16	5.3	5.3
	301-900 BD	128	42.7	48.0
	901-1500 BD	104	34.7	82.7
	1501 BD And Above	52	17.3	100.0
Family Number	2	23	7.7	7.7
	3-5	151	50.3	58.0
	6-8	109	36.3	94.3
	9 And Above	17	5.7	100.0
Home Type	House	206	68.7	68.7
	Flat	91	30.3	100.0
	Total	300	100.0	

8.5 Confirmatory Factor Analysis

After obtaining the data of 300 respondents, the researcher performed the confirmatory factor analysis (CFA) in order to establish the dimensionality of the questionnaire. The results indicated that there are three dimensions of the overall awareness of respondents about household waste management**.** CFA is visually described in Figure 8.1.

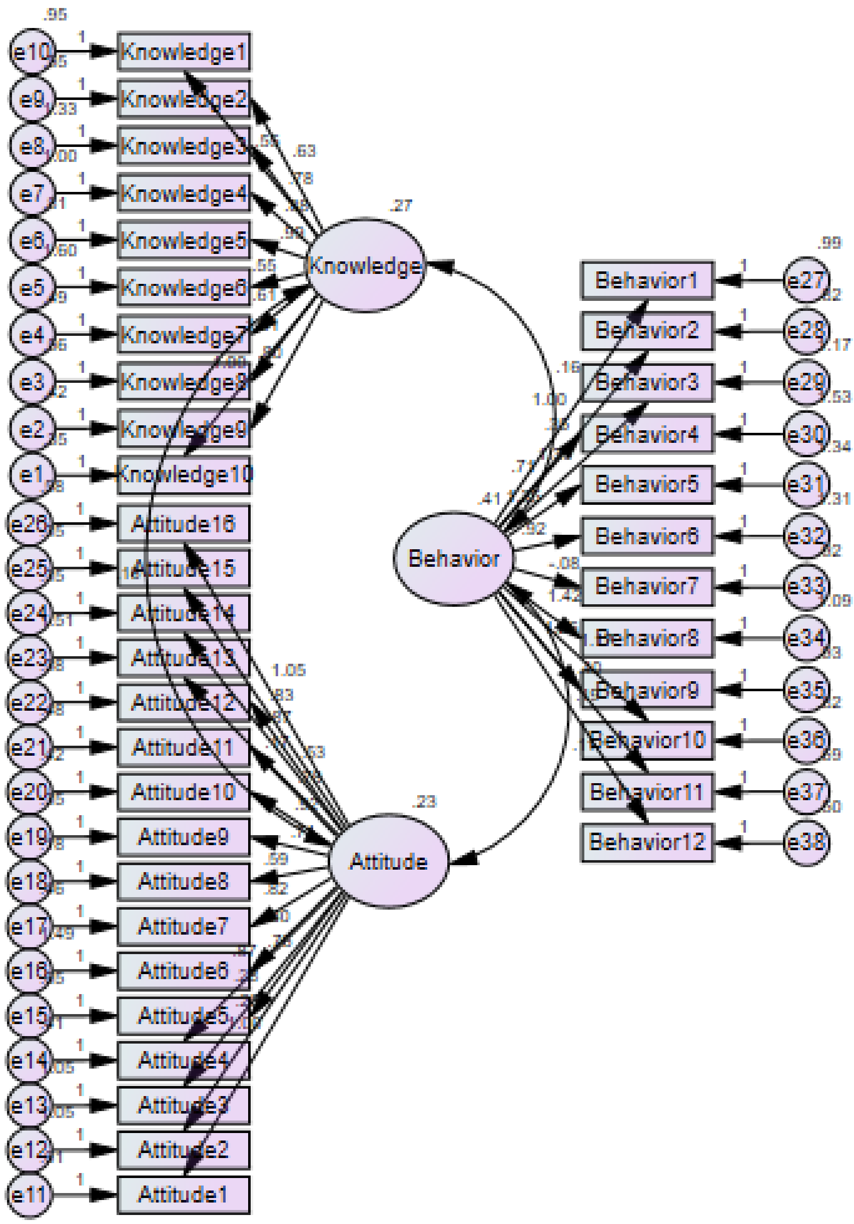

Figure 8.1: Confirmatory Factor Analysis (CFA)

Table 8.7 showed the factor loadings of Knowledge about household waste management. Since the factor loading is acceptable if it was greater than 0.5, the results indicated four items whose factor loading is higher than 0.50, whereas there are six items of Knowledge with factor loadings of less than 0.50. Kline (2011) recommended that the items having factor loadings of lower than 0.50 should be deleted from the list and that the final analysis should be performed on items which have loadings greater than 0.50.

Table 8.7: Factor Loadings of Knowledge about household waste management

Dimensions of Awareness	**Question Items**	**Estimate**
Knowledge about household waste management and related issues	I know where the domestic waste is taken daily and how it disposed	0.281
	I understand the environmental and health damage caused by dumping of household waste	0.406
	Sorting waste components by type at home (glass, plastic, food, paper, ...) is very important	0.332
	I know the quantum of fine for throwing of waste in areas other than the designated places	0.419
	I know who is responsible for collecting and disposing household waste	0.501
	Burning household waste in a modern and safe facility is a very effective way of lowering its size	0.223
	I know the meaning of waste recycling	0.416
	Household waste can be used as an energy source	0.575
	Some food waste can be converted into compost	0.541

Dimensions of Awareness	Question Items	Estimate
	I know what is meant by environmentally friendly products	0.66

In the dimension of Attitude and Trend in household waste management, 9 items have factor loadings of greater than 0.50 whereas 6 items have factor loadings lower than 0.50. In this case, these items needed to be deleted.

Table 8.8: Attitude and trends in Household Waste Management

Dimension of Awareness	Question Items	Estimate
Attitude and trends in household waste management	I am ready to separate the waste in the house in separate containers by type if the municipalities ask me to do so	.522
	I am satisfied with how domestic waste is currently collected.	.113
	I am satisfied with how domestic waste is currently disposed.	.127
	Responsibility for waste management is a fundamental partnership between every individual in the society and relevant institutions	.543
	I am imposing fines on dumping waste in areas other than the designated ones	.409
	I am willing to pay extra municipal fees to have the municipality	.297

	distribute coloured containers for sorting household waste	
	Curricula should be used at all levels to promote environmental awareness about the importance of household waste management within the community	.501
	Media and social communication should be used to spread environmental awareness about household waste management in the community	.554
	I think giving incentives and rewards to people for recycling some of their household waste helps reduce them	.503
	I am ready to cooperate with municipalities regarding the implementation of a national plan to better manage household waste	.564
	I prefer buying environmentally friendly goods over other goods, if available	.473
	Disposal of waste in environmentally friendly ways contributes to enhancement of the beautiful image of the country and revitalizing tourism	.380

	I think the containers presently used to collect waste outside the houses are suitable	.067
	I think it is necessary to provide citizens and residents with appropriate information on household waste and the proportion of each type	.577
	The contribution of community members to voluntary clean-up campaigns is civilized	.559
	The issue of household waste management assumes significance to me	.550

The dimension of practice and behaviour in household waste management features 12 items. Among these 12 items, 6 items were found to have loadings greater than .50 whereas the remaining 6 items have loadings of less than 0.50.

Table 8.9: The practice and behaviour in household waste management

Dimension of Awareness	Question Items	Estimate
The Practice and Behaviour in household waste management	I am keen to watch documentaries on environmental issues	.539
	I am careful to guide others not to throw waste in the street and only use the allocated places	.240

	I am currently separating household waste components into special containers or bags at home (food, plastic, glass, paper, ...)	.634
	I use some of my food waste to feed animals or fish	.344
	I utilize some food waste by turning it into fertilizer for agriculture	.597
	I reuse some household waste components (empty plastic cans, bottles, etc.) in useful things	.457
	When I go on a trip to parks and others public places, I make sure to remove all the waste before leaving the place and putting them in the allocated containers	-.051
	Be sure to attend and participate in environmental-related events (seminars, workshops, courses, lectures ...)	.656
	I encourage others to reuse some of the household waste components to take advantage of them	.639
	I buy environmentally friendly products (such as reusable water bottles instead of plastic containers)	.636
	Make sure to remove the waste bags from my house daily at a specific time	.290

	I put the waste bags inside the containers and not outside when taking them out of the house	.166

According to Slavin (1994), a minimum of two or three items are required for one dimension to be acceptable. Therefore, Knowledge has four items, Attitude has 9 items and Behaviour or Practice has six items with a factor loading of above 0.5.

8.6 Questionnaire Results and Discussion

The questionnaire included a Likert scale of 5 responses in the analysis; the two positive and two negative answers were combined to be considered as one in order to have a scale of three results: agree, neutral and disagree generally. In terms of Knowledge, the results indicated that the majority (64.3%) of respondents knew who is responsible for collecting and disposing of household waste in Bahrain, and 76.9% of the respondents believed that household waste can be used as an energy source. Similarly, 87% and 83% of respondents recognized that some food waste can be converted into compost, and knew what environmentally friendly products means. The results indicate that there is a high level of knowledge among people and most of them knew the basics of household waste management. People also answered other questions under Knowledge, but these questions were excluded due to the low factor loading (below 0.5) according to the confirmatory factor analysis. For example, 67.9% knew where domestic waste is taken daily and how it disposed of. Similarly, 85.6% understood the magnitude of environmental and health damage caused by the dumping of household waste, and 76.7% agreed that sorting of waste components by type at home (glass, plastic, food, paper, etc.) is very important. On the other hand, 59.4% of the respondents were aware of the fine imposition of throwing waste in places other than their designated places. When asked if burning household waste in a modern and safe facility is a very effective way of reducing its size, only 48.1 % agreed, whereas 28.1% were neutral (not sure), and 23.7% disagreed. A large percentage (90.3%) was aware of the meaning of waste recycling.

Regarding Attitude, 78.6% of respondents expressed their willingness to separate domestic waste in separate containers by type if the municipalities asked them to do so, which is a positive indicator of people's attitude and reflects their cooperation for any further segregation practices for technology adoption in the future. Notably, 90.8% believed that responsibility for waste management is a fundamental partnership between every individual in society and relevant institutions, while 91.2% thought that curricula must be used at all levels to promote environmental awareness about the importance of household waste management within the community. Moreover, 98% of respondents opined that media and social communication must be used to spread environmental awareness about household waste management in the community, which is a high percentage that reflects a high level of awareness. In addition, 90.6% opined that giving incentives and rewards to people to recycle some of their household waste helps reduce them, whereas 82.2% said they are ready to cooperate with municipalities regarding the implementation of a national plan for the management of household waste. When asked if it is necessary to provide citizens and residents with information on household waste and the proportion of each type, 90.9% answered with acceptance, and 93% opined that the contribution of community members to voluntary clean-up campaigns is a civilized behaviour. When asked whether the issue of household waste management assumes importance for them, 83.3% agreed. Other questions were asked but their factor loading was below 0.5; thus, they were excluded from the analysis. Only the frequency was obtained to each of these items; for example, when asked if they are satisfied with the current way of domestic waste collection and domestic waste disposal, 61.3% and 54.4% were satisfied, respectively. Notably, 87.8% of respondents are in favour of imposing fines on dumping waste in places other than the designated ones, while only 48.3% are willing to pay extra municipal fees in exchange for the municipality to distribute coloured containers for sorting household waste. Moreover, 81.1% of respondents preferred to buy environmentally friendly goods on other goods if available, and 94.2% thought that disposal of waste in environmentally friendly ways contributes to highlighting the beautiful image of the country and revitalizing tourism. When asked if the containers currently used to collect waste outside the houses are suitable, more than half of them (53.2%) agreed, 21.4% were not sure, whereas near a quarter of them (25.4%) disagreed.

In terms of Behaviour and Practice, 63.9% are keen to watch documentaries on environmental issues, and 44.8% of them are currently separating household waste components into special containers or bags domestically (food, plastic, glass, paper, etc.). Also, 27.5% are using some food waste by turning it into fertilizer for agriculture, when asked if they are being sure to attend and participate in related environmental events (seminars, workshops, courses, lectures ...), only 37.2% did. In addition, 62.5% always or at least sometimes encourage others to reuse some of their household waste components, and 67.4% buy environmentally friendly products (such as reusable water bottles instead of plastic containers). Other items with a factor loading of below 0.5 were excluded from the refined questionnaire results, but frequencies can be displayed as follows: 86.9% always or sometimes guide others not to throw the waste in the street and only throw it in the allocated places. 72.3% always or at least sometimes use some of their food waste to feed animals or fish. In addition, 65.2% reuse some household waste components (empty plastic cans, bottles, etc.) in useful things, while 90% of the respondents stated that when going on a trip to the parks and other public places, they remove all the waste before leaving the place and put it in the allocated containers. Results also show that 89.3% of the respondents make sure to remove the waste bags from their houses at a specific time daily, while 83.3% put the waste bags inside the containers and not outside when taking them out of house.

The refined questionnaire with the answers percentages are shown in table 8.10:

Table 8.10: The refined questionnaire with the percentage of the answers

	Question Items (Knowledge)	**Totally true and True**	**Neutral**	**Not true and not true at all**
1	I know who is responsible for collecting and disposing household waste	64.3%	26.6%	9%
2	Household waste can be used as an energy source	76.9%	18.7%	4.3%
3	Some food waste can be converted into compost	87.0%	11.4%	1.7%
4	I know what environmentally friendly products means	83%	15.7%	1.3%
	Question Items (Attitude)	**Strongly Agree and Agree**	**Neutral**	**Disagree and Strongly Disagree**
1	I am ready to separate domestic waste in separate containers by type if the municipalities asked me to do so	78.6%	15.4%	6.1%
2	Responsibility for waste management is a fundamental	90.8%	7.1%	2.1%

	partnership between every individual in society and relevant institutions			
3	Curricula should be used at all levels to promote environmental awareness about the importance of household waste management within the community	91.2%	6.4%	2.4%
4	Media and social communication should be used to spread environmental awareness about household waste management within the community	98%	2%	0%
5	I think giving incentives and rewards to people to recycle some of their household waste helps reduce them	90.6%	9.1%	0.3%
6	I am ready to cooperate with municipalities regarding the implementation of a national plan to manage household waste	82.2%	16.5%	1.3%
7	I think it is necessary to provide citizens and residents with information on household waste as well as the proportion of each type	90.9%	6.4%	2.7%
8	The contribution of community members to voluntary clean-up campaigns is civilized	93%	5%	2%
9	The issue of household waste management is important to me	83.3%	12.4%	4.3%
	Question Items (Behaviour)	**Always, Sometimes**	**Neutral**	**Rarely, Never**
1	I am keen to watch documentaries on environmental issues	63.9%	10.4%	25.7%
2	I am currently separating household waste components into special containers or bags at home (food, plastic, glass, paper, etc.)	44.8%	15.4%	39.8%

3	I use some food waste by turning it into fertilizer for agriculture	27.5%	9.4%	63.1%
4	Be sure to attend and participate in environmental-related events (seminars, workshops, courses, lectures ...)	37.2%	12.8%	50%
5	I encourage others to reuse some of the household waste components	62.5%	14.4%	23.1%
6	I buy environmentally friendly products (such as reusable water bottles instead of plastic containers)	67.4%	13.1%	19.5%

From the table of results, it evident that people have positive answers for all of the Knowledge and Attitude items with a high percentage of true and totally true answers, and strongly agree and agree, respectively. In terms of Behaviour, most people rarely or never used food waste by turning it to fertilizer, which might be attributed to the lack of suitable location for composting inside homes, the small sizes of the houses with absence of the backyard, or because they consider it as harmful and something that may cause diseases (cultural barrier). In addition, people are rarely or are never sure to attend and participate in environmental-related events. This can be justified by the lack of suitable workshops and related events to participate in; timing might be not suitable, or it could be because this requires a high participation fee (financial barrier). Religious barrier may also play an important role in that many ladies may want to participate but the participation of both men and women makes them avoid attendance, which is considered a very common phenomenon in Bahraini Society, especially amongst the housewives.

8.7 Analysis of Individuals Knowledge in Household Waste Management

To perform the analysis on the knowledge dimension in household management, this research used items having higher than 0.50 loading; thus, four items of knowledge were used to aggregate the score of knowledge dimension. In order to compare the knowledge of household waste management, this study applied the one way ANOVA and Dunnt T3 test for post hoc analysis.

a. **Comparisons of individuals' knowledge of household waste management in different age groups**

The results demonstrated a significant difference in all age groups in their knowledge of household waste management ($p<0.05$). Post hoc analysis found that there was a knowledge difference among the younger (18-20 Years) and an older age group people (41-50 Years) in that older people had a higher knowledge than the younger group. This can be justified by life style differences between the two groups, since the younger group mostly comprises of students and experience is obtained by older group in addition to the difference of interests, as well as the sense of responsibility of older people to learn about waste management that they might deal with on a daily basis and not by the younger ones. Please refer to Table 8.11 for further details.

Table 8.11: Comparison of knowledge in household waste management at different age levels

(I) age	(J) age	Mean Difference (I-J)	Sig.	P value ANOVA
18-20	21-30	-0.08773	1	0.037
	31-40	-0.20139	0.563	
	41-50	**-0.32988**	**0.058***	
	51-60	-0.20439	0.906	
	61 and above	0.10009	1	
21-30	18-20	0.08773	1	
	31-40	-0.11365	0.992	
	41-50	-0.24214	0.418	
	51-60	-0.11666	1	
	61 and above	0.18783	0.997	
31-40	18-20	0.20139	0.563	
	21-30	0.11365	0.992	

	41-50	-0.12849	0.944
	51-60	-0.00301	1
	61 and above	0.30148	0.884
41-50	**18-20**	**0.32988**	**0.058***
	21-30	0.24214	0.418
	31-40	0.12849	0.944
	51-60	0.12548	0.998
	61 and above	0.42997	0.609
51-60	18-20	0.20439	0.906
	21-30	0.11666	1
	31-40	0.00301	1
	41-50	-0.12548	0.998
	61 and above	0.30449	0.933
61 and above	18-20	-0.10009	1
	21-30	-0.18783	0.997
	31-40	-0.30148	0.884
	41-50	-0.42997	0.609
	51-60	-0.30449	0.933

b. Comparisons of individuals' knowledge of household waste management in different genders

In order to perform this analysis, I performed Independent Sample t-test. The results showed a significant difference across male and female in their knowledge of household waste management (p<.05). The knowledge of male individuals was found to be higher than female counterparts (See Table 8.12).

Table 8.12: Comparisons of individuals' knowledge level in household waste management across different genders

Gender	Mean	SD	Mean Difference	P value
Male	4.3003	0.615	0.17733	0.021
Female	4.1229	0.61085	0.17733	

This finding disagreed with Plavsic (2013), who found that females reported more favourable and appreciative attitudes towards the environment in that males were also more concerned with mastering the environment whereas females took a more emotional and nurturing approach. Female students were also known to show more environmental responsibility (e.g., recycling) than their male counterparts (Plavsic, 2013).

c. **Comparisons of individuals' knowledge of household waste management in different Educational Groups**

To determine the difference between the individuals' knowledge of household waste management across the respondents' educational levels, I performed the One Way ANOVA Test. The results did not reveal any significant difference in the knowledge of individuals, regardless of their education level (p<0.05). The description of these comparisons is available in Table 8.13.

Table 8.13: Comparisons of individuals' knowledge level at different education level

(I) education	**(J) education**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**P Value**
	secondary school	-.12453	.24391	.995	.7130

Intermediate school and below	undergraduate degree	-.15850	.24112	.983
	higher education	-.21667	.26277	.952
secondary school	Intermediate school and below	.12453	.24391	.995
	undergraduate degree	-.03396	.07671	.998
	higher education	-.09213	.12960	.978
undergraduate degree	Intermediate school and below	.15850	.24112	.983
	secondary school	.03396	.07671	.998
	higher education	-.05817	.12427	.998
higher education	Intermediate school and below	.21667	.26277	.952
	secondary school	.09213	.12960	.978
	undergraduate degree	.05817	.12427	.998

d. Comparisons of individuals knowledge of household waste management according to the marital Status

The comparison of individuals about their knowledge of household waste management in accordance with their marital status helps to understand the phenomena of household waste management. The One Way ANOVA did not find any significant difference between the single married and other people related to their knowledge about household waste management (See Table 8.14).

