DETERMINATION OF WASTE TREATMENT FEE PRICING MECHANISM FOR MUNICIPAL SOLID WASTE BY MECHANICAL BIOLOGICAL TREATMENT METHOD UTILISING THE PUBLIC PRIVATE PARTNERSHIP MODEL IN THAILAND

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การกำหนดกลไกราคาค่าธรรมเนียมการบำบัดของเสียสำหรับการบำบัดชีวภาพเชิงกลของขยะมูลฝอยชุมชนโดยใช้แบบจำลองความสัมพันธ์รัฐและเอกชนในประเทศไทย

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เอเดรียน พอล ราจ : การกำหนดกลไกราคาค่าธรรมเนียมการบำบัดของเสียสำหรับการบำบัดชีวภาพเชิงกลของขยะมูลฝอยชุมชนโดยใช้แบบจำลองความสัมพันธ์รัฐและเอกชนในประเทศไทย (DETERMINATION OF WASTE TREATMENT FEE PRICING MECHANISM FOR MUNICIPAL SOLID WASTE BY MECHANICAL BIOLOGICAL TREATMENT METHOD UTILISING THE PUBLIC PRIVATE PARTNERSHIP MODEL IN THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ปารเมศ ชุติมา, 142 หน้า.

บทบาทของภาคเอกชนในการพัฒนาโครงการบำบัดขยะมูลฝอยของเทศบาลผ่านทางแบบจำลองความร่วมมือของภาครัฐและเอกชนเร่งให้เกิดการนำเทคโนโลยีการบำบัดแบบยั่งยืน อาทิ เทคโนโลยีการบำบัดขยะโดยวิธีทางกลและชีวภาพ (MBT) มาใช้ในประเทศกำลังพัฒนาโดยไม่สร้างภาระการลงทุนทางด้านโครงสร้างพื้นฐานแก่รัฐบาลจนเกินควร การกำหนดกลไกราคาล่วงหน้าเพื่อควบคุมโครงสร้างค่าธรรมเนียมในการบำบัดขยะที่เป็นไปได้บนพื้นฐานของอัตราผลตอบแทนภายในของโครงการที่กำหนดไว้ล่วงหน้าช่วยบรรเทาความเสี่ยงต่อหลายฝ่าย เช่น โอกาสที่โครงการของผู้พัฒนาจะขาดทุน โอกาสในการค้ากำไรเกินควร โดยงานวิจัยนี้จะครอบคลุมการประเมินทางเทคนิคต่อเงื่อนไขโครงการในการใช้เทคโนโลยีที่จำเป็น การวิเคราะห์เชิงพาณิชย์ของรายจ่ายในการลงทุนของโครงการ (CAPEX) ค่าใช้จ่ายในการดำเนินงาน (OPEX) รวมถึงการประเมินรายได้จากการใช้เทคโนโลยี แบบจำลองทางคอมพิวเตอร์จะจำลองข้อมูลเชิงพาณิชย์จากกรณีศึกษาโรงบำบัดขยะของ MBT อัตรา 600 ตันต่อวันซึ่งมีค่าธรรมเนียมการบำบัดขยะปีแรกอยู่ที่ 546 บาท 709 บาท และ 890 บาท ขึ้นอยู่กับอัตราผลตอบแทนภายในโครงการที่กำหนดไว้ล่วงหน้าที่ 8% 10% และ 12% ตามลำดับ อิทธิพลของข้อมูลทางเศรษฐศาสตร์มหภาคในส่วนของกลไกราคามีอิทธิพลระยะยาวต่อโครงสร้างค่าธรรมเนียมการคิดราคาในการใช้เทคโนโลยีเพื่อบรรเทาความเสี่ยงในเชิงพาณิชย์ของโครงการต่อไป

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
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Private participation in the development of municipal solid waste treatment projects through public-private partnership models accelerate the implementation of sustainable treatment technologies such as Mechanical Biological Treatment (MBT) facilities within developing countries without creating excessive burden to government infrastructure investment. The introduction of preset pricing mechanism to regulate potential waste treatment fee structure based on pre-determined project internal rate-of-return mitigates multi-party risks, such as the potential developer project losses or the opportunity to profiteer. Research encompasses technical assessment of project requirements for implementation of required technologies, commercial analysis of project capital expenditure (CAPEX), operational expenditure (OPEX) and assessment of revenue streams of the facility. Computer simulation of commercial data computes the case study of a 600 tonne per day MBT facility's first-year waste treatment fee of THB 546.00, THB 709.00 and THB 890.00 based on pre-determined project internal rate of returns of 8.00%, 10.00% and 12.00% respectively. Macroeconomic data influences within pricing mechanism determines long-term effects to facility pricing fee structure to further mitigate project commercial risks.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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Abbreviations

AD	:	Anaerobic digestion
ASTM	:	American Society of Testing & Materials
BMA	:	Bangkok Metropolitan Authority
BOI	:	Board of Investment, Thailand
BOT	:	Built-Operate and Transfer
CAPEX	:	Capital expenditure
CPI	:	Consumer pricing index
DEDE	:	Department of Alternative Energy Development and Efficiency, Thailand
E-IRR	:	Equity internal rate-of-return
EPCC	:	Engineering, Procurement, Construction & Commissioning
FiT	:	Feed-in tariff
GDP	:	Gross Domestic Product
HHW	:	Household Hazardous Waste
HVAC	:	Heating, Ventilation & Air-Conditioning
IRR	:	Internal rate-of-return
MBT	:	Mechanical Biological Treatment
MSW	:	Municipal solid waste
NEPC	:	National Energy Policy Commission
NPV	:	Net Present Value
O&M	:	Operation & Maintenance
OPEX	:	Operational expenditure
PPP	:	Public-Private Partnership
RDF	:	Refuse-derived fuel
THB	:	Thailand Baht
TOR	:	Terms of Reference
VSPP	:	Very Small Power Producer

CHAPTER 1 INTRODUCTION

This chapter provides an overview of the current municipal solid waste management landscape within Thailand; justification and objectives of this study; hypothesis and expected outcomes; and the outline of this study.

1.1 Background

Municipal solid waste (MSW) is defined as unwanted products which have been discarded by households, but can include similar waste products that are discarded from commercial, public areas and offices which are collected by municipal or private haulers for disposal through the waste management system (EEA, 2013) Approximately 2 billion tonnes of MSW is generated globally each year (UNEP, 2015).

Unsustainable municipal solid waste (MSW) management practices remains a major problem globally, Improper MSW disposal practices such as open waste dumping poses a serious threat to public health and environmental pollution. Public health concerns include the spread of commutable illnesses such as cholera and Hepatitis, and rises in vector populations (rodents, flies, mosquitos, scavenger animals & birds) around surrounding areas, among others. Environmental pollution concerns include leachate seepage into surface and groundwater, uncontrolled peat fires, release of toxic emissions from open burning of MSW and large-scale contamination alongside waterways, rivers and the sea, disrupting the marine food chain, among others.

A major component within MSW stream is organic waste, derived from food waste, landscaping and gardening waste. Organic waste is a major source of greenhouse gas (GHG) emission into the atmosphere. Annually, anaerobic breakdown of organic material from unlined landfills release large quantities of methane gas into the atmosphere. Methane gas is considered highly detrimental to global warming, having a global warming potential (GWP) time horizon of 86 over a 20-year period. (IPCC, 2013).

Further to release of methane, open burning of other waste components such as waste plastics leads to the release of toxic gases such as Black Carbon (BC) and Nitrous Oxide (NO), with GWP time horizons of 1,200-3,200 and 270 respectively over a 20-year period. (IPCC, 2013). The release of carbon particulates into the atmosphere increases the prevalence of smog, with inhalation ultrafine particles (UFP) lower than 100 nanometres (nm) increasing the risk of cardiovascular health problems (Vora, et al., 2014).

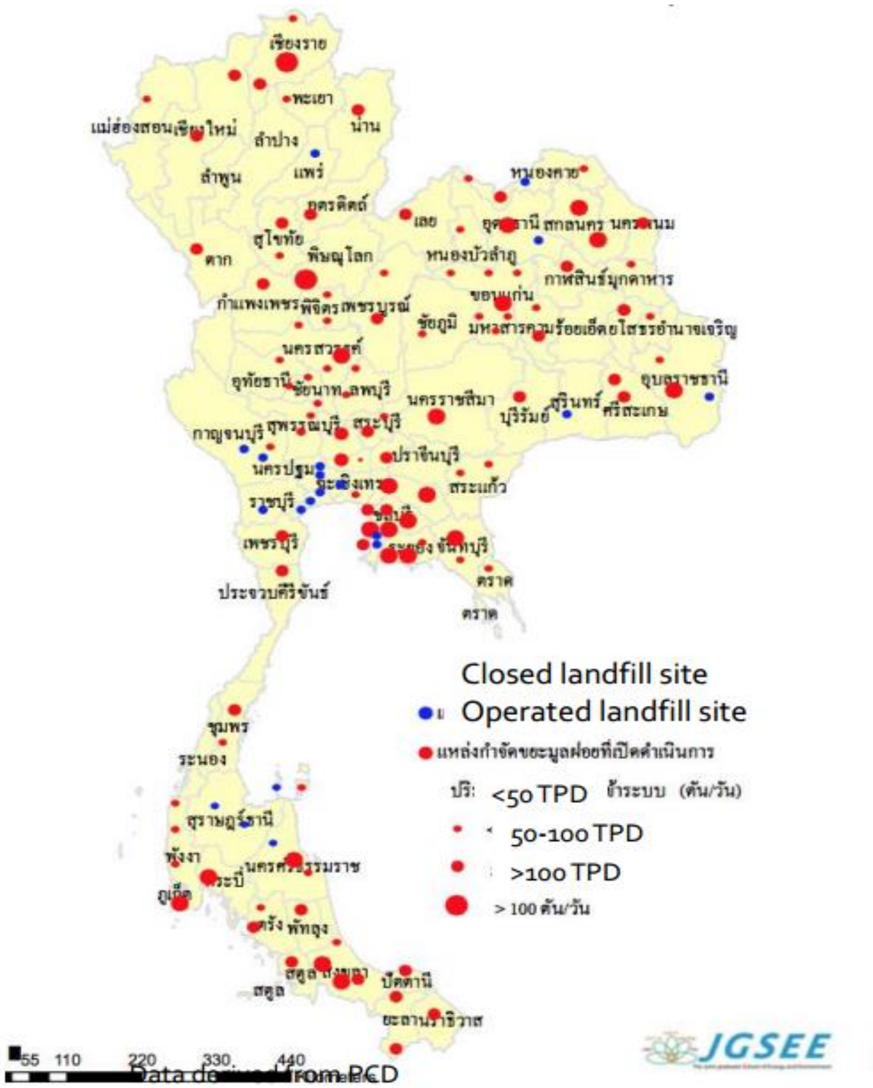
Managing solid waste sustainably has the potential of reducing GHG emission levels by 15-20% across each nation's economy, creating between 9 to 25 million new jobs within the solid waste management sector globally. (UNEP, 2015). A key economic driver for the implementation of proper solid waste management is the opportunity to reduce costs to society by a factor of 5 to 10 times from reduced healthcare, lost productivity, floods and effects of losses to tourism and business activities, creating by the effects of unsustainable waste management practices (UNEP, 2015).

1.2 Waste Management in Thailand

Current municipal solid waste generation (as of year 2015) in Thailand amounts to 26.85 million tonnes, of which almost 51% (13.53 million tonnes) are disposed improperly such as in waste dumps, 31% (8.34 million tonnes) disposed at lined landfills and 18% (4.94 million tonnes) utilised for recycling activities or energy generation (Towprayoon, 2016). Most MSW generated is disposed of at one of 106 landfills in operation across Thailand. A snapshot of the location of current landfills in operation is illustrated in Figure 1-1.

As the majority of landfills in Thailand comprise of open, unlined waste pits, several incidences of landfill fires have been reported in recent years, among them highly publicised landfill fires at the Phraeksa landfill site at Samut Prakan Province, on the outskirts of Bangkok in March 2014 (Wiwanitkit, 2016) and the Phuket City Waste Management Facility in Saphan Hin, Phuket in March 2015 (Mueanhawong, 2015).

Figure 1-1: Landfill Locations in Thailand as of 2014 *(Towprayoon, 2016)*

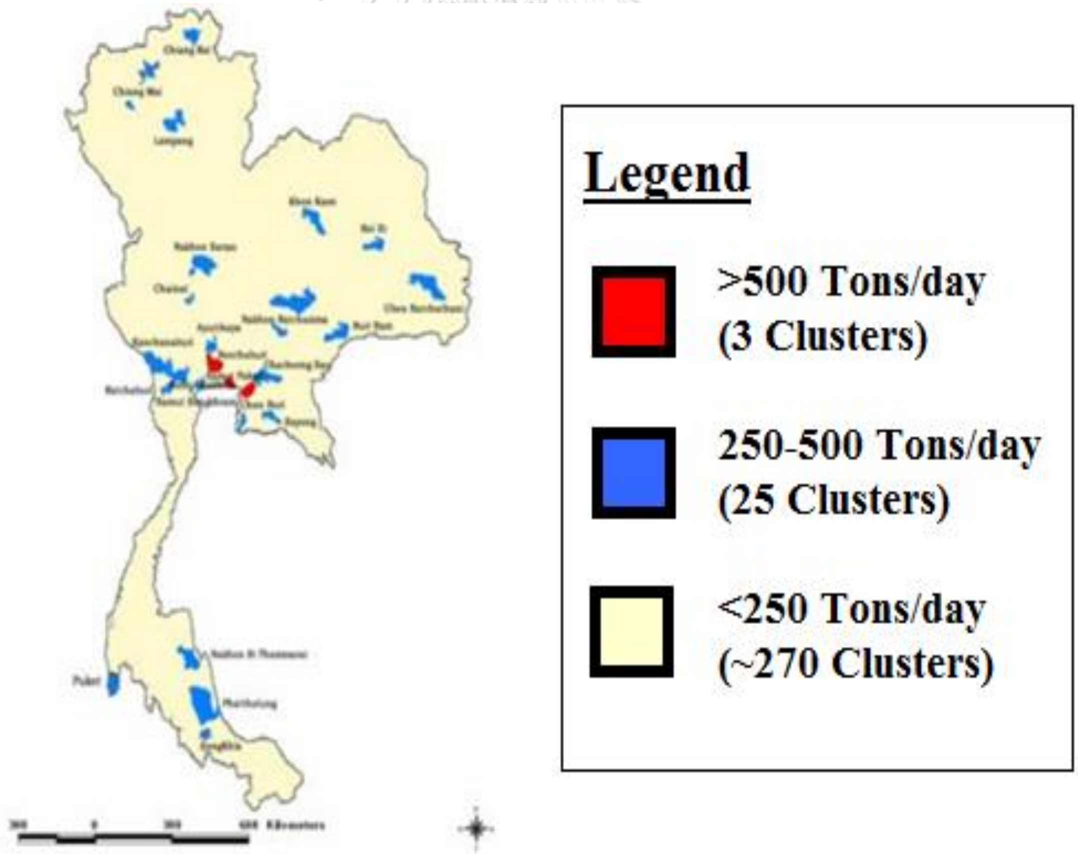


Several waste-to-energy facilities (comprising of landfill gas capture, anaerobic digestion, incineration and gasification) have been constructed to generate electricity waste across Thailand. As of 2016, the Department of Alternative Energy Development and Efficiency, Thailand (DEDE) reports that 23 waste power plants are in operation, with a cumulative electrical installed capacity of 141.82 MW. This is expected to increase in 2018 through the completion of 18 new facilities, increasing installed electrical generation capacity by 115MW (Towprayoon, 2016).

A key concern that hampers private sector involvement in municipal solid waste management under the Public-Private Partnership (PPP) model is the small waste catchment areas of smaller municipalities that reduces a project's commercial viability. To overcome this, the government introduced the "Waste Cluster" concept by dividing Thailand into 298 municipal solid waste collection clusters with the goal of identifying possible waste generation areas for development of waste treatment projects.

These clusters are categorised by waste catchment volume potential. Large waste clusters are earmarked for incineration or integrated waste complexes, while lined-landfills with gas collection were proposed for smaller clusters (Chvajarernpun, et al., 2006). A snapshot of solid waste clusters in Thailand is shown in Figure 1-2.

Figure 1-2: Clustering of MSW Catchment Areas Promoting Waste Treatment (Chvajarernpun, et al., 2006)



In overcoming Thailand's solid waste management problem, the government announced the inclusion of sustainable waste management as a key agenda in their environmental management policy, In 2015, the government announced sustainable municipal solid waste management as National Agenda No. 1, to promote proper and sustainable methods for disposal of municipal solid waste, with the "emphasis on resource recovery wherever possible & energy recovery whenever possible".

1.3 Problem Statement

At present, municipal solid waste collection, treatment and disposal fall under the purview of the respective municipality of which the waste is generated within. The high operating costs incurred in treating MSW hampers each municipality's ability to optimise annual operating budget distribution for community development, such as upgrading of public infrastructure or investing in more sustainable waste treatment options.

The participation of the private sector in providing capital investment and/or undertaking MSW treatment provides an opportunity for municipalities to potentially reduce operating expenses and fast-track the introduction of more efficient waste management solutions that may resolve current environment issues. This allows the municipality's local council to revert to their core competency of local administration and regulating waste management services, reducing current strain on infrastructure and service spending.

The introduction of the waste treatment concessions through the Public-Private Partnership (PPP) model raises questions on a suitable concession rate that safeguard the interest of all parties. Private investors seek concession agreements that provide low-risk and reasonable rate of return on their investment to justify such partnerships while the public sector and the public are concerned about project profiteering through project that artificially report higher project investment and operating expenses to inflate facility waste treatment fees. The absence of a structured pricing mechanism in Thailand reduces stakeholder confidence in developing such ventures, hampering project realisation.

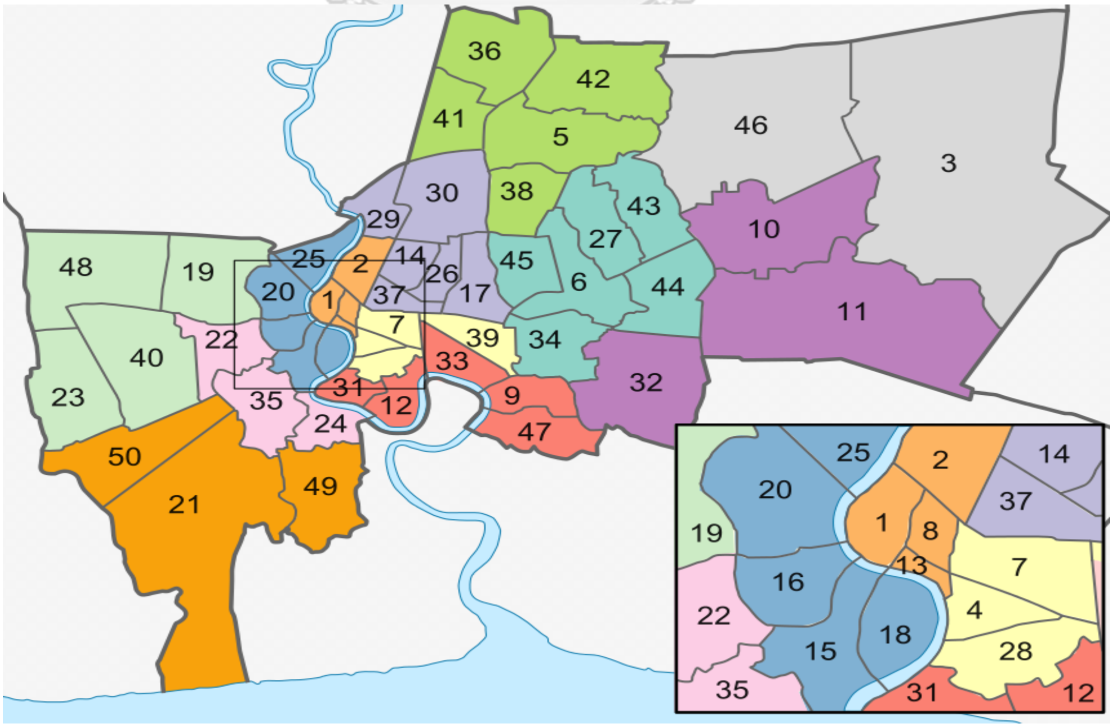
1.4 Research Objectives

The objective of this research is to formulate an appropriate waste treatment fee calculation mechanism under the Public Private Partnership (PPP) model which is transparent, flexible and repeatable that scrutinises investor profitability within an acceptable project internal rate-of-return (IRR) range, reducing the potential of project developer "profiteering".

1.5 Case Study Area – On Nut, Bangkok

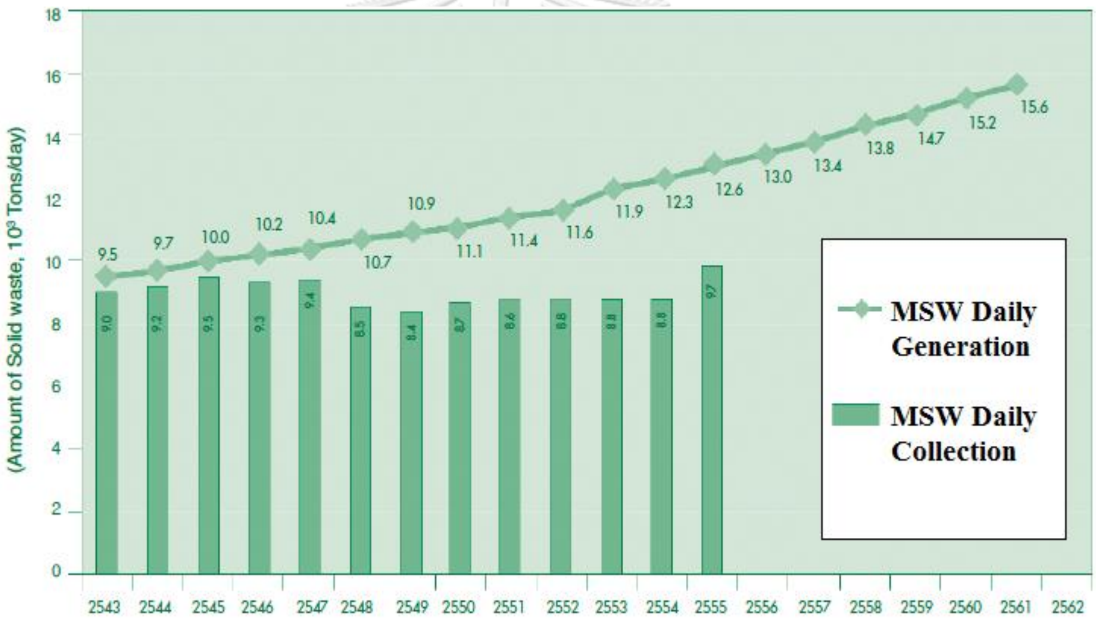
The city of Bangkok has been selected as the case study location for this study. Bangkok is the capital and largest city in Thailand with a population of 9.6 million inhabitants within a 2,100 square kilometre area, encompassing approximately 80% of Thailand's overall urban area (World Bank, 2015). Bangkok is recognised as a Special Administrative Region and is administered by the Bangkok Metropolitan Authority (BMA). The city is divided into 50 districts, as shown in Figure 1-3.