Table 8.14: The Comparisons of individuals' knowledge level in accordance of their Marital Status

Marital Status	Marital Status	Mean Difference	Std. Error	Sig.	P Value
single	married	-.10991	.08073	.438	.0810
	others	-.37658	.16605	.102	
married	single	.10991	.08073	.438	
	others	-.26667	.15704	.287	
others	single	.37658	.16605	.102	
	married	.26667	.15704	.287	

8.8 Analysis of Individuals Attitude toward Household Waste Management

The attitude of individuals toward household waste management was also analysed with the perspective of their different demographics. In this section, 9 items having factor loadings of greater than 0.50 were used. The aggregate score was used to perform further analysis. As in previous analysis, this study also performed the independent Sample T Test along with One Way ANOVA.

a. Comparison of attitude toward household waste Management at different age levels

In order to compare the attitude of individuals toward household waste management, this study applied the one way ANOVA and Dunnt T3 test for post hoc analysis. According to the findings, there is a significant difference among all age groups in their attitude toward household waste management ($p<0.05$). In addition, difference was found, through post hoc analysis, among the individuals of 21-30 years and old age group people (41-50 Years). Please refer to Table 8.15 for further details.

Table 8.15: Comparison of attitude toward household waste Management at different age groups

(I) age	(J) age	Mean Difference (I-J)	Sig.	P value ANOVA
18-20	21-30	0.04138	1.000	
	31-40	-0.15150	0.565	
	41-50	-0.21930	0.076	
	51-60	-0.25038	0.240	
	61 and above	0.02170	1.000	
21-30	18-20	-0.04138	1.000	
	31-40	-0.19288	0.293	
	41-50	**-.26068***	**0.033**	
	51-60	-0.29176	0.122	
	61 and above	-0.01968	1.000	0.005
31-40	18-20	0.15150	0.565	
	21-30	0.19288	0.293	
	41-50	-0.06780	0.997	
	51-60	-0.09888	0.995	
	61 and above	0.17320	0.984	
41-50	18-20	0.21930	0.076	
	21-30	**.26068***	**0.033**	
	31-40	0.06780	0.997	
	51-60	-0.03108	1.000	

	61 and above	0.24100	0.886
51-60	18-20	0.25038	0.240
	21-30	0.29176	0.122
	31-40	0.09888	0.995
	41-50	0.03108	1.000
	61 and above	0.27208	0.865
61 and above	18-20	-0.02170	1.000
	21-30	0.01968	1.000
	31-40	-0.17320	0.984
	41-50	-0.24100	0.886
	51-60	-0.27208	0.865

The age group of 41-50 exhibited a higher positive attitude to household waste management as opposed to the age group of 21-30. This can again be attributed to their experience, maturity, social culture and lifestyle. Apart from higher knowledge, this age group (41-50 years) showed a high attitude, which indicates their higher level of public awareness with regard to household management in Muharraq.

b. Comparisons of individuals' attitude toward household waste management in different genders

I performed Independent Sample T Test to perform the analysis. The results did not find any significant difference across male and female in their attitude toward household waste management ($p>.05$) (See Table 8.16).

Table 8.16: Comparisons of individuals' attitude toward household waste management across different genders

Gender	Mean	SD	Mean Difference	P value
Male	4.43	.51	.01	0.87
Female	4.42	.44	.01	

c. **Comparisons of individuals' attitude toward household waste management in different Educational Groups**

In order to determine the difference between the individuals' attitude toward household waste management regardless of the respondents' educational levels, I performed the One Way ANOVA Test. According to the results, no significant difference was found in the attitude of individuals who are high or low in their education (p>0.05). A description of these comparisons is available in Table 8.17.

Table 8.17: The Comparisons of individuals' attitude toward household waste management at different education levels

(I) education	(J) education	Mean Difference (I-J)	Std. Error	Sig.	P Value
Intermediate school and below	secondary school	0.16903	0.12807	0.712	.14
	undergraduate degree	0.04723	0.12383	0.999	
	higher education	0.00165	0.15340	1.000	
secondary school	Intermediate school and below	-0.16903	0.12807	0.712	

	undergraduate degree	-0.12179	0.05957	0.227
	higher education	-0.16738	0.10838	0.552
undergraduate degree	Intermediate school and below	-0.04723	0.12383	0.999
	secondary school	0.12179	0.05957	0.227
	higher education	-0.04559	0.10335	0.998
higher education	Intermediate school and below	-0.00165	0.15340	1.000
	secondary school	0.16738	0.10838	0.552
	undergraduate degree	0.04559	0.10335	0.998

d. Comparisons of individuals attitude toward household waste management according to the marital Status

The comparison of individuals about their attitude to household waste management as per their marital status helps to better understand the phenomena of household waste management. The One Way ANOVA found significant differences between single, married and other people about their attitude towards household waste management. Married people were shown to have a higher positive attitude than single people (See Table 8.18). this can be justified by the higher sense of responsibility that married people may have as compared to singles; cultural factors tend to make married people more adept at handling the responsibility of family waste management and underpin the need to cut cost and make smart purchase to save money for family purposes, which makes them more aware of the importance of reusing and recycling waste items in a beneficial way.

Table 8.18: Comparisons of individuals' attitude toward household waste management in accordance of their Marital Status

Marital Status	Marital Status	Mean Difference	Std. Error	Sig.	P Value
single	**married**	**-.15226***	**0.05915**	**0.032**	
	others	0.01625	0.16536	0.999	
married	**single**	**.15226***	**0.05915**	**0.032**	.02
	others	0.16852	0.16068	0.658	
others	single	-0.01625	0.16536	0.999	
	married	-0.16852	0.16068	0.658	

8.9 Analysis of Individuals Behaviour in Household Waste Management

To perform the analysis on the action and behavioural dimension of household management, this research used items with factor loadings of over 0.50. Out of 12 items, only 6 items could qualify for the final analysis. In order to compare the action and behaviour regarding household waste management, this study applied the one way ANOVA and Dunnt T3 test for post hoc analysis.

a. **Comparison of action and behaviour related to household waste Management at different age levels**

To start with, the analysis on the age levels was performed. The results demonstrated a significant difference among all age groups in their actions and behaviour pertaining to house waste management ($p<0.05$). In addition, the post hoc analysis found significant behavioural differences among the younger (18-20 Years) and adults age group people (21-30 Years) in that the younger (mostly students) people have higher positive behaviour toward household waste management issues, probably due to their commitment toward their school or university, their interest, and social culture. Moreover, another significant difference appeared between (21-30 years) and (41-50 years), which shows that the older group has a higher positive behaviour as compared to the younger one. The age group again proves that it has the highest knowledge, attitude and behaviour toward household waste management, indicating their high level of environmental public awareness. See Table 8.19 for further details.

Table 8.19: Comparison of action and behaviour related to household waste management at different age groups

(I) age	(J) age	Mean Difference (I-J)	Sig.	P value ANOVA
18-20	**21-30**	**.57557**	**0.018***	0.015
	31-40	0.10985	1.000	
	41-50	0.05101	1.000	
	51-60	0.09359	1.000	
	61 and above	0.37564	0.870	
21-30	**18-20**	**-.57557***	**0.018**	
	31-40	-0.46573	0.067	
	41-50	**-.52456***	**0.033**	
	51-60	-0.48198	0.226	
	61 and above	-0.19993	0.999	
31-40	18-20	-0.10985	1.000	
	21-30	0.46573	0.067	
	41-50	-0.05883	1.000	
	51-60	-0.01626	1.000	
	61 and above	0.26579	0.979	

41-50	18-20	-0.05101	1.000
	21-30	**.52456***	**0.033**
	31-40	0.05883	1.000
	51-60	0.04258	1.000
	61 and above	0.32463	0.934
51-60	18-20	-0.09359	1.000
	21-30	0.48198	0.226
	31-40	0.01626	1.000
	41-50	-0.04258	1.000
	61 and above	0.28205	0.987
61 and above	18-20	-0.37564	0.870
	21-30	0.19993	0.999
	31-40	-0.26579	0.979
	41-50	-0.32463	0.934
	51-60	-0.28205	0.987

b. Comparisons of individuals' action and behaviour related to household waste management in different genders

I performed Independent Sample T Test to perform this analysis. The results did not reveal any significant difference across male and female in their behaviour pertaining to household waste management ($p>.05$). The behaviour of male individuals was equivalent to that of female participants (See Table 8.20).

Table 8.20: Comparisons of individuals' actions and behaviour of household waste management across different genders

Gender	Mean	SD	Mean Difference	P value
Male	3.04	0.89	-.14	0.22
Female	3.18	0.93	-.14	

c. **Comparisons of individuals action and behaviour of household waste management in different Educational Groups**

One Way ANOVA Test was performed to determine the difference between the individuals' behaviour of household waste management across the educational level,. The results did not reveal any significant difference in the behaviour of individuals regardless of their education level (p>0.05). A description of these comparisons is available in Table 20.

Table 8.21: Comparisons of individuals' actions and behaviour of household waste management at different education levels

(I) education	(J) education	Mean Difference (I-J)	Std. Error	Sig.	P Value
Intermediate school and below	secondary school	0.16903	0.12807	0.712	.18
	undergraduate degree	0.04723	0.12383	0.999	
	higher education	0.00165	0.15340	1.000	
secondary school	Intermediate school and below	-0.16903	0.12807	0.712	

	undergraduate degree	-0.12179	0.05957	0.227
	higher education	-0.16738	0.10838	0.552
undergraduate degree	Intermediate school and below	-0.04723	0.12383	0.999
	secondary school	0.12179	0.05957	0.227
	higher education	-0.04559	0.10335	0.998
higher education	Intermediate school and below	-0.00165	0.15340	1.000
	secondary school	0.16738	0.10838	0.552
	undergraduate degree	0.04559	0.10335	0.998

d. Comparisons of individuals actions and behaviour related to household waste management according to the marital Status

The comparison of individuals about their behaviour towards household waste management as per their marital status helps to understand the phenomena of household waste management. The One Way ANOVA did not find any significant difference between single, married and other people in terms of their behaviour related to household waste management (See Table 8.22).

Table 8.22: Comparisons of individuals' actions and behaviour of household waste management as per their marital status

Marital Status	Marital Status	Mean Difference	Std. Error	Sig.	P Value
single	married	-0.02149	0.11777	0.997	.97

	others	-0.05788	0.33344	0.997
married	single	0.02149	0.11777	0.997
	others	-0.03639	0.32449	0.999
others	single	0.05788	0.33344	0.997
	married	0.03639	0.32449	0.999

8.10 Total Awareness and its Relationship with other Factors

The main objective of this study was to measure the total awareness of household waste management as well as its related factors. To that end, I performed the correlation analysis; the results demonstrated that age (.125, $p<.05$) and nationality (.14, $p<.05$) are important factors which influence the individuals' total awareness of household waste management. In addition, the results did not find any significant relationship of total awareness in terms of any other factor such as gender, education, marital status, residential area, job, income, family members and home type (See Table 8.23).

Table 8.23: Correlation Analysis

Variable	Total Awareness
Age	**.125***
Gender	-0.016
Education	0.015
Marital Status	0.091
Nationality	**.143***
Residential area	-0.079
Job	-0.037
Income	0.055

Family numbers	0.079
Home type	0.031

a. **The individual total awareness of household waste management across the different age levels**

The One Way ANOVA results did find significant difference in the total awareness about household waste management across different age groups (ANOVA p<.05). The major difference was observed in the age group of 21-30 and 41-50 (mean difference= -.35, p<.05). Meanwhile no significant difference was found among other age group individuals about their total awareness (Refer to Table 23).

Table 8.24: Total awareness across different age groups

(I) age	(J) age	Mean Difference (I-J)	Sig.	P value ANOVA
18-20	21-30	0.17641	0.672	0.005
	31-40	-0.08101	0.997	
	41-50	-0.16605	0.598	
	51-60	-0.12039	0.986	
	61 and above	0.16581	0.964	
21-30	18-20	-0.17641	0.672	
	31-40	-0.25742	0.069	
	41-50	**-.34246***	**0.006**	
	51-60	-0.29680	0.137	
	61 and above	-0.01059	1.000	

	18-20	0.08101	0.997
	21-30	0.25742	0.069
31-40	41-50	-0.08504	0.991
	51-60	-0.03938	1.000
	61 and above	0.24682	0.691
	18-20	0.16605	0.598
	21-30	**.34246***	**0.006**
41-50	31-40	0.08504	0.991
	51-60	0.04566	1.000
	61 and above	0.33187	0.393
	18-20	0.12039	0.986
	21-30	0.29680	0.137
51-60	31-40	0.03938	1.000
	41-50	-0.04566	1.000
	61 and above	0.28621	0.643
	18-20	-0.16581	0.964
	21-30	0.01059	1.000
61 and above	31-40	-0.24682	0.691
	41-50	-0.33187	0.393
	51-60	0.17641	0.672

b. The total awareness of household waste management in different nationalities

The total awareness was found to be significantly different in Bahraini and Resident individuals ($p<.01$). The results of Independent Sample t-test found the difference among the Bahraini and Residence to be -.24 in that residence people are more aware as compared to their Bahraini counterparts probably due to culture, lifestyle, experience, and social background. (Refer to Table 24)

Table 8.25: The Total Awareness of household waste management across different nationalities

Nationality	Mean	SD	Mean Difference	P value
Bahraini	3.89	0.50	-.24	0.01
Residence	4.13	0.48	-.24	

8.11 Conclusion

In conclusion, this study analysed the individuals' total awareness about the household waste management. Using existing literature and advanced statistical analysis, the total awareness was classified in three dimensions such as Knowledge, Attitude and Behaviour about the total awareness of household waste management. The results established the validity of these dimensions via confirmatory factor analysis. In addition, these dimensions were analysed across different genders, age, educational levels etc. The results indicated that the Total Awareness (sum of KAP) is significantly different across different age levels and nationality. Moreover, it shows a high public awareness toward household waste management among people in the Muharraq Governorate, which indicated that the society has the basics for enabling technologies adoption, which may help everyone to overcome the social barrier represented by low public awareness. Furthermore, males tended to have a better knowledge and attitude about household waste management than females in the Muharraq Governorate. According to OECD (1998 report), women and men may view domestic waste and its disposal differently; they manage waste differently and put different priorities on its disposal.

Laor et al. (2018) stated that the respondents with good knowledge also have a good level of practice; and those who have good attitude also have a good level of practice. He added that socio-demographic factors and suitable way of promoting an effective MSW management should be considered.

In addition, that the findings reveal that married people have a better attitude toward household waste management than single people. This is due to the responsibilities of marriage, and the culture of marriage which stressed upon the responsibility of family health, safety and protection especially by males who naturally take the responsibility of providing wealth to their families.

Accordingly, the government should prioritize females and singles in order to promote knowledge on effective household waste management, as well as prioritize singles to promote attitude. Also, the age group of 21-30 must be prioritized to promote behaviour or practice, attitude, and total awareness in the Muharraq Governorate, since the age groups of 18-20 years and 41-50 years are shown to have a higher positive behaviour than those belonging to the 21-30 age group. While the age group of 18-20 is prioritized to promote the knowledge.

At the end of this chapter, the last objective of this research *"to measure the public awareness toward household waste management via its components: knowledge, attitude, and behaviour, and find any significant correlation between the variables and public awareness components"* was achieved.

CHAPTER 9: Conclusion and Recommendations

9.1 Introduction

The work conducted in this thesis aimed to explore the opportunity for the preferred OHW management technology options based on the OHW characteristics of Muharraq Governorate, whilst exploring the enablers and barriers to the selected technologies adoption in Bahrain. The objectives and research questions that were achieved and answered through this research are:

1. To develop an organic household waste "parameter/technology" selection matrix. (Chapter 2 and 5)

-What are the optimum OHW physical and chemical characteristics for each technology option?

2. To determine the characteristics of the organic household waste in Bahrain represented by Muharraq Governorate OHW during two seasons: Normal and Ramadan (fasting month) (Chapter 5)

-To identify the OHW chemical and physical characteristics of Muharraq Governorate.

-Explore if there are differences in the OHW characteristics between the regular days and Ramadan season.

3. To determine the preferred technology by short-listing and selecting based on the organic waste parameter/technology matrix. (Chapter 5)

4. To evaluate the economic feasibility of the selected technologies using CBA (Chapter 6)

5. Exploring barriers and enablers to the adoption of the selected OHW management technologies. (Chapter 7)

To identify the enablers and barriers to the OHW management technologies.

6. To measure the public awareness toward the household waste management via its components: Knowledge, Attitude, and Behaviour, and find any significant correlation between the variables and public awareness components. These dependent variables are (age, gender, residential place type, educational level, marital status, and monthly income) as one of the key players in succeeding in any waste management practices in the country. (Chapter 8)

9.2 Most preferred OHWM Technologies for Muharraq Governorate

Assessment of different technologies available for OHWM in the Muharraq Governorate indicated that anaerobic digestion (AD) and incineration technologies are the most viable options for delivering a sustainable solution to manage OHW in the Muharraq Governorate specifically, and the Kingdom of Bahrain generally, based on the three criteria for technology selection discussed in this research: Technical Criteria (Waste Characterization, (Chapter 5)), Economic Criteria (Cost-Benefit Analysis, (Chapter 6)) and Social Criteria (Enablers and Barriers and Public Awareness Surveys , (Chapter 7 and 8)). This thesis started by developing the matrix of OHW parameter/ technology option, stating that all of the parameters required by each technology from the literature. The empirical investigation followed in order to have the full OHW characteristics for Muharraq Governorate during the fasting month (Ramadan) and normal days. No difference was found between the two seasons in terms of waste characterization, which indicates that the technology selection can fit both seasons. Based on the literature review, it was observed that there were very limited references that set criteria to select the most preferred waste management options and considered waste characterization as the criteria for technology selection.

Each technology will be discussed by combining all the criteria used (technical (objectives 1, 2 and 3), economic (Objective 4) and social (objectives 5 and 6)) and arrive at the following conclusion:

9.2.1 AD as an Option

The results of matching showed that Anaerobic Digestion (AD) is the most suitable technology to treat OHW using the pre-treatment of OHW prior adoption.

Based on the cost benefit analysis in Chapter 6, the AD is considered to be a feasible, viable and profitable solution to manage the OHW in Muharraq Governorate regardless of whether the government invests in it or the private sector expressed by the second or the first scenarios respectively, considering the high fertiliser cost (140USD/ton), beside its viability under the second scenario considering the low cost of fertiliser (6USD/ton). In addition to the suitability of the OHW of Muharraq Governorate to the AD as seen in Chapter 5 after adjusting pH and C:N ratio, the cost-benefit analysis supports this selection and gives an additional economic evidence to recommend the AD technology to the nation's decision makers to manage the OHW of Muharraq Governorate, which can then be embedded into the national legal and policy frameworks. However, AD is receiving increasing attention as a possible option of energy recovery from waste in the urban context. However, the operation of biogas plants from heterogeneous MSW poses a major challenge in terms of operational, safety and financial requirements. As a consequence, there are very few successful examples of biogas from MSW in developing countries (Mutz et al., 2017)

The requisite pre-treatment is needed to increase the C:N ratio and reach (16-30) through co-digestion by adding high carbon source waste such as: meat, fruits and vegetables. In addition, pH must be raised by adjusting it via adding an alkaline source to reach the optimum range (6.4- 8.5). All other parameters (e.g. moisture) are perfect for AD. The major challenge to the success of AD operation is guaranteeing a consistently well separated organic waste fraction (Mutz et al., 2017). Organic waste is often mixed with inorganic matter such as plastics, metals and other contaminants in developing countries, including Bahrain, which often impedes the success of AD at larger scales (Mutz et al., 2017). Moreover, it was concluded that AD needs a highly skilled manpower and infrastructure, the lack of training and technical support of various mechanical and management issues associated with methane digesters has directly contributed to the low adoption of this technology (Libarle, 2014). With regard to economic barriers, although AD systems were found to be a feasible and viable solution according to the economic criteria, they face a number of financial barriers, which make lenders reluctant to fund them. Many of these barriers can be overcome by adopting policies designed to improve the understanding of the financial information associated with AD adoption and establishing markets for the end products to attain the benefits attributed to AD installation (Gloy and Dressler, 2010). Absence of incentives to investment is also an important barrier to AD adoption. Lantz et al. (2007) argued that AD adoption needs increased incentives of different kinds to reach profitability levels which are often motivated from an energy and environmental point of view. Furthermore, Edwards et al. (2015) claimed that with the help of supportive government policy for the technology that considers the wide-ranging benefits of AD, investors will be more likely to show interest in the developing AD industry, which underpins the importance of governmental policy and support to enable AD adoption since the political barriers to AD found in this research are denoted by the lack of governmental policy and strategy and also by the absence of governmental support. In Germany, the regulation on its own was not sufficient to foster investment in AD. Even with generous incentives from the German government, increasing construction costs and the rising cost of energy crops jeopardised the financial viability of AD (Wilkinson, 2011). Our study agreed with the findings of Solan and Wennstrom (2012) who stated that improved technology, high energy costs, national commitment to reduce carbon emissions, and governmental support are important enablers to AD adoption. Our study also agrees with Akinbami et al. (2001) who concluded that barriers to AD adoption include economic, technical and socio–cultural. Chapter 8 showed that people have the awareness to accept sustainable waste management solutions and cooperate with the government to succeed in the most preferred technology adoption e.g.: they are ready to segregate waste at source. However, in Qatar, policy makers have encouraged recycling and reuse strategies to reduce the demand for raw materials as well as to bring down the quantity of waste going to landfill (Al-Maaded et al., 2012). Similarly, our study shows that experts in Bahrain prioritize the enabling of principals or basics of waste management: reduce, reuse and recycle to reduce waste volume going to landfill, by formulating the required policies, regulations and legislations, applying a segregation at source policy, and basically formulating an integrated national waste management strategy by centralizing the responsibility of managing the waste sector within the nation, under the "Waste management Authority" to be responsible for improving public awareness. This includes materials relating to reduction awareness, implementing the national waste management strategy, waste management related policy-making, accepting and coordinating investment and technology adoption in the country, as well as providing a database and all associated information about waste in the country, and providing training programs for national capacity building. In a comparative study in the KSA, AD technology proved to be the most suitable technology for (Ouda et al., 2016). In addition, compared to composting, AD is considered more environmentally friendly than composting, besides the suitability of materials and feasibility of technology. (Al Seadi, et al., 2013).

9.2.2 Incineration as an Option

Thermochemical conversion occupied the second place as most suitable technologies for OHWM in Muharraq Governorate based on waste characterization due to high calorific value, low heavy metals content, low sulphur content (mainly attributed to incineration, pyrolysis and gasification) and possible options with low expected environmental impacts. To enable thermochemical conversion, the high amount of moisture can be reduced through solar drying or using driers prior to combustion since the higher moisture content weakens the combustion process (Li et al., 2008).

Despite the negative effect of moisture on incineration, Li et al. (2008) concluded that the resulted CO and NOx concentration descend with an increase of moisture content, which reveals that moisture has a positive effect on the combustion, which supports the incineration technology selection decision making.

Incineration and gasification were both economically feasible under the second scenario, but not in the first scenario as stated in Chapter 6. Incineration was recommended as the best solution to manage OHW in Bahrain by four experts, despite the possible harmful environmental impact; the highly efficient state-of-the–art incineration technology with a highly controlled emission monitoring system is recommended to ensure avoiding these impacts. This technology is available and well recognized globally, and leads to the reduction in waste volume with electricity generation. The results of Oman MSW characterization by (Baauwain et al., 2017) showed the total energy content of MSW in Oman is 15.2 MJ/kg to 23.7 MJ/kg. In comparison, the total energy content in Muharraq OHW is 18.5 MJ/kg, which falls in the range of Oman waste energy content. According to Baawain et al, (2017), a "waste-to-energy" program was recommended due to the high-energy content of the MSWs (>15,000 kJ/kg) in Mascut city, which is consistent with our results. Therefore, incineration with heat recovery is considered to be the best economical method of waste management compared to plain incineration and landfill (similarly, in Bahrain, landfill needs a large area). Incineration saves a lot of money on transport of waste to landfills and also lowers carbon emissions released during the transportation process apart from reducing the waste volume. Moreover, designing of incinerators is being constantly evolved to increase efficiencies and reduce dioxin production. (Baawain et al., 2017). This research found that OHW inceniration leads to generate 126.5 GWh which represents 2.2 percent of Al-Hidd power plant annual generation which serves Muharraq Governorate, and contributes to Bahrain total power generation with 0.74 percent. In addition, the World Energy Council (2016) claimed that incineration of MSW continues to offer the most desirable economic conditions in the market, and is therefore the preferred option in most markets. Moreover, an official consultant in Bahrain recommended Incineration for inclusion in the long-list for a number of waste streams. Therefore, to enable incineration, a suitable and safe location must be provided, which is difficult in a small country like Bahrain. However, Mutz et al. (2017) stated that the community living next to the site of a planned incinerator is engaged with, and their interests are considered from the very beginning. Besides, he emphasized the importance of transparent communication and adequate engagement as a pre-condition. Tang and Tang (2007) claimed that the poor profit-making ability and the negative environmental impact are the two main barriers hampering incineration technology adoption. Incineration might be not feasible for larger scale, but in this research, it was found profitable considering the existence of the market of end products which made some sales, as well as considering treating a small volume of OHW (62,000 tonne/year). Incineration is considered neither feasible nor viable solution to manage the OHW in Muharraq Governorate under first scenario. Whereas by considering the saving earned from discontinuing OHW dumping in the second secnario, the net profit and NPV will increase, and therefore the project will become viable and profitable. As compared to the AD technology CBA, AD still earns higher profits and obtains higher returns on economy; in addition, the payback period is shorter and IRR is higher. However, both technologies are strongly recommended based on the technical and economic criteria, noting that in order to have a viable incineration, the government must invest in this project and discontinue the waste dumping consequently.

Skilled staff can be hired and retained to enable incineration (Mutz et al., 2017). It was found that the current energy subsidy represents a main barrier against transformation to renewable energy and green technologies, including waste incineration. In addition, reforming policy making and recruitment policy are important for enabling incineration adoption in Bahrain, according to the experts. People are aware in that almost half of them agreed that burning household waste in a modern and safe facility is a very effective way of lowering its size, compared to only 23.7% who disagreed, which is an indicator of public acceptance of incinerator adoption.

9.2.3 Gasification and Pyrolysis as Options

Gasification was identified as a viable technology under the second scenario according to the economic criteria. Despite the profitability, the capital cost of gasification is one of the highest, which represents a main barrier against its adoption. Pyrolysis - on the other hand - has a high initial cost as well as high O & M cost which made it unfeasible for managing OHW in Muharraq Governorate under all scenarios. Pyrolysis came at the fourth position in the list of recommended technologies in this research based on technical and economic criteria, whereas it was not recommended by any expert due its barriers based on social criteria with gasification. Both technologies were referred to as very complex, not efficient with mixed waste so that they needed a source segregation of waste to ensure high efficiency; thus the calculation of the cost benefit analysis of gasification was ideal considering the high efficiency with mixed waste, which is not the case with Bahrain due to the mixed waste and absence of segregation at source, a main technical barrier against their adoption, according to the experts. The high moisture of OHW of Muharraq Governorate represents a barrier to these thermo-conversion technologies as it was intended for incineration, albeit with higher sensitivity to moisture unlike incineration, which may need further costs for special pre-treatment (drying) of OHW before use.

According to Simone et al. (2009), the main barriers to gasification adoption are 1) The variable properties of waste with inflexibility of gasifier to process different kinds of feed; 2) The high moisture content limits the process' energetic efficiency; 3) Problems arising from solid handling and management; 4) Ash can form particulates and alkaline vapours; 5) The presence of tar in the gas can lead to fouling and plugging of the plant pipelines. The pyrolysis process is highly complex (Lievens et al., 2009). According to the official consultant working for the Bahrain government, "pyrolysis is not recommended for inclusion in the long-list as the scale is too small for the tonnages required for Bahrain and pyrolysis is not yet proven for mixed waste streams."

Mutz et al., (2017) stated that pyrolysis is not recommended for either mixed municipal waste, or for an environment wherein robust and proven technologies are needed. Pyrolysis or gasification cannot be considered easy to handle stand-alone technologies but need to be a component of the overall waste management system. Operation requires good understanding of the composition of incoming waste and process knowledge. According to past experiences, trouble free operation of a pyrolysis plant requires highly skilled technicians. It must be assumed that environmental legislation does not deal with the application of pyrolysis and gasification in most developing countries as combustion (or WtE) technology. This renders the entire process of impact assessment and operation licensing quite complicated and time consuming (Mutz et al., 2017).

Besides these technical barriers, our study found that economic barriers are the most dominant against these technologies adoption in Bahrain. The current subsidized fuel cost makes the investment in these technologies unattractive, in addition to the absence of incentives to investment as well as the absence of the market of end products (Samolada and Zabaniotou, 2014) affects their viability. Moreover, in addition to non-feasibility, the lack of capacity building required to operate them is another managerial barrier. Luo et al. (2018) stated that there are socio-environmental barriers, such as health concerns, environmental issues and public fears linked to gasification adoption. Our study agreed with the authors' findings in that the society is still not ready for the adoption of these new technologies, which are also not commonly available or used in the GCC region; the cultural barrier besides lack of public awareness about these technologies represent the main social barriers against their adoption. Furthermore, the absence of a national waste management strategy is a common barrier against all technologies' adoption in the country. Mutz et al. (2017) argued that environmental legislation in most developing countries does not deal with the application of pyrolysis and gasification as combustion (or WtE) technology, which makes the entire process of impact assessment and operation licensing quite complicated and time consuming, if not impossible.

9.2.4 RDF as an Option

Considering the use of RDF with incineration, RDF will be a viable solution with higher energy produced as compared to incineration alone, as shown in Chapter 6. This is because the segregation of waste was supposed to takes place in the Material Recovery Facility (MRF), which enhances the efficiency of incineration and yields more energy. Based on the waste characterization results, RDF was not found to be suitable for OHW of Muharraq Governorate due to the high organic matter content and low ash content, which affected the RDF quality. The main barrier to RDF adoption in Bahrain is the lack of the market of the end product. Since RDF is used only in cement plants as a substituent of coal, oil and natural gas (Mutz et al., 2017), the lack of cement plants in Bahrain affects the technology's utility. Without RDF market, the project will not be feasible due to the lack of sales, which is the case in Bahrain. Moreover, Mutz et al. (2017) stated that operational personnel must be trained according to the specific needs. He added: "*Due to the high technical complexity of co-processing, effective enforcement and regular inspections by public authorities require adequately qualified and equipped staff members*." (p.29).

Since RDF technology is a kind of waste pre-processing that aims to maximize the calorific value to be within the suitable range for combustion (mainly 10-23 MJ/Kg) to be used in cement plants. The absence of market of RDF and cement plants utilizing RDF makes this technology not suitable for Bahrain. Although, the estimated calorific value of the resulting RDF was almost the same as Muharraq OHW, which already has a high gross calorific value (18.5MJ/Kg) and was measured empirically earlier in this research; it is almost ready for combustion, which makes this technology not necessary and not useful for Muharraq OHW. Consequently, the project RDF technology is not viable.

However, all experts concurred that RDF is not suitable to manage OHW in Bahrain since the society is not ready for complex technologies as well as for the aforementioned reasons. Based on the waste characterization criteria in this research, RDF came at the end of the list and was found to be not suitable to manage OHW in the Muharraq Governorate.

9.2.5 Composting as an Option

Composting on small scale was recommended by three experts as a solution at the current status of mixed waste. The small scale means the feedstock is provided from the vegetable and fruits waste from the central market and not from the household waste. West Asian Bank, 2011 claimed that source-segregation program can improve the quality of composting end product. In case source segregation is not done properly, it is recommended to use vegetable market waste and wet organic waste from hotels and restaurants. In order to enable composting at a large scale for OHW management, segregation at source is essential, and the government must provide incentives to investment and the support, in addition to recognising the importance of formulating a national waste management strategy. Composting is simple, well recognized and accepted option to produce a marketable end product; it has the lowest capital, but the high O & M cost makes it not viable solution. West Asian Bank, 2011 claimed that the low heavy metal is required and high moisture is suitable, which are all available in the OHW of Muharraq Governorate as shown in Chapter 5. Calorific value 7-10 MJ/kg- 800-1000kcal/kg is suitable, but the results show that higher CV may affect the composting process. Moreover, carbon deficiency (low C:N ratio) can be fixed by adding wood chips, dry leaves, or sawdust. In order to facilitate the waste segregation, Baawain et al. (2017) argued that the use of color-coded containers for designated waste types must be advertised to promote recycling behaviours. Furthermore, he claimed that towing to the high percentage of organic materials, (>43 percent) the MSWs of Muscat is found to be suitable for compost production. Thus, in addition to recycling, composting can be used as one of the solutions to bring down the amount of disposing.

Despite these advantages, it is very sensitive to the quality of the input which affects the quality of the resulted compost and causes failure in marketing the low quality compost. The lack of local compost market represents another barrier to its adoption, so creating a market and raising public awareness in local products is essential to enable composting adoption. Besides, applying segregation at source policy is very important to ensure a high quality end product. Another barrier to composting in large scale is land limitation, since Bahrain has a limited geographical area, and composting needs a huge space with continuous aeration to be able to achieve it. Using in-vessel technology has a higher cost, but it may save land and prevent odours; thus it is considered more suitable for Bahrain. Due to the high cost and low benefits, Composting is considered not feasible solution to manage OHW in Muharraq Governorate (Chapter 6). In terms of waste characterization, the OHW in Muharraq Governorate has a low ash content, which is not suitable for composting as it needs a high ash % to work efficiently and produce good compost; this might be attributed to the mixed waste and impurities.

9.3 Public Awareness in Muharraq Governorate

The results indicated the Total Awareness (sum of KAP) is significantly different across different age levels and nationality. Moreover, it shows a high public awareness toward household waste management among the people in Muharraq Governorate, which indicated that the society is aware and has the basics to build on in terms of technologies adoption, which may help overcome the social barrier represented by low public awareness mentioned in Chapter 7. Furthermore, males tended to have a better knowledge about household waste management than females in the Muharraq Governorate. According to an OECD (1998) report, women and men may view domestic waste and its disposal differently; they manage waste differently and put different priorities on its disposal.

Metson and Bennett (2015) argued that the public awareness and culture play an important role in the success of any management practice. Laor et al. (2018) stated that respondents who have good knowledge also have a good level of practice; and those who have good attitude also have a good level of practice. He added that socio-demographic factors and suitable ways of promoting an effective MSW management should be considered.

He added the concerns over organic waste bins being smelly and attracting flies, maggots, and rodents are widespread, exacerbating the challenge of changing existing habits of not segregating organic from non-organic waste. The lack of information and knowledge about waste separation and composting also impedes the adoption of the waste management plan

In addition, results show that married people have a better attitude toward household waste management than single people. This is due to the lifestyle of married people and the different sense of responsibilities between the two groups. A study by Grover and Helliwell (2014) found that marriage can significantly boost life satisfaction, particularly for those approaching middle-age. This may explain by the positive attitude toward life aspects, including household waste management by married people, particularly those belonging to the 41-50 age group who found that they have a significantly high positive behaviour and total awareness than other age groups.

Accordingly, the government should prioritize females and singles to promote knowledge and attitude on effective household waste management in order to promote their attitude. Also, the age group 21-30 must be prioritized to promote behaviour or practice and attitude, and increase total awareness in Muharraq Governorate, since the age groups 18-20 years and 41-50 years have a higher positive behaviour.

However, Hasan (2004) argued that public awareness is the key to successful waste management. He claimed that public awareness and participation are critical components in any waste management program apart from appropriate legislation, strong technical support, and adequate funding. “Involve people in their own community decisions and actions, to avoid “not my business”– syndrome, and ensure “maximum participation” (Al-Seadi et al., 2013). It is useful to raise awareness about the purpose of the separation of food waste before the actual implementation. Amasuomo et al. (2015) opined that awareness and education is an important tool for increasing public participation in sustainable waste management programs. Moreover, they concluded that the barriers preventing public participation in sustainable solid waste management include the lack of information on how and where the wastes are to be disposed of, the unwillingness of public due to wastes and environmental levies, lack of adequate support from the government and other stakeholders, and poor government policies, amongst others.

Raising awareness about municipal solid waste management is an essential component of effective waste management. Moreover, community participation has a direct effect on efficient solid waste management plan (Wahid, 2015).

Korai et al. (2017) concluded that lack of pre-planning, infrastructure, public awareness and many other factors have become the root factors for worsening municipal solid waste management in Pakistan which agrees with our results. Abe and Didham (2013) stated that public awareness of appropriate solid waste management practices is the starting point and fundamental ingredient of a sound material-cycle and resource-efficient society. Furthermore, they argued that public awareness is the foundation of public capacity, which enables the public to undertake actual actions of each element of the 3Rs. Consequently, such actions become the input for the advancement or "performance" of 3Rs for a sound material-cycle society. Central and local governments, environmental NGOs, entrepreneurs, and mass-media, influence public awareness through their policies, practices, and operations, which leads to "capacity development".

9.4 Summary

This thesis is the first one to investigate six different OHWM technology options based on the waste characterization criteria, combining technical, economic and social criteria represented by: waste characterization, CBA and enablers and barriers investigation to their adoption in addition to public awareness measurement in the selection of the most preferred technology options to manage the OHW of Muharraq Governorate in the Kingdom of Bahrain. AD was found to be the most preferred technology to manage OHW in the Muharraq Governorate. This research concluded that in order to enable a successful adoption, the government has to apply a mandatory segregation-at-source policy. Moreover, according to the OHW characterization results shown in Chapter 5, a pre-treatment of OHW is needed to raise the C:N ratio by adding a carbon source (e.g. vegetables and fruits waste, wood chips) to reach the optimum range for AD operation (16-30). In addition, the pH also must be raised since it is acidic and the optimum is neutral to basic (about 6.5-8). However, at the current status of mixed waste, incineration was found to be the most recommended technology using the state-of-the-art technology to ensure the mitigation of negative environmental impacts associated with the incinerator adoption. According to the OHW characterization results (Chapter 5), the OHW of Muharraq Governorate contains low sulphur and low heavy metals, which are considered safe for incineration to avoid SOx emissions and heavy metals in the bottom or flying ash dumping or reusing. In order to enable incineration technically, it is important to use the pre-treatment of drying the OHW to increase the efficiency attributed to high moisture content. By implementing the OHWM technology project in Muharraq Governorate, the reduction of the landfill emission will reach 55,376 tonne/year of CO_2e by discontinuing OHW dumping into the landfill, assuming the existing OHW generation rate in Muharraq Governorate.

This might represent an opportunity for the Bahraini government to benefit from the CDM since Bahrain is a signatory on Kyoto protocol in 2006, as stated in Chapter 4. Further study is recommended to find out if each project is eligible to be registered as a CDM project and satisfies the criteria set by Kyoto Protocol. If so, there will be additional revenue from the sales of the CERs which will increase the profitability of each project.

In general, the enablers and barriers to OHWM technologies adoption in Bahrain fall under the following six main categories: Political, Technical, Managerial, Social, Economic and Environmental. In order to enable any technology adoption in Bahrain, the following barriers need to be overcome: Under the political barriers, the government must start with the deployment of a national waste management strategy that includes all regulations, legislations and organizing policies pertaining to the country's waste management sector, in addition to "Centralizing" the waste management responsibility under a single governmental authority that is responsible for waste management process liaising and coordinating, policy making, monitoring, attracting investment providing incentives, providing database and representing a centre of waste sector information in the country. This would be of great help in detecting the problems encountered at different waste management stream stages: awareness and smart purchasing for prevention of waste generation, waste generation, segregation at source, collection, pre-treatment upon technology requirements, technology adoption for waste treatment, detecting points of improvements, auditing production process and ensuring compliance of end products quality with the international standards, and finally marketing of the end products. Furthermore, the recruitment policy by the government must be reformed in that only well qualified people with sufficient knowledge must be recruited in the decision making positions in the waste management and municipalities sector to avoid losing the opportunities of improvement and investment in the OHWM technologies in the countries apart from the fact that their wrong decisions pose an obstacle against waste sector improvement in Bahrain.