Figure 1-3: Map of Bangkok



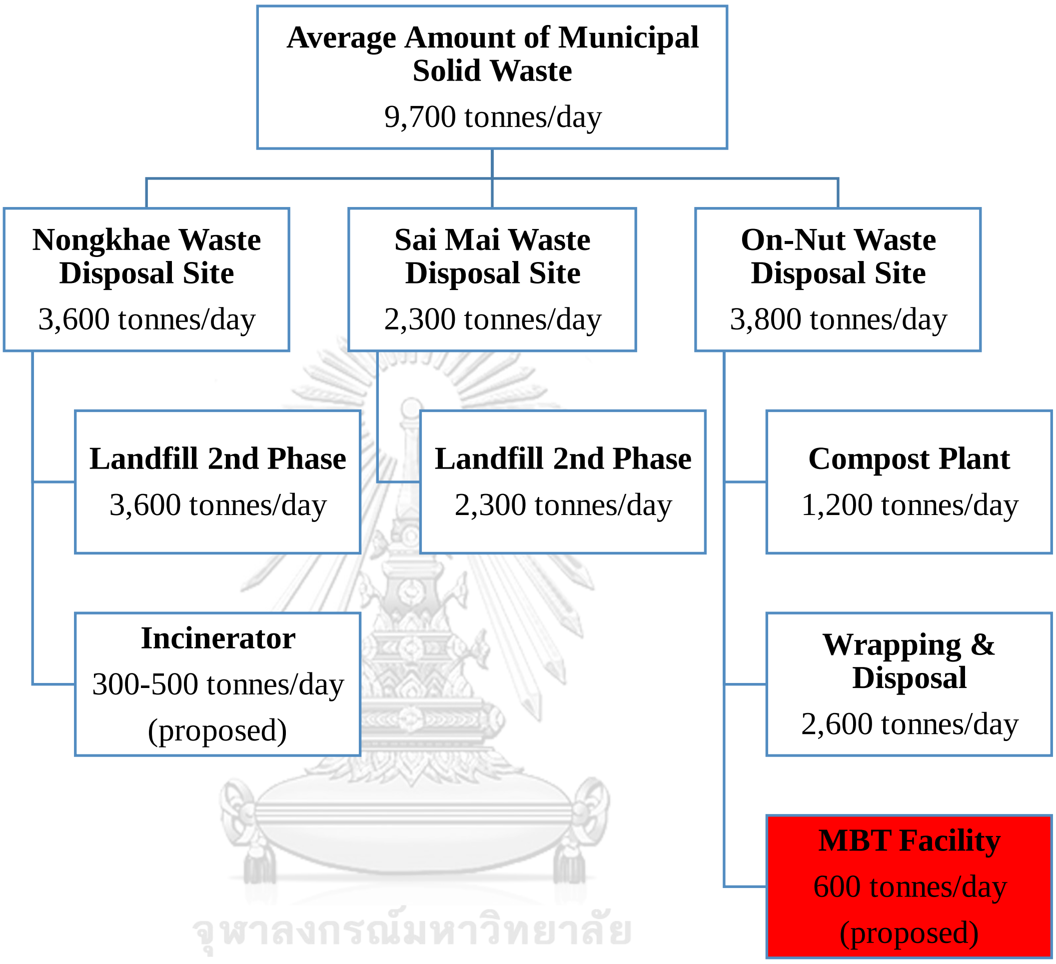
As a Special Administrative Region, Bangkok is accorded the right to develop and manage all waste streams generated within their boundaries under the Bangkok Metropolis Administration Act, BE 2528 (1985). In 2012, the city recorded annual MSW generation of 4,599,000 tonnes, averaging 12,600 tonnes per day (BMA, 2012). City council MSW collection stands at 76.9% of total waste generated, amounting to 9,700 tonnes per day. Differences between generation and collection data is attributed to the city's recycling and source-separation programmes. MSW daily generation and collection data from 2543-2555 B.E. (2000-2012) is presented in Figure 1-4.

Figure 1-4: Bangkok Daily MSW Generation & Collection 2000-2012 (BMA, 2012)



At present, MSW collected by BMA collection vehicles are sent to one of three waste collection and disposal sites at Nongkhae, Saimai and On Nut on the outskirts of Bangkok. These waste disposal sites serve as transit points for compaction and waste preparation prior to transport to MSW disposal landfills, namely the Kamphaeng Saen sanitary landfill at Nakhon Pathom Province. The BMA is introducing on-site waste treatment facilities at these disposal sites to increase waste treatment efficiency. A summary of waste treatment activities conducted at each waste disposal site is illustrated in Figure 1-5.

Figure 1-5: Bangkok MSW Disposal Site Utilisation (BMA, 2012)



The case study for this study is the proposed 600 tonnes per day Mechanical Biological Treatment (MBT) currently under construction at the On-Nut waste disposal site and expected to be operational by 2019. The plant shall receive a portion of MSW intended for disposal at the On-Nut Wrapping plant, which is currently operating above its design capacity due to increasing MSW generation.

1.6 Scope

1.6.1 Scope of Research

The scope of this research includes deliverables as stated below;

1. Table-top review of existing mechanical & biological treatment (MBT) technologies & evaluation of the best suited technologies to be used for the treatment of MSW based waste composition and qualitative testing done for the case study.

2. Capital expenditure (CAPEX) assessment & investment requirement of a complete Mechanical Biological Treatment (MBT) facility in Thailand. Evaluation of Engineering, Procurement, Construction & Commissioning (EPCC) deliverables & schedule.

3. Operation & Maintenance (O&M) phase assessment, operation expense (OPEX) evaluation, and study of revenue streams of facility based on current market information including sale of energy, tipping fee & sale of waste products.

4. Overall life cycle analysis of the facility based on project CAPEX, OPEX and revenue streams for the design lifetime of the facility to determine the expected project Internal Rate-of-Return (IRR) & Equity Rate-of-Return (E-IRR)

5. Design of a pricing mechanism model to determine appropriate waste treatment fees to meet investor income requirements of Internal Rate-of-Return (IRR) of 8%, 10% and 12%.

1.6.2 Assumption of Research Scope

Assumptions of this research shall be based on actual project details presented for the formulation of our pricing mechanism. Among assumptions are as below;

i. The facility is designed based on municipal solid waste (MSW) composition with the city of Bangkok. A comprehensive municipal solid waste (MSW) composition analysis was done in August 2014 as part of the feasibility study for the project.

ii. The facility shall be designed to treat approximately of 600 tonnes/day of municipal solid waste (MSW). The facility's capital investment shall be based on actual project technology selection.

iii. The facility shall be designed to produce electricity-from-waste. As the Mechanical Biological Treatment (MBT) has multiple energy-from-waste possibilities, the energy component shall be limited to nett electricity generation from the biological component of the process.

iv. The electricity Feed-in Tariff (FiT) shall be set based on current rates set by the Energy Regulatory Commission of Thailand (ERC) for waste-from-energy projects. All income streams from other waste products (compost, liquid fertilizer, Refuse-derived Fuel, metals) shall be based upon current local market prices. If a waste product doesn't yet have any commercial value in Thailand, it shall be assumed as a non-income product.

v. All incomes & expenditure shall take into account the average year-to-year Core Inflation Rate throughout the life of the facility.

vi. The facility shall be funded through private capital investment on the basis of equity-to debt ratio of 20:80 based on current Base Lending Rate (BLR) with a lending period of 12 years. Depreciation of the facility shall be set as 20 years.

1.6.3 Exclusion of Research Scope

Exclusions to this research are listed as below;

a. Unproven technology categorised as “Mechanical Biological Treatment”. This shall include technologies which have had multiple process failures.

b. Project funding assistance through green funds or/and government tax-break programs including Board of Investment Incentive Program.

c. The use of untested income streams within Thailand such as waste heat and inert material due to inability to predict realistic data for project life-cycle evaluation.

d. Any other waste type such as commercial or industrial waste.

1.7 Thesis Methodology

In preparation of the study, the author utilises and adapt several assessment techniques and models to achieve the research objective. Each technique is modified to operate within the limitation of scope of research. Table 1-1 presents the research framework and methodology utilised is this research.

Table 1-1: Research Framework & Methodology

	Step	Methodology	Tools
1	Defining project requirements	Identification of research objective, scope and limitation of study	Literature review, review of project scope and deliverables
2	Technology background	Definition of technology, classification of waste treatment concepts	Literature review, survey of existing facilities,
3	Current waste treatment fee mechanism	Assessment of current practices in determination waste treatment fee	Literature review, data collection
4	Determination of project capacity and process flow	Data analysis, mass flow balance and energy balance	Data collection from waste study, Mass flow modelling
5	Determination of project CAPEX and OPEX	Data analysis, compilation of capital and operation costs	Data collection from technology providers, historical performance data
6	Formulation of Waste Treatment Fee Mechanism	Creation of mathematical formula	Simulation software modelling
7	Evaluation of Waste Treatment Fee Mechanism	Validation and running of simulation, scenario	Simulation software

1.8 Expected Benefit of Study

The primary purpose of this study is to formulate and propose an independent, transparent and non-partisan pricing mechanism to overcome the current issue of non-uniform waste treatment fees between privatised MSW treatment facilities within Thailand, with the intention of eliminating the possibility of "profiteering" through the Public-Private-Partnership model.

The study analyses the general technical and operational make-up of a Mechanical Biological Treatment (MBT) facility and divides these processes into key groupings that allow project developers the ability to price similar facilities utilising different technologies suites to meet project-specific requirements based on individual client requirements and intended business models.

By combining the MBT facility's capital and operational expenses into a singular and integrated pricing mechanism, incorporating macroeconomic factors such as core inflation rate and expected tax rates over the lifecycle of the proposed facility, the study introduces a computerised simulation model that is able to propose a suitable waste treatment fee based on pre-determined project internal rate-of-return (IRR).

The incorporation of the proposed pricing model in the assessment of suitable project treatment fee ranges for MBT facilities under the PPP- model allows project end-users a method to validate project financials in a standardised setting to eliminate the opportunity of unscrupulous attempts profiteer through higher than market-accepted project IRR rates.

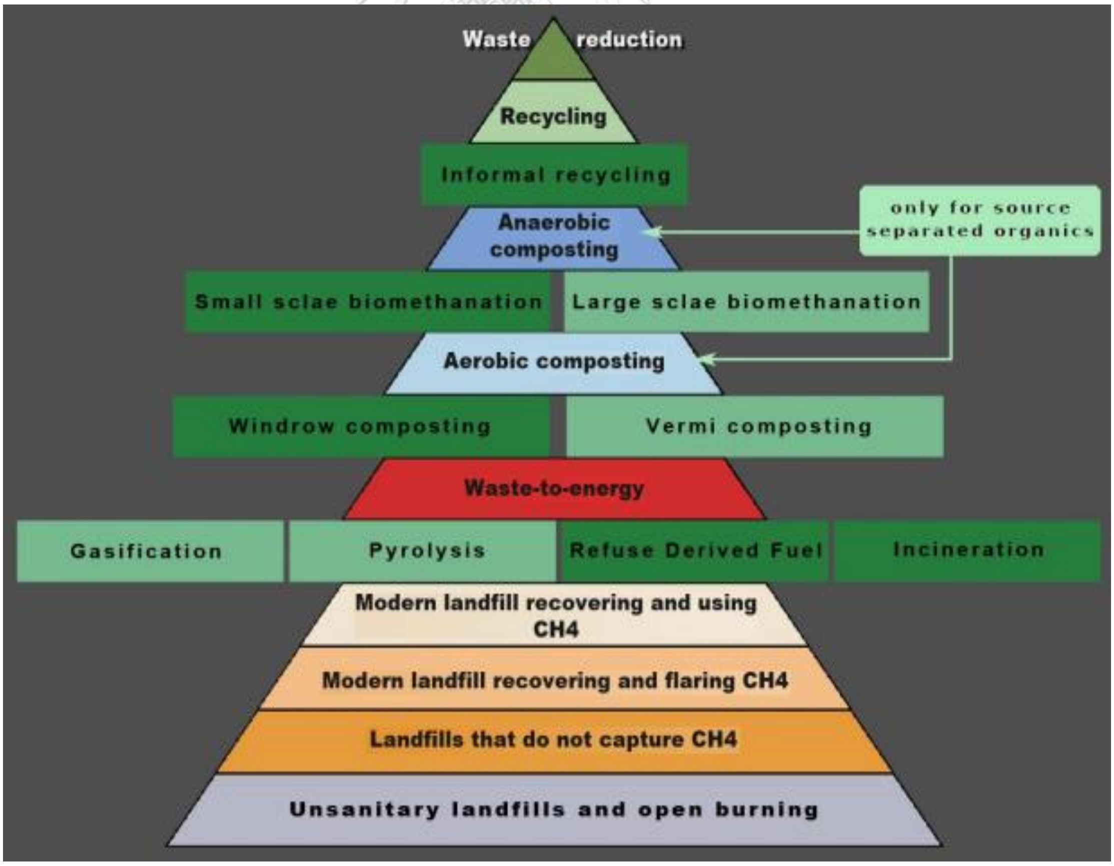
CHAPTER 2 LITERATURE REVIEW

This chapter provides an overview of waste treatment technologies, definition of the mechanical biological treatment (MBT) concept, current waste treatment pricing mechanism concepts and legislative frameworks for the promotion and privatisation of waste treatment facilities within Thailand.

2.1 Solid Waste Treatment Technologies

Globally, there are several key pathways for the treatment of municipal solid waste. In essence, this is divided to 5 main categories; recycling (material recovery), anaerobic digestion, aerobic digestion, waste-to-energy and landfilling. A snapshot illustrating different waste treatment concepts under the 5 waste treatment categories is illustrated in Figure 2-1.

Figure 2-1: Hierarchy of MSW Management (Annepu, 2012)



Each waste treatment concept may incorporate a mix of differing technology but can be defined as below;

i. *Recycling* – recovery of specific waste components within a waste stream by means of mechanical or manual separation for re-use as an ingredient in a domestic or industrial process, either as an effective substitute or as the original process ingredient (EPA, 2014).

ii. *Anaerobic digestion* – breakdown of organic matter within the waste stream by microorganisms in the absence of oxygen, creating bi-products such as methane, carbon dioxide, water vapour and residual digestate. Methane gas within process is may be utilised within a power engine to produce mechanical power, heat and/or electricity and digestate may be processed to be used as fertiliser or fuel for combustion process (EPA, 2016)

iii. *Aerobic Composting* – Controlled biological decomposition and curing of organic matter within the waste stream by microorganisms in the presence of oxygen to biologically decompose organic matter to generate heat, carbon dioxide, water vapour and finished compost. Finished compost may be utilised as fertiliser, soil cover or fuel for combustion process (Chen, et al., 2011)

iv. *Waste*-to-Energy – Thermochemical conversion of waste through incineration, thermal gasification or pyrolysis for the purposes of waste volume and mass reduction, creating waste products which are defined by each process such as heat, electricity, steam, hydrogen, methane, syngas, char, aerosols, combustion gases, ash and water vapour (WEP, 2017)

v. *Landfilling* – "Deposit of waste onto or into land, including internal waste disposal where a waste producer is caring out its own waste disposal at the place of waste generation, or a permanent site which is used for the temporary storage of waste that excludes any location or facility which waste is unloaded to permit its preparation for further transport for recovery, treatment of disposal elsewhere or storage for a period less than 3 years as a general rule" (EC, 2012).

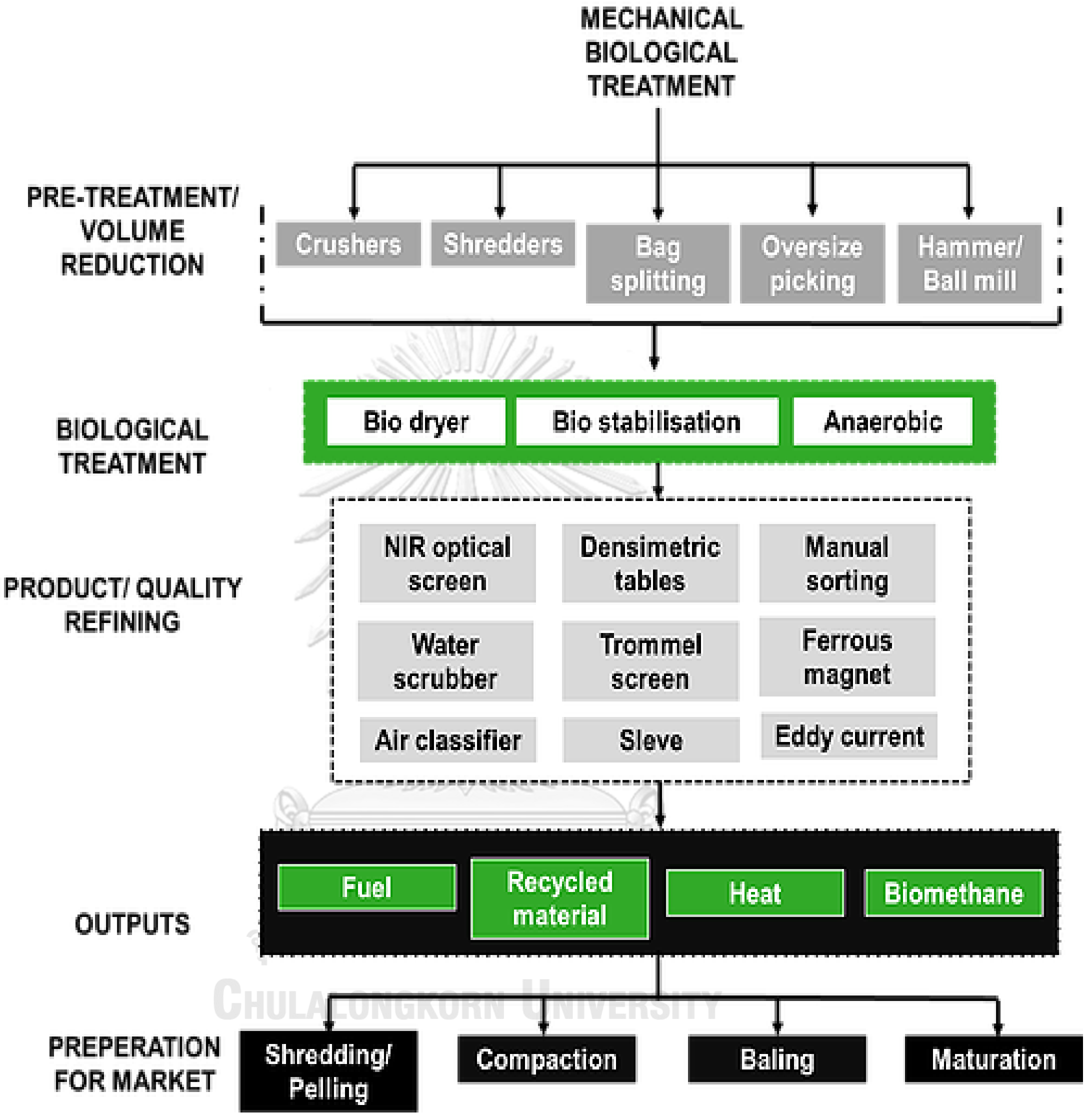
Different decision models can be utilised for the technology selection process. Hokkannen & Salminen (1997) had utilised the ELECTRE III decision-aid in determining the optimum waste treatment technologies to be utilised in Oulu, Finland which recommended proper landfilling utilisation and energy recovery as key deliverables. Caruso (1993) utilised a mathematical model as a tool to determine the technologies, numbers and locations of waste treatment facilities, using the Lambardy region in Italy as case study. The model allowed for assessment between the region's current and alternative designs for ease of decision-making.

In assessing waste treatment mass balances, Eichner & Pethig (2001) had utilised a general equilibrium model for determination of waste constituents to determine the benefits of material recovery in relation to potential environmental damages and evaluate policy instruments to optimise green waste recovery processes. On the use of anaerobic digestion for the treatment of municipal solid waste, Braber (1995) determined that anaerobic digestion is a viable technology in the production of energy from the organic portion of municipal solid waste, with end product potential in closing the carbon cycle and promoting environmental sustainability.

2.2 Mechanical Biological Treatment Concept

The mechanical biological treatment (MBT) concept is defined as the combination of recycling (material recovery) and anaerobic digestion or aerobic waste treatment concepts for the comprehensive treatment of mixed municipal solid waste. In general, a MBT plant consists of mechanised sorting facility, aerobic rotating (or anaerobic) bioreactors, forced-aeration stabilisation air-tunnels, ripening platforms and a sanitary landfill site (Bayard, et al., 2010). The purpose of the MBT concept is the promotion of waste component recovery for recycling activities compared to other waste treatment categories. The MBT process utilises a mix of different waste treatment option dependent on waste composition and project economic budget and justification. The snapshot of different options available for incorporation into a potential MBT overall process is illustrated as per Figure 2-2.

Figure 2-2: Key Components & Method Selection Options within a MBT Setup (Department of Environmental Affairs, South Africa, 2017)



2.3 MSW Treatment Tariffs & Fee Structure

In general, MSW collection and treatment fee structures are divided into flat rate and unit-based pricing. For the flat rate fee structure, waste collection and treatment is charged as lump sum by the administrative council for a fixed period of service, usually over an annualised period. This is charged as property or general assessment payment for each premise that receives the service. In this regard, waste collection and treatment is not regulated by premise. The flat rate fee carries the advantage of constant, recurrent revenue generation for the administrative council but may not promote waste reduction initiatives among waste generators due to the lack of economic incentive in this regard. It had been observed that income generation through this fee collection method provides insufficient coverage to support current waste management practices, reducing the ability of administrative councils to introduce any improvement to current waste management processes (Bartone, 1999).

The unit-based fee structure comprises of a system in which MSW generators are charged either through weight-based or volume-based fee structures. Advantages of this concept include equity as MSW generators pay based on actual use of service and the promotion of waste reduction and recycling through economic incentive without limiting the waste generator's access to the service (Skumatz, 2002). The utilisation of this fee collection concept had reported reduction of waste generation rate per capita in South Korea, by reducing household waste generation per capita from 2.3kg to 1.04kg per capita since the introduction of MSW unit pricing concept (Lee & Haik, 2011).

It has been observed that waste treatment tariff methods can be attributed to each nation's economic status; with high-income nations preferring to implement unit-based fees and developing/low income nations maintaining fixed fee MSW tariffs. A snapshot of MSW tariffs for selection countries within Asia are listed in Table 2-1.

Table 2-1: MSW Treatment Tariff Collection Methods within Asia

Country	Income Status (World Bank, 2012)	GDP Per Capita USD (World Bank, 2016)	MSW Tariff Method	Payment Vehicle	Remarks	Reference
Japan	High Income	47,607.70	Unit-Based	Weight-based	Source separation compulsory for all households	(Franscisco, 2014)
China	Lower Middle Income	6,894.50	Flat Rate	General tax	Nil	(World Bank, 2015)
Indonesia	Lower Middle Income	3,974.10	Flat Rate	Direct charge	Nil	(Aprilia, et al., 2012)
Malaysia	Upper Middle Income	11,028.20	Flat Rate	Property assessment	Private buildings and commercial entities pay by	(Afroz & Masud, 2011)
Singapore	High Income	52,600.60	Flat Rate	Property assessment	Private buildings and commercial entities pay by	(NEA, 2017)
Thailand	Lower Middle Income	5,901.40	Flat Rate	Direct charge	Private buildings and commercial entities pay by	(BMA, 2012)

Table 2-1: MSW Treatment Tariff Collection Methods within Asia (cont.)

Country	Income Status (World Bank, 2012)	GDP Per Capita USD (World Bank, 2016)	MSW Tariff Method	Payment Vehicle	Remarks	Reference
Bangladesh	Low Income	1,029.60	Flat Rate	Direct Charge	Private buildings and commercial entities pay by	(Ahsan & Zahman, 2014)
India	Lower Middle Income	1,861.50	Flat Rate	Property assessment	Nil	(Zhu, et al., 2008)
South Korea	High Income	25,458.90	Unit-Based	Weight-based	Nil	(Lee & Haik, 2011)
Sri Lanka	Lower Middle Income	3,759.20	Flat Rate	Property assessment	Private buildings and commercial entities pay by	(UNEP, 2001)
Philippines	Lower Middle Income	2,753.30	Flat Rate	Direct charge	Nil	(Geganzo, 2013)

In Thailand, waste treatment costs are divided between waste collection and waste disposal fees. These fees remain a heavy burden in the operating budgets of city councils and municipal administrative councils due to lower waste collection fees when compared to actual operating costs. MSW collection fees in Bangkok in 2012 amount to 7.26% of actual cost of MSW collection and treatment. MSW collection fees amount to 58% of overall solid waste expenses. Table 2-2 summarises the average MSW generation, collection & treatment costs and fee collection between 2003 and 2012.

Table 2-2: Summary of Costs of MSW Management in Comparison with the Fees Collected for Fiscal Years 2003-2012 (BMA, 2012)

ปี งบประมาณ (Fiscal year)	ปริมาณ มูลฝอย ต่อปี (Amount of solid waste per year) (ตัน/ปี) (Tons/year)	ปริมาณ มูลฝอย เฉลี่ยต่อวัน (Average daily volume of solid waste) (ตัน/วัน) (Tons/day)	ค่าใช้จ่าย ในการเก็บขน มูลฝอย ต่อปี (Cost of solid waste collection per year) (ล้านบาท/ปี) (Million baht/ year)	ค่าใช้ใจ่าย ในการกำจัด มูลฝอย ต่อปี (Cost of waste disposal per year) (ล้านบาท/ปี) (Million baht/ year)	รวมค่าใช้จ่าย การเก็บขน และการกำจัด ต่อปี (Total cost per year of waste collection and disposal) (ล้านบาท/ปี) (Million baht/ year)	ค่าใช้จ่าย การเก็บขน มูลฝอยและ กำจัดมูลฝอย ต่อตัน (Cost per ton of solid waste collection and disposal) (บาท/ตัน) (Baht/tons)	ค่าธรรมเนียม เก็บขน มูลฝอย (Solid waste collection fee) (ล้านบาท/ปี) (Million baht/ year)	ความแตกต่าง ของการจัดการ มูลฝอยกับ ค่าธรรมเนียม (Difference in fees between solid waste management and solid waste collection) (ล้านบาท) (Million baht)
2546/2003	3,412,750	9,350	1,386.88	1,124.19	2,511.07	735.79	138.33	2,372.74
2547/2004	3,415,305	9,357	1,797.91	1,142.32	2,940.23	860.90	273.18	2,667.05
2548/2005	3,101,040	8,496	2,080.63	1,131.89	3,212.52	1,035.95	409.86	2,802.66
2549/2006	3,057,605	8,377	2,617.96	1,270.95	3,888.91	1,271.88	377.52	3,511.39
2550/2007	3,182,435	8,719	2,856.23	1,455.89	4,312.12	1,354.98	399.88	3,912.24
2551/2008	3,204,700	8,780	3,117.56	1,632.98	4,750.54	1,482.37	415.88	4,334.66
2552/2009	3,207,620	8,788	2,974.02	1,496.45	4,470.47	1,393.70	419.07	4,051.40
2553/2010	3,199,590	8,766	3,247.08	1,780.43	5,027.51	1,571.30	424.32	4,603.19
2554/2011	3,264,195	8,943	3,408.93	2,319.56	5,728.49	1,754.95	438.11	5,290.38
2555/2012	3,558,020	9,748	3,564.37	2,624.70	6,189.07	1,739.47	419.34	5,769.73

Literature review has found no fixed payment model for determination of an appropriate waste treatment fee for waste treatment facilities under the proposed Public-Private Partnership (PPP) agreement within Thailand. Current practice involves the project developer proposing a waste treatment fee based on their respective financial model, with the city council agreeing to the proposed fee based on budgetary capability. This practice brings the risk of non-standardised waste treatment fees being introduced within Thailand, opening up the possibility of profiteering within the sector.

2.4 Operating Costs utilising Different MSW Treatment Technologies

The introduction of new MSW treatment technologies have significantly increased overall treatment costs when compared to traditional waste landfilling or open dumping practices of the past. Waste treatment costs shall take into account the overall MSW treatment value chain, which includes the identification of costs patterns accompanying the design, execution and operation of the a specific waste facility (Aleluia & Ferrao, 2017).

MSW collection and transportation for disposal can constitute a large portion of the overall waste treatment fee. Waste collection costs at locations with reduced population density or requiring longer travel distances had incurred between 26 to 48% of overall treatment costs (OECD, 2013). A facilities treatment costs may differ significantly based on multiple factor which includes technology selection, financing route and operation life, among others. The estimated MSW costs by MSW disposal method is presented in Table 2-3.

Table 2-3: Estimated Treatment Cost by MSW Disposal Method (World Bank, 2012)

	Low Income Countries	Lower Mid Inc Countries	Upper Mid Inc Countries	High Income Countries
Income (GNI/capita)	<$876	$876-3,465	$3,466-10,725	>$10,725
Waste Generation (tonnes/capita/yr)	0.22	0.29	0.42	0.78
Collection Efficiency (percent collected)	43%	68%	85%	98%
Cost of Collection and Disposal (US$/tonne)				
Collection[2]	20-50	30-75	40-90	85-250
Sanitary Landfill	10-30	15-40	25-65	40-100
Open Dumping	2-8	3-10	NA	NA
Composting[3]	5-30	10-40	20-75	35-90
Waste -to-Energy Incineration[4]	NA	40-100	60-150	70-200
Anaerobic Digestion[5]	NA	20-80	50-100	65-150

2.5 Economic Approaches towards Waste Reduction & Recycling

Several studies have evaluated economic policies to optimise waste generation and promote recycling & waste recovery. According to Dinan (1993), introduction of combined taxes such as a combination of virgin material and disposal taxes may be used by municipalities to optimise waste management charges, providing the potential to reduce waste generation. Additionally, Calcott and Walls (2005) had evaluated policies that promote recycling and found that recycling may be successfully promoted by combining deposit-refund of recyclables or segregating recyclables for a lower disposal fee.

Palmer and Walls (1997) suggested that waste disposal optimisation may be achieved by utilising disposal-refund approach to allow for better recovery of recyclables. Pearce and Turner (1993) asserted that all current approaches; packaging taxes, deposit-refunds and marketable permits have imperative merits and limitation based on regulatory approach. Based on their experience in South Africa, Nahman and Godfrey (2010) had determined that several key fundamentals must be put in place for the successful implementation of waste management; promulgation of relevant acts, political willpower, education, awareness cost recovery and development of the relevant infrastructure and enforcement of policy.

In assessing the entry of the private sector into the market, Bel and Warner (2008) concluded that while cost savings through privatisation of waste treatment are not systemic, transaction costs are best regulated when contracts are given as complete packages with pre-set market and operating structures. Additionally, oversight and regulation play an important role in optimizing privatisation of services. Haynes & Goddard (1995) had found that while solid waste management policies remain incomplete, economic literature shows that current treatment fees for rationalisation of investment in waste management technologies remain incorrect.

Assessment of unit pricing of residential waste conducted by Miranda & Aldy (1998) highlighted that communities tend to reduce waste generation once unit pricing mechanisms are introduced, with source separation behaviour becoming more apparent due to economic benefits of doing so. Linderhof et. al (2001) has assessed the effects of weight-based pricing on waste components in Holland and found sizable pricing effects for compostable and non-recyclable household waste. Fluctuation in weight-based pricing makes public investment in waste technologies highly risky due to uncontrolled income.

Within Asia, Hong (1999) had studied the effects of unit pricing of household waste within South Korea and found that increased unit pricing had increased household recycling rates, creating the need for additional recyclables collection trips but maintaining waste collection numbers over time, allowing for ease in designing future waste treatment facilities for processing of municipal solid waste.

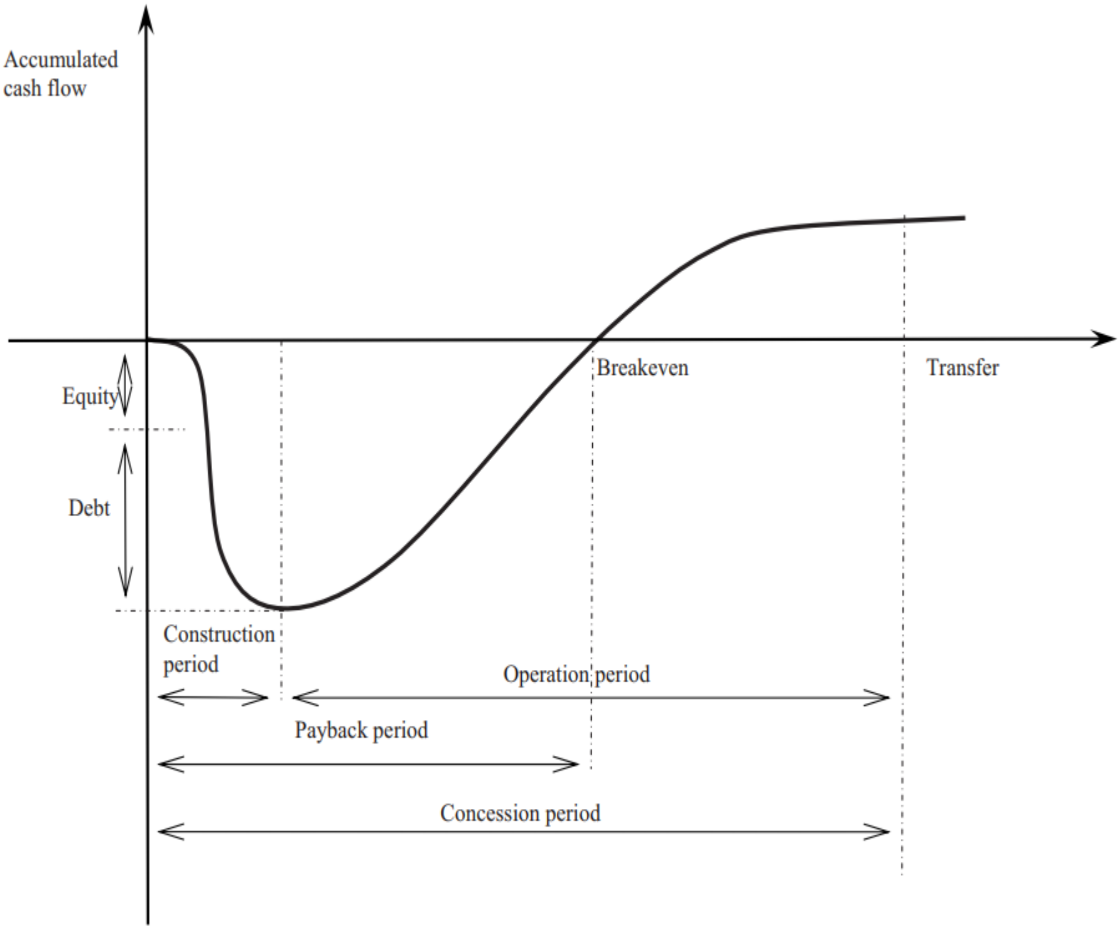
2.6 Approaches in Determination of Project IRR under the PPP Model

Turley & Semple (2013) state that private sector's investment and participation in public infrastructure projects must, at the least be able to cover initial principal investment and corresponding interest incurred through project financing either by debt finance or equity finance; with sufficient dividends paid for project involvement. Due to the higher capital investment surrounding infrastructure projects compared to operational costs, consideration is made to "economies of scale" to lower operational costs per unit to create more attractive investoment opportunities for potential investors.

In determining a suitable IRR for infrastructure projects, Ye & Tiong (2003) highlighted that a project's intended concession period and government incentive schemes play a pivotal role in the financial viability and risk management of PPP projects, with equal consideration to be taken to potential challenges and unforeseen risks over longer concession periods. It had been observed that fixed-term concession did not lead to efficient selection of concessionaires in the past.

In Hong Kong, (Zhang, 2009) had studied infrastructure projects developed under the PPP- Build, Operate and Transfer (BOT) model and had proposed that the development of a detailed work breakdown structure which takes into account capital costs, construction period and market revenue variables is utilised in the determination the a project's concession award period. Zhang had proposed that a project's concession period be sufficient to cover the project developer's equity and debt-financing responsibility while providing sufficient profit to ensure a "win-win" situation between the government and the private sector, with the typical cash flow of a BOT project illustrated in Figure 2-3.

Figure 2-3: Typical Cash Flow Model of a BOT Project (Zhang, 2009)



While the determination of a suitable project IRR is dependent on several factors such as the project's expected concession period and overall project risk management, Martins, et al (2014) in assessing PPP models for airports, had proposed that PPP models be designed to have the flexibility to adapt to internal and external market changes, taking into account latent value of such investments in achieving overall national objectives.

2.7 Legislative Framework on MSW Treatment in Thailand

In Thailand, ownership of MSW falls under the purview of individual local administrative authorities which are divided into two categories; special local governments and ordinary local government. The first category comprise the cities of Bangkok and Pattaya. Ownership and decision-making for privatisation of waste treatment are made by respective city councils without the requirement of ratification from the central government.

The City of Bangkok, through the Bangkok Metropolitan Authority (BMA) has several legislative acts and ordinances, specifically designed for solid waste management within the city. Among legislation (CCAC, 2015) include the following;

1. **The Bangkok Metropolitan Administration Act B.E.2528 (1985) Section 92** authorising the BMA to provide services of waste collection and treatment to governments agencies, the private sector, state-owned organisations and local administration at a fee.
2. BMA Ordinance: Management of the Solid Waste or Night soil Collection/Disposal Operator or those who benefit from this service B.E.2541 (1998)
3. BMA Ordinance: Service Fee B.E 2543 (2000)
4. BMA Ordinance: Collection, Transportation and Disposal of Night Soil and Waste B.E. 2544 (2001)
5. BMA Ordinance: Solid Waste and Night Soil Collection Fee According to the Public Health Act (2003)
6. BMA Ordinance: Solid Waste and Night Soil Collection Fee According to the Public Health Act (Second Issue) (2005)
7. BMA Ordinance: Criteria for the Solid Waste and Nightsoil Management of Building and Public Health Facilities (2002)
8. BMA Ordinance: Designate Date, Time and Place to Dispose Solid Waste for BMA Citizens

In the second category, ownership of waste management falls under the purview of individual municipalities within individual provinces in Thailand. As provincial contract authorisation is capped at 4 years (as per the election term of each local council), central government approval shall be sought for longer-term waste treatment concession agreements. Currently, consideration and approval for of waste treatment facilities under the public-private participation model require the final approval of the Provincial Administration Authority, Ministry of Interior.

2.8 Legislative Framework on Privatisation of MSW Treatment

To promote private investment in infrastructure projects within Thailand, the government had introduced the Private Investment in State Undertaking Act B.E.2556 (2013), drafted to promote the private sector's involvement in the implementation of new infrastructure projects through the Private-Public Partnership (PPP) model with the goal of increasing trade competitiveness of Thailand.

The government, by the power vested within the Constitution of the Kingdom of Thailand of 2540 B.E (1997) had through the Pollution Control Department (PCD), Ministry of the Environment & Natural Resources introduced a framework to allow for participation of public-private participation for the collection and treatment of MSW within provinces throughout the Kingdom (Pollution Control Department, 2005).

The purpose of the privatisation framework is to enable stakeholder participation in the design, execution and operation of privately MSW treatment facilities with the objective of providing transparency in such ventures. The summarised process flow for application of privatisation and setup of a solid waste management treatment facility is shown in Table 2-4.

Table 2-4: Process Flow for Application of Privatisation and Setup of a MSW Treatment Facility (PCD, 2015)

Step 1	**Establishment of Joint Committee**
• A joint-committee consisting of local (or municipal) public and/or private companies who submit interest in development of a proposed waste treatment facility. The committee shall also comprise NGOs, the public, the media and academic local educational institutions. • The joint-committee shall set the policies, plans and measures to manage waste management within the province and shall set interim framework for the creation of a privatised waste treatment facility.	
Step 2	**Project Feasibility Phase**
• Two committees are established; the first consisting of a study team to study the technical and commercial feasibility of the proposed project & the second consisting of study team to evaluate health, environmental, economical, societal, cultural and political impacts of the proposed project • Both committees shall present their findings to the joint-committee. The joint-committee may invite participants to provide further information for consideration. All deliverables within this stage shall be completed within the allocated timeline	

Table 2-4: Process Flow for Application of Privatisation and Setup of a MSW Treatment Facility (PCD, 2015)(cont.)

Step 3	**Project Feasibility Decision Making**
• The Joint-Committee's co-ordinator shall prepare a project plan based on the results of the project feasibility phase in accordance with the selected waste treatment system. Subject experts, including renowned scholars, experienced project managers may be invited to provide assistance and guidance in the preparation of project plan. • The Joint-Committee shall develop a Project Management Plan through "Participatory Project Management" which engages the public in the decision-making process.	
Step 4	**Public Hearing & Forum**
• The joint-committee shall organise a public hearing to present the proposed construction of the solid waste treatment facility within the selected municipality as accordance with the regulation. The joint-committee shall conduct follow-up public hearings until all public concerns of the public are satisfactorily resolved.	
Step 5	**Compensation Negotiations**
• The project developer shall organise meeting with the affected community to determine the quantum of compensation to be paid. The compensation shall take into account hardships during project development, construction and operation of the facility.	
Step 6	**Construction of Waste Treatment Plant**
• The project developer shall work closely with the Construction Control Board to ensure compliance to all construction regulations and standards. Additionally, individuals are allowed to set up committees to monitor construction activities and monitor potential project impacts.	

Table 2-4: Process Flow for Application of Privatisation and Setup of a MSW Treatment Facility (PCD, 2015)(cont.)

Step 7	**Operation of Waste Treatment Facility**
• The project developer shall work closely with the Solid Waste Department officials to report operation progress. The public may establish a committee to closely monitor plant operation and potential impacts, in close coordination with the government and developer • The project developer shall also take relevant steps to follow-up and evaluate plant operation and overall impact. The developer shall conduct continual improvement on plant process and operation	

2.9 Analysis of Literature Review

On review of literature as presented within this chapter, mechanised biological treatment is defined as the integration of material recovery and biological treatment components into a single facility. This concept is considered a viable method for sustainably treating organically-rich commingled MSW as found with urban settings in the developing world such as Bangkok. The MBT concept provides the opportunity for resource-recovery and renewable energy generation from waste to be implemented in an economical and environmentally-viable manner, in line Thailand's National Agenda No.1.

Globally, waste treatment fee collection is divided between flat-rate and unit-based pricing. While developed nations favour unit-based pricing mechanism, many developing nations including Thailand impose flat rates for municipality services. The latter concept can often leave municipalities with significant operating deficit due to insufficient collection tariffs, as experienced in Bangkok. Currently, privatised MSW treatment facility contracts are awarding through direct negotiation with project developers based on a municipalities' financial capability, rather than fixed IRR rates.

In assessing the non-treatment fee income potential of MBT facilities, earlier research has shown that public policy and regulation play a key role in this regard, with examples such as the implementation of source separation, combination taxation, disposal taxes and disposal-refund relief playing a major role in the treatment income potential of such facilities. It is important that project developers be given the opportunity to earn their principal investment, interest payment and sufficient dividends to justify their participation.

Past research has shown that fixed-term concessions may not be the optimal method for determining the profitability of infrastructure projects, rather the understanding of the complete work breakdown structure of the project is required to provide a holistic approach to the determination of concession fees and durations, with sufficient flexibility provided to incorporate internal and external factors over the project lifecycle.

While detailed procedures exist for the setting up of waste treatment facilities under the public-private partnership (PPP) model have been introduced in Thailand for over a decade, no specific details are available regarding the determination of suitable concession tariffs for such projects. Further to this, while several nations including Singapore have adopted income ceilings for infrastructure project under the PPP-model, no evidence exists to show that a similar concept is implemented within Thailand.

CHAPTER 3 RESEARCH FRAMEWORK

This chapter explains the thesis research strategy and framework for the study. Firstly, the author presents the detailed research approach, followed by the identification of data required for this research prior to discussion of the study's proposed mathematical model for the determination of waste treatment fee.

3.1 Case Study Project Details

The Bangkok Metropolitan Authority (BMA) proposed the implementation of waste treatment facilities incorporating resource and energy recovery to be built at existing waste disposal sites through the Private-Public Partnership (PPP) model. BMA released 2 Terms of Reference (TOR); for incineration at the Nongkhae Waste Disposal Site and mechanical biological treatment at On-Nut Waste Disposal Site, each with treatment capacity of 300 and 600 tonnes per day respectively. The case study project encompasses the On-Nut Mechanical Biological Treatment (MBT) facility on a 20-rai (7.90 acres) plot located at On-Nut Soi (Road) 86, Bangkok, adjacent to the BMA current Waste Disposal & Wrapping Plant. Project location is illustrated in Figure 3-1.

Figure 3-1: Case Study Project Location

Under the project's PPP terms, the project shall be privately-funded and be operated under a 20-year operation concession. The facility shall be designed with minimum operation availability of 85% with a minimum processing capacity of 120% of concession requirement. BMA, as waste owner shall guarantee daily MSW delivery and shall pay a waste treatment fee, which shall be adjusted annually based on core inflation rate reporting. All income streams from energy and waste treatment shall form part of the project developer's business model.

3.2 Research Design

This section presents the methods utilised for the development of the MSW treatment fee mechanism, which is divided into 5 specific steps. They are (1) determination of MSW characteristics, (2) selection of mechanical biological treatment method, (3) determination of project capital (CAPEX) & operational (OPEX) expenditure and revenue streams, (4) formulation of the waste treatment pricing mechanism, and (5) designing a software simulation to generate MSW treatment fee.

3.2.1 Determination of MSW Composition & Characteristics

The selection of the appropriate technology combination requires detailed understanding of the MSW characteristics that shall be treated by the plant. The project's Terms of Reference (TOR) had provided Bangkok's annualised MSW composition over the last 10 years for references purposes. In confirming the MSW composition and properties, quantitative and qualitative waste sampling was carried out over a 7-day period on incoming waste received at the On-Nut Waste Disposal Site.

Determination of sampling size and waste composition testing was conducted utilising ASTM D5231-92(2008): Standard Test Method for Determination of Composition of Unprocessed Municipal Solid Waste. Quantitative sampling involved the determination of MSW composition categories analysed as listed in Table 3-1. Qualitative sampling comprised of MSW chemical property testing on the recovered organic portion for mass and energy balance forecasting purposes. For qualitative testing, all MSW samples were sent to an external testing laboratory with experience in MSW testing, using relevant ASTM standard testing methods, as listed in Table 3-2.

Table 3-1: Quantitative MSW Composition Sampling Categories

Waste Category		**Percentile Determination**	
		By Weight (%)	**By Volume (%)**
Total MSW		X	X
Organic Waste	Food Waste	X	X
	Yard and Garden Waste	X	X
	Mixed Paper	X	X
Mixed Plastics		X	
Wood & Fibre		X	
Rubber & Leather		X	
Ferrous Metal		X	
Stainless Steel		X	
Copper		X	
Aluminium		X	
Glass		X	
Ceramic, Tiles & Stones		X	
Foam		X	
Fabric & Textiles		X	
Hazardous Waste		X	
Other Waste (undefined)		X	

Table 3-2: Waste Chemical Composition Testing Parameters

Chemical Parameter	**Standard Method**	**Reporting Unit**
MSW Moisture	ASTM E790-87 (2004)	%
pH	ASTE D4980-89 (2003)	NA
Total Solid Content	Calculated	%
Carbon Content (C)	ASTM E777-87 (2004)	%
Nitrogen Content (N)	ASTM E778-87 (2004)	%
Sulphur Content (S)	ASTM E775-87 (2004)	mg/kg
C/N Ratio	Calculated	NA
Calorific Value (Dry)	ASTM E775-87 (2004)	kJ/kg
Calorific Value (Wet)	Calculated	kJ/kg

For data collection for MSW waste sampling, the systematic sampling method was utilised to capture different collection timing and collection days, based on historical weighbridge data obtained at the On-Nut Waste Disposal Site.

3.2.2 Selection of Mechanical Biological Treatment (MBT) Method

Technology selection for the proposed mechanical biological treatment (MBT) facility is based on the outcome of MSW composition and chemical composition testing conducted at the On-Nut Waste Disposal Site. In principle, the MBT process encompasses the integration of 4 separate waste treatment processes: (1) pre-treatment/volume reduction, (2) biological treatment, (3) product/quality refining, and (4) preparation for market. Selection of the treatment process is dependent on project objectives, technological viability, commercial value of intended resources for recovery, and project budget.

A MBT facility can comprise of one or a combination of technologies for each waste treatment process, which in general are summarised as below;

1. **Pre-Treatment/Volume Reduction** – preparation of incoming MSW received at a waste treatment facility to a predefined physical status prior to commencement of waste treatment process. Key methods utilised in this process category are defined as follows;
   a. *Crushing* – reduction of material size by use of breaking, cutting and/or compression force to the required dimensions utilising high-speed cutting blades, rotary crushing or hydraulic extrusion through a press.
   b. *Shredding* – reduction of material size by the use of tearing, fracturing and/or shearing force to the required dimensions utilising medium to high-speed rotary cutting blades.
   c. *Bag Splitting* – process of spilling, shearing and breaking larger MSW components, specifically MSW plastic packaging to loosen and release MSW contents by the utilisation of low-to-medium speed rotary cutting blades.
   d. *Oversize Picking* – automated or manual process of sorting MSW by dimension by the use of a trommel, sieve or human operators.
   e. *Hammer/Ball Mill* – pulverising of material through a vertical or horizontal rotating shaft consisting of hammers, balls or bearings to achieve the required dimensions.