Technically, besides the importance of enabling segregation at source to enable OHWM technologies adoption, the technology availability in the region, suitability of location and land availability as well as the existence of suitable infrastructure are all important technical enablers to adopt the OHWM technologies. Economically, the fuel cost subsidy by the government represents a barrier to transformation to renewable energy resources in the country. Thus, the lack of governmental support as well as the lack of incentives to investment in the waste management technologies represents a main barrier to the technologies' adoption. The high capital cost represents an important barrier. The lack of market of the end products as well as the local mistrust in the local products and their quality (e.g. local compost) affect the profitability and viability of these projects. Socially, public awareness was found to play an important role to enable the success of any waste management technology adoption in the country. If it was high, public acceptance and cooperation to adopt the technology adoption will exist. Public awareness can be expressed as the sum of the public: Knowledge, Attitude and Behaviour. Didham (2013) stated that public awareness of appropriate solid waste management practices is the starting point and fundamental ingredient of a sound material-cycle and resource-efficient society. The government was strongly recommended to prioritize reduce, reuse and recycle (3Rs) principle to prepare the society for more advanced technologies. As concluded in Chapter 8, the people of Muharraq Governorate were found to be aware toward the importance of household waste management and its related issues, which can enable the adoption of any technology in the country. This study also recommended that the government should prioritize females to promote knowledge and attitude on effective household waste management, as well as prioritize singles in order to promote attitude. Also the age group (21-30) must be prioritized to promote behaviour or practice and attitude and total awareness in Muharraq Governorate, since the age groups 18-20 years and 41-50 years have a higher positive behaviour than 21-30 years group. Moreover, total public awareness was significantly correlated with the nationality in that residence (non-Bahraini) have a higher awareness than Bahraini people, which can be justified by the lower number of non-Bahraini participants as compared to Bahraini, and they might be of a specific occupation mostly e.g. teachers which will have a higher awareness than other groups with mixed educational levels and occupations.

Furthermore, our results agreed with Abe and Didham (2013) who argued that public awareness forms the basis of public capacity, which enables the public to undertake actual actions of each element of the 3Rs. He added that central and local governments, environmental NGOs, entrepreneurs, and mass-media influence public awareness through their policies, practices, and operations, which leads to "capacity development". Therefore, national capacity building is also an important managerial enabler; it includes providing training for highly skilled manpower preparation to ensure that the technologies are efficient and have an effective operation. Special statistical and monitoring systems are essential to create a database about waste and associated information to represent a reference for any research, investors and feasibility studies, as well as opportunities of improvement detection. In addition, privatization of the waste sector is highly recommended to improve it in order to promote competitiveness and innovative solutions in waste management in Bahrain.

9.5 Limitation of the Study

This thesis presents some limitations that might need to be addressed during further research:

1. Sufficient fund for the characterization phase of the study was not provided, if given, the empirical lab analysis could be done in several seasons and different time periods in order to have more readings for more accurate results.

2. The available data from MWMUPA is very general and not sufficient, which included scattered statistics that are just organized to serve their basic purposes, without focusing on organic household waste, estimating the possible GHG emissions from it, or including any plan or action to mitigate these emissions.

3. In general, the lack of research focusing on the organic waste in Bahrain, despite the quantity of the high organic waste produced, as well as its contribution towards GHG generation in particular, does not have much value in planning and decision making processes.

4. Limitation and confidentiality of the available data all affects the research progress to some degree.

5. Preliminary efforts have been made in the study to explore the opportunity for OHWM technology options for the Muharraq Governorate. This task was difficult due to the non-availability of the sufficient literature. It was very difficult to compare the study's results with literature, in which a similar approach in combining the three criteria (waste characterization, CBA, and enablers and barriers and public awareness) in an empirical investigation for exploring the most preferred technology option for OHWM in a specific context did not exist in the literature; thus it necessitates a new approach with some improvement at some points. However, this study could serve as a point of reference and open up a new horizon for future research work in this field.

6. The limitation of time in achieving such a massive research does not make it possible to further pursue for the environmental impact assessment for each technology (Environmental Criteria) to complete the sustainability triangle (social, economic and environmental), which was supposed to be one of the main objectives of the research. However, it might be one of the future recommendations to complete such an important study for the Bahrain context.

9.6 Recommendations for Future Work

Given the findings of this study it is recommended that in order to successfully implement OHWM technology in the Muharraq Governorate specifically and in Bahrain generally, for delivering a sustainable solution to manage household waste in the country, the following approach should be taken: Firstly, steps need to be taken by the local or national government to formulate a national waste management strategy that includes designing and implementing comprehensive and robust policies to support the adoption of OHWM technologies. These policies should primarily set the framework by which OHWM projects can be financially supported by providing incentives to attract investment in these green and sustainable projects. The provision of development grants, affordable loans and subsidies should be considered.

Secondly, policy makers should consider the Clean Development Mechanism (CDM) in any sustainable and green project, including waste management projects. The CDM is an option that contributes in overcoming the barrier of high cost that may appear for some technologies, wherein the emission reduction realized by the project activity can be exchanged with the 'certified emission reduction' (CER) credits that enhance the revenues of the project and in effect, increase the profitability and viability (UNFCCC, 2014).

In addition, the mixed approach followed in this research can be improved to develop a "Selection Model" so as to facilitate OHWM preferred technology selection in any context. Moreover, it can be improved to a new "methodology" or tool that aims to select the most preferred technology for OHW management, combining it with a computer system that converts the entire data to the soft matrices database: the soft parameter/technology matrix, the CBA/technology matrix, and the enablers and barriers/technology matrix. The user just needs to enter their parameter (characterization), and the most preferred technology will appear before them with all expected costs, enablers and barriers along with a ranking list from the most prioritized options for the user's context, to the least one. This system can be suggested to be called: WCTSA (Waste

Characterization-based-Technology Selection Approach). It can be helpful in determining the best technologies to manage OHW and be used as a decision-making tool within the country, which will save time, efforts and cost, in addition to providing evidence-based suggestions to the decision makers.

Following the waste management pyramid and focusing on enabling prevention practices, reduce, reuse and recycle (3R) is highly recommended and prioritized to start with in Bahrain society in order to create more awareness in the community, which will have smart purchasing behaviour, dematerialization in consumption to prevent or reduce waste generation, as well as the role of education at a very early stage and curriculum in building awareness, which will reflect positively on the society. Furthermore, segregation at source is a key player in order to enable the 3Rs principle along with any waste management technology adoption in the future. However, enabling the waste management technologies means that we skip the waste management pyramid and ignore the basic solutions to prevent, reduce, reuse and recycle of waste, which also means that waste must be generated to ensure the sufficient feedstock in order to guarantee a consistent and efficient operation, which is -at its origin- and not considered sustainable.

The final recommendation is to generalize the study for Bahrain by characterizing the OHW of the entire country rather than Muharraq, in both Ramadan season and normal days, whilst making a comparison between them and matching it with the matrix to confirm if it is the same characteristics or not. In addition, measuring public awareness in all Bahraini governorates and making a comparison is recommended. A larger number of participants (> 300) can be considered to ensure the accuracy of the findings.

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Appendices

Appendix 1: Empirical Stage Photos

a. Waste Sampling and Sorting Photos

1. Household Waste Collection

2. Evacuation at the landfill location

3. Sorting

4. Sorting

b. Pictures of OHW as received to the Lab prior analysis

SAMPLE RECEIVED – 03 APRIL 2017

SAMPLE RECEIVED – 04 APRIL 2017

SAMPLE RECEIVED – 06 APRIL 2017

Appendix 2: Lab Analysis Results Reports (total of 4 Reports: 3 normal days and 1 in Ramadan)

a. **Ramadan Report**

AL HOTY
ANALYTICAL SERVICES W.L.L.

الحوطي
AL HOTY
لخدمات التحليل
ANALYTICAL SERVICES

CERTIFICATE OF ANALYSIS

ARABIAN GULF UNIVERSITY

Manama, Kingdom of Bahrain

DATE : 20.07.2017
REQ. NO. : OTHQ-170717/627
SAMPLE NO. : OTHS-170717/1
REPORT NO. : OTHR-170717/797

SAMPLE DESCRIPTION : Food Waste
DATE SUBMITTED : 22.06.2017
DATE TESTED : 22.06.2017 - 18.07.2017

S. NO.	PARAMETER	TEST METHOD	UNIT	RESULT
1	pH (1:2.5 water extract)	USEPA 9045 D	-	4.7
2	Ash Content @ 750 °C	Ignition	%	1.4
3	Organic Matter @ 550 °C			83.1
4	Cadmium (Cd)	USEPA 3050 B / 6010 B	mg/kg	<0.01
5	Chromium (Cr)			3.3
6	Lead (Pb)			<0.5
7	Copper (Cu)			5.3
8	Nickel (Ni)			2.8
9	Zinc (Zn)			26
10	Mercury (Hg)			<0.2
11	Oil & Grease	USEPA 9071 B	%	9.3
12	Total Phosphorous	Spectrophotometer		0.62
13	Moisture	Oven Dry		73.5
14	Total Organic Carbon (TOC)	APHA 5310 B	mg/kg	43760
15	Total Ammonial Nitrogen (TAN)	Distillation		469
16	Total Nitrogen	APHA 4500 N-C		3840
17	Chemical Oxygen Demand (COD)	APHA 5220 D		183000
18	Biologial Oxygen Demand (BOD)	APHA 5210 B		29280
19	Carbonate	Titration	%	0.6
20	Ammonium Salts	Distillation		605
21	*Gross Calorific Value	ASTM D 4809	MJ/Kg	16.89
22	*Sulphur	ASTM D 4294	%	0.06
23	Total Coliforms	APHA 9221 B	MPN Index/100mL	94×10^5
24	Escherichia Coli	APHA 9221 F	MPN Index/100mL	70×10^3

*Outsource

SAPPANI MUTHIAH
Chemistry Laboratory Manager

CHEMICAL DEPARTMENT
Kingdom of Bahrain
AL HOTY ANALYTICAL SERVICES W.L.L.

Checked by: /Cza

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b. Normal days Reports

AL HOTY
ANALYTICAL SERVICES W.L.L.

CERTIFICATE OF ANALYSIS

ARABIAN GULF UNIVERSITY

Manama, Kingdom of Bahrain

DATE : 03.05.2017
REQ. NO. : OTHQ-170427/388
SAMPLE NO. : OTHS-170427/1
REPORT NO. : OTHR-170427/488

SAMPLE DESCRIPTION : Food Waste
DATE SUBMITTED : 04.04.2017
DATE TESTED : 04.04.2017 - 03.05.2017

S. NO.	PARAMETER	TEST METHOD	UNIT	RESULT
1	pH (1:2.5 water extract)	USEPA 9045 D	-	5.1
2	Ash Content @ 750 °C	Ignition	%	5.4
3	Organic Matter @ 550 °C			92.7
4	Cadmium (Cd)	USEPA 3050 B / 6010 B	mg/kg	<0.01
5	Chromium (Cr)			<0.01
6	Lead (Pb)			<0.5
7	Copper (Cu)			17
8	Nickel (Ni)			1.6
9	Zinc (Zn)			113
10	Mercury (Hg)			<0.2
11	Oil & Grease	USEPA 9071 B	%	3.6
12	Total Phosphorous	Spectrophotometer		0.07
13	Moisture	Oven Dry		66.2
14	Total Organic Carbon (TOC)	APHA 5310 B	mg/kg	64480
15	Total Ammonial Nitrogen (TAN)	Distillation		935
16	Total Nitrogen	APHA 4500 N-C		3117
17	Chemical Oxygen Demand (COD)	APHA 5220 D		154000
18	Biologial Oxygen Demand (BOD)	APHA 5210 B		38500
19	Carbonate	Titration	%	0.9
20	Ammonium Salts	Distillation		1206
21	*Gross Calorific Value	ASTM D 4809	MJ/Kg	19.08
22	*Sulphur	ASTM D 4294	%	0.13
23	Total Coliforms	APHA 9221 B	MPN Index/100mL	$17x10^5$
24	Escherichia Coli	APHA 9221 F	MPN Index/100mL	$70x10^3$

*Outsource

CHEMICAL DEPARTMENT

SAPPANI MUTHIAH
Chemistry Laboratory Manager

Checked by: ____

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AL HOTY ANALYTICAL SERVICES W.L.L.	CERTIFICATE OF ANALYSIS	DATE : 03.05.2017
		REQ. NO. : OTHQ-170427/389
	ARABIAN GULF UNIVERSITY	SAMPLE NO. : OTHS-170427/1
		REPORT NO. : OTHR-170427/489
	Manama, Kingdom of Bahrain	

SAMPLE DESCRIPTION : Food Waste
DATE SUBMITTED : 06.04.2017
DATE TESTED : 06.04.2017 - 03.05.2017

S. NO.	PARAMETER	TEST METHOD	UNIT	RESULT
1	pH (1:2.5 water extract)	USEPA 9045 D	-	**4.5**
2	Ash Content @ 750 °C	Ignition	%	**3.5**
3	Organic Matter @ 550 °C			**96.1**
4	Cadmium (Cd)	USEPA 3050 B / 6010 B	mg/kg	**<0.01**
5	Chromium (Cr)			**<0.01**
6	Lead (Pb)			**<0.5**
7	Copper (Cu)			**17**
8	Nickel (Ni)			**3.3**
9	Zinc (Zn)			**104**
10	Mercury (Hg)			**<0.2**
11	Oil & Grease	USEPA 9071 B	%	**7.8**
12	Total Phosphorous	Spectrophotometer		**0.21**
13	Moisture	Oven Dry		**74.8**
14	Total Organic Carbon (TOC)	APHA 5310 B	mg/kg	**45520**
15	Total Ammonial Nitrogen (TAN)	Distillation		**1612**
16	Total Nitrogen	APHA 4500 N-C		**7900**
17	Chemical Oxygen Demand (COD)	APHA 5220 D		**134000**
18	Biologial Oxygen Demand (BOD)	APHA 5210 B		**34840**
19	Carbonate	Titration	%	**0.6**
20	Ammonium Salts	Distillation		**2079**
21	*Gross Calorific Value	ASTM D 4809	MJ/Kg	**15.22**
22	*Sulphur	ASTM D 4294	%	**0.11**
23	Total Coliforms	APHA 9221 B	MPN Index/100mL	**$9.3x10^6$**
24	Escherichia Coli	APHA 9221 F	MPN Index/100mL	**$14x10^3$**

*Outsource

الحوطي لخدمات التحليل ذ.م.م CHEMICAL DEPARTMENT Kingdom of Bahrain ANALYTICAL SERVICES W.L.L.

SAPPANI MUTHIAH
Chemistry Laboratory Manager

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AL HOTY ANALYTICAL SERVICES W.L.L.	CERTIFICATE OF ANALYSIS	DATE : 03.05.2017
		REQ. NO. : OTHQ-170427/387
	ARABIAN GULF UNIVERSITY	SAMPLE NO. : OTHS-170427/1
		REPORT NO. : OTHR-170427/487
	Manama, Kingdom of Bahrain	

SAMPLE DESCRIPTION : Food Waste
DATE SUBMITTED : 03.04.2017
DATE TESTED : 03.04.2017 - 03.05.2017

S. NO.	PARAMETER	TEST METHOD	UNIT	RESULT
1	pH (1:2.5 water extract)	USEPA 9045 D	-	4.8
2	Ash Content @ 750 °C	Ignition	%	5.5
3	Organic Matter @ 550 °C			93.5
4	Cadmium (Cd)	USEPA 3050 B / 6010 B	mg/kg	<0.01
5	Chromium (Cr)			<0.01
6	Lead (Pb)			<0.5
7	Copper (Cu)			15
8	Nickel (Ni)			4.6
9	Zinc (Zn)			89
10	Mercury (Hg)			<0.2
11	Oil & Grease	USEPA 9071 B	%	7.3
12	Total Phosphorous	Spectrophotometer		0.13
13	Moisture	Oven Dry		76.7
14	Total Organic Carbon (TOC)	APHA 5310 B	mg/kg	45720
15	Total Ammonial Nitrogen (TAN)	Distillation		1070
16	Total Nitrogen	APHA 4500 N-C		6156
17	Chemical Oxygen Demand (COD)	APHA 5220 D		117000
18	Biologial Oxygen Demand (BOD)	APHA 5210 B		29250
19	Carbonate	Titration	%	0.6
20	Ammonium Salts	Distillation		1380
21	*Gross Calorific Value	ASTM D 4809	MJ/Kg	21.18
22	*Sulphur	ASTM D 4294	%	0.11
23	Total Coliforms	APHA 9221 B	MPN Index/100mL	4.5×10^6
24	Escherichia Coli	APHA 9221 F	MPN Index/100mL	17×10^4

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Appendix 3: CBA and Calculations

a. Cost-Benefit Analysis and Cash Flows per Technology in (Excel)

Anaerobic Digestion (AD) Scenario 1	
Description	USD
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	1,260,000
Total O&M Cost/Year	1,015,000
Benefit/year	
Electricity	649,802
Fertiliser	1,722,840
Total Benefit/year	2,372,642
Net Profit / Year	1,357,642

YEAR	CASH FLOW
0	(1,260,000)
1	1,357,642
2	1,357,642
3	1,357,642
4	1,357,642
5	1,357,642
6	1,357,642
7	1,357,642
8	1,357,642
9	1,357,642
10	1,357,642
11	1,357,642
12	1,357,642
13	1,357,642
14	1,357,642
15	1,357,642

DISCOUNT RATE	10%
NPV	9,066,333
IRR	108%
PBP	0.93

Anaerobic Digestion (AD) Scenario 2	
Description	USD
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	1,260,000
Total O&M Cost/ Year	1,015,000
Benefit/Year	
Fertiliser	1,722,840
Electricity	649,802
Direct saving by discontinuing waste dumping	981,539
Total Benefit/year	3,354,181
Net Profit / Year	2,339,181

YEAR	CASH FLOW
0	(1,260,000)
1	2,339,181
2	2,339,181
3	2,339,181
4	2,339,181
5	2,339,181
6	2,339,181
7	2,339,181
8	2,339,181
9	2,339,181
10	2,339,181
11	2,339,181
12	2,339,181
13	2,339,181
14	2,339,181
15	2,339,181

DISCOUNT RATE	10%
NPV	16,531,997
IRR	186%
PBP	0.54

Incineration Scenario 1	
Description	USD
Capital cost $/ton	44.7
O & M Cost $/ton	27.5
Total Capital Cost	3,129,000
Total O&M Cost/ year	1,925,000
Benefit/year	
Electricity	1,011,800
Ash	6,000
Total Benefit/year	1,017,800
Net Profit / Year	(907,200)

YEAR	CASH FLOW
0	(3,129,000)
1	(907,200)
2	(907,200)
3	(907,200)
4	(907,200)
5	(907,200)
6	(907,200)
7	(907,200)
8	(907,200)
9	(907,200)
10	(907,200)
11	(907,200)
12	(907,200)
13	(907,200)
14	(907,200)
15	(907,200)

DISCOUNT RATE	10%
NPV	(10,029,235)
IRR	NA
PBP	NA

Incineration Scenario 2	
Description	USD
Capital cost $/ton	18.0
O & M Cost $/ton	14.5
Total Capital Cost	1,260,000
Total O&M Cost/ year	1,015,000
Benefit/year	
Electricity	1,722,840
Ash	6,000
Direct saving by discontinuing waste dumping	981,539
Total benefit/year	2,710,379
Net Profit / Year	1,695,379

YEAR	CASH FLOW
0	(1,260,000)
1	1,695,379
2	1,695,379
3	1,695,379
4	1,695,379
5	1,695,379
6	1,695,379
7	1,695,379
8	1,695,379
9	1,695,379
10	1,695,379
11	1,695,379
12	1,695,379
13	1,695,379
14	1,695,379
15	1,695,379

DISCOUNT RATE	10%
NPV	11,635,187
IRR	135%
PBP	0.74

Gasification Scenario 1	
Description	USD
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	3,248,000
Total O&M Cost/Year	2,842,000
Benefit/year	
Electricity	2,759,482
Total Benefit/year	2,759,482
Net Profit / Year	(82,518)

YEAR	CASH FLOW
0	(3,248,000)
1	(82,518)
2	(82,518)
3	(82,518)
4	(82,518)
5	(82,518)
6	(82,518)
7	(82,518)
8	(82,518)
9	(82,518)
10	(82,518)
11	(82,518)
12	(82,518)
13	(82,518)
14	(82,518)
15	(82,518)