2. **Biological Treatment** – treatment of MSW organic components by the use of microorganisms, oxygen or heat for generation of specific by-products or stabilisation for disposal purposes. Key methods utilised in this process category are defined as follows;
   a. *Bio drying* - convective evaporation of water content within biodegradable waste with the support of self-generated heat from aerobic biodegradation process, which may be complimented by the use of mechanically-assisted

airflow to with the objective of mass reduction and moisture removal for further processing or disposal.

b. *Bio stabilisation* - aerobic and/or anaerobic biodegradation process by microorganisms for the purposes of mass reduction and the creation a sanitised and chemically stabilised product for further processing or disposal.

c. *Anaerobic digestion* - breakdown of organic matter within the waste stream by microorganisms in the absence of oxygen, creating bi-products such as methane, carbon dioxide, water vapour and residual digestate for further processing or disposal.

3. **Product/Quality Refining** – automated or manual resource conditioning or recovery process to remove specific MSW components for the purposes of further processing or disposal. Key methods utilised in this process category are defined as follows;

a. *NIR Optical Screen* – the use of electromagnetic, near-infrared light frequencies to identify and automatically remove (by means of compressed air burst or conveyor belt) specific waste components based on user requirement.

b. *Densimetric tables*- separation of waste components by density by use of rising air through a perforated inclined tray that vibrates in an elliptical motion. The heavier fraction will travel on the tray onto the top of the table while lighter fraction will fall and be recovered at the bottom of the table.

c. *Manual sorting* – the use of manual labour to identify and remove specific waste components by way of use of a conveyor belt through a sorting cabin or picking over a dedicated holding area.

d. *Water scrubber* – immersion of MSW stream in water to separate soluble waste components such as dissolvable organics which is recovery within the water stream, with lighter and heavy waste fractions are recovered separately.

e. *Trommel screen* – mechanical waste separation by size utilising centrifugal force within a perforated horizontal drum. Waste components smaller than the perforation diameter will fall through while components larger than the perforation diameter will pass through the drum.

f. *Ferrous magnet* – Recovery of ferrous metal components within the MSW stream by use of a rotating magnet over a conveyor belt.

g. *Air classifier*- mechanical waste separation by density and weight utilising air within a sorting chamber. Lighter fractions are lifted and collected at the top of the sorting chamber while gravity causes heavier fractions to fall for collection at the bottom of the chamber.

h. *Sieve* - mechanical waste separation by size utilising rotating drum or star sieves across a horizontal or inclined platform . Waste components smaller than the perforation diameter will fall through while components larger than the perforation diameter will pass through over the sieve.

i. *Eddy current* – Recovery of non-magnetic metals within the MSW stream by the creation of a magnetic field by an eddy-current rotor which lifts and expels non-ferrous metals across a conveyor belt.

4. **Preparation for Market** – preparation of recovered products from mechanical and biological processing activities based on end-user requirement or prepare waste product volume/density to optimise waste transportation for final disposal, use or export. Key methods utilised in this process category are defined as follows;

   a. *Shredding/Pelting*- reduction of waste product size by the use of tearing, fracturing and/or shearing force to the required dimensions utilising medium to high-speed rotary cutting blades.

   b. *Compaction*- process of increasing product density by use of mechanical compression or pressing to optimise product delivery potential or disposal efficiency.

   c. *Baling* - process of compressing and forming waste products in pre-determined cubical, cuboidal or cylindrical forms to optimise product delivery or disposal efficiency. The process may include fastening with wire or wrapping with packaging to maintain dimensions or reduce leaching or material loosening.

   d. *Maturation* – aerobic and/or anaerobic biodegradation process by microorganisms for the purposes of mass reduction and the creation of a sanitised and chemically stabilised product for further processing or disposal.

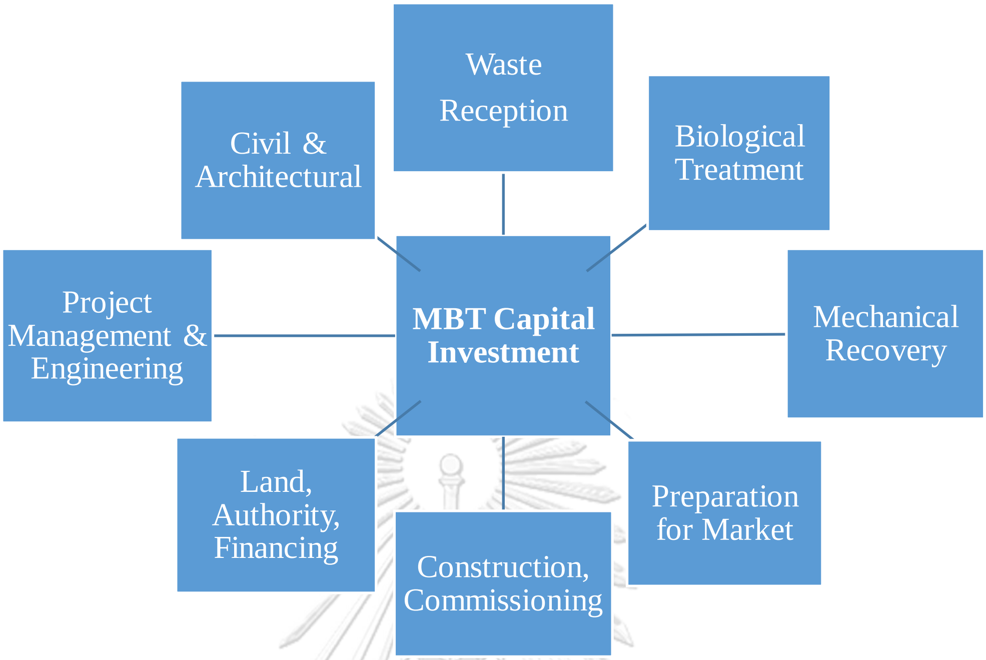
3.2.3 Determination of Project Capital & Operational Expenditure and Revenue Streams

The assessment of a project's expenditure and revenue stream is dependent analysis of technical and commercial primary and secondary data collected during the project's development phase. Technology selection for specific projects are dependent on the ability of the process the recover resources above the resources utilised, apart from legislative requirements such as a country's recycling targets. Technical ability to recover such resources are to be commercially justified to allow for project long-term sustainability. The case study project's financial model is determined in three stages; (1) determination of project capital and investment costs, (2) assessment of project operating expenses, and (3) evaluation of project income streams.

1. Determination of Project Capital and Investment Costs

In assessing a project overall capital investment costs, the project developer shall first determine a project's technical deliverables, through technical data analysis and the assessment of the Employer's requirements. Investment costs for a MBT facility is dependent on several key factors such as plant development size, treatment capacity, location, intended operation life, level of automation, pollution control, intended processes and redundancy requirement. Even as MBT facilities differ due to these factors, a MBT facility's capital investment can be divided into 8 key categories as shown in Figure 3-2.

Figure 3-2: Capital Expenditure (CAPEX) Categories within a MBT Facility

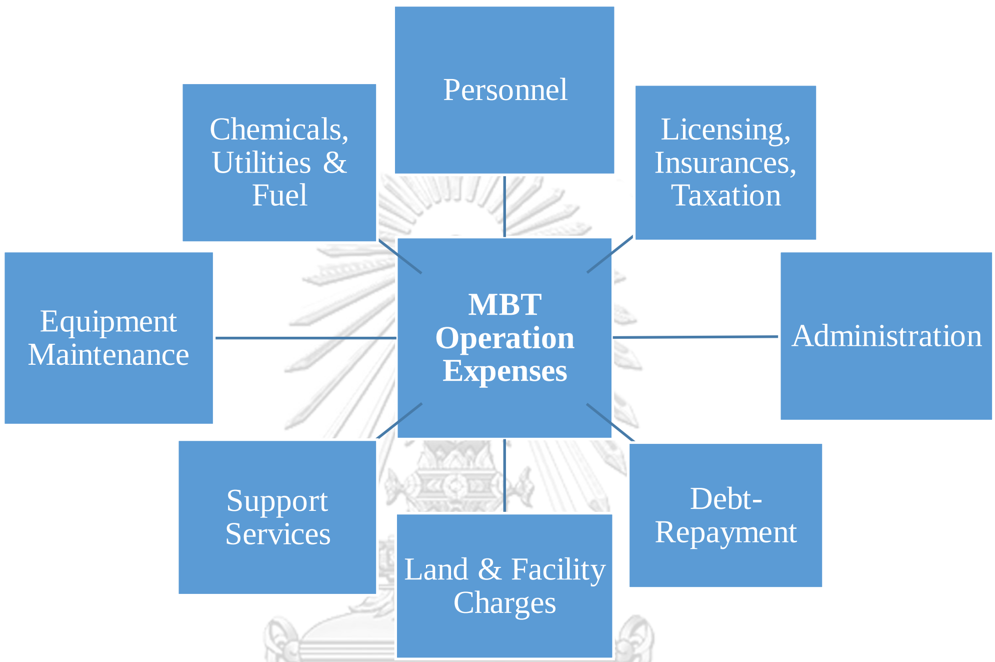


Data collection for project capital expenditure is obtained through a combination of primary data from selected technology specialists for equipment supply and secondary data for respective categories, which includes provisions of construction financing, the absorption of project advance and security bonds and other expenses generated in relation to project delivery. Project capital costs validation is conducted through verification of project detailed pricing to reduce the risk of project pricing replication.

2. Assessment of Project Operating Expenses

A MBT facility's operation expenditure is divided into fixed and variable operating costs. Fixed costs comprise of expenses that the facility incurs irrespective of plant operational status such as manpower, financing charges, licences. Plant variable costs consists of all expenditure incurred through the operation and maintenance (O&M) of the facility such as utility costs and maintenance costs due to wear and tear. Project operating costs are be forecasted over the lifetime of the facility based on project availability and expected preventive and predictive maintenance expenses. An important component of project lifecycle analysis shall be the inclusion of consumer pricing index (CPI) in the consideration of project costing. The main cost components within a project's O&M phase is illustrated as per Figure 3-3.

Figure 3-3: Operation & Maintenance (O&M) Expense Categories of a MBT Facility

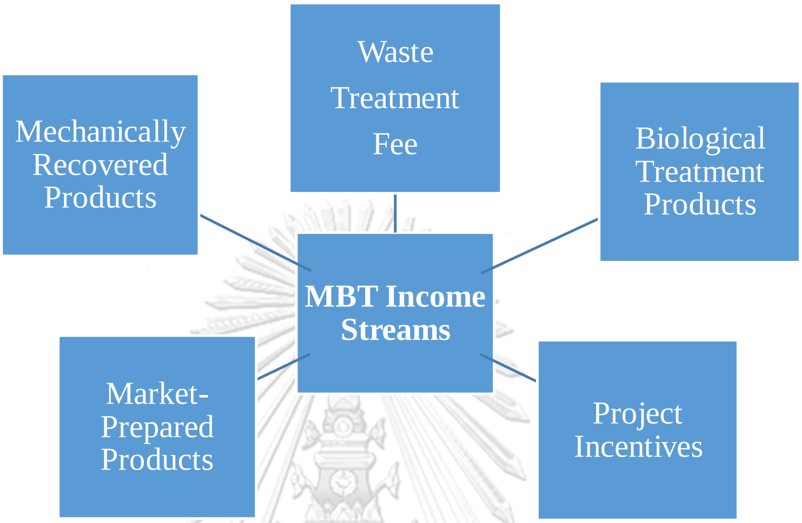


Data collection for the case study's Operation & Maintenance (O&M) phase is obtained through secondary data based on historical records of similar facilities and is projected over the facilities' expected life, which is set at 20 years as per the case study concession period. Additionally, consumer pricing index (CPI) over the facility's life is assumed based on case study country's 5-year CPI average data.

3. Evaluation of Project Income Streams

The project's income stream evaluation shall be based on 2 categories; (1) contracted income and (2) open-market determined income. Both income categories are performance-dependent, with open-market determined income further dependent on prevailing market rates. Contracted income streams are based on long-term supply contracts and account for the majority of a MBT facility's income. For MBT facilities, income streams are be divided into 5 categories, as illustrated in Figure 3-4.

Figure 3-4: Revenue Streams of a MBT Facility



The description of each income category and examples of incomes generated under each category are listed within Table 3-3.

Table 3-3: MBT Facility Income Streams

Category	Description of Income Category	Example
MSW Treatment (Tipping) Fee	Payment imposed by a waste treatment operator, owner or municipal authority for receipt, treatment and/disposal of MSW, which may be charged by type, source, weight, volume or at a fixed value. Income excludes MSW collection and haulage fees	• Direct payment by individual/ organisational disposing MSW at facility • Payment by private or public MSW hauler • Fixed/variable payment by municipal authority

Mechanically Recovered Products	Income generated by the sale of MSW products recovered through the mechanical recovery process and sold “as recovered” for the purposes of further processing or disposal.	• Metals • Plastics • Organics • Glass/Ceramics • Paper/Cardboard • Electronic Waste
Biological Treatment Products	Income generated by the sale of MSW products recovered through the biological treatment process, which may be sold “as is” or treated and sold for the purposes of further processing or disposal.	• Biogas • Electricity • Heat • Digestate • Liquid Fertiliser
Market Prepared Products	Income generated by the sale of MSW products through either mechanical and/or biological treatment processes, and further processed or refined to increase commercial value or to meet buyer requirement	• Refused-derived fuel • Baled products • Finished Compost • Enhanced liquid fertilizer • Washed products • Re-processed material • Shredded products
Project Incentives	indirect income/subsidy received through public or private entities to promote, subsidised or sustain MBT facility operations	• Carbon credit • Disposal tax income • Council tax income • Grants

In determining the recovery viability for each waste component, each component is separated by commercial proposition, statutory or TOR requirement and potential recovery and treatment stream, as shown in Table 3-4.

Table 3-4: MSW Component Recovery & Treatment Options

Waste Category	Project/ Statutory Recovery Requirement	Potential Recovery/Treatment Stream			
		Mechanical Recovered	Biological Treatment	Market Prepared	Disposal
Food Waste	Project		X		
Yard/Garden Waste	Project		X		
Mixed Paper	Optional	X		X	
Mixed Plastics	Optional	X		X	
Wood & Fibre	Optional	X		X	
Rubber & Leather	Optional				X
Ferrous Metal	Optional	X		X	
Stainless Steel	Optional	X		X	
Copper	Optional	X		X	
Aluminium	Optional	X		X	
Glass	Optional	X		X	X
Ceramics & Stones	Optional	X			X
Foam	Optional	X			X
Fabric & Textiles	Optional	X		X	X
Hazardous Waste	Statutory	X		X	
Other Waste	Optional				X

Data collection of the case study's income streams are collected through a combination of primary and secondary data. Primary data is obtained through direct negotiation with direct stakeholders on contracted income streams, particularly biological treatment products. Secondary data is obtained through market rates for sale of recovered and market-prepared products.

3.2.4 Development of Waste Treatment Pricing Mechanism

The development of the proposed waste treatment pricing mechanism shall be based on the standpoint of a pre-set Internal Rate-of-Return (IRR) of the project based on the Public-Private Partnership (PPP) model. The pricing mechanism is based on assessment of acceptable waste treatment fee at pre-set project IRR rates of 8%, 10% and 12%.

A key deliverable of this research shall be the creation of a pricing mechanism to determine the suitable waste treatment fee based on pre-set internal rate-of-return (IRR) rates for the proposed mechanical biological treatment (MBT) facility to be built under the Public-Private Partnership model. The project's IRR is the discount rate that is determined when a project's Net Present Value (NPV) equals to zero. The pricing mechanism shall be based on a modified version of the mathematical formula for IRR, as shown in Figure 3-5.

Figure 3-5: Mathematical Formula for Internal Rate-of-Return (Blomster, 2016)

$$\begin{aligned} \text{NPV} &= CF_0 + \frac{CF_1}{(1+r)^1} + \ldots + \frac{CF_n}{(1+r)^n} \\ &= CF_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}, \end{aligned}$$

As per the base formula presented in Figure 9, the pricing mechanism shall be derived from pre-set IRR values and data sets obtained in Section 3.2. The pricing mechanism shall take into account inflation, debt-financing and other variables as additional measures to ensure data accuracy.

In essence, the determination of possible waste treatment fees at pre-set IRR rates of 8%, 10% and 12% shall be based the assessment of the expected tonnage of the facility based on the assumed turnover of the facility. This encompasses the overall income and expenses of the facility throughout the lifecycle of the facility. The formula for determination of the waste treatment fee first begins with determination of the Net Present Value of the facility over the lifetime of project implementation, as shown in Figure 3-6.

Figure 3-6: Formula for Determining Lifetime Net Present Value (Determann, 2015)

$$NPV = \sum_{t=1}^{n} \frac{NCF_t}{(1 + k)^t} - NCF_0$$

Where NCF_0 = Initial cash outlay of the project

NCF_t = net cash flow generated by project at time t

n = life of the project

k = required rate of return

Utilising the formula in Figure 11, we first determine the initial project investment quantum by assessing the project's capital investment. Next, determination of the project's cash flow (CF) shall be based on the project's expected annual turnover over the lifecycle of the facility. The formula for determination of the project's cash flow is can be interpreted as illustrated in Figure 3-7.

Figure 3-7: Determination of Project Cash Flow

CF_X = Facility Revenue – Facility Expenditure

= (Waste Treatment Fee + Other Revenue Streams) - Facility Expenditure

The expected IRR (listed as "r" in the formula) shall be set at 8%, 10% and 12% for the simulation of the 3 scenarios selected for this study. Based on set data, the formula is then modified to determine the waste treatment fee required to achieve the pre-set IRR value over the lifecycle of the facility.

In order to determine the waste treatment fee per tonne received, the result attained is further expanded to include total waste receipt, facility availability rate and expected inflation rate over the life of the facility. This is attained through the use of the proposed formula as shown in Figure 3-8.

Figure 3-8: Formula for Determination of Waste Treatment Fee

$$\text{Waste Treatment Fee/Tonne (THB)} = \left\{ \frac{\left(\dfrac{\text{Waste Treatment Fee}}{\text{Facility Design Throughput}} \right) \times \text{Facility Availability}}{\text{Consumer Pricing Index}} \right\}$$

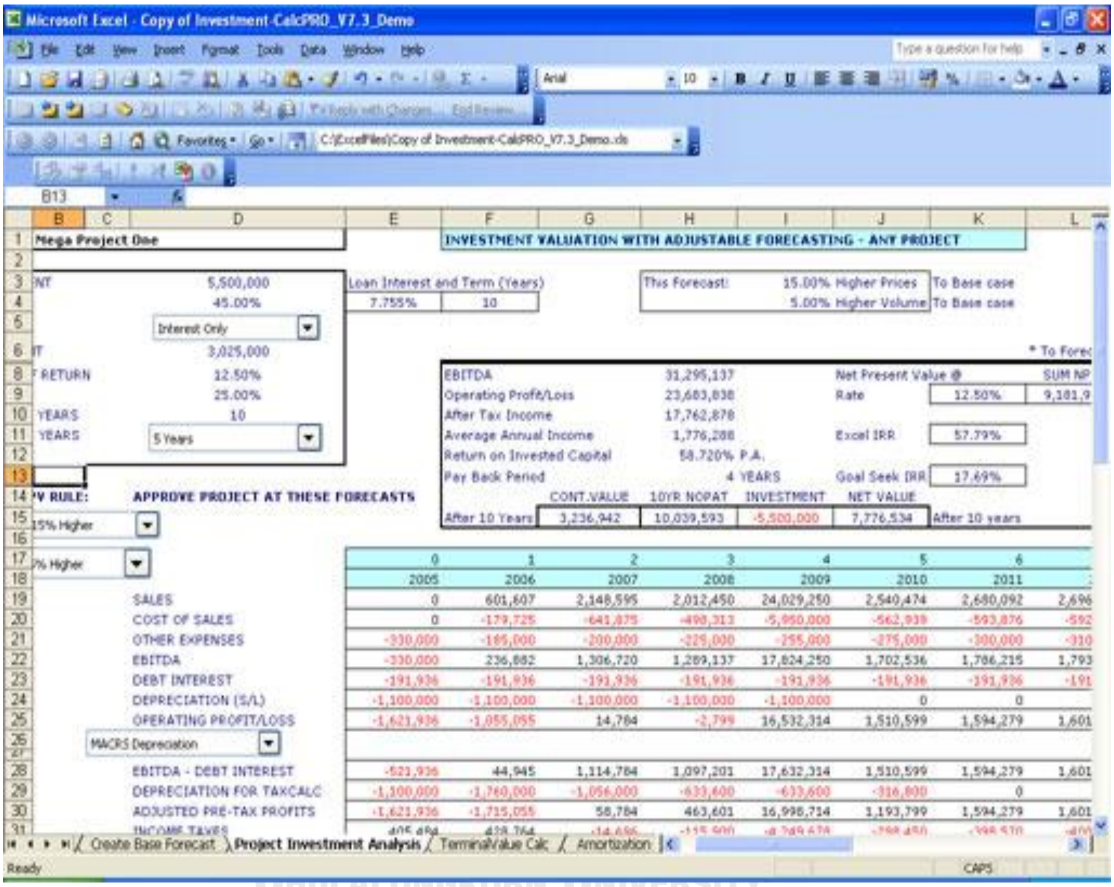
Data collected is incorporated into the original IRR formula to obtain projected IRR. The formula is validated by testing other income streams to ensure formula viability. On completion of data validation, the proposed pricing mechanism formula is digitally incorporated into a computational software to allow for instantaneous data processing for the determination of possible waste treatment fees.

3.2.5 Formulation of Pricing Mechanism

The calculation of waste tipping rate encompasses the entry of the case study's data sets over the projected lifecycle of the facility. To allow for instantaneous price project using our pricing mechanism, the formula shall be incorporated into a suitable computational financial software.

Our assessment of possible computational software for our research has found several software that are able to be utilised for the creation of a comprehensive calculation sheet for use. Among computer software for consideration include Microsoft Excel, C++ and TValue Computational Software. On assessment of different computational software, Microsoft Excel is selected for the study due to the program's mass utilisation factor and ease of editing to cater for differing pricing scenarios.

Figure 3-9: Example of Project Calculation Sheet using Computational Software (Model Advisor, 2012)



3.2.5.1 Pricing Mechanism utilising Different Scenarios

For validation of the accuracy of the proposed pricing mechanism, the formula shall be tested using several project conditions, namely differing plant availability rates, changes in project income streams and effects of consumer pricing index. The formula shall be analysed for consistency, through the computational model. The computational models findings will then be verified through manual calculation for accuracy purposes. Minor adjustments to the pricing mechanism have been made to fine tune accuracy of calculation of the waste treatment fee.

3.3 Conclusion of the Chapter

This chapter starts by providing a general overview of the proposed 600 tonnes per day Mechanical Biological Treatment (MBT) project in On Nut, Bangkok that forms the case study that is the basis of research presented within this dissertation. Accordingly, the chapter outlines the research strategy for data collection for this study, beginning with the methodology for testing and determination of the quantitative and qualitative properties of MSW that forms the basis of the case study's design philosophy, which encompasses technology selection, process, energy and mass flow of the proposed MBT facility.

Subsequently, the chapter explains capital expenditure (CAPEX) and operational expenditure (OPEX) categories for the case study's life cycle analysis and identifies data collection method, consisting of primary and secondary data collection from selected design, engineering and technology packages. Data collected shall cover the complete construction and operation phases of the case study. In addition to CAPEX and OPEX analysis, the study identifies possible revenue routes and facility income streams such as electricity generation, waste treatment fee and income from sale of process products.

The final component within the research strategy is the identification of suitable mathematical formulas that can be used to determine the intended facility waste treatment fee based on pre-determined project internal rate-of-return (IRR). These formulas are further streamlined to meet their intended use for this study. The chapter also identifies possible computer programs for incorporation of the pricing mechanism and selects Microsoft Excel as the intended software due to widespread utilisation and availability and its ease-of-use design for easy manipulation of formulas to meet custom plant requirements.

CHAPTER 4 Technical Data Collection & Analysis

This chapter details and analyses the case study's technical data as the basis for the creation and validation of the proposed MSW treatment fee mechanism. The chapter presents MSW quantitative and qualitative data collected from the case study's MSW sampling exercise; MSW component recovery potential; the case study's concept design based on MSW sampling data; the facility's proposed process and mass flow, and conceptual project layout for the case study.

4.1 Case Study MSW Sampling

MSW sampling was conducted at the On-Nut Wrapping & Disposal Plant located at On-Nut Soi (Road) 86, Bangkok. Sampling was conducted over a seven-day period (2nd August 2014- 8th August 2014) between 0500hrs and 1600hrs daily. While the plant operates over a 24-hour period, MSW sample collection was limited over a 12-hour period which accounts for the majority of MSW received at the disposal site.

MSW sampling and data collection was conducted in line with ASTM D5231-92(2008): Standard Test Method for Determination of Composition of Unprocessed Municipal Solid Waste. For qualitative sampling of organic portion of MSW, each sample collection was reduced using the quartering method until reaching 2 homogenous specimens (primary and back-up), each weighing 2kg. All portions are sealed and placed in an ice bath to maintain sample chemical integrity prior to transport to the appointed independent testing laboratory, located in Bangkok.

Table 4.1 presents the summary of collection timing and collected sample quantities for each MSW collection cycle during the MSW sampling exercise.

Table 4-1: MSW Sampling Time Table and Collection Quantities

Date of Sampling	**Sample Collection Time (hrs)**			
	0500-0800	**0801-1100**	**1101- 1400**	**1401-1700**
02/08/2014 (Saturday)	Sample 1 (109.93kg)	Sample 2 (86.38kg)	Sample 3 (87.80kg)	Sample 4 (92.88kg)
03/08/2014 (Sunday)	Sample 5 (84.58kg)	Sample 6 (99.84kg)	Sample 7 (83.03kg)	Sample 8 (93.60kg)
04/08/2014 (Monday)	Sample 9 (85.29kg)	Sample 10 (109.21kg)	Sample 11 (100.00kg)	Sample 12 (98.79kg)
05/08/2014 (Tuesday)	Sample 13 (113.38kg)	Sample 14 (97.59kg)	Sample 15 (108.10kg)	Sample 16 (129.94kg)
06/08/2014 (Wednesday)	Sample 17 (101.63kg)	Sample 18 (106.36kg)	Sample 19 (106.99kg)	Sample 20 (106.11kg)
07/08/2014 (Thursday)	Sample 21 (105.88kg)	Sample 22 (114.42kg)	Sample 23 (102.70kg)	Sample 24 (105.29kg)
08/08/2014 (Friday)	Sample 25 (93.52kg)	Sample 26 (103.59kg)	Sample 27 (100.63kg)	Sample 28 (98.22kg)
	Total: 28 Samples (2,825.76 kg)			

4.1.1 Quantitative Sampling

MSW quantitative sampling involved the random collection of comingled MSW at the plant's tipping area, followed by separation of each sample (weighing approximately 100kg each) manually into 16 categories. Each waste category is then weighed individually using a digital weighing scale. For organic waste categories (food waste, garden & yard waste, and mixed paper), waste volumes are recorded and compared in relation to the overall sample volume.

Table 4.2 reports the summarised mean weight and volume results (by percentage) for all samples collected during the MSW quantitative sampling exercise.

Table 4-2: Quantitative MSW Composition Sampling Categories

MSW Component	Percentile Determination (Mean)	
	By Weight (%)	**By Volume (%)**
Food Waste	46.86	28.32
Yard and Garden Waste	5.53	10.80
Mixed Paper	10.75	12.06
Mixed Plastics	21.03	
Wood & Fibre	0.73	
Rubber & Leather	0.55	
Ferrous Metal	0.46	
Stainless Steel	0.02	
Copper	0.03	
Aluminium	0.16	48.82
Glass	3.03	
Ceramic, Tiles & Stones	1.76	
Foam	0.83	
Fabric & Textiles	3.96	
Hazardous Waste	0.14	
Other Waste (undefined)	4.16	
Total MSW	**100.00**	**100.00**

Assessment of quantitative sampling data show that On Nut's MSW comprise mainly of digestible or compostable organic waste components such as food, gardening and green waste. Mixed plastics constitute one-fifth of total MSW generated at the case study area. Metal content within the MSW stream is reported at 0.67% with undefined waste components reported at 4.16%.

4.1.2 Qualitative Sampling

MSW qualitative sampling is limited to the organic components, recovered during the MSW sampling exercise. Organic samples are reduced by the "quartering" method to 2 portions (primary & back-up) of the required sample size of 2 kg for analysis at the appointed independent laboratory. The summarised mean qualitative results for all organics samples collected during the MSW sampling exercise is listed within Table 4-3.

Table 4-3: MSW Organic Stream Qualitative Testing Results

Chemical Properties	Reporting Unit	Testing Results (Mean)
MSW Moisture	%	70.92
pH	NA	6.73
Total Solid Content	%	29.08
Carbon Content (C)	%	42.58
Nitrogen Content (N)	%	1.89
Sulphur Content (S)	mg/kg	1,003
C/N Ratio	NA	23.30
Calorific Value (Dry)	kJ/kg	15,510
Calorific Value (Wet)	kJ/kg	2,388

Assessment of the chemical properties within the MSW organic stream shows that the wet waste component reports an average calorific value (wet) reported of 2,388kJ/kg, implying contamination of high-energy waste components such as mixed plastics within the stream. This is due to the “mixed’ nature of MSW collection that homogenises waste components.

4.2 Determination of Waste Components for Recovery

The case study’s Terms of Reference (TOR) specifies daily MSW receipt at 600 tonnes per day on the basis of plant availability of 85% or 311 days per calendar year, amounting to an annual plant MSW input of 186,600 tonnes. In forecasting MSW component recovery potential, quantitative data from the case study’s MSW sampling exercise is expanded to forecast annual recovery potential for each waste type, as shown in Table 4-4.

Table 4-4: Projected MSW Component Annual Recovery Potential

MSW Component	Mean Composition by Weight (%)	Annual MSW Recovery Potential (tonnes/year)
Food Waste	46.86	87,440.76
Yard and Garden Waste	5.53	10,318.98
Mixed Paper	10.75	20,059.50
Mixed Plastics	21.03	39,241.98
Wood & Fibre	0.73	1,362.18
Rubber & Leather	0.55	1,026.30
Ferrous Metal	0.46	858.36

Stainless Steel	0.02	37.32
Copper	0.03	55.98
Aluminium	0.16	298.58
Glass	3.03	5,653.98
Ceramics & Stones	1.76	3,284.16
Foam	0.83	1,548.78
Fabric & Textiles	3.96	7,389.36
Hazardous Waste	0.14	261.24
Other Waste	4.16	7,762.56
Total MSW	**100.00**	**186,600.00**

In determining the facilities' MSW component recovery and utilisation potential, each waste component is grouped by main recovery or treatment method, dependent on the intended use of each product. For the case study, recovery and treatment of waste components are divided into mechanical recovery, biological treatment and market preparation categories.

Further to waste components within the MSW stream, the biological treatment process generates by-products such as biogas and digestate that potentially requires additional treatment prior to export. These by-products are further regrouped by treatment method and intended use. Table 4-5 summarises waste components by recovery/treatment method and lists down the intended use of each product.

Table 4.5: Recovery/Treatment Method & Intended Use of Waste Components

Waste Component/By-Product		Recovery/Treatment Method	Intended Use of Product
Mechanical Recovery	Ferrous Metal	Magnetic Recovery	Scrap Metal "as is" Basis
	Stainless Steel	Eddy-Current Separation	
	Copper		
	Aluminium		
	Glass	Densimetric Table, Near Infra-Red Optical Separation & Manual Picking	Disposal "as is" Basis
	Ceramics & Stones		
	Household Hazardous Waste (HHW)		Disposal in Secured Landfill
Biological Treatment	Food Waste	Size Separation, Anaerobic Digestion	Biogas & Digestate for further processing
	Yard & Garden Waste		
	Recovered Leachate		
Market Prepared	Fabric & Textiles	Fine Shredding & Baling	Refused Derived Fuel (RDF) for Export
	Foam		
	Mixed Paper		
	Mixed Plastics		
	Wood & Fibre		
	Rubber & Leather		
	Other Wastes		
	Biogas	Biogas Scrubbing & Biogas Engine Use	Electricity
	Digestate	Dewatering & Aerobic Composting	Compost & Liquid Fertiliser

On assessment of MSW sampling data and case study's intended component recovery and treatment plan, each phase is designed individually before being integrated into the finalised MBT process.

4.2.1 Mechanical Recovery Phase

This phase encompasses the MSW reception and the mechanical recovery phase of the facility. This phase consists of waste reception, bag splitting and size reduction and recovery of respective MSW components.

i. Waste Reception

All incoming MSW collection vehicles shall be weighed at a dedicated weighbridge station on entry and exit from the facility. On passing the weighbridge, vehicles shall tip MSW contents into a deep bunker, having a minimum storage capacity of 3 days as per the project's Terms of Reference. The selection of a waste bunker as opposed to a tipping floor as waste reception for the case study is due to the following;

a. Larger storage volume for area size to minimise building footprint
b. Better ability to drain inherent water & leachate due to increased head
c. Ability to manage incoming waste to optimise draining of inherent water

MSW movement inside the incoming waste bunker shall be managed by the use of overhead gantry cranes utilising orange peel grabs. Due to the critical nature of this portion of Works for all downstream activities, the case study is designed with 2 gantry cranes, providing 100% equipment redundancy in the event of equipment failure.

ii. Bag Splitting

In Thailand, it is common practice for household MSW to be placed in plastic carrier bags which are securely tied prior to disposal. The first step in the mechanical recovery process involved the splitting of such bags to release MSW contents for processing. This activity involves the feeding of MSW received at the waste bunker into a dedicated bag splitting machine utilising slow-rotating cutting blades to shear plastic packaging to release and loosen MSW contents.

The slow-rotating cutting blades' secondary function cuts larger components into smaller dimensions. Materials that pass these cutting blades shall pass through a large sieve-screen with a clearance of 300mm. All MSW components below this sieve size passes through into an outgoing conveyor for waste processing while oversized components are returned into the waste bunker for subsequent refeeding into the bag splitting machine.

iii. Recovery of Organic Stream

The organic stream within MSW consists mostly of smaller size fractions, with organics' purity increasing as size fractions reduce. Due to the high organic content within Thailand's MSW, separation of waste components below 100mm recovers a majority of the organics from the waste stream, albeit with organics' purity reducing as recovery dimensions increase. The case study's separation size is set at 60mm.

The recovery process for removal of organics from mixed MSW is mainly conducted through size separation, either by the use of trommel screen or sieve. On assessment of the case study's waste characteristics, the selection of a dynamic sieve is selected as preferred method for the separation of organics from the MSW stream. This is based on the assumption that the high moisture and mixed plastic reduces trommel separation efficiency by clogging separation openings during operation.

iv. Recovery of Ferrous Metals

Ferrous metals consists of metals containing the magnetic characteristics of iron. Recovery of ferrous metals is done by the use of a rotating magnetic belt over a moving waste conveyor to extract ferrous metals by magnetic force into a dedicated conveyor or collection area. The recovery process may extract non-ferrous materials attached to the respective ferrous object, potentially reducing recovery purity.

v. Recovery of Non-Ferrous Metals

Non-ferrous metals consist of metals that do not possess the magnetic characteristics of iron, hence are not attracted by magnetic force. Metal of this nature consist of aluminium, copper, brass, lead, zinc and stainless steel. The recovery of non-ferrous metals is done by the use of eddy-current separation. The electromagnetic field generated by a rotating eddy-current motor over a moving conveyor shall lift these metals into a separate conveyor or collection area.

vi. Recovery of Inert Materials

Inert materials consist of stable/non-reactive waste components such as glass, ceramic and stones. These materials are comparatively dense do not react to either magnetic or electromagnetic fields. In the case study, the removal of these components are done utilising a combination of separation equipment to optimize component recovery rate.

A densimetric table shall first be utilised to remove these components by using air to separate out lighter fractions while an inclined plate separates the heavier fraction downwards of the equipment for collection. Inert materials that failed to be recovered may be recovered during the subsequent process (the Near Infra-Red Optical separation) in which waste components are removed using compressed air pulses, which push selected waste into a dedicated conveyor or collection area. Alternatively, manual picking can be used to recover inert materials from the MSW stream.

vii. Recovery of Household Hazardous Waste

Household hazardous waste comprise of materials which are either flammable, chemically-reactive or toxic such as aerosols, paints, batteries, oils and household chemicals (detergents, pesticides and cleaners). For the case study, separation of HHW shall involve the combination of metals recovery, near infra-red optical separation and manual picking.

Metal separation shall extract metallic containers containing HHW such as aerosol cans and batteries while near infra-red optical separators will be programmed to identify HHW packaging by dimension. Manual picking shall be used to recover larger HHW such as aerosol cans and canisters from the MSW stream.

4.2.2 Biological Treatment Phase

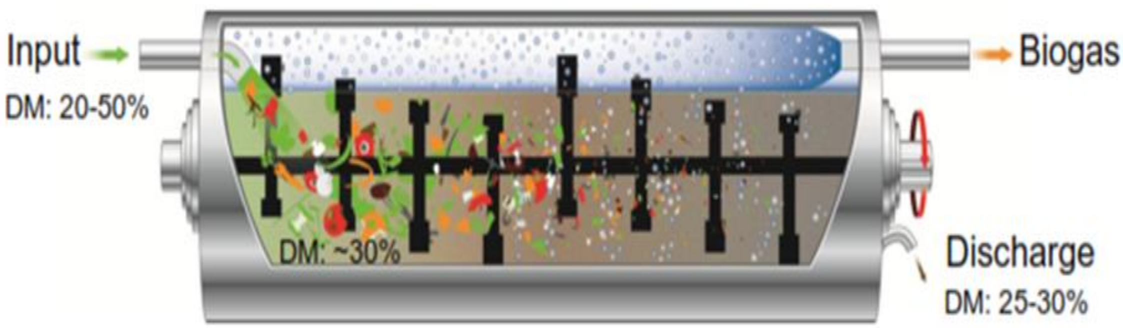
The case study Terms of Reference (TOR) states that the recovered organics portion shall be treated using a operationally-proven anaerobic digestion (AD) technology for the purposes of electricity generation and production of a compost-type soil conditioner, with emphasis on minimising external process water use, area use and wastewater generation.

On assessment of qualitative sampling results of the MSW organic portion, it is observed that recovered organics possess high-moisture content and significant levels (recorded at 10%) of non-organic contamination. It was determined that dry, thermophilic anaerobic digestion meets the case study requirements. The "Kompogas" process was selected for the case study.

Key reasons for the selection of this process is its ability to process contaminated organics, mainly due to digester's horizontal design which increases surface area for release of biogas. Additionally, the "dry" AD process maintains a sludge-type digestate consistency to reduce the potential of contaminant separation that affect process efficiency, apart from the reduced use of external process water.

The "Kompogas" horizontal digester has a design length of 33 meters, with a digester diameter of 8 meters. A slow-moving single shaft runs the length of the digester to aid within mixing of digestate to aid digestion and release gases. The process is divided into 3 phases – feeding, digestion and extraction with an overall treatment duration of between 12-16 days, dependent on facility treatment throughput. The general design concept of the horizontal, thermophilic AD process is illustrated in Figure 4-1.

Figure 4-1: Design concept - horizontal thermophilic AD process



During the feeding phase, the recovered organic stream shall be fed into the horizontal digester through a feeding screw, based on calculated input cycles spread over a 24-hour period. A separate liquid fraction consisting of recycled digestate, process leachate and fresh waste (if needed) shall be fed into the digester to regulate digestate Total Solid (TS) content within the 30% range.

During the digestion phase, anaerobic microorganisms consume and convert volatile organics into heat, methane gas and carbon dioxide. As the “Kompogas” process utilises thermophilic AD, the biogas engine’s jacket cooling water is circulated through the digester by the use of heating tubes to maintain the digester temperature of between 55°C and 57°C. Digestate moves along the digester by “plug flow”, reaching the extraction side within 14 days.

On reaching the end of the digester, digestate is extracted from the digestion by the use of a piston pump. Extracted digestate passes through a screw press to separate the digestate into solid and liquid fractions. The solid fraction is send for further processing to be converted into compost. The separated liquid fraction is further decanted to remove residual solids, which is collected and sent for processing to become compost. A portion of the decanted liquid fraction is reused as inoculate during the feeding phase, with excess exported as nutrient-rich liquid fertiliser.

4.2.3 Material Preparation Phase

For the case study, this phase involves the preparation of remaining MSW components for preparation into Refused-derived fuel (RDF), while biogas and digestate generated during the AD phase, shall be prepared to electricity and compost respectively.

i. Refuse-Derived Fuel (RDF)

Remaining components within the mechanical recovery stream consists primarily of mixed plastics, paper and waste components with moderate to high calorific values. These are prepared to meet local industrial RDF specifications for sale and use of cement kilns. Waste components are shredded into sizes not exceeding 50mm by the use of high-speed fine shredder. Once shredded, contents are compacted to a compaction ratio of 10:1 and baled using steel wire.

ii. Biogas Utilisation

Biogas generated through the AD process consist of a mix of methane gas, carbon dioxide, hydrogen sulphide, nitric acids, residual gases and water vapour. Biogas is passed through a biological scrubber to remove hydrogen sulphide and a freeze-drying unit to remove water vapour prior to combustion in biogas engine to be converted into electricity for internal facility use and with net excess exported to the national grid. Waste heat from the combustion process is captured by the water jacket around individual gas engines and circulated to provide heating for maintenance of the plant's thermophilic AD process temperature.

iii. Digestate Utilisation

Recovered solid digestate fraction from the AD process consists of structural organic matter, contaminants, nutrients, minerals, water and thermophilic microorganisms, among others. The solid digestate is mixed by volume with a portion of re-circulated compost and transferred to static aerated windrow composting boxes. Each windrow is covered by a semi-permeable sheet to retain moisture. The windrow is forced aerated by use of a blower to accelerate the aerobic composting process. Windrow air flow is automatically regulated based on oxygen content readings. Windrow composting takes between 25 to 28 days.

Composted digestate is further matured under the sunlight for an additional 8-12 weeks to complete bacterial activity, reduce moisture and stabilise remaining volatile organics. Matured compost is sieved to remove residual contaminants such as plastics and grinded into required specification for export.

4.3 Project Process Flow & Mass Balance

Individual waste component recovery and treatment methods are integrated to create the case study's overall concept design. The MBT facility's process flow is presented as two separate, inter-connected phases – 1) mechanical recovery and 2) biological treatment.

4.3.1 Mechanical Recovery Phase

The mechanical recovery phase is designed for 12 hours continuous operation and encompasses waste receipt, waste component recovery and preparation of refused-derived fuel (RDF). MSW received at the facility is weighed at a dedicated incoming weighbridge and unloaded into the incoming waste bunker. A waste gantry crane shall mix incoming waste within the bunker to loosen waste and release inherent water. The crane operator shall implement "bunker management" and sort waste within the bunker by receipt timing to ensure sufficient MSW retention time prior to feeding.

The gantry crane transports MSW into the charging hopper of the bag splitting machine to release and loosen MSW contents by shearing plastic bags and cut larger components and pass through a 300mm screen. MSW components larger than 300mm are returned to the incoming waste bunker through a chute. MSW that pass the sieve is transported by conveyor to a dynamic sieve for size separation. The sieve shall divide MSW into 3 separate size fractions – below 60mm, between 60mm to 140mm and between 140mm to 300mm.

The separated fraction below 60 mm is transported by conveyor through a magnetic separator to remove ferrous metals and passes through an eddy-current separator to recover non-ferrous metals, with remaining MSW being transported to the intermediate waste bunker at the anaerobic digestion plant.

The 60 mm – 140 mm fraction is transported by conveyor and passes through a densimetric table to recover heavy waste components such as glass, stones and ceramics prior to recovery of ferrous and non-ferrous metal by magnetic separation and eddy-current separation respectively to remove inherent metals within the stream. The waste stream passes through a near infra-red optical separator to recover hazardous material such as polyvinyl chloride (PVC) and batteries. Remaining waste is directed and mixed with remaining waste fraction from the 140 mm -300 mm stream at the intermediate hopper of the fine shredder.

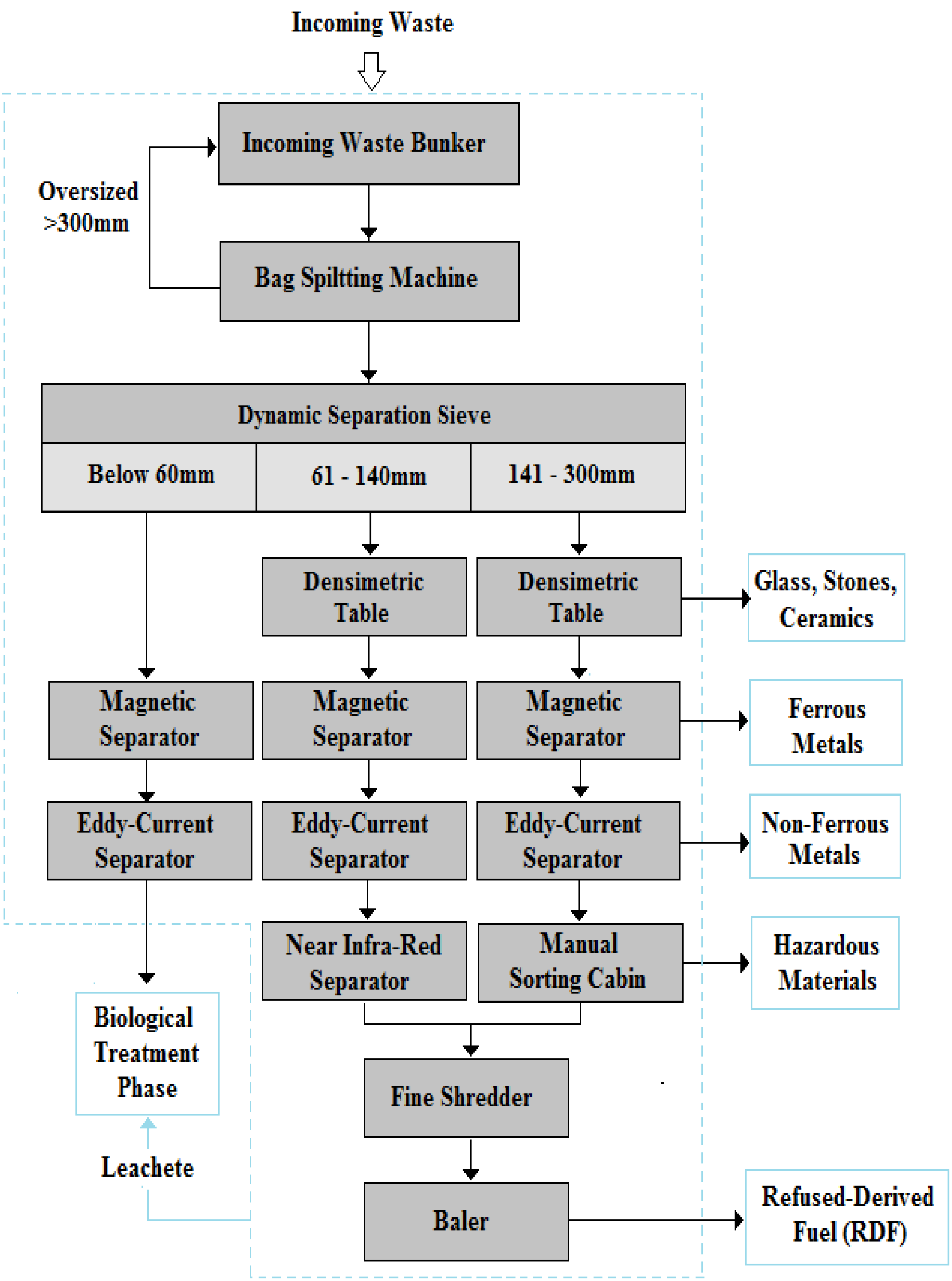
The 140 mm – 300 mm separated fraction is transported by conveyor and passes through a densimetric table to recover heavy waste components such as glass, stones and ceramics prior to recovery of ferrous and non-ferrous metal by magnetic separation and eddy-current separation respectively to remove inherent metals within the stream. Due to the larger fraction size, waste is sent through a manual picking & inspection cabin for manual removal of hazardous materials. Remaining waste is directed and mixed with remaining waste from the 60 mm – 140 mm stream at the intermediate hopper of the fine shredder.