DISCOUNT RATE	10%
NPV	(3,875,635)
IRR	NA
PBP	NA

Gasification Scenario 2	
Description	USD
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	3,248,000
Total O&M Cost/ Year	2,842,000
Benefit/Year	
Electricity	2,759,482
Direct saving by discontinuing waste dumping	981,539
Total Benefit/year	3,741,021
Net Profit / Year	899,021

YEAR	CASH FLOW
0	(3,248,000)
1	899,021
2	899,021
3	899,021
4	899,021
5	899,021
6	899,021
7	899,021
8	899,021
9	899,021
10	899,021
11	899,021
12	899,021
13	899,021
14	899,021
15	899,021

DISCOUNT RATE	10%
NPV	3,590,028
IRR	27%
PBP	3.61

Pyrolysis Scenario 1	
Description	USD
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	3,248,000
Total O&M Cost/Year	2,842,000
Benefit/year	
Bio-Oil	837,312
Total Benefit/year	837,312
Net Profit / Year	(2,004,688)

YEAR	CASH FLOW
0	(3,248,000)
1	(2,004,688)
2	(2,004,688)
3	(2,004,688)
4	(2,004,688)
5	(2,004,688)
6	(2,004,688)
7	(2,004,688)
8	(2,004,688)
9	(2,004,688)
10	(2,004,688)
11	(2,004,688)
12	(2,004,688)
13	(2,004,688)
14	(2,004,688)
15	(2,004,688)

DISCOUNT RATE	10%
NPV	(18,495,816)
IRR	NA
PBP	NA

Pyrolysis Scenario 2	
Description	USD
Capital cost $/ton	46.4
O & M Cost $/ton	40.6
Total Capital Cost	3,248,000
Total O&M Cost/ Year	2,842,000
Benefit/Year	
Bio-Oil	837,312
Direct saving by discontinuing waste dumping	981,539
Total Benefit/year	1,818,851
Net Profit / Year	(1,023,149)

YEAR	CASH FLOW
0	(3,248,000)
1	(1,023,149)
2	(1,023,149)
3	(1,023,149)
4	(1,023,149)
5	(1,023,149)
6	(1,023,149)
7	(1,023,149)
8	(1,023,149)
9	(1,023,149)
10	(1,023,149)
11	(1,023,149)
12	(1,023,149)
13	(1,023,149)
14	(1,023,149)
15	(1,023,149)

DISCOUNT RATE	10%
NPV	(11,030,153)
IRR	NA
PBP	NA

RDF Scenario 1	
Description	USD
Capital cost $/ton	20.3
O & M Cost $/ton	17.4
Total Capital Cost	1,421,000
Total O&M Cost/Year	1,218,000
Benefit/year	
RDF	243,600
Total Benefit/year	243,600
Net Profit / Year	(974,400)

YEAR	CASH FLOW
0	(1,421,000)
1	(974,400)
2	(974,400)
3	(974,400)
4	(974,400)
5	(974,400)
6	(974,400)
7	(974,400)
8	(974,400)
9	(974,400)
10	(974,400)
11	(974,400)
12	(974,400)
13	(974,400)
14	(974,400)
15	(974,400)

DISCOUNT RATE	10%
NPV	(8,832,364)
IRR	NA
PBP	NA

RDF Scenario 2	
Description	USD
Capital cost $/ton	20.3
O & M Cost $/ton	17.4
Total Capital Cost	1,421,000
Total O&M Cost/ Year	1,218,000
Benefit/Year	
Bio-Oil	243,600
Direct saving by discontinuing waste dumping	981,539
Total Benefit/year	1,225,139
Net Profit / Year	7,139

YEAR	CASH FLOW
0	(1,421,000)
1	7,139
2	7,139
3	7,139
4	7,139
5	7,139
6	7,139
7	7,139
8	7,139
9	7,139
10	7,139
11	7,139
12	7,139
13	7,139
14	7,139
15	7,139

DISCOUNT RATE	10%
NPV	(1,366,700)
IRR	NA
PBP	NA

Composting Scenario 1	
Description	USD
Capital cost $/ton	13.6
O & M Cost $/ton	45.0
Total Capital Cost	952,000
Total O&M Cost/Year	3,150,000
Benefit/year	
Compost	199,969
Total Benefit/year	199,969
Net Profit / Year	(2,950,031)

YEAR	CASH FLOW
0	(952,000)
1	(2,950,031)
2	(2,950,031)
3	(2,950,031)
4	(2,950,031)
5	(2,950,031)
6	(2,950,031)
7	(2,950,031)
8	(2,950,031)
9	(2,950,031)
10	(2,950,031)
11	(2,950,031)
12	(2,950,031)
13	(2,950,031)
14	(2,950,031)
15	(2,950,031)

DISCOUNT RATE	10%
NPV	(23,390,168)
IRR	NA
PBP	NA

Composting Scenario 2	
Description	USD
Capital cost $/ton	13.6
O & M Cost $/ton	45.0
Total Capital Cost	952,000
Total O&M Cost/ Year	3,150,000
Benefit/Year	
Compost	199,969
Direct saving by discontinuing waste dumping	981,539
Total Benefit/year	1,181,508
Net Profit / Year	(1,968,492)

YEAR	CASH FLOW
0	(952,000)
1	(1,968,492)
2	(1,968,492)
3	(1,968,492)
4	(1,968,492)
5	(1,968,492)
6	(1,968,492)
7	(1,968,492)
8	(1,968,492)
9	(1,968,492)
10	(1,968,492)
11	(1,968,492)
12	(1,968,492)
13	(1,968,492)
14	(1,968,492)
15	(1,968,492)

DISCOUNT RATE	10%
NPV	(15,924,505)
IRR	NA
PBP	NA

b. Calculations for Power and Sales per Technology

Description	Millions (BHD)	Millions (USD)
Overall Cost / Year	17	45.05
Labour		
Containers		
Offices		
Overhead		
Dumping cost / Year		
Gate fees		

Description	Millions (BHD)	Millions (USD)
Dumping / Year	**11.0**	**29.2**
Gate fees	**1.2**	**3.2**
Total Dumping Cost	**12.2**	**32.3**
Dumping cost %	**71.8%**	

Description	Ton / Year	Cubic Meter Biogas	Cubic Meter Biogas/Ton	KWh/Ton	Total Energy Output (KWh)	Domestic Cost BHD/KWh	Domestic Cost USD/KWh	Benefit	Benefit $
Saudi OW	7,600,000	3,420,000,000	450	398.5	3,028,812,800	0.22		SAR 666,338,816	179,911,480
Total Bahrain OHW (41% of HW)	240,966	108,434,700	450	398.5	96,031,698	0.01	0.02	BHD 960,317	2,544,840
Muharraq OHW (60% of HW)	61,529	27,687,844	450	398.5	24,520,847	0.01	0.02	BHD 245,208	649,802

Description	Ton / Yr
Total Bahrain MSW to landfill	2,026,631
% From total Bahrain OHW from Dumping Cost	11.9%
Total Bahrain OHW from Dumping Cost (Million USD)	3.844
% From Muharraq OHW From Dumping Cost	3.0%
Muharraq OHW From Dumping Cost (Million USD)	0.982

Description	ton CO2e	kg CH4	kg waste
EMISSION / KG		0.036	1
EMISSIONS FROM MUHARRAQ WASTE	55,376	2,215	61,528,542

Incineration	MJ	kwh	Kg	MJ	ton	kwh	MJ/kg
kg			1	18.5	1	700	17
1	3.6	1	61,528,542	1,138	1	752	19
1	18.5	5.14		316,188,341	61,529	46	
61,528,542		126					
1000		2,056					
1000	550	126,475,336					
1000	1000						

AD	ton	kwh	usd
	1	398.00	0.02
Biogas	61,529	24.49	489,770.84
		Gwh	

ton digestate	USD
1	140

TOTAL TONNE FOR MUHARRAQ	61,529
TOTAL KWH FROM MUHARRAQ WASTE	126,475,336
1 KWH SALES IN USD	0.02
EFFECIENCY 100%- TOTAL SALES USD	2,529,507
EFFECIENCY 40%- TOTAL SALES USD	1,011,803

Gasification	KWh	Gwh	USD
1 ton	3,737		
61,529	229,956,869	138	2,759,482
Ash / Year (Sales)			6,000

MSW Mton	Ash Mton	Ash %
33	9	28%
0.62	0.17	

Composting	ton waste	ton compost	USD
	1	0.065	50
	61,529	3,999	199,969

Appendix 4: Ethical Approval
a. BSREC Full Approval

WARWICK
THE UNIVERSITY OF WARWICK

PRIVATE
Miss S Abbas
WMG
University of Warwick
Coventry
CV4 7AL

14 February 2018

Dear Ms Abbas

Study Title and BSREC Reference: *Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical Investigation for Muharraq City* REGO-2017-2140

Thank you for submitting the revisions to the above-named study to the University of Warwick's Biomedical and Scientific Research Ethics Sub-Committee for approval.

I am pleased to confirm that approval is granted and that your study may commence.

In undertaking your study, you are required to comply with the University of Warwick's *Research Data Management Policy*, details of which may be found on the Research and Impact Services' webpages, under "Codes of Practice & Policies" » "Research Code of Practice" » "Data & Records" » "Research Data Management Policy", at: http://www2.warwick.ac.uk/services/ris/research_integrity/code_of_practice_and_policies/research_code_of_practice/datacollection_retention/research_data_mgt_policy

You are also required to comply with the University of Warwick's *Information Classification and Handling Procedure*, details of which may be found on the University's Governance webpages, under "Governance" » "Information Security" » "Information Classification and Handling Procedure", at: http://www2.warwick.ac.uk/services/gov/informationsecurity/handling.
Investigators should familiarise themselves with the classifications of information defined therein, and the requirements for the storage and transportation of information within the different classifications:

Information Classifications:
http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/classifications
Handling Electronic Information:
http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/electronic/
Handling Paper or other media
http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/paper/.

Please also be aware that BSREC grants **ethical approval** for studies. **The seeking and obtaining of *all* other necessary approvals is the responsibility of the investigator.**

These other approvals may include, but are not limited to:

www.warwick.ac.uk

1. Any necessary agreements, approvals, or permissions required in order to comply with the University of Warwick's Financial Regulations and Procedures.
2. Any necessary approval or permission required in order to comply with the University of Warwick's Quality Management System and Standard Operating Procedures for the governance, acquisition, storage, use, and disposal of human samples for research.
3. All relevant University, Faculty, and Divisional/Departmental approvals, if an employee or student of the University of Warwick.
4. Approval from the applicant's academic supervisor and course/module leader (as appropriate), if a student of the University of Warwick.
5. NHS Trust R&D Management Approval, for research studies undertaken in NHS Trusts.
6. NHS Trust Clinical Audit Approval, for clinical audit studies undertaken in NHS Trusts.
7. Approval from Departmental or Divisional Heads, as required under local procedures, within Health and Social Care organisations hosting the study.
8. Local ethical approval for studies undertaken overseas, or in other HE institutions in the UK.
9. Approval from Heads (or delegates thereof) of UK Medical Schools, for studies involving medical students as participants.
10. Permission from Warwick Medical School to access medical students or medical student data for research or evaluation purposes.
11. NHS Trust Caldicott Guardian Approval, for studies where identifiable data is being transferred outside of the direct clinical care team. Individual NHS Trust procedures vary in their implementation of Caldicott guidance, and local guidance must be sought.
12. Any other approval required by the institution hosting the study, or by the applicant's employer.

There is no requirement to supply documentary evidence of any of the above to BSREC, but applicants should hold such evidence in their Study Master File for University of Warwick auditing and monitoring purposes. You may be required to supply evidence of any necessary approvals to other University functions, e.g. The Finance Office, Research & Impact Services (RIS), or your Department/School.

May I take this opportunity to wish you success with your study, and to remind you that any Substantial Amendments to your study require approval from BSREC before they may be implemented.

Yours sincerely

pp. E Dight

Dr David Ellard
Chair
Biomedical and Scientific
Research Ethics Sub-Committee

Biomedical and Scientific
Research Ethics Sub-Committee
Research & Impact Services
University of Warwick
Coventry, CV4 8UW.
E: BSREC@Warwick.ac.uk

http://www2.warwick.ac.uk/services/ris/research_integrity/researchethicscommittees/biomed

b. Consent Forms signed by the Experts

BIOMEDICAL AND SCIENTIFIC RESEARCH ETHICS COMMITTEE TEMPLATE CONSENT FORM

Study Number:

Patient Identification Number for this study:

Title of Project: Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical Investigation for Muharraq City

Name of Researcher(s): Sumaya Yusuf

Please initial all boxes

1. I confirm that I have read and understood the information sheet dated **[10 April 2018]** for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical, social care, education, or legal rights being affected. ☐
3. I understand that relevant sections of data collected during the study may be looked at by individuals from the University of Warwick (the study supervisors and the study reviewers) where it is relevant to my taking part in this study. I permit for these individuals to have access to my records. ☐
4. I agree to take part in the above study. ☐

Sumaya Yusuf 10th April 2018

Name of person taking consent Date Signature

Appendix 5: Interviews

a. Interview Questions

Semi-Structured Interview with Waste Management Experts

Aim: To Explore the enablers and barriers to the adoption of Organic Household Waste (OHW) management technologies for Bahrain generally and Muharraq Specifically

1. Among the available technologies, and from your expertise point of view, which technologies are suitable to manage the Organic Household Waste for Bahrain? And Why?

2. The empirical results of this research show that the Anaerobic Digestion (AD) is one of the preferable technologies for Muharraq OHW based on its characterisation criteria. Though it needs pretreatment to increase the C: N ratio by adding more fruit, vegetables, and wood chip waste, as well as raising the pH.
    a. So what do you think about this option?
    b. What are the enablers to the AD technology adoption?
    c. What are the barriers against AD adoption in Bahrain/Muharraq?
    d. How to overcome these barriers?

3. Incineration is also selected as one of the preferable technologies to manage OHW based on its characterisation, due to the high Calorific Value and low heavy metals and sulfur, though it needs drying as a pretreatment, what do you think about this option? Why?
    a. What are the enablers and barriers to incineration technology adoption in Bahrain /Muharraq?
    b. How to overcome these barriers?
    c. What are the pros and cons of having an incinerator in Muharraq?

4. What about Refused Derived Fuel (RDF)? And if it combined with the incineration? What do you think?
    a. What are the barriers and enablers to RDF technology for Bahrain /Muharraq?
    b. And how to overcome the barriers?

5. Composting seems to be a suitable technology if C: N and pH were adjusted, what are your thoughts about this technology to manage the OHW in Bahrain/ Muharraq?
    a. What are the enablers and barriers to composting adoption in Bahrain?
    b. How to overcome these barriers?
    c. What are the pros and cons of having a composting plant in Muharraq?

6. What about Gasification technology as an OHW management technology option for Bahrain/Muharraq?
    a. What are the enablers and barriers to gasification adoption for OHW management in Bahrain/Muharraq?

b. How to overcome the barriers?

7. And what about Pyrolysis technology as an option?
   a. What are the enablers and barriers to its adoption in Bahrain/ Muharraq?
   b. How to overcome the barriers?

8. Comparing the above technologies, what is the most preferred one for Bahrain in your opinion?
9. What other ways considered essential to managing the OHW and we haven't discussed yet?
10. If we can categorise the main enablers and barriers to main categories, what these will be?
11. Anything more to add to the above?

Thank you very much for your cooperation which is highly appreciated

b. Full Interview Transcript

Interview 1:

Time: Monday, 9th April 2018

Duration: from 8:00am-9:30am

Language: Arabic more, little English

Interview Details:

First of all, the Prof to be interviewed was informed by a phone call 2 days prior the interview, the call was a direct call by the researcher cell phone, the researcher has the personal phone contact, who welcomed the expert and requested a face-to-face meeting that aims to explore the enablers and barriers to the OHW technologies adoption in Bahrain.

The interview scheduled upon the expert suitable timing.

At the beginning of the interview, the researcher explained a brief overview about the thesis title, aim and objectives: Thank you very much for accepting my request to hold a meeting, as one of the recognised experts in the waste management field in Bahrain. And many thanks for your continued cooperation and support to the researchers. Expert replied: it is my pleasure and it is our commitment and responsibility toward the students and researchers.

The expert told the researcher “let’s consider Bahrain as a whole which can apply to Muharraq Governorate.”

The researcher started the questions by asking

1. Among the available technologies, and from your expertise point of view, which technologies are suitable to manage the Organic Household Waste for Bahrain? And Why?

Immediately, the expert answered “incineration is the superior technology to manage the organic household waste in Bahrain, in a most stringent environment. Since Bahrain has a limited geographical area, and the developmental activities are increasing, the land will be in high demand and Bahrain will need more areas. Landfilling consumes a large area of land while Bahrain is a small island. Sea reclamation for land as currently happening is wasting of important resources for the country, so we need to reduce the volume of waste as we can, and this will not realise without incineration. This technology will end up with a small volume of ash that can be easily dumped into the landfill and it will not use a big area. The resulted ash need to dispose of. The incineration will lead to producing energy to generate electricity that may operate the incinerator itself or another utility.”

2. The empirical results of this research show that the Anaerobic Digestion (AD) is one of the superior technologies for Muharraq OHW based on its characterisation criteria. Though it needs a pretreatment to increase the C: N ratio by adding more fruit, vegetables, and wood chips, as well as raising the pH.

a. So what do you think about this option?

b. What are the enablers and barriers to the AD technology adoption in Bahrain?

The expert was against this technology adoption for Bahrain from the beginning. However, he said:" AD mainly need segregated waste, and waste in Bahrain is mixed which is the main barrier. It has a high cost, besides the pretreatment that is needed, this makes it a costly option. Moreover, the end product of the AD has no market in Bahrain; the evidence is that the methane is a combined gas already produced from the oil wells, and they just let it go, and it is already available for free! So why we spend a high cost to produce an existing gas which has no attention nor value here?! So it is economically not a feasible solution, and other barriers to AD adoption in Bahrain are: the area is limited and no place for an AD utility, it is a complex technology compared to incineration, complex with regard to its operation and maintenance, need high skilled trained manpower, not very common in the GCC countries."

The researcher replied" the empirical results shows that the C: N is very low which makes it another barrier to succeed this technology adoption, as well as the pH is low (waste is acidic) which is again not suitable for the AD bacteria to work efficiently, which represent another technical barrier against the AD adoption in Bahrain.

The researcher was keeping asking the expert within the speech for more clarifications so the written answer is the whole and final expert's answer.

So in the other hand, in case one day the government decided that they want to adopt AD, how to enable AD adoption in this case?

"We need to get rid of all the above negativities combined with this technology, while the easier alternatives exist and have more benefits" he added.

"A very obvious and the only solution for the domestic waste in Bahrain is in front of the decision makers which is incineration, but the politics represent the main barrier against its adoption. There is high competition between the investors to win this project, and the enablers are: availability of the technology, already applied in the GCC region, do not need highly skilled manpower, even very few numbers of workers might be needed, financial support exists, and the governmental support to the investors."

The researcher replied with a supporting evidence to the incineration as a preferred option that the empirical results of OHW samples characterization shows for the first time in Bahrain that the gross calorific value is very high, and it reaches 18.5MJ/kg, beside the low heavy metal content that will make the ash safe to be disposed in the landfill, as well as the low sulfur content which indicates low resulted in SOX when incinerated. The expert was so excited to hear that and gives him more confidence to defend his choice. Besides, the high moisture of the OHW is easier to be pre-treated by exposing it to the sun for solar drying which is free due to the hot weather in the country all over the year. The land for the drying process might be limited.

"The waste management is costly to the government, so one of the enablers might be to privatise the final disposal to minimise the cost."

“Any project needs financial support, and the absence of a national waste management strategy is another barrier to any technology adoption.”

What about RDF? What do you think about this technology?

“This is a pretreatment to ease the combustion process and to increase its efficiency, but it has a high cost for minimal benefits. Since the waste also in Bahrain is mixed, which make the segregation an additional cost, thus for Bahrain no need for this technology, direct incineration is enough and suitable.”

The researcher replied” recently the sound which is against waste incineration are increasing, what do you think?