Waste directed to the intermediate hopper of the fine shredder is shredded to a maximum size of 50 mm, compacted and baled for export as per RDF off taker requirement. RDF bales are stored at a designated area within the mechanical recovery building.

Further to processes described, a substantial volume of leachate is collected during the mechanical recovery phase, particularly from the incoming waste bunker, bag splitting and size separation activities. All leachate collected is channelled to the biological treatment phase for treatment along with recovered organics within the anaerobic digestion plant.

The summarised process flow for the mechanical recovery phase of the MBT facility is illustrated in Figure 4.2.

Figure 4-2: Process Flow – Mechanical Recovery Phase



4.3.2 Biological Treatment Phase

The biological treatment phase is designed for 24-hour continuous operation, comprising of anaerobic digestion of recovered organics and leachate from the mechanical recovery phase, followed by biogas utilisation for electricity generation and treatment of digestate into finished compost for export.

Recovered organics are transferred to an intermediate waste bunker, with a design storage capacity of 24 hours. The requirement of the additional intermediate bunker is to ensure sufficient feedstock buffer and regulate continuous feeding into the anaerobic digester due to differing throughputs and operation hours between the mechanical and biological treatment phases. Organics are fed by an automated gantry crane into a weighted feeding box based on the pre-set AD feeding cycle.

Organics enter the digester through an Archimedes screw based at pre-determined intervals over a 24-hour period. Fresh leachate, recirculated digestate and process water (if required) is fed into the horizontal, plug-flow digester through separate feeding pipes, with emphasis on substrate physical consistency and moisture. The slow-moving shaft homogenises incoming waste within the digester. Organics are anaerobically digested over a period of between 12-14 days under a thermophilic setting of between 55°C to 57°C.

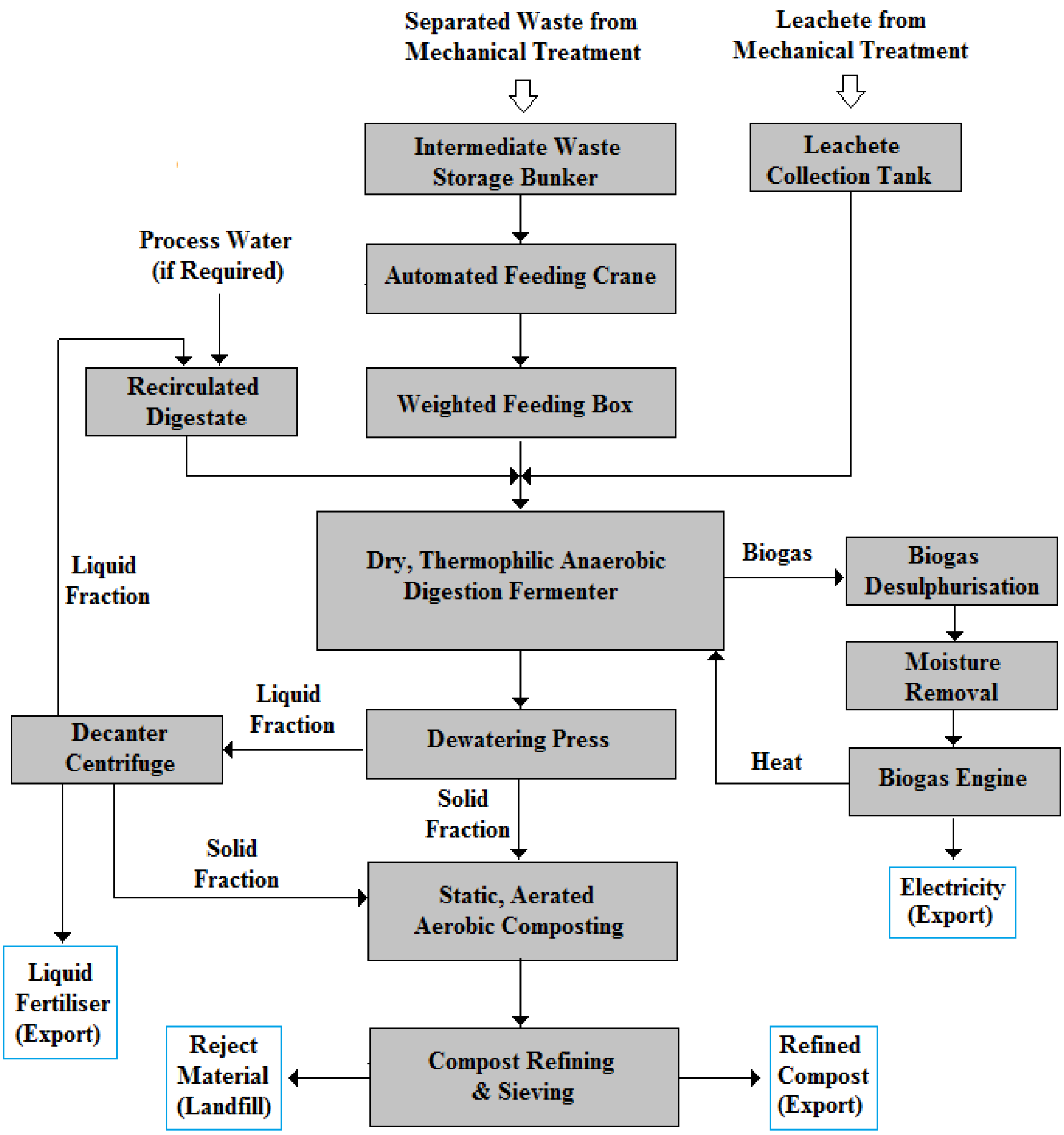
On reaching the extraction side, digestate is extracted by a piston pump and passed through a screw press to separate digestate into solid and liquid fractions. The liquid fraction is processed in a decanter centrifuge to separate residual solids. Recovered liquid digestate is stored in the liquid digestate tank for future recirculation within the AD process, with excess digestate exported as liquid fertiliser.

Solid digestate is placed in forced aeration aerobic composting boxes for between 25-28 days to be aerobically composted. On completion of the aerobic composting process, the solid fraction is matured under the sunlight for 8-12 weeks prior to sieving, grinding and refining to produce finished compost for export.

Biogas generated by the AD process is passed through a biological scrubber to remove hydrogen sulphide and a freeze-drying unit to remove water vapour prior to combustion in biogas engine to be converted to electricity for facility use and power export.

The summarised process flow for the biological treatment phase of the MBT facility is illustrated in Figure 4.3.

Figure 4-3: Process Flow – Biological Treatment Phase



4.4 Case Study Mass & Energy Balance

The case study's mass balance is divided into the mechanical recovery and biological treatment phases. Each phase's mass balance incorporates assumed MSW component recovery efficiency based on equipment supplier-attested track record and process performance guarantees, with project mass and energy balance reported based on hourly, daily and annualised figures.

4.4.1 Mechanical Recovery Phase

The mechanical recovery phase is designed for 12 hour continuous operation, on the basis of treatment throughput of 50 tonnes/hour. MSW component recovery throughput is reliant to changes in MSW composition, with key consideration given to recovery efficiency of individual components based on separation and recovery technology selection. Table 4.6 summarises technology specialist guaranteed recovery efficiency of each component, based on selected technology suite.

Table 4.6: MSW Component Recovery Efficiency based on Selected Technology

Technology	**MSW Component**	**Separation Efficiency (%)**
Magnetic Recovery	Ferrous Metals	**90**
Eddy-Current Separation	Non-Ferrous Metals	**90**
Densimetric Table	Glass, Ceramics, Stones	**80**
Near Infra-Red Optical Separation	PVC, HHW	**90**

Due to the inability to deduce leachate collection during the mechanical recovery phase, leachate is assumed as a portion of organics recovery. The hourly and annualised mass balance for the mechanical recovery phase, inclusive of the expected recovery potential of each MSW component of the case study is presented in Table 4.8.

Table 4.7: Daily & Annualised Case Study Mass Balance & MSW Component Recovery – Mechanical Recovery Phase

Mechanical Recovery Phase Size Separation Spilt													MSW Recovered Component Stream			
MSW Component	Composition	Annual Tonnage	Hourly Tonnage	Fraction 0mm-60mm			Fraction 60mm-140mm			Fraction 140mm-300mm			Recovered MSW Component	Recovery Efficiency	Annual Tonnage	Hourly Tonnage
	%	t/y	t/h	%	t/y	t/h	%	t/y	t/h	%	t/y	t/h		%	t/y	t/h
Food Waste	46.86%	87,441	23.43	85%	74,324.65	19.916	10%	8,744	2.343	5%	4,372.04	1.172	Organics	NA	82,976.88	22.23
Wood/Green Waste	5.53%	10,319	2.77	85%	8,771.13	2.350	10%	1,032	0.277	5%	515.95	0.138				
Ferrous Metal	0.46%	858	0.23	10%	85.84	0.023	70%	601	0.161	20%	171.67	0.046	Ferrous Metals	90%	772.52	0.207
Stainless Steel	0.02%	37	0.01	10%	3.73	0.001	50%	19	0.005	40%	14.93	0.004	Non-Ferrous Metals	90%	352.67	0.095
Copper	0.03%	56	0.02	12%	6.72	0.002	48%	27	0.007	40%	22.39	0.006				
Aluminum	0.16%	299	0.08	12%	35.83	0.010	60%	179	0.048	28%	83.60	0.022				
Glass	3.03%	5,654	1.52	20%	1,130.80	0.303	40%	2,262	0.606	40%	2,261.59	0.606	Inerts	80%	7,150.51	1.92
Ceramics & Stones	1.76%	3,284	0.88	20%	656.83	0.176	50%	1,642	0.440	30%	985.25	0.264				
Hazardous Waste	0.14%	261	0.07	5%	13.06	0.004	70%	183	0.049	25%	65.31	0.018	Hazardous Waste	90%	235.12	0.063
Mixed Paper	10.75%	20,060	5.38	50%	10,029.75	2.688	30%	6,018	1.613	20%	4,011.90	1.075	Refused-Derived Fuel	NA	95,112.30	25.49
Mixed Plastics	21.03%	39,242	10.52	5%	1,962.10	0.526	70%	27,469	7.361	25%	9,810.50	2.629				
Wood & Fibre	0.73%	1,362	0.37	7%	95.35	0.026	63%	858	0.230	30%	408.65	0.110				
Rubber & Leather	0.55%	1,026	0.28	10%	102.63	0.028	40%	411	0.110	50%	513.15	0.138				
Foam	0.83%	1,549	0.42	10%	154.88	0.042	30%	465	0.125	60%	929.27	0.249				
Fabric & Textiles	3.96%	7,389	1.98	10%	738.94	0.198	30%	2,217	0.594	60%	4,433.62	1.188				
Other Waste	4.16%	7,763	2.08	20%	1,552.51	0.416	50%	3,881	1.040	30%	2,328.77	0.624				
Total Composition	**100.00%**	**186,600**	**50.00**		**98,112**	**26.71**		**56,007**	**15.01**		**30,929**	**8.29**			**186,600**	**50.00**

4.4.2 Biological Treatment Phase

The case study's biological treatment phase is divided into two separate mass balances, encompassing anaerobic digestion and aerobic composting treatment. The mass balance for both portions is limited to the recovered organics stream (0-60mm) fraction from the mechanical recovery phase.

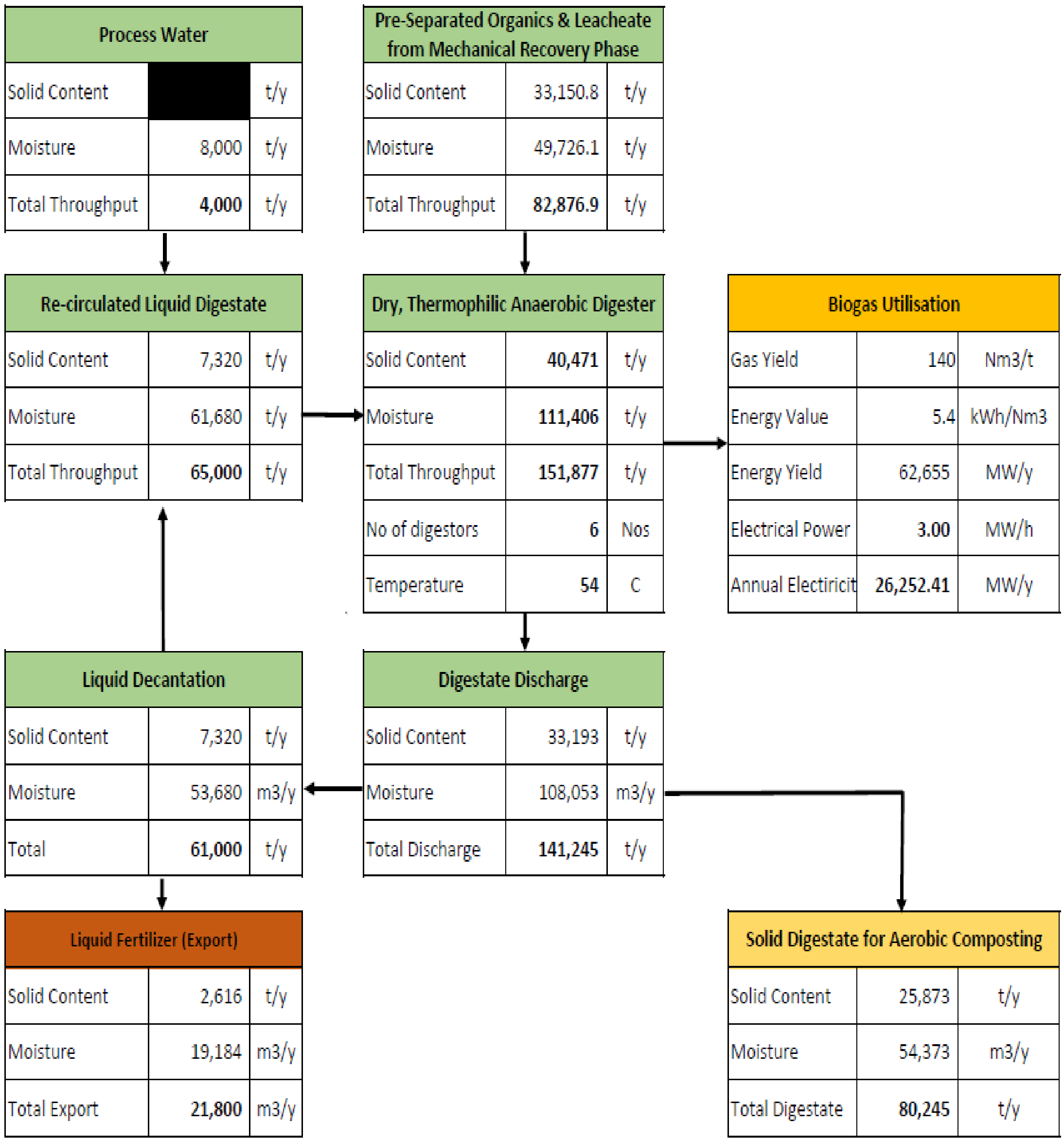
a. Anaerobic Digestion Treatment

The AD plant is designed on the basis of pre-determined feeding cycles over a 24-hour period to ensure stable and continuous biogas production throughout plant operation. Biogas production is dependent on volatile organic content within the recovered organics stream, with organics expected purity average at 83% of total input material for the case study.

Due to complexity in determining leachate capture during the mechanical recovery phase, the case study's mass balance calculation assumes leachate as a portion of recovered organics for anaerobic digestion treatment. The input stream is be divided equally among 6 digester tanks, on assumption of identical performance parameters among individual tanks which is unlikely but is expected to be within similar ranges during actual operation. In this regard, performance data differences among individual digesters are assumed as negligible over the overall operating life of the plant.

The case study's biogas engine system comprise of two 2MWA units, based on plant electrical power generation yield of 3.7MWh, recording nett electrical export generation potential of 3.00MWh. Plant power generation information is based on the performance data of high-efficiency biogas engines, with technology specialist guaranteed electrical generation and thermal efficiencies of 42% and 39% respectively. Figure 4.4 shows the case study mass and energy balance of the anaerobic digestion plant.

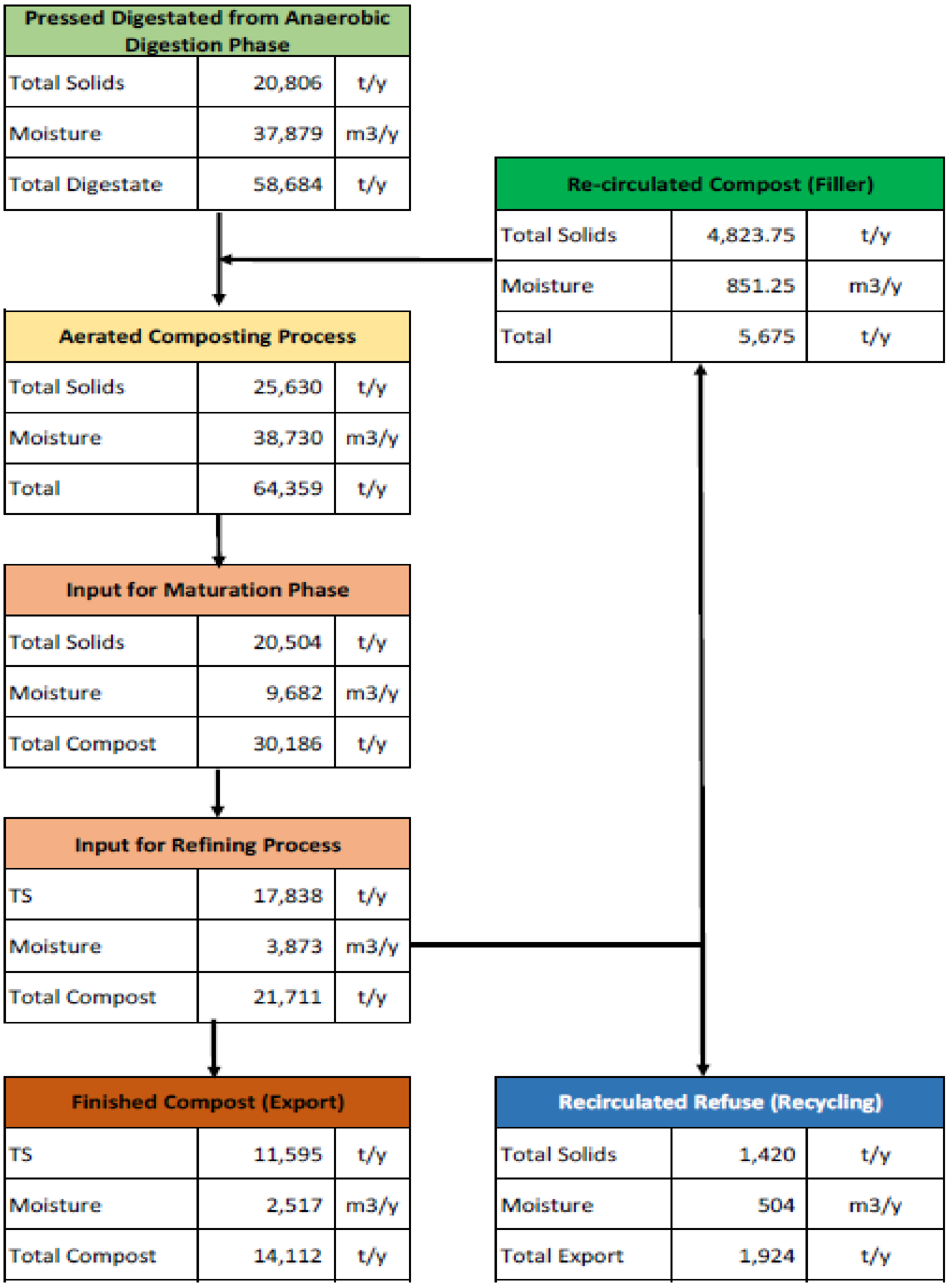
Figure 4.4: Mass & Energy Balance - Anaerobic Digestion Treatment Phase



b. Aerobic Composting Treatment

Recovered digestate from the AD process is aerobically treated utilising the static, active aeration aerobic composting method to remove moisture, stabilise and mature extracted digestate into compost. Key volume losses are the results of water evaporation while solid mass losses are the result of degradation of remaining volatile organics by aerobic microorganisms into water vapour, carbon and carbon dioxide. Figure 4.5 presents the mass balance of the case study aerobic composting and associated refining processes.

Figure 4.5: Mass Balance of Case Study - Aerobic Composting Phase

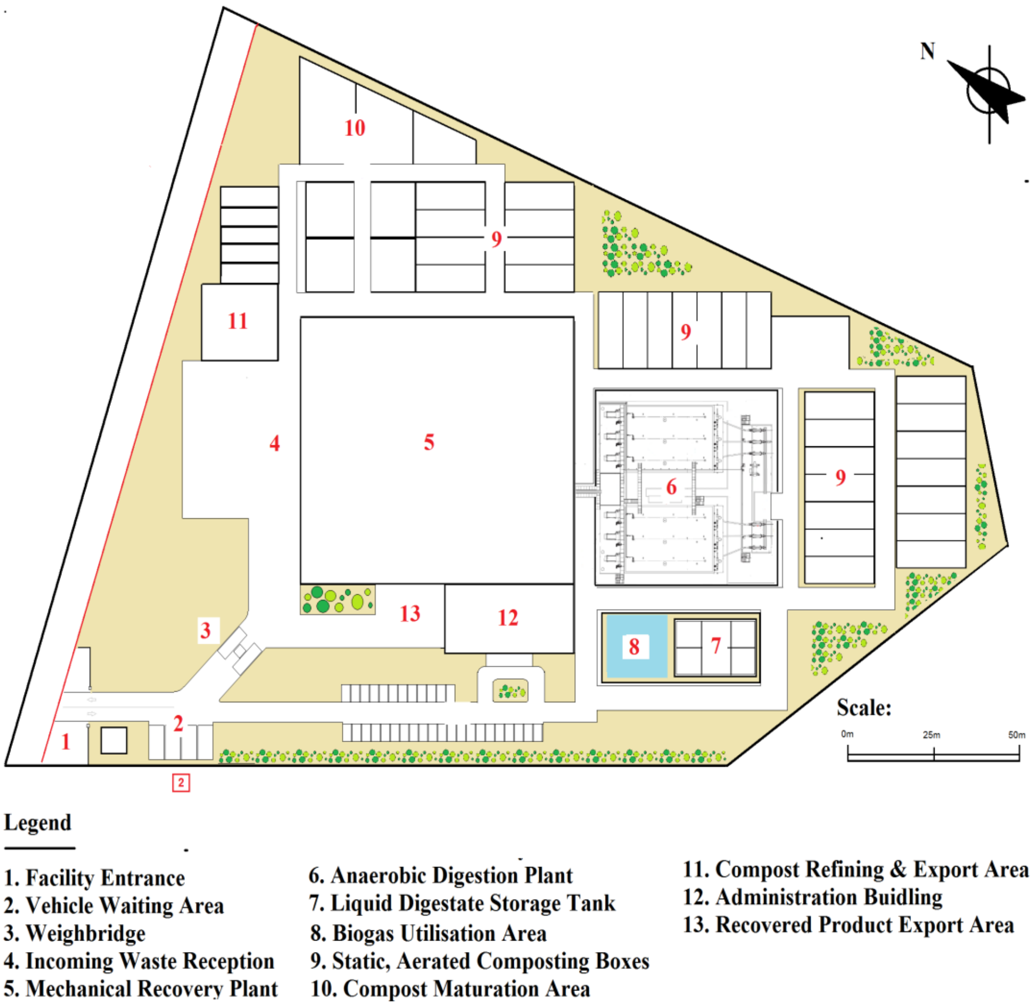


4.5 Project Layout

The case study's concept layout is designed in line with the overall project process flow and mass balance with added consideration on the possibility for future expansion, as stated within the case study's TOR. Further consideration is made to site investigation data and neighbouring facility profiles.

Key buildings are concentrated at the middle and northern side of the plot area as site investigation data highlighted swampy ground conditions at the east and southern portions of the site. Figure 4.6 presents the case study project layout on the proposed site, located at On-Nut, Bangkok.

Figure 4.6: Case Study MBT Plant Layout



4.6 Conclusion of the Chapter

Quantitative and qualitative MSW sample testing within the case study's catchment area has determined that Bangkok's MSW comprise mainly (approximately 52% content) of digestible organics such as food waste and garden waste. The second and third highest components found within Bangkok's MSW stream are mixed plastics and paper (cumulatively 31%), which form main constituents of refuse-derived fuels. Sample organics mean moisture content is reported at 70% with wet calorific value of 2,388kJ/kg. Sampling results indicates higher MSW compatibility for MBT processing, rather than thermal treatment as high moisture impedes thermal energy recovery.

Sampling data obtained is further analysed to approximate potential MSW waste component recovery based on the case study's contracted annualised availability rate of 85% or 311 days. Waste components are divided into mechanical recovery, biological treatment and market-prepared categories, for subsequent selection of recovery & treatment methodology for each MSW component based on the intended use of stated components.

The mechanical recovery phase is designed for 12 hour operation, comprising of waste reception and deep bunker, bag splitting, size separation into below 60mm, 60-140mm and 140-300mm streams, and proceeding with MSW component recovery by magnetic separator, eddy-current separation, densimetric table and near infra-red optical separation. Recovered components are channelled and stored at designated locations prior to export or further treatment.

The biological treatment phase comprises "dry" horizontal, thermophilic anaerobic digestion (AD) process of the recovered organic fraction. The treatment method is selected based on high levels of non-organic contamination and lower organic moisture levels for wet AD processing. Organics are digested over a period of 12-14 days under a thermophilic temperature setting of between 55°C-57°C, producing biogas and digestate which are extracted for further processing.

Extracted digestate is aerobically composted over 28 days to stabilise volatile organics and reduce moisture. Composted digestate is cured for a further 8-12 weeks prior to export. Biogas generated and recovered from the AD process is scrubbed off H_2S gases and moisture, and combusted by a biogas engine to convert biogas to electricity. Heat captured through the biogas engine cooling water jackets are used to maintain anaerobic digester thermophilic operating temperature.

CHAPTER 5 Commercial Data Collection & Analysis

This chapter consolidates the Mechanical Biological Treatment (MBT) facility's commercial information, utilising the case study's technical specifications and operational deliverables as basis for the determination of an appropriate MSW treatment fee range. This chapter presents the case study capital investment, operation income and expenditure over the project's concession 20-year agreement period.

5.1 Project Capital Investment & Expenditure

A project's capital investment encompasses expenditure incurred from project conception through to the granting of a project's final acceptance certificate. As outlined within Chapter 3.2.3, data from the case study is utilised to assess the MBT facility's capital expenditure, divided into 8 categories and presented in Thailand Baht (THB).

5.1.1 Land, Authority and Financing

This section analyses costs involving land acquisition and preparation, geotechnical studies, authority approvals, construction permits and financing charges for the development of the MBT facility. Table 5.1 outlines the case study's land, authority and project financing expenditure.

Table 5.1: Project Capital Investment – Land, Authority & Financing

No	Description	Cost (THB)
1	Land Land acquisition, rezoning, land clearance works, backfilling activities, erection of temporary perimeter hoarding, erection of project signage and other associated works such as temporary drainage. (Case study land leased for 22-year period)	8,750,000.00

2	Geotechnical Survey Drilling and coring tests, mechanical cone penetration tests, soil compaction testing, dynamic penetration soil density test, water infiltration tests.	1,275,800.00
3	Detailed Environmental Impact Assessment (DEIA) Independent environmental assessment of proposed development as part of authoritative approval requirement of the Kingdom of Thailand which shall include public presentation and inquiry sessions.	3,150,500.00
4	Application of Development Order & Building Plan Provincial authority approval for issuance of building and construction permit, technical authority and utility approvals for construction of facility.	430,700.00
5	Application of Project Financing Appointment of project accountant, preparation of independent financial report for application debt-financing and other associated fees.	364,700.00
6	Pre-Project Tender & Development Costs Expenses in relation to project development, plant visits, tender preparation, clarification meeting attendance and finalisation of Public-Private Partnership agreement.	7,698,500.00
	Sub-Total: Land, Authority & Financing (THB)	**21,670,200.00**

5.1.2 Engineering & Project Management

This section covers relevant costs relating to the provision of detailed design, professional engineering technical consulting and project management consultant (PMC) services, among others. Table 5.2 outlines the case study's project management and engineering expenditure.

Table 5.2: Project Capital Investment – Engineering & Project Management

No	Description	Cost (THB)
1	Detailed Design – Overall Process Design Provision of specialised detail design, process layout and equipment selection of mechanical recovery, biological treatment and power generation of MBT facility, inclusive of construction supervision and advisory services during first 12 months of facility operation.	37,863,569.00
2	Detailed Design – Civil & Structural, Building Services Civil & Structural detailed design works of the main building and support structures, electrical distribution, utilities (HVAC, Lighting, Fire Fighting, Drainage, Roadworks, Water Reticulation and Sewerage).	8,795,000.00
3	Consultancy Services – Technical Engineering Professional engineering services, technical advisory and review and validation of all detailed design works for submission to respective authorities for relevant approvals as per local regulatory requirements.	4,650,000.00
4	Consultancy Services – Project & Cost Management Project Management Consultant (PMC) and Cost Management services during Engineering, Procurement, Construction and Commissioning (EPCC) phase, schedule management and project quality and Works verification.	29,500,000.00
	Sub-Total: Engineering & Project Management (THB)	**80,808,569.00**

5.1.3 Civil & Architectural Works

This section outlines project expenditure in relation to the erection of project civil buildings, structures, tanks, road works, ducts, drainage and sewerage lines, steel access points and staircases – inclusive of material and installation works. Table 5.3 lists the case study's civil and architectural expenditure.

Table 5.3: Project Capital Investment – Civil & Architectural Works

No	Description	Dimension	Cost (THB)
1	Mechanical Recovery Building Single-storey, steel-walled building (10m height) with reinforced concrete (RC) flooring, incorporating 2500m3 deep-bunker.	5600m2	65,500,000.00
2	Biological Treatment Support Buildings Two-storey, RC organics feeding building incorporating 1000m3 deep-bunker and liquid storage tank & two-storey RC digestate extraction building incorporating liquid storage tank and electrical room.	730m2	32,880,500.00
3	Aerated, Aerobic Composting Boxes 29 Nos. 20m x 6m of RC open air composting boxes, with pre-installed air tubes on base of individual boxes.	3480m2	38,700,000.00
4	Administration Building & Workshop Two-storey brink-wall building, housing office space, pantry, workshop and store.	480m2	6,890,000.00

5	Access Road and Compost Storage Yard Jointed-reinforced concrete pavement (JRCP) for roadway, maintenance access, compost storage yard and parking area of facility.	8532m2	3,095,240.00
6	Drainage, Sewerage and Perimeter Fencing Pre-cast concrete trench drain, underground gravity sewerage line, along with maintenance manhole and 2.5m brick-wall fencing and 3 Nos. steel gate at entrance.	1580m (drain) 870m (fence)	3,650,500.00
7	Support Structures and Tanks Brick-wall guard house, HDPE water storage tank (200m3), liquid fertilizer storage tank and associated works.	Misc.	2,380,000.00
		Sub-Total: Civil & Architectural Works (THB)	**153,096,240.00**

5.1.4 Waste Reception

This section lists procurement and installation costs for the case study's waste reception works. Scope of works cover weighbridge, incoming waste bunker and leachate collection. Table 5.4 outlines case study's waste reception expenditure.

Table 5.4: Project Capital Investment – Waste Reception

No	Description	Origin	Cost (THB)
1	Weighbridge System 2 Nos. bi-directional above-ground extended weighbridges, gantry and signalling, data collection & log server, printer, installation and commissioning.	Thailand	1,260,000.00

2	<u>Incoming Reception Refuse Crane</u> 2 Nos. refuse gantry crane, with 8m3 orange-peel electric grab, operator chair, control and load log system, installation and commissioning.	Germany/ Thailand	8,270,300.00
3	<u>Leachate Collection</u> Bunker leachate screen, filter, submersible pump and accessories.	Thailand	2,160,500.00
	Sub-Total: Waste Reception (THB)		**11,690,800.00**

5.1.5 Mechanical Recovery

This section covers procurement and installation costs for equipment within the mechanical recovery phase of the MBT facility - encompassing bag splitting, MSW component recovery, size reduction, baling, and MSW conveying and transporting. Table 5.5 lists the case study' mechanical recovery expenditure.

Table 5.5: Project Capital Investment – Mechanical Recovery

No	Description	Origin	Cost (THB)
1	<u>Bag Splitting Machine</u> 100m3/hr dual-shaft, slow shredder machine, utilising variable frequency control	Finland	9,450,000.00
2	<u>Dynamic Separation Screen</u> 1500mm-width dual-layer hexagonal-sieve screen, 60mm and 140mm separation size.	Italy	7,880,000.00
3	<u>Densimetric Table</u> 2 nos. densimetric table, incorporating single vibrating screen and air blower.	Germany	6,125,398.00

4	Magnetic Separator 3 nos. single-direction electromagnetic belt separator with retractable pulley positioning.	Austria	1,466,765.10
5	Eddy-Current Separator 3 nos. 1800mm- width high speed, non-metallic rotating drum system.	UK	6,957,436.00
6	Near Infra-Red Optical Separator 1800mm-width high speed conveying system incorporating multi-spectral imaging	Holland	9,998,674.52
7	Manual Sorting Cabin Air-conditioned steel-shell single-line sorting cabin with 4 nos. sorter platforms.	Thailand	1,254,640.00
8	Fine Shredder 30m3/h dual-rotor rotating blade shredder with manual positioning and lifting system.	Germany	7,274,278.92
9	Baling Machine “Hardox”-coated 135-tonne hydraulic counter pressure-5:1 compaction ratio.	Italy	14,573,244.23
10	Conveying System 14-conveyors, motors, rollers, galvanized steel structure, access platform and staircases.	Thailand	9,224,948.00
11	Automated Sorting Control System Custom-designed digital control system, simatic control panel, instrumentation, cabling, electrical wiring, motor control centre (MCC), inclusive of installation and commissioning.	Misc.	56,320,000.00
		Sub-Total: Mechanical Recovery (THB)	**130,525,384.77**

5.1.6 Biological Treatment

This section highlights equipment procurement and installation costs for the biological treatment phase of the MBT facility, covering intermediate raw material storage, feeding, humidification, anaerobic digestion and digestate extraction of the facility. Table 5.6 lists the case study biological treatment expenditure.

Table 5.6: Project Capital Investment – Biological Treatment

No	Description	Origin	Cost (THB)
1	Automated Organics Feeding Crane 2 Nos. refuse gantry crane, with 2m3 orange-peel electric grab, Infra-red mapping and positioning sensors, manual control override option, load log system, installation and commissioning.	Switzerland	9,745,293.00
2	Leachate Intermediate Storage and Feeding Transfer pump from Mechanical Recovery phase, strainer, lifting station, diaphragm feeding pump, piping, flow meter and automated transfer valves to individual digesters (excluding civil Works).	Thailand	5,438,240.00
3	Organics Feeding System 6 Nos. 10m3 moving-floor feeding box with load logging, feeding screw, automated screw removal system, centralised lubrication system & manual override control panel.	Germany	18,300,000.00

4	Anaerobic Digester 6 Nos. 1800m3, 33 meter length "Kompogas" steel, insulated horizontal digester tanks, fitted with central internal shaft, associated feeding, extraction and biogas release fittings and accessories, stairway & reinforced concrete foundation.	Fabrication (Thailand) Fittings (Misc.)	318,000,000.00
5	Digestate Extraction System 6 Nos. digestate extraction system comprising hydraulic piston pumps, digestate screw press separator, solid-liquid decanter, transfer pumps & accessories.	Misc.	59,436,293.00
6	Anaerobic Digester Heating System Water jacket heat exchanger, insulation piping Works, water transfer pump and accumulator tank, heating tubes, 150kWth start-up diesel boiler, control system.	Switzerland	27,300,500.00
7	Biogas Capture & Safety System Biogas capture piping, anaerobic digester over-pressure safety system, over-pressure rupture disk, emergency flaring system & biogas online quality meter.	Misc.	23,453,560.00
8	Anaerobic Digestion Control System Custom-designed digital control system, simatic control panel, instrumentation, cabling, electrical wiring, motor control centre (MCC), inclusive of installation and commissioning.	Misc.	95,300,000.00
Sub-Total: Anaerobic Digestion (THB)			**556,973,886.00**

5.1.7 Preparation for Market

This section highlights equipment procurement and installation costs for MBT facility's preparation of waste products for export; covering biogas utilisation and aerobic composting of solid digestate from the anaerobic digestion phase. Table 5.7 outlines the case study preparation to market expenditure.

Table 5.7: Project Capital Investment – Preparation for Market

No	Description	Origin	Cost (THB)
1	Biogas Utilisation System Turn-key system comprising of 1000m3/h biological desulphurisation system, freeze-drying moisture removal unit, 2 operation flares (used during Engine downtime), 2 nos. 2MWe 20V biogas generators incorporating 736 kWth heat recovery through water jacket, electronically controlled gas metering valve and control system.	Engine (Germany) Scrubbers (Thailand)	69,500,500.00
2	Aerobic Composting System 26 nos. active-aeration composting cells (accessories excluding civil works), self-retracting permeable composting covers, blower fan, temperature measurement and control system, leachate drainage and sump & 2 nos. 4.0m3 front loader vehicles.	Engineering (France) Equipment (Thailand)	123,500,000.00

3	Finished Compost Refining System 25m3/h automated star-sieve sieve, air-sifting, grinding and separation system with optional 1m3 pallet bagging system.	Germany	47,500,000.00
		Sub-Total: Preparation for Market (THB)	**240,500,500.00**

5.1.8 Construction & Commissioning

General equipment, consumables and manpower for construction, installation, process integration, testing and commissioning activities are done by appointed general subcontractors and individual technology specialists, above and beyond equipment procurement and installation costs. Table 5.8 outlines the case study construction and commissioning expenditure.

Table 5.8: Project Capital Expenditure – Construction & Commissioning

No	**Description**	**Cost (THB)**
1	Civil & Structural General Contracting Equipment and general manpower supply & supervision of excavation & backfilling works, scaffolding, lifting, dumping, masonry and other associated works not covered within the scope of supply of other categories.	68,500,000.00
2	Mechanical & Piping General Contracting Equipment and general manpower supply & supervision of mechanical and piping Works, including supply of lifting equipment, welding works, piping fabrication and installation, equipment installation and associated works not covered within the scope of supply of other categories.	78,769,000.00

3	Electrical, Instrumentation & Automation Installation Supply and installation of HV/LV equipment (transformer, switchgears), 11kV, 400V, 240V, 10VDC electrical cabling installation, motor control centre (MCC), instrumentation cabling, junction boxes, automation system installation, setup of Centralised Control Room (CCR), server and battery room.	124,050,000.00
4	Construction/Commissioning Utilities & Consumables Utilities services (electricity, potable water, construction water and sewerage) for construction & commissioning activities, commissioning consumables including process chemicals, commissioning wear and spare parts and safety/quality consumables.	12,360,000.00
5	Construction & Commissioning Support Manpower Support manpower during project construction and commissioning inclusive of material control, security, administrative support, supervisory staff, commissioning operators, cleaners and pest control.	69,305,354.00
	Sub-Total: Construction & Commissioning (THB)	**352,984,354.00**

5.1.9 Overall Project Capital Expenditure

Project capital expenditure categories are consolidated to determine the overall project cost. Additional capital budget is set aside as project contingency and construction financing budgets to cover for project uncertainties, risks and ensure project liquidity throughout the project execution phase.

A project's contingency budget is determined above the project base cost estimate either through range estimating, expected value or probabilistic method.

The case study sets a contingency budget and construction budget of 10% and 5% respectively, above the based cost estimate. Table 5.9 summarised the case study's overall capital expenditure.

Table 5.9: Case Study Overall Capital Expenditure

No	Capital Expenditure Category		Cost (THB)
1	Land, Authority & Financing		21,670,200.00
2	Engineering & Project Management		80,808,569.00
3	Civil and Architectural Works		153,096,240.00
4	Waste Reception		11,690,800.00
5	Material Recovery		130,525,384.77
6	Biological Treatment		556,973,886.00
7	Preparation for Market		240,500,500.00
8	Construction & Commissioning		352,984,354.00
Project Capital Base Cost Estimate (THB)			**1,548,249,933.77**
9	Project Contingency	10% of Base Cost Estimate	154,824,993.38
10	Construction Financing	5% of Base Cost Estimate	77,412,496.69
Overall Project Capital Expenditure (THB)			**1,780,487,423.84**

5.2 Project Operation Expenditure

A Mechanical Biological Treatment (MBT) facility's operational expenditure is defined as all direct and indirect expenses incurred during the facility's operation lifetime, from the date of granting of the project's final acceptance certificate until the decommissioning and disposal of remaining facility assets. As outlined within Chapter 3.2.3, data from the case study is utilised to assess the MBT facility's operational expenditure, divided into 8 categories and presented in Thailand Baht (THB).

5.2.1 Personnel

Personnel expenditure comprise of wages, bonuses, benefits and all direct and indirect expenses relating to the facility's manpower under the facility's direct employment. Manpower costs is based on the expected facility personnel mobilisation and shall incorporate the country's annual inflation rate over the operating life of the facility.

The case study Operation & Maintenance (O&M) team comprise personnel representing the Operations, Maintenance and Administration departments. Table 5.10 outlines the case study's first year personnel operational expenditure, inclusive of provident fund contribution & annual bonus pay out.

Table 5.10: Personnel Operational Expenditure

No	Personnel	Available Positions	Cost (THB)
1	General Manager	1	2,030,000.00
2	Operations Manager	1	1,305,000.00
3	Senior Operations Engineer	1	1,087,500.00
4	Operations Engineer	2	1,305,000.00
5	Assistant Operations Engineer	2	1,015,000.00

6	Biological Treatment Specialist	1	507,500.00
7	Operation Shift Lead	3	1,522,500.00
8	Operation Shift Technician	15	5,437,500.00
9	Weighbridge Operator	3	870,000.00
10	Heavy Machinery Operator	2	725,000.00
11	Maintenance Superintendent	1	797,500.00
12	Maintenance Engineer	2	1,015,000.00
13	Maintenance Technician	7	2,030,000.00
14	Mechanical Fitter	2	551,000.00
15	Electrician	1	362,500.00
16	Administration Manager	1	725,000.00
17	Purchasing Officer	1	362,500.00
18	Administration Executive	3	783,000.00
19	Finance Executive	1	261,000.00
20	Office Driver	1	333,500.00
21	Store Keeper	1	362,500.00
22	Store Assistant	1	232,000.00
	Total Provident Fund Contribution (THB)		3,543,075.00
	Employee Insurance Premium Payment (THB)		3,180,000.00
	Sub-Total: Personnel (THB)	**53**	**30,343,575.00**

5.2.2 Land & Facility Expenditure

This category covers operational expenditure relating to the usage of the facility's land and infrastructure. Among expenses incurred include annual land leasing and assessment charges, waterway connection charges and access roadway maintenance charges. Table 5.11 lists the case study's land and facility annual operational expenditure.

Table 5.11: Land & Facility Expenditure

No	Land & Facility Charges	Cost (THB)
1	Land Lease Charges Fixed leasing fee of THB108/year per sq. meter for 7.80 acres (31,970m2) plot over a 22-year period (20-year O&M phase + 2-year decommissioning period).	3,452,760.00
2	Land Assessment Tax Land assessment taxes and land development charges payable to Bangkok Metropolitan Authority (BMA) based on a percentage of the land's value.	690,552.00
3	Infrastructure Charges Annual maintenance charges payable to local infrastructure authorities for upkeep of public access, waterways, street lighting and sewerage connections.	270,000.00
	Sub-Total: Land & Facility Charges (THB)	**4,413,312.00**

5.2.3 Equipment Maintenance

This section covers facility scheduled, preventive and breakdown maintenance charges during the operating life of the facility. Maintenance charges are divided into 4 categories – reception & mechanical recovery, biological treatment, preparation for market and general plant facilities. Table 5.12 outlines the case study's annual maintenance expenditure.

Table 5.12: Equipment Maintenance Expenditure

No	Equipment Maintenance Expenditure	Cost (THB)
1	Reception & Mechanical Recovery Maintenance and spare/wear part expenditure relating to weighbridge, waste reception area, waste refuse crane, separation & material recovery and RDF preparation and baling activities.	11,571,200.00
2	Biological Treatment Maintenance and spare/wear part expenditure relating to automated feeding crane, feeding, humidification, anaerobic digesters, biogas safety, digestate extraction, dewatering & control system.	16,977,000.00
3	Preparation for Market Maintenance and spare/wear part expenditure relating to biogas utilisation, aerobic composting of extracted digestate & compost refining.	13,915,000.00
4	General Plant Facilities Maintenance and spare/wear part expenditure relating to the facility's civil and structural works, building services, electrical distribution services, emergency power and common auxiliary system.	4,305,500.00
	Sub-Total: Equipment Maintenance (THB)	**46,768,700.00**

5.2.4 Chemicals, Utilities & Fuel

This section discusses plant expenditure relating to process chemical use, utilities (water, sewerage and electricity), heavy machinery fuel utilisation and other consumables. Table 5.13 lists the case study's chemical, utilities and fuel annual operational expenditure.

Table 5.13: Chemicals, Utilities & Fuel Expenditure

No	Chemicals, Utilities & Fuel Expenditure	Cost (THB)
1	<u>Operations Utilities Consumption</u> Process & potable water consumption and power importation during power generation downtime and maintenance period.	4,177,174.00
2	<u>Operations Consumables & Inert Disposal</u> Annual utilisation of EHS-related consumables, maintenance consumables, baling wire ropes, inert transportation and disposal charges.	22,688,062.50
3	<u>Heavy Machinery Fuel, Oils & Lubricants</u> Fuel utilisation by heavy vehicles such as front loaders for transportation of waste products within plant. Cost category includes plant lubrication greases and oils.	4,273,308.00
4	<u>Plant Chemicals</u> Process chemical utilisation for anaerobic digestion, biological utilisation and aerobic composting process. Budget includes plant deodorisation and cleaning chemicals.	2,104,000.00
	Sub-Total: Chemicals, Lubricants and Oils (THB)	**33,242,544,50**

5.2.5 Support Services

This category covers all external support services in relation to technology special process supervision, heavy vehicle maintenance, plant security and building service maintenance and outsourced service contracts during the facility's operation period. Table 5.14 lists the case study's support services expenditure.

Table 5.14: Support Services Expenditure

No	Support Services Expenditure	Cost (THB)
1	Process-based Support Services Technology provider process support service, inclusive of scheduled expert supervision visits during plant overhaul period.	3,120,000.00
2	Maintenance-based Support Services Annual maintenance support packages for plant's heavy vehicles and machinery, biogas utilisation, electrical distribution system.	2,094,400.00
3	Facility & Building Services Outsourcing of facility's security and building services such as building maintenance, security, CCTV, HVAC and pest control.	1,608,000.00
4	Manpower Support Services Outsourcing of plant operation general workers, plant cleaners and pantry staff.	2,944,000.00
	Sub-Total: Support Services (THB)	**9,766,400.00**

5.2.6 Licencing, Insurance, Quality Management and Taxation

This category lists all expenses in relation to the facility's statutory, quality and insurance obligations while operating a MBT facility. The plant's annual insurance premium is dependent on its risk profile and overall coverage while corporate taxation shall be based on prevailing tax rates based on the plant's overall profitability. Table 5.15 explains the case study's licensing and insurance expenses.

Table 5.15: Licencing & Insurance Expenditure

No	Licencing & Insurance Expenditure	Cost (THB)
1	Statutory Operating Licenses MBT facility annual operating licence, statutory equipment permit, facility registration renewal fees.	690,000.00
2	Operating Insurances Plant & equipment insurance, social security, business interruption insurance, Workman Compensation insurance	1,725,000.00
3	Facility Quality, Calibration and ISO Certification Product quality and toxicity testing, ISO certification and annual renewal, calibration of statutory equipment	805,000.00
	Sub-Total: Licencing & Insurances (THB)	**3,220,000.00**

5.2.7 Administration

This section covers a MBT facility's administration expenditure such as telecommunication, record-keeping, human-resource related activities and light vehicle utilisation. Table 5.16 breakdowns the case study's first-year administration expenditure.