Every day, the technologies are improving, and manufacturers and suppliers are considering the environment more and more for reputation and economic reasons, as well as to reduce pollutants, and it is changing positively. This can be proved by looking to the developed countries, which are operating the incinerators and continuing in investing in it. It is considered a simple technology, not complicated in many aspects, and safe to human and environment. So when the developed countries are applying it and find it safe, how we can stop it and try to prove the opposite with no evidence?! It is all about politics in Bahrain” he mentioned a project of an incinerator that was proposed to be established in 2011, but the SCE has stopped it for environmental reasons. Because the decision makers are listening and recruiting people representatives in the municipality councils who are not well qualified and their knowledge is very limited to specific areas, but still, they gave themselves the right to say wrong information and they are listed to by the government!”

“It is an important and main barriers against technology adoption in Bahrain”.

Thank you. Based on the empirical results;

5. Composting seems to be a suitable technology if C: N and pH were adjusted, what are your thoughts about this technology to manage the OHW in Bahrain/ Muharraq?

a. What are the enablers and barriers to composting adoption in Bahrain?

“The advantages of Composting are hat it has a low cost, simple technology, the only thing that it needs is the aeration, and almost all countries in the world are using this technology a long time ago, so it is not new.

The barriers are: it needs a large area, the absence of a market, so marketing the end product is another main barrier and problem.”

6. what about Gasification and pyrolysis technologies as OHW management options for Bahrain?

And what are the enablers and barriers to gasification adoption for OHW management in Bahrain/Muharraq?

These technologies are NOT suitable for Bahrain, because of the high cost, not common in the world, complicated, need exceptional training programs and very highly skilled workforce, and the end product of them is difficult to be used and has no market. So why to even consider them and go to hard solutions while the easier, more efficient and cheaper are available?! “He meant the incineration.

- Anything more to add?

The political aspect represents the main problem in Bahrain against improvement and technology adoption, so they recruit the wrong people, making decisions based on this, all about political considerations.”

Thank you very much for your time and information.

“Thank you and good luck.”

Interview 2:

Tuesday 10/4/2018

8:45am-10:00am

Thank you for acceptance, explain the Aim, the first question is

1. Among the available technologies, and from your expertise point of view, which technologies are suitable to manage the Organic Household Waste for Bahrain? And Why?

Currently, the domestic waste is dumped into the landfill which is considered the easiest and cheapest option for Bahrain. Regarding technologies, Composting is a good option to start with, because of it simple, it is efficiently utilised, easy to understand and operate, with no need for equipment nor power, so it is not complicated to operate.

Bahrain needs to start with simple technologies, then gradually move to more complex solutions to consider.

So you have mentioned composting as a preferred alternative to start with to manage the OHW, so what are the barriers against composting in Bahrain?

The main barrier to adopt composting in Bahrain is the marketability for the end product (compost) and the public acceptance. The absence of waste segregation is also a barrier in that it affects the quality of the compost, which may lead to the existence of glasses or plastics in it which makes it in low quality. Therefore people will not buy it and will miss the trust in the local product. The public experience also and understanding affects this technology adoption in that people need to be aware and educated. People perception need to be improved. The example in Karachi, due to lack of local knowledge, they make composting and end up with local compost full of glass and people will put this image in their mind for years and refuse to buy the local fertiliser even if it was improved. By the way in Bahrain, URBACER company that serves the northern and middle governorate do compost for the central vegetable and fruits market, as well as the restaurants waste in Bahrain, which mainly includes the biodegradable portion, and no need to segregate, so the produced compost. Here Bahraini people prefer to buy German fertiliser and not a local one for the above reasons. This composting project is a small scale one between the government and private sectors.

It is located in Salmabad (middle of Bahrain), they make burials and throw all the biodegradable waste in it with continuous aeration.

The SCE totally accepts composting due to no harmful environmental impacts; it is located in the agricultural open area, away enough from the residential area.

3. The empirical results of this research show that the Anaerobic Digestion (AD) is one of the superior technologies for Muharraq OHW based on its characterisation criteria. Though it needs pretreatment to increase the C: N ratio by adding more fruit, vegetables, and wood chip waste, as well as raising the pH.

a. So what do you think about this option?

The AD is a new technology, and it is highly complicated to operate in the Gulf area, so it is decidedly advance to start with as an alternative to landfill.

So what are the main barriers to the AD technology adoption in Bahrain?

There is no source segregation in Bahrain, and the mixed waste is not suitable for the AD. This is a significant barrier. AD end products are biogas and digestate, with unknown quality (might be high or low), besides there is no market for these end products in Bahrain. Moreover, the lack of infrastructure, governmental support to complicated projects, moral and financial aid, beside the high operation and maintenance cost all make it a difficult option to implement, in addition to your empirical results that add an additional cost to justify the C:N and pH which makes it more difficult and not feasible.

To enable it, it needs incentives and segregation of waste.

What about incineration as a management option? And what are the barriers

It needs mass burn system. It has environmental impacts. Adoption in Bahrain is difficult because Bahrain is small, lands are limited, and so the absence of a suitable location is a barrier. It has to have a safe distance from the residence, need air collecting model, high operation cost, high initial cost, and the main problem with incineration is the dioxin and furans emissions that cause serious health problems, besides the fly and bottom ash disposal. Flue gases may contain heavy metals. Also in that energy is not a problem in Bahrain, and fuel can be provided in low price, so why to burn waste and add cost just to produce electricity and reduce volume in high cost?! (He is against incineration)

There is no health statistics in Bahrain, internationally, it is evident that people living next to incinerators have health problems. In big countries who have safe distances and availability of lands, it is okay to adopt this technology. Dubai has a robust WtE plant by incineration. In Bahrain to build an incinerator, we may need to reclaim the see to provide safe land which is very expensive.

What about legislation and regulations?

They support any practice that is safe and feasible and possible base on its nature and assessment for Bahraini context.

The private sector is better to manage the waste sector, so incentives are needed to attract investment in this sector in Bahrain (lack of incentives to attract private investment is a barrier to improve waste sector and adopt new technologies in Bahrain), financial barriers, area, cost-effective and social acceptance and the culture. Many techniques like Incineration has high operation and maintenance cost.

What do you think about RDF?

Bahrain is far from it. It is very advanced and too early to think about. Internationally, it is commonly used in Cement plants only and export it; it is not a feasible option. It is complicated, the infrastructure needed, not widely used locally or regionally, and no market for the end product.

What about Gasification and Pyrolysis technologies as OHW management options for Bahrain?

They are not well recognised or utilized, not common in the Gulf region, and complicated. A small country cannot test new technology but should go to a sound operation in the gulf area.

Also of the very high cost and it is not tested in the gulf.

Anything more to add?

OW is a resource that needs to utilise it properly. The technology to be adopted must have no environmental impact and must be feasible. We need to go step by step, and we need to plan an Integrated Waste Management System in Bahrain at first to enable any good practice in the future.

Centralization of waste management sector in Bahrain makes a better effect.

I forgot to mention that incentives are needed to encourage reduction and recycling among people in Bahrain generally, and awareness must start at the very early stage by improving children school curriculums to raise public awareness to prepare the ground to transform the community to be smart enough to accept and cooperate with regard of any technology adoption.

Interview 3:

I would like to thank you for accepting holding the interview which is highly appreciated.

You are welcome; I would like to invite the Mot Macdonald Expert and the Ministry of Works to attend the interview to help to answer your questions since they are parties in strategy planning currently if you don't mind.

Yes, Sure my pleasure. Welcome, all three experts in 1 interview who share answering the question by coordinating and agreement. After explaining the research aim and objectives as well as the main interview aim, the first question is what is the most preferred technology to manage the OHW in Bahrain? And what are the barriers to its adoption?

Bob: As you know, Bahrain has mixed waste, and there is no segregation for it, so we can say that AD and composting are not preferred options, due to no market for the low-quality digestate and compost. So these technologies will not be economically feasible, and the main OHW challenge is to be separated at the source first.

Dan added that unsorted waste plus the high content of fibres might cause clogging up the digester in the case of an AD, so it is not a good option for the meantime. Though the AD can be applied on a small scale by using the central market vegetable and fruit waste that is 100% consist of biodegradables, and the mechanical separation might be easier if needed.

Integrating incineration and RDF for some parts of waste and others AD. This needs labour to segregate.

And it needs little investment in this, and the lack of investment represents a significant barrier to technology adoption in Bahrain

Bob added: As we are pioneers in outsourcing the collection of waste in the region, the cultural barriers are the main barrier to technology adoption in Bahrain, and the high tipping fee of the AD project (300mBD) makes it not economically attractive. E.g. the current cost of waste dumping is less than 1 BD/ton, then it will jump to 50BD/ton which is a considerable change.

Waste to energy is recommended with mechanical separation, mainly incineration.

One of the critical enablers is Public awareness improvement toward separation and recycling. Because the feedstock needs to be clean enough or there will be no market for the low-quality end product.

So let's talk more about incineration as an option?

Bob said: Incineration is a proven solution in the GCC countries, so it is very suitable to be applied in Bahrain, besides it is simple compared to other technologies (e.g. gasification and pyrolysis are not recommended at all)

Dan: In incineration, the main problem is with the bottom ash, and to clean up gases, which makes the need for continuous monitoring. Bob Added: in Beijing, the incineration of unsorted waste with lower controlled combustion caused severe health problems like cancer.

It needs finance, operate properly, find land for the incinerator, and need to improve the public perception of energy from waste since it is very negative in Bahrain, besides enhancing the people purchasing behaviour.

To enable it, it should gradually prepare the ground by improving public awareness and purchasing behaviour, as well as let people pay for the plastic bags for example.

To improve perception and awareness, we should start with education, lack of proper information and educational curriculums need to be developed.

What about Composting?

There is no segregation in Bahrain and even no market for the compost. So it is not the preferred option. It can be enabled by source segregation, creating a market, and give incentives.

The main problem in Bahrain is the Monopoly by the government and no incentives and therefore no attraction of investment.

Composting needs lands which makes it difficult for Bahrain with the limited space, but this technology is simple and of low cost. As a solution, we can do composting on the current landfill surface.

The barrier encountered the composting is the low quality of the compost, and there is a big chance to be contaminated with glasses and plastics.

In-vessel composting is expensive.

Let’s talk about the RDF?

There is no market for the RDF nor the infrastructure.

What about gasification and pyrolysis?

They are unproven in the region and unable to handle. They are complex technologies and not promoting.

There was a project plan to use pyrolysis for Tubli wastewater plant sludge, and it was rejected recently due to it is not economically feasible nor successful.

Since the CV is high, using direct combustion is more recommended since it is proven in the Gulf region.

Limited technical experience, need for highly trained labour.

The risk associated with gasification lead to failure of the project in the UK.

Other barriers to these technologies are Limited land, financing instruction to developers, private vs legal, source separation and cost.

Cultural barrier, supportive regulations, incentives for investment, and the need to educate the next generation. The fragmented regulations and legislation here in Bahrain that make them concentrate on the hazardous waste and general environmental issues and no focus on the MSW management at all. And there is no central authority which is entirely responsible for managing waste sector which makes it out of proper control and coordination.

To improve waste management in Bahrain, it is essential to create a Waste Management Directorate which is a kind of Centralization of the waste management responsibility.

And everyone who wants to deal with waste must be authorised and permitted to do so. (Scavengers)

Anything to add?

Bahrain needs a clear national waste management strategy, which we are working on currently.

It needs to encourage investment to recycle and to waste management projects. Political stability affects the investment. There is no land availability, so there is a need to reduce waste volume by improving public awareness and incineration, to save the land.

Interview 4:

11/4/2018, at 1:30pm- 3:00pm

Welcoming and informing the aim of the research in general and the interview aim. What do you think about waste management technologies adoption in Bahrain?

First of all, we can't ignore the role and the importance of improving the awareness and services toward the waste management to succeed in any technology adoption in the future. To do so, we currently started to apply the "business whats app" to work on social media and be close to people needs and listen to their complains via a hotline. This service was just launched recently which help to ease communicating with people and receive their suggestions and respond to them immediately.

As a beginning, the company has brought and distributed the recycling cabinets that receives the empty bottles, but because there was no rewards or incentives, the project was rejected by the government.

So what is the optimum way to manage the OHW in your opinion?

Composting is considered one of the successful and common ways to manage the OHW, it has low environmental impacts compared to incineration, and it ends up with a product which is the compost that can be used locally. An advantage is it is simple technology, and it has low initial startup and operation costs. But in the other hand, it needs a large area with a safe distance of at least 3 KM from residences which make it a disadvantage for a small country with minimal space available.

All technologies need supportive policies to work correctly, besides the governmental support.

The cost of enhancing the current landfill is very high and not attractive, and the sea reclamation to provide land is even higher.

The main barrier is that the efforts of waste management are scattered, and there is no specific "Center" for decision making in this regard in Bahrain, which makes lots of effort to be lost or useless.

The AD might not be possible in the meantime due to the absence of segregation, and the operation and maintenance costs are high. The government has the significant responsibility to set strict rules and regulations to motivate people to segregate and recycle. These two practices are a priority in my opinion before any other technology adoption.

Main barriers to any technology adoption in Bahrain are that there are many initiatives from the private sector and NGOs that are not supported by the government, and the complexity of the procedure to approve it make it not possible.

As you know, the cost of NG is low as a source of energy, and the government subsidises the electricity price, so the incineration of waste to get power is considered of a high cost which may make it not economically feasible nor affordable for Bahrain, besides the environmental impacts. Thus if we were in a non-oil country, this might be an excellent option to get energy since currently the most significant oil well in Bahrain history was just discovered and it will secure the next and next generations from power.

Incineration as an option to save land and reduce waste volume, also, to produce energy, using very high and advanced technology, was proven to be environmentally safe. It needs strong governmental support for investment. The resulted ash can be reused, and the produced energy can be utilised to operate the same incinerator.

The incinerator needs social acceptance.

Segregation at source is considered a key factor to succeed any technology adoption efficiency in Bahrain. In the meantime, we need to enforce separation at source, through raising the public awareness at first.

Currently, the GCCC Company started to try the public acceptance of waste segregation by distributing coloured segregation containers in 31 points in Muharraq and Capital Governorates. The statistics were counted in 6 months: we yield only 2.5 tons papers, 120 tons cans, and 1.7 tons plastics. This low amount reflects the social unacceptance or that it needs more incentives to enforce people to do so.

One challenge is the availability of space inside homes to segregate waste at source since the number of the container might not be less than 3 for different domestic waste components. This might be a little bit challenging for small houses or flats.

Moreover, an interesting notice was that there was a governmental allowance for inflation was paid to people, when this allowance stopped, the purchasing power was decreased, and the waste amount decreased by 3%.

The awareness of smart purchasing help in decreasing waste generation. And the most effective way to enforce people and commit to it for Bahrain society is monetary penalties and taxes.

To summarise, with segregation existence, composting is most recommended in my opinion, in the absence of segregation, incineration using high tech is recommended.

Scavengers help in waste segregation currently, they are looking for aluminium cans, plastics and cardboard. But the absence of penalties make them “steal” the segregated items from the current segregation trial points to sell them (plastic market price 30BD/Ton)

RDF is not recommended. Gasification and pyrolysis are not economically attractive, who will invest in them?!” due to no market for the end product, they are complicated.

What do you like to add as a final word?

Talking is easy but applying is difficult, people are aware but they do not act, so as a priority we should talk to people from a cultural and general trend perspective to be listened to, in addition, to make people aware and handle the responsibility of dealing with their waste without feeling it is somebody else's responsibility, so I don't care!", beside the main barrier in Bahrain is that there are many unqualified persons in the decision making positions, which makes an obstacle against improvement, and the complications of procedures are any good practice wanted to be adopted for improvement. "

Thank you. Ended at 3:00 pm

Interview 5:

Thursday 12/4/2018.

Started with welcoming and thanking.

Which technology is considered best for OHW management?

There is no single technology considered optimum. It is subjected to social acceptance, political, economic and financial. So any satisfied will be optimum.

The society is shallow in technology management, the AD is costly and will not work, so there are economic burdens and financial loss.

We should not look to advance technologies above the social acceptance.

We need segregation at source. Here a question comes to mind: how big is the kitchen and is it big enough to put the segregation containers? So the availability of supportive infrastructure is vital to succeed any technology adoption.

People in the society must be aware of why they sort waste? Deposit refund scheme is essential. For example: at the meantime, it is possible to make a kind of agreement between the waste company and government with the hypermarkets to put the segregation containers in the car parks and get some rewards on their purchasing items as incentives for segregation. This will enhance the image of the hypermarket which considers the environment in its supply chain.

-the empirical results show that OHW has a low C: N ratio as well as low pH which is not supporting the AD adoption, so how you can generalise the main barriers to AD adoption in Bahrain?

The barriers against AD are: feedstock needs pretreatment which has additional cost, it is not feasible, and since Bahrain has a severe problem of air quality, the AD may not be a good option, and it will worsen the problem. So it has environmental impacts risk. It is complicated for Bahrain. Bahrain needs something simpler and easier to manage its waste. And the priority for Bahrain is to reduce the waste volume to save the land.

Beside public awareness, we need two more pillars: command and control, use of economic and financial reward.

Waste is considered a renewable resource.

What about incineration as an option?

It is not a necessity that if the technology was commonly used, so it is the best.

This technology has an environmental cost, and it needs a highly qualified and skilled workforce.

It is a problem with technology transfer, social and religious constraints are essential.

Sometimes the technology is feasible, but it is not socially acceptable. (e.g. reusing of cooking oil)

RDF is not feasible and not recommended.

Composting:

Is feasible, simple, viable, but has land limitation barriers in Bahrain. So if it were adopted on a small scale, it would be a good option.

It has environmental impacts, the problem with odour. Digging ditches is an excellent way to compost.

The end product might be used locally by people.

Bahrain needs innovative solutions. They should start from NGOs

What about pyrolysis and gasification?

They are good solutions but not feasible, due to the subsidised fuel cost by the government, so there will be no market for the energy produced which is of a high price, nor for the end products.

They are complicated and need a highly trained workforce.

End Word?

To extend the lifespan of the landfill by using innovative solutions, will create jobs, conserve the environment.

Thank you

Ends at 10:00 am

Interview 6:

Thursday 12/4/2018

What are the barriers to technology adoption in our countries?

The absence of a national waste management strategy

No clear vision.

It needs capacity building

No investment

The governments depend on foreign experts who miss the perception of the nature of our countries and ignore the national expertise in many situations.

The absence of interlink between the whole system parties, since it is a nexus so efforts must be integrated and complementary, and lack of planning.

In the Gulf region, there is no financial barrier, but there are no trained people.

Main barriers are political,

The regulations and legislation are not adopted,

No centralisation of decision making in the waste management.

No public environmental awareness

The recruitment of unqualified person in the decision making positions about waste for personal reasons only.

Thank you. Call ends at 5:50 pm

Interview 7:

23rd April, 1:30-2:00pm

Technologies to manage OHW:

The AD is considered the best technology to treat the OHW, due to the climate in Bahrain that is hot. Emissions are lower and are considered a safer and cleaner technology (no possible dioxin emissions as combines with the thermochemical conversion technologies)

Gasification and pyrolysis are not feasible and "not capable of being effective" for mixed waste

The main barrier to the AD is that there is no segregation in Bahrain so this might not be possible.

Composting is the most suitable option for restaurants, vegetable and fruit wastes in small scale and this is currently the most suitable option in my opinion for Bahraini society.

Incineration is a simpler and more accessible than pyrolysis and gasification, the concern with these technologies is that both are not yet tested in the Gulf region,

The fears about incineration are the low efficiency which does not exceed 15-17%, which is a deficient percentage, and it operates on high temperature and may have problems with hydrogen chloride formation which affects the efficiency of the incinerator.

In my opinion, the efforts must be focused on reduction of waste generation from source as a main priority by the government, because when you encourage a technology adoption by enabling it, this means that indirectly you are promoting the waste generation to increase the feedstock availability and prove that the waste generation is not a matter! So producing more waste is better for business and suppliers to have a job!

The competitiveness between companies and the private sector is a barrier against reduction practices adoption, because they need to guarantee the availability of waste in enormous amounts for let's say coming 25 years, so this is a barrier against the reduction of waste generation as a priority, and it must be the main priority for the government.

Increasing the public awareness is another priority to start with to have a proper waste management strategy. In Sweden, sending the organic waste to the landfill is illegal and has a penalty by the government.

The power to make a change in the society starts with the education; people must be aware enough. The economy is the primary barrier to the reduction of waste since it encourages the consumption and therefore production of more waste, advertising to push people always to buy and gain new products, these are all against good waste management.

Thank you very much.

Interview 8:

Thur. 19/4/2018, 12:30-2:00pm

As you know, different technologies might be suitable to manage OHW, including AD, composting, gasification, pyrolysis and incineration, in addition to the RDF as a pretreatment. From your expertise point of view, what are the enablers and barriers to the technology adoption in Bahrain in general?

Bahrain is an oil country, which means that there is no need for new energy resource practically, and the fuel cost is subsidised by the government which indicates the availability of fuel at low cost. This represents a barrier against the waste to energy projects initiatives in the country because getting energy is not a priority for the government and thus the lack of the incentives to the investment in these projects in the country represent another barrier, so these projects never get the green light.

Can you give me more details about it?

The technologies are available in the market, but there is no demand for the end products resulted from the waste management technologies in Bahrain, which makes it not feasible or economically attractive. For example, no one will buy a costly unit of energy produced by waste to energy facility at a high cost, while the government provides it with a low price in the market! The top energy unit has no preference over the cheap one unless we say that it acts as the special Rolls-rise of the energy! (Joking)

There are zero incentives, no land availability, as well as it is difficult to find a safe location to establish the facility. The well-trained workforce is required, and they need the expertise to operate them.

These projects might be attractive for the government by changing the point of attraction; when the priority from the plan was to reduce the waste volume, get rid of odours, and have a safe disposal, then these technologies might be more attractive. Loop system in reusing and recycling and recovering is the best way to manage the waste, for example, tires can be shredded and reused as an alternative to the asphalt, this way will prevent any environmental impacts of tires disposal.

What would you like to add?

National Capacity building is strongly encouraged; public awareness is an essential enabler to prepare the society for advanced technologies.

Thank you very much.

Interview 9:

Thursday 26/4, 12:30pm-1:45pm

We are doing the waste to energy pyrolysis project in Tubli bay to treat the sludge and get rid of the odours in that area. People were complaining, and it was a very urgent response from the government to find a sustainable solution to this problem. So they came to us to propose the suitable solution which will be operated by 2020.

What are the main barriers to technology adoption in Bahrain?

Any project needs a feasibility study. And all goes back to the economic. The government subsidises the fuel cost and the electricity in Bahrain, and there are no incentives to the green technologies including the renewable energy projects, and they are not economically desirable.

The primary barrier is that there are no regulations for tariff for renewable energy projects, but the good thing is the governments have recently established the new Sustainable Energy Unit (SEU) which belongs to the Ministry of Electricity and Water Affairs, and it may improve the regulations in this regard.

So our project has direct governmental support for environmental and social reasons, to save the marine life in Tubli bay which was a natural reservation area, which needs to enhance the air quality, gets rid of odours and improve the social satisfaction for this area residence. But no incentives.

Can you talk about other technologies like an AD?

The AD has the disadvantage in that it needs a harvesting time that reaches 21 days, and it depends entirely on the microbial activity. This might be a sensitive situation, and you cannot guarantee a consistent level of end product and efficiency, which makes it more complicated and need more maintenance.

So the main barrier to technology adoption in Bahrain can be lack of regulations, no structured tariff, low tariff proposals for government and no incentives.

Pyrolysis at a high temperature in the absence of air to produce 10MWh energy. Sludge calorific value was 23 on a dry basis. Pretreatment is needed to get rid of moisture which represents 80% of the sludge so we pyrolysis the rest 20% only.

This project was economically feasible.

What about incineration?

The incinerator is a big furnace, and it is a way to reduce volume. But the efficiency to get energy from water by this technology is very low since the waste is mixed, so it is a way of waste disposal. The produced ash might be a problem; it needs to be landfilled.

With pyrolysis, we can yield good syngas which is commercialised, biochar and tar which can be sold to construction materials industries, or cement plants.

The same facility will ultimately use the produced syngas, and there will be no need to use the grid fuel. We need to use the grid energy only to start up the production.

The AD was one of the considered solutions, but due to the enormous capital cost and each ton will lead to only 50% byproduct (low efficiency), besides it needs a harvest time all make it not a good option.

Interview 10:

28/4 Saturday at 5:00-6:00 pm

Among the OHW management technologies, which is the most suitable one in your opinion?

I think composting is the most appropriate technology for Bahraini society, due to the lack of the sufficient awareness as well as the absence of the very primary principals among people which are prioritised to start with to have a successful waste management strategy. These principals are reduced, reuse and recycle, so people are still not aware of them and thus they are not ready for more advanced options.

What makes composting a good option?

Compared to AD and incineration, for example, Composting is the cheapest and simplest option, and do not need the energy to be operated. Besides, it has the lowest negative environmental impacts and is considered a safe alternative for human health.

The barriers to most waste management technologies adoption (including AD, incineration, gasification, and pyrolysis are: there are no incentives by the government to these technologies, they are not economically feasible, and not cost-effective, no infrastructure suitable to their adoption (even for composting the limitation of land is a barrier), and the most significant obstacle is the lack of waste segregation at source (which will affect the efficiency of technologies.

And we cannot ignore the cultural barrier in that the public awareness needs to be raised, and even if there is awareness; there is no commitment to segregate for example.

How can we raise the awareness in your opinion?

We should start with the school curriculums in the very early stage of education, to build an aware generation who will work effectively for a better future.

The AD is an expensive option, segregation is highly needed, and infrastructure is required. Since there is no policy for separation nor incentives, thus we need to return to the basics to start within Bahrain, and then gradually we can move to the next and more advanced stages which might include more advanced technologies.

What do you think about the incineration of waste?

People are not aware enough. And they might not accept having an incinerator as the primary technology to treat their waste. It needs to have the most state-of-the-art technologies to prevent the hazardous emissions of dioxin and furans which are main results of the waste incineration process. The land use is another barrier. The land is very limited in Bahrain, and having land for an incinerator that is away enough from the residential area with a safe distance is another problem encountered with incineration. Besides, due to the small budget specified for the waste management in Bahrain, the priority for the decision makers might be the economic aspect, so they might have many contractors compete for the technology adoption in Bahrain, but they might choose the cheaper whatever the efficiency was. This might represent a risk to human health and the environment. The contractor must be highly qualified and professional and not just prioritise to commercialise their products without considering the safety aspects.

Also, the political barrier is essential. Policymaking and integrated waste management strategy adoption are critical. To start with the basics and priorities the ways to manage waste according to the waste management hierarchy is highly encouraged. In Bahrain, besides the absence of source segregation practice, no MRF plant is responsible for separating the mixed waste before disposal, which is a barrier against many technologies adoption.

What about gasification and pyrolysis?

They are not recommended at all for Bahrain, they are complex technologies to start with, and there is not enough public awareness to realise the importance of these technologies and therefore cooperate effectively. So we need to build the culture at first.

One of the promising initiatives is that currently, the government in collaboration with the private sector are now working to make a national strategy for waste management, but hopefully, we can get one reference to refer to when dealing with waste management issue since currently there are multilateral from the government, private, NGOs,…etc. Who is responsible for each part of the waste, which leads to weakness in waste management in the country. So we need to centralise the responsibility under a national waste management authority.

Do you like to add more points to end with?

I would like to add that in Bahrain, the budget designated for the waste management is low, this will lower the investment in this sector and make it not attractive to investors. There are lots of potentials in Bahrain, but it needs a proper collaboration to detect and invest in them.

Thank you for your cooperation.

Interview 11:

What is the most suitable OHW management technology option for Bahrain?

In my opinion, there is no alternative to the AD and composting for management of organic fraction of MSW.

But the empirical results show low C: N and high moisture which are not supporting these technologies?

Low C: N ratio can be increased, and moisture can be decreased to acceptable levels (for AD and composting) by adding dry leaves, grass clippings, sawdust, paper and wood chips.

Solar drying of raw MSW can also reduce high moisture for 24-48 hours before its composting or anaerobic digestion.

These preprocessing steps will not be a burden financially.

Can you give me more details, please?

The best options for treating organic household wastes in Bahrain are composting and anaerobic digestion (AD). Composting and AD are well-proven, widely practised and eco-friendly organic waste management technologies, and well-suited for household waste in Bahrain which is rich in the biodegradable matter.

We must remember that biological process relies on the initial input of waste material – if this already contains harmful or toxic matter, then we cannot expect to produce a pure, toxin-free fertiliser in the result. It requires both the industry and consumer to change existing habits to achieve a safer outcome.

Thank you, so what possible Barriers and enablers do you think appears in Bahrain to the recommended technology/ies adoption?

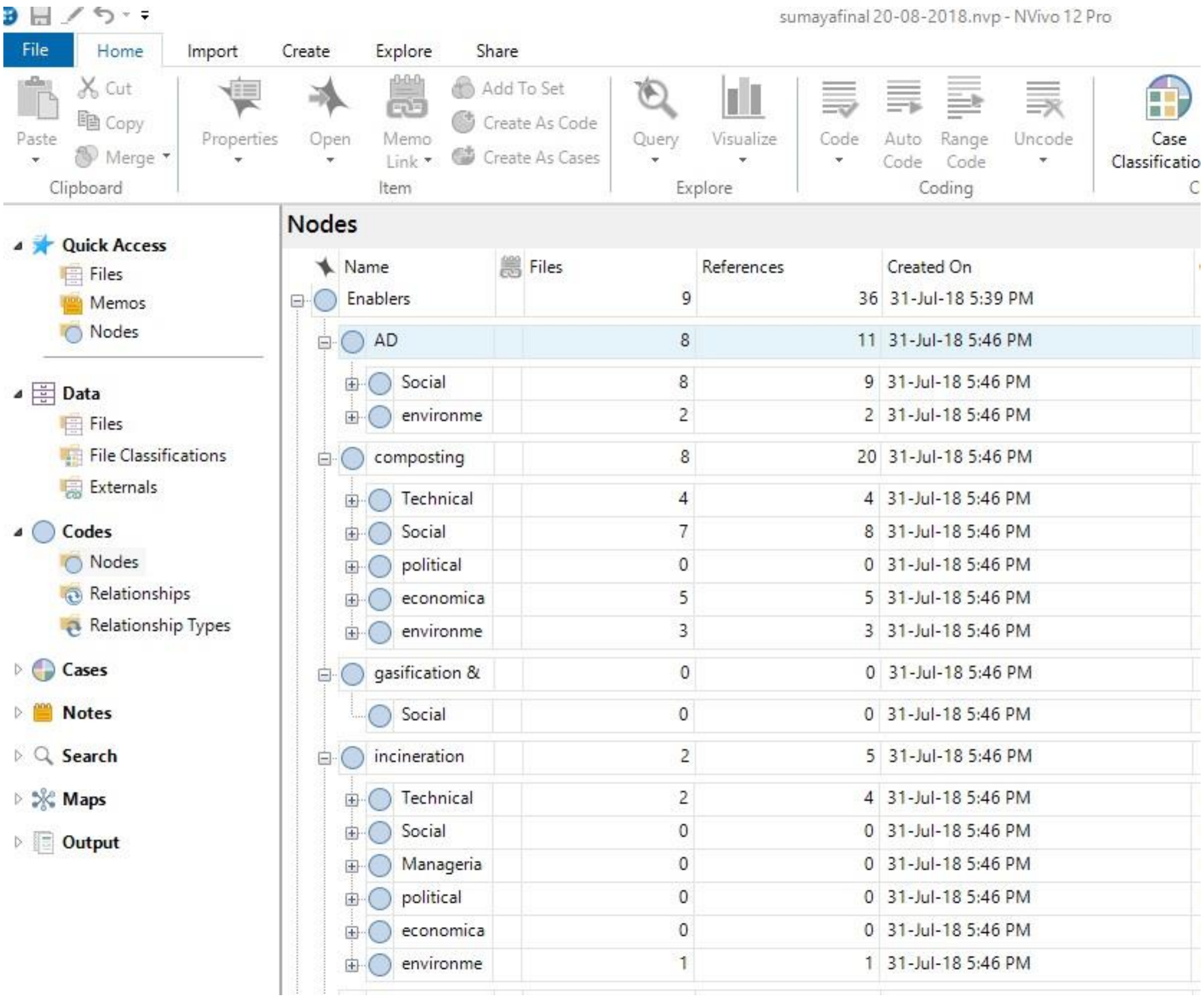
Key barriers are (1) Lack of source-segregation, (2) Lack of government strategy for organic waste management, (3) Lack of support from the government, (4) Lack of locally-available technologies, (5) Lack of public awareness

Please refer to my articles which are published on http://www.ecomena.org/swm-middle-east/

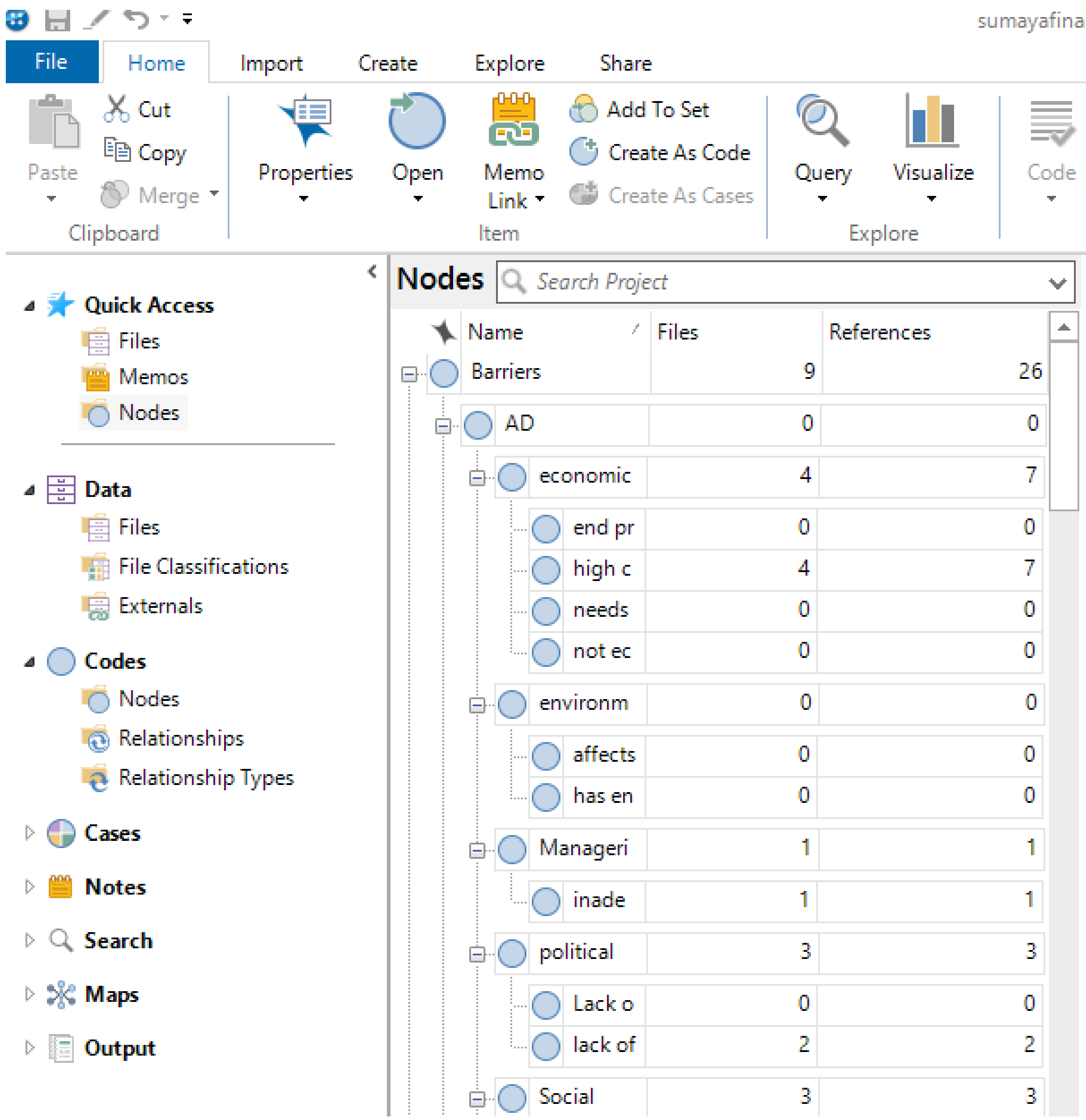
Thank you very much for accepting answering my questions.

Appendix 6: Interview Qualitative Analysis (Nvivo 12)

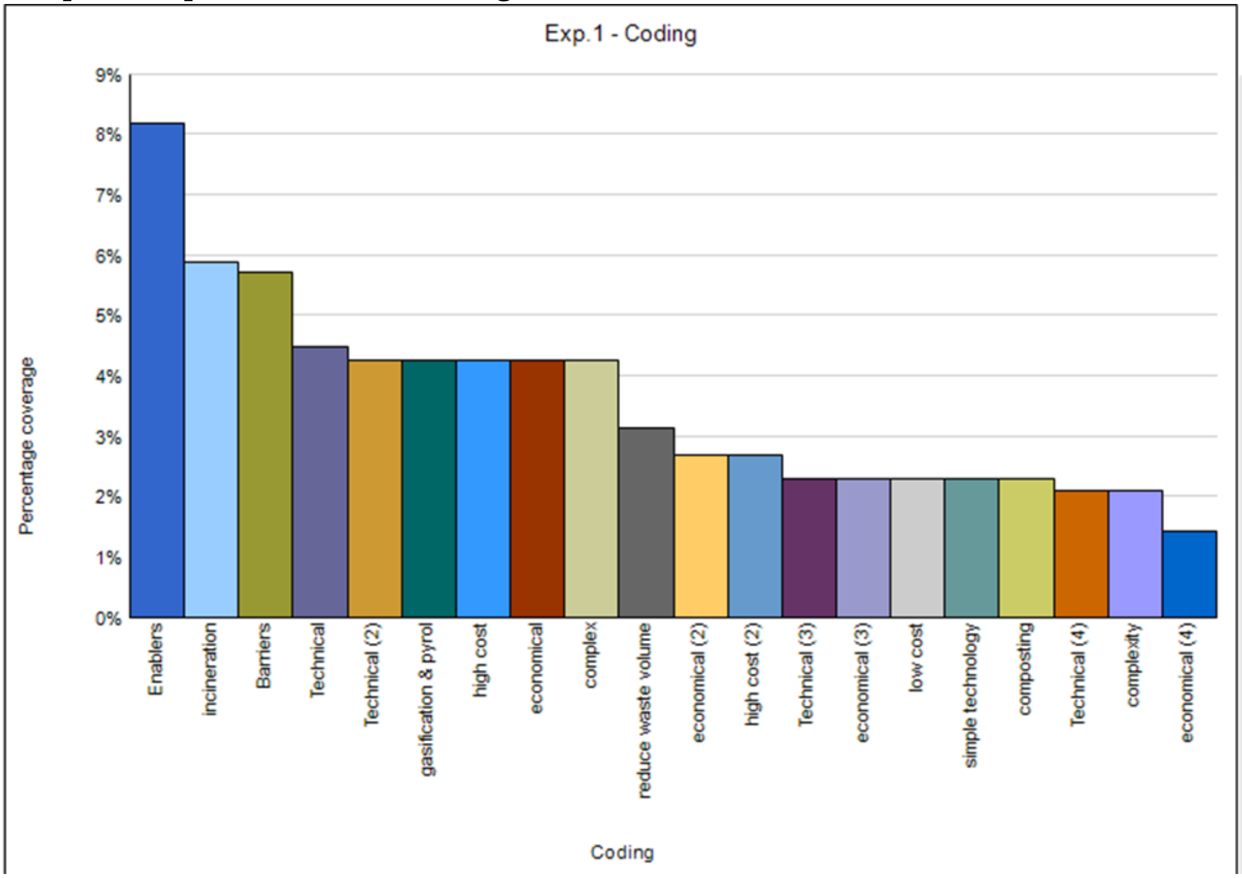
a. Nodes with Themes.



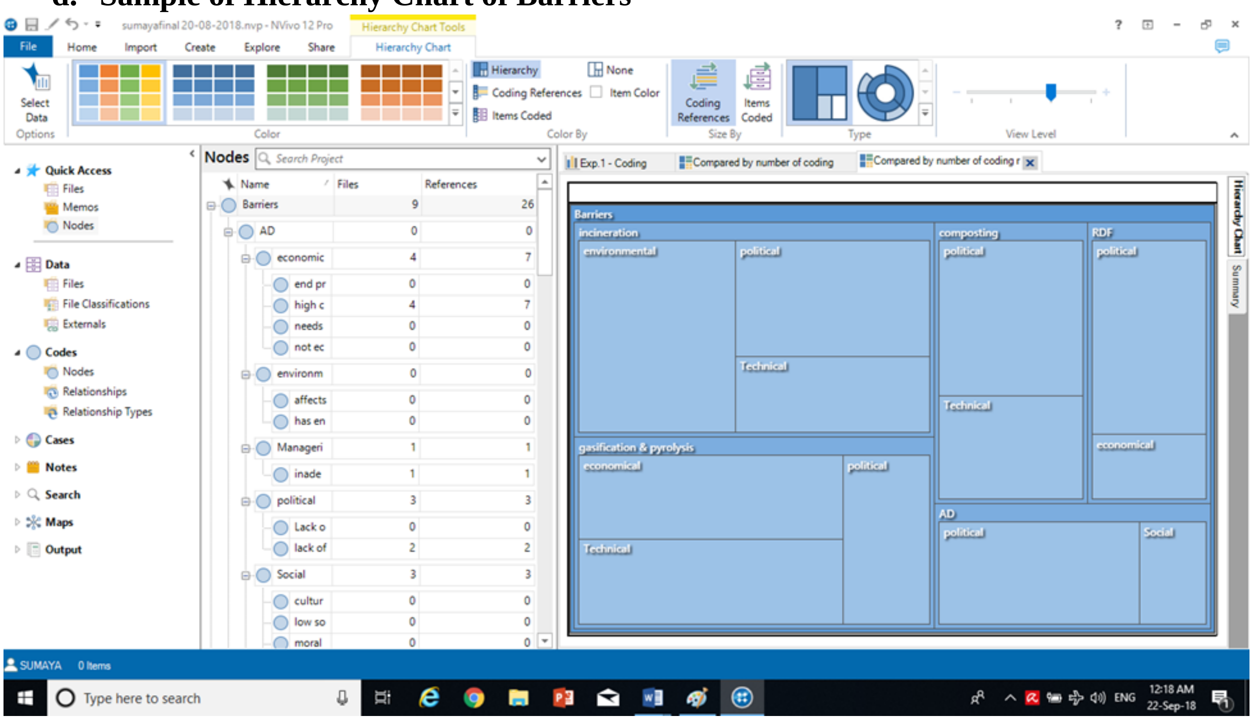
b. Nodes, Themes and Sub-themes (codes)



c. Sample of Expert 1 Interview Coding



d. Sample of Hierarchy Chart of Barriers



Appendix 7: Questionnaire for Public Awareness

a. **The translated English version:**

Measuring the Environmental Public Awareness toward Household Waste Management in Muharraq Governorate

Introduction

The public environmental awareness about household waste management is an essential key to the success of implementing a national waste management strategy, as well as a critical decision-making tool which leads to improving the household waste management practices in the country, to be used as a resource in the future.

This questionnaire is part of a PhD study entitled "Exploring the Opportunities for Organic Household Waste Management Technological Options: A Case Study of Muharraq Governorate" by the Bahraini researcher Sumaya Abbas, a student at the University of Warwick, UK.

This Questionnaire contains two parts: the First one is the personal profile, and the second one is the questionnaire statements, which fall into three sections: first aims to measuring the Knowledge (perception), second is to measure the attitude, and third is to regulate the behaviour.

Participation in this questionnaire is voluntary, and it takes 15 minutes or less. The data in the survey will be kept in a high-privacy location and treated with strict confidentiality.

The participant has every freedom to choose whether to fill out the questionnaire or not, and he is entitled to withdraw from it at any time he wishes and will cancel his participation according to his desire and in any secret and will not entail any harm in any way.

For any inquiry related to this questionnaire, please contact the researcher on mobile: 00973 36577772, or send an email to sumaya.abbas@warwick.ac.uk

Part 1: Personal Profile

Please circle the answers of the below questions:

Age	1. 18-20 years 2. 21-30 3. 31-40 4. 41-50 5. 51-60 6. 61 and above
Gender	1.Male 2.Female
Educational Level	1.Intermediate and below 2.Secondary 3.Under graduate 4.Post graduate
Marital Status	1.Single 2.Married 3.Others
Nationality	1.Bahraini 2.Non-Bahraini
Area of Living	1.Hidd 2.Qalali 3. Arad 4. Busaiteen 5. AlDair 6. Samaheej 7. Muharraq 8. Halat 9. Others
Occupation	
Monthly Family Income	1. BD 300 and below 2.BD301-900 3.BD 901-1500 4.BD1501 and above
Family Number	1. (2 persons) 2. (3-5 persons) 3. (6-8 persons) 4. (9 persons and above)
Place of Residence Type	1. House 2. Flat

Part 2: Questionnaire Statements

1. **Measuring knowledge about household waste management and related issues**

#	Statement	Totally True	True	Not Sure	Not True	Not True at all
1	I know where the domestic waste is taken daily and how it disposed of					
2	I understand the environmental and health damage caused by the dumping of household waste					
3	Sorting waste components by type at home (glass, plastic, food, paper, ...) is essential to take advantage of it					
4	I know the fine of throwing of waste in places other than their designated places					
5	I know who is responsible for collecting and disposing of household waste					
6	Burning household waste in a modern and safe facility is a very effective way to reduce its size and take advantage of it					
7	I know the meaning of waste recycling					
8	Household waste can be used as an energy source					
9	Some food waste can be converted to compost					
10	I know what it means by environmentally friendly products					

2. **Measuring the Attitude and trends in household waste management**

#	Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
11	I am ready to separate the waste in the house in separate containers by type if the municipalities ask me to do so					
12	I am satisfied with the current way of domestic waste collection.					
13	I am satisfied with the current way of domestic waste disposal					
14	Responsibility for waste management is a fundamental partnership between every individual in society and relevant institutions					
15	I am imposing fines on dumping waste in places other than the designated ones					
16	I am willing to pay extra municipal fees in exchange for the municipality to distribute coloured containers for sorting household waste					
17	Curricula should be used at all levels to promote environmental awareness about the importance of household waste management in the community					
18	Media and social communication should be used to spread environmental awareness about household waste management in the community					
19	I think giving incentives and rewards to people to recycle some of their household waste helps reduce them					
20	I am ready to cooperate with municipalities regarding the implementation of a national plan for the management of household waste					
21	I prefer to buy environmentally friendly goods for other goods if available					
22	Disposal of waste in environmentally friendly ways contributes to highlighting the beautiful image of the country and revitalising tourism in it					
23	I think the containers currently used to collect waste outside the houses are suitable					
24	I think it is necessary to provide citizens and residents with information on household waste and the proportion of each type					
25	The contribution of community members to voluntary clean-up campaigns is civilised					
26	The issue of household waste management is essential to me					

3. **Measuring the Practice and Behavior in household waste management**						
#	**Statement**	**Always**	**Sometimes**	**Not Sure**	**Rarely**	**Never**
27	I am keen to watch documentaries on environmental issues					
28	I am careful to guide others not to throw the waste in the street and throw it in the allocated places					
29	I am currently separating household waste components into individual containers or bags at home (food, plastic, glass, paper, ...)					
30	I use some of my food waste to feed animals or fish					
31	I use some food waste by turning it into fertiliser for agriculture					
32	I reuse some household waste components (empty plastic cans, bottles, etc.) in useful things					
33	When I go on a trip to the parks and others, I make sure to remove all the waste before leaving the place and put it in the allocated containers					
34	Be sure to attend and participate in the related environmental events related (seminars, workshops, courses, lectures ...)					
35	I encourage others to reuse some of the household waste components to take advantage of them					
36	I buy environmentally friendly products (such as reusable water bottles instead of plastic containers)					
37	Make sure to remove the waste bags from my house daily at a specific time					
38	I put the waste bags inside the containers and not outside when they are taken out of the house					

b. The original Arabic version:

إستبيان قياس الوعي البيئي العام حول إدارة المخلفات المنزلية في محافظة المحرق

مقدمة

يهدف الإستبيان إلى قياس الوعي البيئي العام لدى الناس حول إدارة المخلفات المنزلية وأهميتها في محافظة المحرق، حيث أن الوعي البيئي العام حول إدارة المخلفات المنزلية يعتبر مفتاحا مهما لنجاح تطبيق استراتيجية وطنية لإدارة المخلفات، وأداة مهمة لصنع القرار، وبالتالي تحسين ممارسات إدارة المخلفات المنزلية في البلاد للاستفاده منها كمورد في المستقبل.

هذا الإستبيان هو جزء من دراسة دكتوراه بعنوان: "إستكشاف الفرص التقنية لإدارة المخلفات المنزلية العضوية: دراسة حالة محافظة المحرق " لباحثة بحرينية بجامعة وارويك بالمملكة المتحدة.

تعتبر المشاركة في مليء الاستبيان تطوعية، وتستغرق 15 دقيقة او أقل، وسيتم حفظ البيانات الموجودة في الإستبيان في مكان عالي الخصوصية والتعامل معها بسرية تامة.

للمشارك كل الحرية في اختياره ملىء الإستبيان من عدمه، ويحق له الإنسحاب من ذلك في أي وقت يشاء وسيتم إلغاء مشاركته حسب رغبته وبكل سرية ولن يترتب على ذلك أي ضرر عليه بأي شكل من الاشكال.

للاستفسار الرجاء التواصل على الرقم 36577772، أو على الايميل: sumayousif@yahoo.co.uk

القسم الأول: معلومات عامة

العمر	1. ☐ 18-20سنة 2.☐21-30 3. ☐31-40 4.☐41-50 5.☐51-60 6. ☐61سنة فأكثر
الجنس	1. ☐ذكر 2. ☐ أنثى
المستوى التعليمي	1. ☐ اعدادي فأقل 2. ☐ ثانوي 3. ☐ جامعي 4. ☐ دراسات عليا
الحالة الاجتماعية	1. ☐ أعزب 2. ☐متزوج 3. ☐أخرى
الجنسية	1. ☐بحريني 2. ☐مقيم
منطقة السكن	1. ☐ الحد 2. ☐ قلالي 3. ☐ عراد 4. ☐ البسيتين 5. ☐ الدير 6.☐ سماهيج 7. ☐المحرق 8. ☐ الحالات 9. ☐ أخرى (أذكر)
المهنة	
الدخل الشهري للأسرة	1. ☐300دينار فأقل 2. ☐301-900 دينار 3. ☐ 901- 1500 دينار 4. ☐ 1501 دينار فأكثر
عدد أفراد الأسرة	1. شخصين 2. (3 - 5 أشخاص) 3. (6 – 8 أشخاص) 4. (9 أشخاص فأكثر)
نوع السكن	1. ☐منزل مستقل 2. ☐شقة

القسم الثاني: عبارات الإستبيان

1. **قياس المعرفة لدى الناس حول إدارة المخلفات المنزلية ومايتعلق بها**

الرقم	العبارة	صحيح تماما	صحيح	لست متأكدا	غير صحيح	غير صحيح أبدا
.1	أعرف أين تؤخذ المخلفات المنزلية يوميا وكيف يتم التخلص منها					
.2	أدرك الأضرار الصحية والبيئية الناتجة عن ردم المخلفات المنزلية					
.3	فرز مكونات المخلفات حسب نوعها في المنزل (زجاج، بلاستيك، طعام، ورق،...) مهم جدا للإستفادة منها					
.4	أعرف غرامة رمي المخلفات في غير أماكنها المخصصة					
.5	أعرف الجهات المسؤولة عن جمع المخلفات المنزلية والتخلص منها					
.6	حرق المخلفات المنزلية في منشأة حديثة وآمنة تعتبر طريقة فعالة جدا لتقليل حجمها والإستفادة منها					
.7	أعرف معنى تدوير المخلفات					
.8	يمكن الإستفادة من المخلفات المنزلية كمصدر للطاقة					
.9	يمكن تحويل بعض مخلفات الطعام الى سماد					
.10	أعرف معنى ان تكون السلع صديقة للبيئة					

2. قياس الإتجاهات لدى الناس فيما يتعلق بإدارة المخلفات المنزلية

الرقم	العبارة	أوافق بشدة	أوافق	لست متأكدا	لا أوافق	لاأوافق بشدة
11	أنا مستعد لفصل المخلفات في المنزل في حاويات منفصلة حسب نوعها إن طلبت مني البلديات ذلك					
12	أنا راض عن الطريقة المتبعة حاليا لجمع المخلفات المنزلية					
13	أنا راض عن الطريقة المتبعة حاليا للتخلص من المخلفات المنزلية					
14	مسؤولية إدارة المخلفات هي شراكة أساسية بين كل فرد في المجتمع والمؤسسات ذات العلاقة					
15	أنا مع فرض غرامات مالية على رمي المخلفات في غير أماكنها المخصصة					
16	أنا مستعد لدفع رسوم بلدية اضافية مقابل قيام البلدية بتوزيع حاويات ملونة خاصة لفرز المخلفات المنزلية					
17	يجب توظيف المناهج الدراسية في جميع المراحل الدراسية لنشر الوعي البيئي حول أهمية إدارة المخلفات المنزلية في المجتمع					
18	يجب استغلال وسائل الإعلام والتواصل الاجتماعي لنشر الوعي البيئي حول إدارة المخلفات المنزلية في المجتمع					
19	أعتقد ان منح حوافز ومكافآت للناس على تدوير بعض مكونات مخلفاتهم المنزلية يساهم في التقليل منها					
20	انا مستعد للتعاون مع البلديات فيما يخص تطبيق خطة وطنية لإدارة المخلفات المنزلية					
21	أفضل شراء السلع الصديقة للبيئة على السلع الأخرى إن توفرت					
22	التخلص من المخلفات بطرق صديقة للبيئة يسهم في إبراز صورة جميلة للبلد وإنعاش السياحة فيها					
23	أعتقد ان الحاويات المستخدمة حاليا لتجميع المخلفات خارج البيوت مناسبة					
24	أعتقد أنه من الضروري تزويد المواطنين والمقيمين بالمعلومات الخاصة بالمخلفات المنزلية ونسبة كل نوع منها					
25	مساهمة أفراد المجتمع في حملات التنظيف التطوعية يعد سلوكا حضاريا					
26	يعتبر موضوع إدارة المخلفات المنزلية مهما بالنسبة لي					

3. قياس السلوك الدال على الوعي البيئي حول إدارة المخلفات المنزلية

الرقم	العبارة	دائما	أحيانا	لست متأكدا	نادرا	أبدا
27	أحرص على مشاهدة الأفلام الوثائقية المتعلقة بقضايا البيئة					
28	أحرص على توجيه الآخرين لعدم رمي المخلفات في الشارع ورميها في الأماكن المخصصة					
29	أنا أقوم حاليا بفصل مكونات المخلفات المنزلية في حاويات أو أكياس خاصة في المنزل (طعام، بلاستيك، زجاج، ورق،...)					
30	أقوم باستخدام بعض مخلفات الطعام لإطعام الحيوانات او الأسماك					
31	أقوم باستخدام بعض مخلفات الطعام بتحويله لسماد للزراعة					
32	أنا أقوم بإعادة استخدام بعض مكونات المخلفات المنزلية (العلب البلاستيكية الفارغة، الزجاجات وغيرها ...) في أشياء مفيدة					
33	عند ذهابي في رحلة للمنتزهات وغيرها أحرص على إزالة كل المخلفات قبل مغادرتي المكان ووضعها في الحاويات المخصصة لها					
34	أحرص على الحضور والمشاركة في الفعاليات البيئية المتعلقة (كالندوات، ورش العمل، دورات، محاضرات..)					
35	أشجع الاخرين على إعادة استخدام بعض مكونات المخلفات المنزلية للإستفادة منها					
36	أقوم بشراء المنتجات الصديقة للبيئة (كزجاجات الماء القابل لإعادة الاستخدام بدلا من االعبوات البلاستيكية)					
37	أحرص على إخراج أكياس المخلفات من منزلي يوميا في وقت محدد					
38	أقوم بوضع أكياس المخلفات بداخل الحاويات الخاصة وليس خارجها عند إخراجها من المنزل					

شكرا على تعاونكم الكريم ولكم خالص الشكر والتقدير والإمتنان

Appendix 8: The questionnaire analysis using SPSS (Sample shot of the entered data)

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	id	Numeric	8	2		None	None	8	Right	Scale	Input
2	age	Numeric	8	2		{1.00, 18-20...	None	8	Right	Nominal	Input
3	gender	Numeric	8	2		{1.00, male}...	None	8	Right	Nominal	Input
4	education	Numeric	8	2		{1.00, Inter...	None	8	Right	Nominal	Input
5	maritalstatus	Numeric	8	2		{1.00, single...	None	8	Right	Nominal	Input
6	nationality	Numeric	8	2		{1.00, Bahra...	None	8	Right	Nominal	Input
7	resntialarea	Numeric	8	2		{1.00, hidd}...	None	8	Right	Nominal	Input
8	job	Numeric	8	2		{1.00, head,...	None	8	Right	Nominal	Input
9	income	Numeric	8	2		{1.00, 300B...	None	8	Right	Nominal	Input
10	familynum	Numeric	8	2		{1.00, 2}...	None	8	Right	Nominal	Input
11	hometype	Numeric	8	2		{1.00, hous...	None	8	Right	Nominal	Input
12	statement1	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
13	statement2	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
14	statement3	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
15	statement4	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
16	statement5	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
17	statement6	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
18	statement7	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
19	statement8	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
20	statement9	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
21	statement10	Numeric	8	2		{1.00, not tr...	None	8	Right	Nominal	Input
22	statement11	Numeric	8	2		{1.00, stron...	None	8	Right	Nominal	Input
23	statement12	Numeric	8	2		{1.00, stron...	None	8	Right	Nominal	Input
24	statement13	Numeric	8	2		{1.00, stron...	None	8	Right	Nominal	Input
25	statement14	Numeric	8	2		{1.00, stron...	None	8	Right	Nominal	Input

Appendix 9: Publications

1. Sumaya Abbas (2017), Exploring the Opportunity for Household Organic Waste Valorisation: An Empirical Investigation for Case Study Muharraq City, WMG Doctoral Research and Innovation Conference International Manufacturing Centre, University of Warwick. (Oral presentation)

2. Sumaya Abbas (2015), Exploring the Opportunity for Household Organic Waste Valorisation: An Empirical Investigation for Case Study Muharraq City, WMG Doctoral Research and Innovation Conference International Manufacturing Centre, University of Warwick. (Poster)

3. Sumaya Hasan (2015), Waste Heat Recovery as a Potential CDM Project: Case Study of a Refinery in Bahrain. Bahrain Society of Engineers, June, 60:14-16

4. Sumaya Yousif (2012), Waste Heat Recovery as Potential CDM Project: Case Study of a Refinery in Bahrain, Women as Global Leaders Conference, Zayed University, UAE. (Oral presentation)

5. Sumaya Yousif (2013), Waste Heat Recovery as Potential CDM Project: Case Study of a Refinery in Bahrain, 1st Energy Management Conference & Exhibition 2013, MOE, Society of Engineers, Manama, Bahrain. (Oral Presentation)

6. Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical Investigation for Muharraq City. A joint event on 5th International Conference on Bioplastics and 6th World Congress on Biopolymers:

Sumaya Yusuf Abbas, University of Warwick, UK

Posters & Accepted Abstracts: J Chem Eng Process Technol

DOI:10.4172/2157-7048-C1-006

https://www.omicsonline.org/proceedings/exploring-the-opportunity-for-organic-household-waste-ohw-management-technology-options-an-empirical-investigation-for-m-72116.html

7. Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical investigation for Muharraq City:

2nd World Congress on Pollution Control & Advances in Environmental Engineering 11th - 12th October 2017, Bangkok, Thailand

Sumaya Yusuf Abbas, University of Warwick- WMG, UK

ISBN: 978-81-932966-1-5

https://bioleagues.com/past/downloads/2nd-GoGreen-Proceedings-book.pdf

8. Exploring the Opportunity for Organic Household Waste (OHW) Management Technology Options: An Empirical investigation for Muharraq City. Waste Management Conference, American Scientific Academy, 15-29 June, 2018, Accepted Paper for Oral Presentation