Table 5.16: Administration Expenditure

No	Administration Expenditure	Cost (THB)
1	Administration Facility administrative running costs including stationary, telecommunication, server services & pantry supplies	1,380,000.00
2	Facility Transportation Charges Personnel official duty mileage charges and facility light vehicle fuel and toll way charges	193,150.00
3	Human Resource-based Expenses Personnel training programs, well-being and social recreation club activities, community programme.	2,024,000.00
	Sub-Total: Administration (THB)	**3,597,150.00**

5.2.8 Debt-Repayment

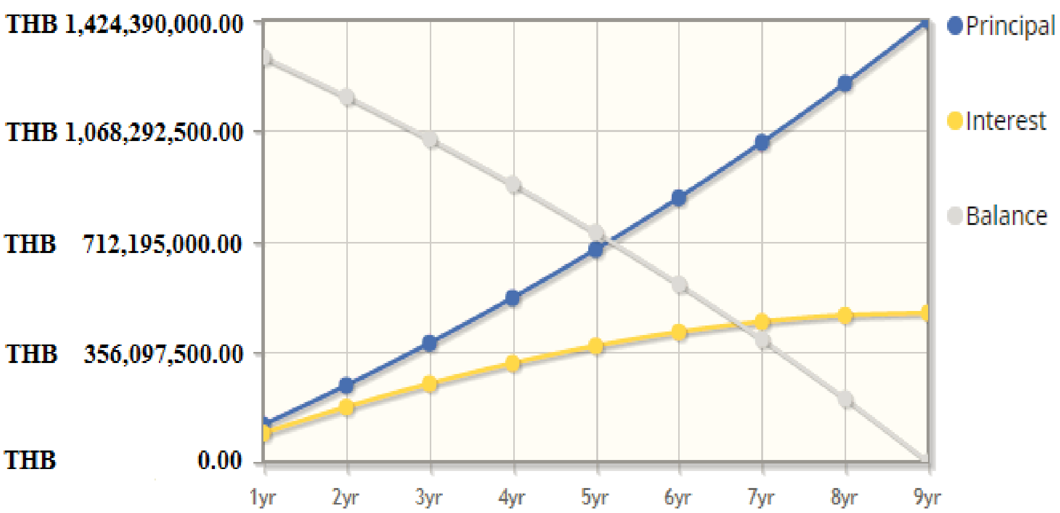
Capital investment and project construction financing for the MBT facility is obtained through project debt-financing. For the case study, project debt-financing is set at 80%, at a base lending rate of 6.75%/year. Debt-repayment period is extended to 9 years through project underwriting by a multilateral development bank.

Project interest rate calculation and debt-repayment commence on receipt of the project's provisional completion certificate or at Month 25 of project execution, whichever begins first. Project base debt for the case study is set at THB 1,424,389,939.07 with debt repayment divided into equal monthly instalments over a 108-month period. Table 5.17 provides the case study's cumulative principal and interest repayment quantum over debt-repayment period.

Table 5.17: Debt-Financing Cumulative Principal & Interest Repayment

Operation Year	Cumulative Principal (THB)	Cumulative Interest (THB)	Cumulative Repayment (THB)
1st Year	119,101,352.05	92,506,400.83	211,607,752.88
2nd Year	119,101,352.05	92,506,400.83	423,215,505.76
3rd Year	119,101,352.05	92,506,400.83	634,823,258,64
4th Year	119,101,352.05	92,506,400.83	846,431,011.52
5th Year	119,101,352.05	92,506,400.83	1,058,038,764.40
6th Year	119,101,352.05	92,506,400.83	1,269,646,517.28
7th Year	119,101,352.05	92,506,400.83	1,481,254,270.16
8th Year	119,101,352.05	92,506,400.83	1,692,862,023.04
9th Year	119,101,352.05	92,506,400.83	1,904,469,775.92
		Total Debt Repayment (THB)	**1,904,469,775.92**
		Monthly Debt Instalment (THB)	**17,633,979.41**

Figure 5.1: Debt Principal & Interest Servicing Repayment Schedule



5.3 Project Income Stream Analysis

The income of a Mechanical Biological Treatment (MBT) facility encompasses tangible and measurable revenues obtained for the receipt, processing and sale of raw or processed products. Revenue generation for MBT facilities consist primarily of operating revenues and are divided into long-term fixed price income and value-based pricing. As outlined within Chapter 3.2.3, market and primary data obtained for the case study is utilised to assess the MBT facility's revenue stream, divided into 5categories and presented in Thailand Baht (THB).

5.3.1 Waste Treatment Fee

A waste treatment facility in practice charges a waste treatment fee (also known as a gate fee or tipping fee) for MSW received and processed. There are two established mechanisms for the charging of waste treatment fees; either by nett disposal weight recorded at the facility's weighbridge or by a fixed disposal rate regardless of weight or volume of disposal. The determination of the appropriate waste treatment fee is the basis of this research and shall be presented based on analysis of all data presented within this study.

5.3.2 Mechanically Recovered Products

Waste components recovered during the mechanical recovery phase of the MBT facility are sold at prevailing market spot rates to local off takers for further processing. Recovery and sale of waste components is dependent on commercial viability or/and legislative/contractual requirements and is sold as "recovered" basis. For the case study, material recovery is limited to ferrous and non-ferrous metals. Table 5.18 lists the case study's revenue potential from sale of recovered metals based on projected wasted component recovery and local spot prices as of 29th November 2017 (Wangpanit Group, 2017)

Table 5.18: Revenue – Mechanically-Recovered Waste Products

Mechanically-Recovered Waste Component	Annualised Recovery Potential (tonne/year)	Market Spot Price (29.11.2017) (THB/tonne)	Annualised Revenue (THB)
Ferrous Metal	772.942	1,700.00	1,314,001.40
Stainless Steel	33.588	26,000.00	873,288.00
Copper	50.382	98,000.00	4,937,436.00
Aluminium	268.722	29,000.00	7,792,938.00
Sub-Total: Mechanically-Recovered Products (THB)			**14,917,663.40**

5.3.3 Biological Treatment Products

This section breakdowns revenue generated by the sale and export of waste products generated by the biological treatment phase of the MBT facility. Product generation is dependent on biological treatment technology selection. For the case study, the selected anaerobic digestion process produces digestate and biogas. Digestate is divided to liquid and solid fractions. The solid fraction requires further processing prior to export but excess liquid fraction is sold as "liquid fertiliser" for general application purposes.

Biogas generated is converted into electricity for export. Electricity export revenue for the case study is based on the National Energy Policy Commission (NEPC) 20-Year Feed-in Tariff (FiT) power purchase agreement for Very Small Power Producers (VSPP). Under the programme, integrated waste management projects shall receive a FiT comprising of a fixed base rate and variable rate adjusted annually based on national inflation rate over a period of 20-years. The project is eligible for additional FiT premium for the first 8 years of operation of utilisation bio-based fuels. Table 5.19 presents the case study's annualised revenue potential from electricity export and sale of liquid fertiliser.

Table 5.19: Revenue – Biological Treatment Products

Biological Treatment Product	Annualised Product Export Potential	Unit Rate (THB/Unit)	Annualised Revenue (THB)
Electrical Power Nett Export	22,392MWhr	6.5/kWhr (Note 1)	145,995,840.00
Liquid Digestate	21,800 m^3	500/m^3 (Note 2)	10,900,000.00
Sub-Total: Biological Treatment (THB)			**156,895,840.00**

Note 1: FiT Rate = Base Rate - THB2.61/kWhr, Variable Rate - THB3.21/kWhr and FiT premium – THB 0.7/kWhr (WFW, 2015)

Note 2: Based on long-term supply contract

5.3.4 Market-prepared Products

Market-prepared products are waste products that undergo further on-site processing prior to sale or export. Product preparation is based by specific off taker requirement through a long-term supply agreement, general market specifications or for purposes of increasing a product's market value.

The case study has secured 2 long-term supply contracts for refused-derived fuel (RDF) and finished compost. RDF is prepared to purchaser specification, collected and transported to be used a cement kiln fuel at Saraburi province, north of Bangkok. Finished compost is exported to the Middle East as a soil conditioner.

Table 5.20 presents the annualised revenue potential from RDF and finished compost sale based on long-term supply contracts.

Table 5.20: Revenue – Market-Prepared Products

Market-Prepared Product	Annualised Product Export Potential (tonne)	Unit Rate (THB/tonne)	Annualised Revenue (THB)
Refuse-derived Fuel (RDF)	95,112.30	490.00 (Note 1)	65,627,487.00
Finished Compost	14,112.00	1,000.00 (Note 2)	14,112,000.00
Sub-Total: Biological Treatment (THB)			**79,739,487.00**

Note 1: Based on long-term supply contract with cement kiln, Saraburi Province
Note 2: Based on long-term export contract to Abu Dhabi, UAE.

5.3.5 Project Incentives

Project incentives are defined as payments, revenues, concessions or motivations that is provided by way of fiscal payment, subsidy, tax reduction or exemption or other methods to stimulate or encourage project investment, execution and operation. Incentives are dependent on respective geopolitical situations, government policy or other motivations and can be provided at any stage of project development or execution. Project incentives received are incorporated into the capital and operational expenditure and revenue components of the simulation model as deemed appropriate.

The case study received Thailand's Board of Investment (BOI) No.2/2557 Investment Promotion Group A1 approval under Section 7.1.1.1: Production of

Electricity or Electricity and steam from garbage or refused derived fuel. Project incentives provided under the Group A1 incentive category are listed as below;

1. 8-year corporate income tax exemption without being subject to a corporate income tax exemption cap
2. Exemption of import duty on machinery
3. Exemption of import duty on raw or essential materials used in manufacturing export products for 1 year, which can be extended as deemed appropriate by the Board
4. Other non-tax incentives.

Project incentives are incorporated within the computer simulation for determination of a suitable waste treatment fee of the case study.

5.4 Conclusion of the Chapter

Project capital investment for a Mechanical Biological Treatment (MBT) facility is divided into 8 categories – land, authority & financing; engineering & project management; civil & architectural works; waste reception; material recovery; biological treatment; preparation for market and construction & commissioning. On assessment of the case study’s technical requirements and equipment selection, the case study’s base cost estimate is determined at THB 1,548,249,933.77. Additionally, 10% and 5% of project base cost estimate is set as project contingency and construction financing buffers respectively, bring the case study’s overall project capital expenditure to THB 1,780,487,423.84.

Project operational expenditure throughout the lifetime of a MBT facility is divided into 8 categories – personnel; land & facility expenditure, equipment maintenance; chemicals, utilities & fuel expenditure; support services, licencing, insurances, quality management & taxation; administration & project debt-repayment. All operational categories are subject to external economic influences such as core inflation adjustment over the facility's operating lifecycle. These adjustments are incorporated within the computer simulation for determining annual changes in waste treatment fee rates over the operating lifetime.

Project revenue potential of a MBT facility is dependent on specific project deliverables and can be divided into 5 general categories – waste treatment fee; mechanically recovered products; biological treatment products, market-prepared products and project incentives. For the case study, revenue from the mechanically-recovered products stream encompass ferrous metals, stainless steel, copper and aluminium recovery.

For the biological treatment phase, the case study generates and export nett electricity and liquid digestate while market-prepared products include refuse-derived fuel (RDF) and finished compost. Facility revenue streams are determined based on current market spot rates and assumed rate increases over the facility lifecycle, facility availability and expected operational efficiency rates, with results calculated through computation utilising the proposed computer simulation.

CHAPTER 6 Financial Model Simulation Results

This chapter presents the proposed pricing mechanism's design framework and results for determination of an appropriate MSW treatment fee pricing for a MBT facility based on pre-set projected internal rate of return (I.R.R). The chapter is divided into 6 sections; introduction to proposed computer simulation; simulation assumptions; data entry and utilisation; output generation; simulation results and validation of simulation results.

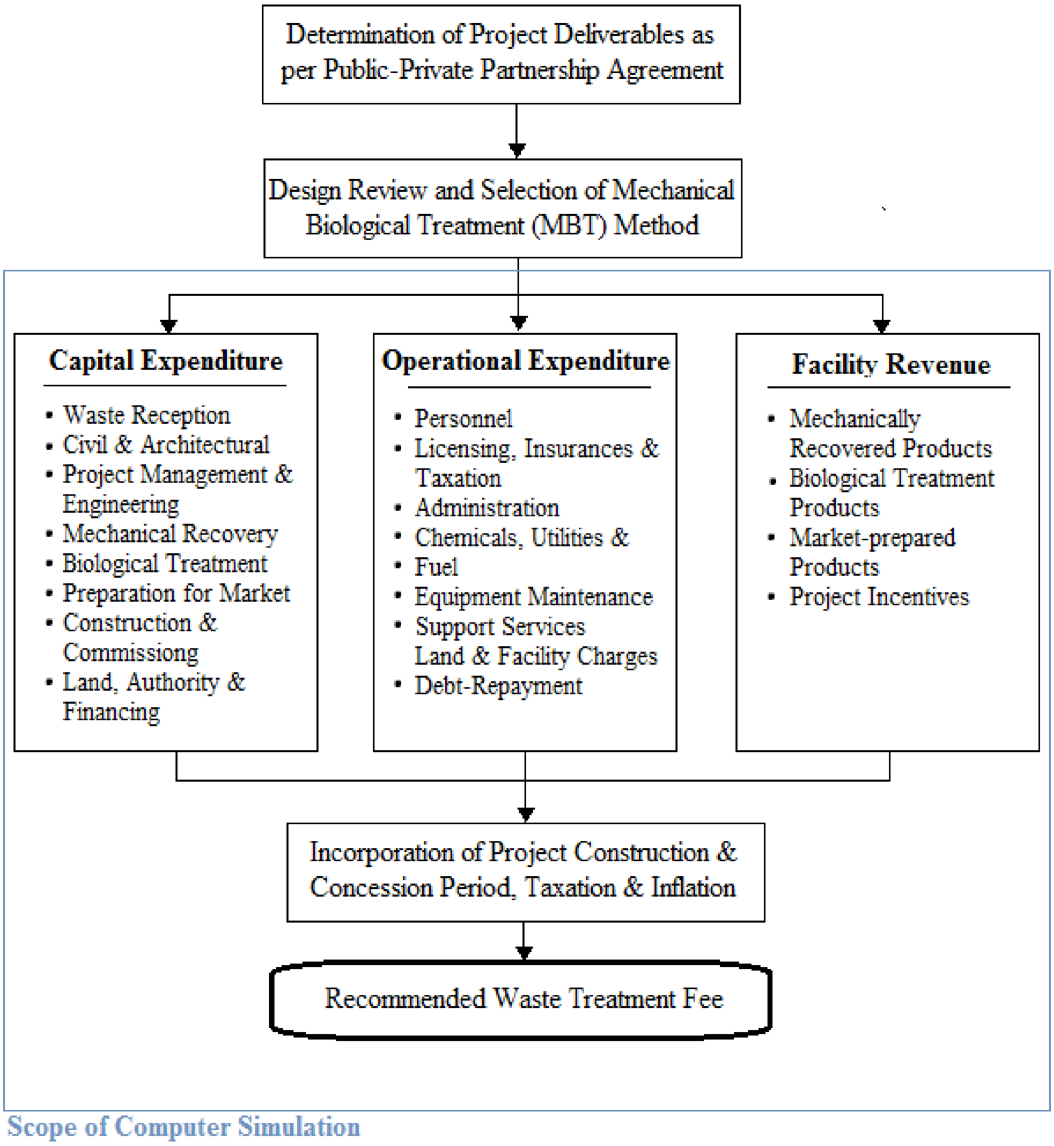
6.1 Introduction to Computer Simulation

The computer simulation is created on the Microsoft Excel 2013 platform. Individual spreadsheets are created within a singular workbook for purposes of data entry and processing, with respective outputs from each spreadsheet hyperlinked to the master spreadsheet for determination of the expected MSW waste treatment fee value.

The computer simulation workbook created for determination of the appropriate waste treatment fee is designed, incorporating case study deliverables as presented within Chapter 4 and 5 of the study. The computer simulation captures capital investment, operational expense and facility revenue that are the foundation of the MBT concept, albeit with minor adjustment based on individual facility specific technical and commercial deliverables.

The program simulates the project's expected cash flow over the duration of project delivery and facility operation in accordance with the expected project concession period and incorporates forecasted inflation rates, taxation, and reduced facility efficiency, among others. Figure 6.1 summarises the computer simulation process and decision flow chart for determination of waste treatment fee based on pre-set internal rate-of-return.

Figure 6.1: Computer Simulation Data Flow Chart for Determination of Waste Treatment Fee



6.2 Computer Simulation Assumption

Results computed using the simulation are based on data obtained during case study, used to simulate comparable conditions as close to actual market conditions. It is impossible to forecast long-term global market trends or replicate identical factors as computed by the simulation. In this regard, assumptions taken into consideration within the simulation are listed along with reasonable justification;

1. Inflation rate is based on Bank of Thailand's 5-year average core consumer price index (2013-2017) recorded at a compounded rate of 0.98% per annum (BOT, 2017)

2. Corporate tax rate is calculated based on Thailand's Board of Investment (BOI) No.2/2557 Investment Promotion Group A1 incentive, providing tax-free status for first 8 years followed by 20% tax rate for proceeding years.

3. Electricity variable feed-in tariff (FiTv) rate is adjusted based on Thailand's 5-year average core consumer price index, at a compounded rate of 0.98% per annum.

4. Recovered/prepared for market commodity sale pricing is recorded at 2017 market rates and increased by 5% at intervals of 5 years (Year 5, Year 10, Year 15 and Year 20) to simulate commodity price increase over the facility's operating period.

5. Facility personnel expenditure is increased at a compounded rate of 5% annually, with other facility expenditure adjusted based on Thailand's 5-year average core consumer price index, at a compounded rate of 0.98% per annum.

6. The simulation selling, general and administrative expenses (SG&A) is computed as 2% of the annual operational expenses (OPEX).

7. Waste treatment fee pricing is adjusted based on Thailand's 5-year average core consumer price index, at a compounded rate of 0.98% per annum.

8. Owner's capital (also known as owner's equity) is retained throughout the operating life of the facility. The case study's Return on Equity (ROE) calculations shall be based on retained assets inclusive of retained profits over the life cycle of the facility.

6.3 Input Data Entry

To best explain the computer simulation analysis, primary and secondary data obtained during the case study's technical and commercial evaluation is presented and inputted into 8 individual spreadsheets within the simulation programme, incorporating project assumptions as provided within Chapter 6.2. Primary and secondary data entry is inputted within the Year 1 data entry columns within the simulation, with the program computing expected revenue and expense streams over the duration of the case study's life cycle. Table 6.1 summarises the contents of each input data entry spreadsheet as presented within the simulation model.

Table 6.1: Summary of Simulation Model Data Input Entry Spreadsheets

Simulation Model Input Data Spreadsheet	Description of Input Data included within Spreadsheet
Project Description	• Project Information • Contracted Waste Receipt & Availability • Revenue Stream Spot Pricing • Pre-Set Waste Treatment Fee • Project Efficiency Data
Project Assumption List	• Core Consumer Pricing Index • Corporate Tax Rate • Variable Electricity FiT Inflation Rate • Commodity Sale Price Increase Quantum • Facility Operational Personnel Inflation Rate • Facility Operational Expense Inflation
Project Waste Data	• Waste Composition Analysis Results (percentage) • Waste Separation Efficiency Data

Simulation Model Input Data Spreadsheet	Description of Input Data included within Spreadsheet
Project CAPEX	• Land, Authority & Financing • Engineering & Project Management • Civil & Architectural Works • Waste Reception • Mechanical Recovery • Biological Treatment • Preparation for Market • Construction & Commissioning • Project Contingency (Percentage) • Construction Financing Margin (Percentage)
Project OPEX	• Land & Facility Charges • Equipment Maintenance • Chemicals, Lubricants and Oils • Support Services • Licencing & Insurances • Administration
Project O&M Manpower	• Personnel Base Salary • Employer Provident Fund Contribution • Annual Personnel Insurance Contribution • Calculated Annual Bonus Payment
Project Revenue	• Electrical Generation • Sale of Recyclables • Sale of Market-Prepared & Process-based Products
Project Debt-Repayment	• Debt/Equity Split Percentage • Debt Repayment Period • Lending Rate per Annum

6.3.1 Calculation of Project CAPEX, OPEX and Revenue Streams

The computer simulation presents case study data by sub-categories, with primary data plugged into respective input data sheets to determine the projects capital investment, operational expenditure and revenue quantum. The determination of the case study annualised operational expenses over the duration of project O&M phase takes into account project assumptions such as core consumer pricing index and inflation rate.

Input data is processed and compounded into CAPEX, OPEX and Revenue summary sheets, presenting the case study's annualised income and expenses. Figure 6.2, 6.3 & 6.4 presents the case study computer simulation OPEX summary sheet and revenue summary sheet, respectively.

Figure 6.2: Annualised OPEX Summary Sheet (Year 3 to Year 22)

Project Expenditure Summary	Note	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Personnel Expenditure	THB			21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52
Cummalative Inflation Rate	Inflation			105.00	110.25	115.76	121.55	127.63	134.01	140.71	147.75	155.13
Annualised Personnel Expenditure	**THB**			**22,289,528.65**	**23,404,005.08**	**24,574,206.34**	**25,802,916.60**	**27,093,061.33**	**28,447,714.45**	**29,870,100.18**	**31,363,605.18**	**32,931,785.44**
Land & Facility Charges	THB			4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Land & Facility Charges	**THB**			**4,456,582.48**	**4,500,238.77**	**4,544,339.09**	**4,588,873.81**	**4,633,844.67**	**4,679,258.25**	**4,725,112.98**	**4,771,419.07**	**4,818,178.88**
Equipment Maintenance	THB			32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Equipment Maintenance	**THB**			**33,089,833.28**	**33,414,113.83**	**33,741,571.94**	**34,072,238.34**	**34,406,147.29**	**34,743,327.53**	**35,083,812.14**	**35,427,633.50**	**35,774,824.31**
Chemicals, Lubricants and Oils	THB			31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Chemicals, Lubricants, Oils	**THB**			**31,548,721.44**	**31,857,898.91**	**32,170,106.32**	**32,485,373.38**	**32,803,730.02**	**33,125,206.57**	**33,449,833.59**	**33,777,641.98**	**34,108,662.88**
Support Services	THB			7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Support Services	**THB**			**7,842,510.72**	**7,919,367.33**	**7,996,977.12**	**8,075,347.50**	**8,154,485.91**	**8,234,399.87**	**8,315,098.99**	**8,396,584.94**	**8,478,871.47**
Licencing & Permits	THB			3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Licencing & Permits	**THB**			**3,251,556.00**	**3,283,421.25**	**3,315,598.78**	**3,348,091.65**	**3,380,902.94**	**3,414,035.79**	**3,447,493.34**	**3,481,278.78**	**3,515,396.31**
Administration	THB			3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00
Cummalative Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Annualised Administration	**THB**			**3,531,422.07**	**3,566,030.01**	**3,600,977.10**	**3,636,266.68**	**3,671,902.09**	**3,707,886.73**	**3,744,224.02**	**3,780,917.42**	**3,817,970.41**
Nett Annualised Expenditure	THB			106,010,134.59	107,946,072.98	109,943,776.68	112,009,107.74	114,144,074.20	116,351,827.20	118,635,673.23	120,999,080.35	123,446,683.77

Project Expenditure Summary	Note	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22
Personnel Expenditure	THB	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52	21,228,122.52
Cummalative Inflation Rate	Inflation	162.89	171.03	179.59	188.56	197.99	207.89	218.29	229.20	240.66	252.70	265.33
Annualised Personnel Expenditure	**THB**	**34,578,374.72**	**36,307,293.45**	**38,122,658.12**	**40,028,791.03**	**42,030,230.58**	**44,131,742.11**	**46,338,329.22**	**48,655,245.68**	**51,088,007.96**	**53,642,408.36**	**56,324,528.78**
Land & Facility Charges	THB	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00	4,413,312.00
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Land & Facility Charges	**THB**	**4,865,387.13**	**4,913,078.02**	**4,961,228.19**	**5,009,848.20**	**5,058,942.70**	**5,108,520.33**	**5,158,583.83**	**5,209,137.98**	**5,260,187.51**	**5,311,737.35**	**5,363,792.37**
Equipment Maintenance	THB	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00	32,768,700.00
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Equipment Maintenance	**THB**	**36,125,417.59**	**36,479,446.68**	**36,836,945.26**	**37,197,947.32**	**37,562,487.21**	**37,930,598.58**	**38,302,319.46**	**38,677,682.19**	**39,056,723.47**	**39,439,479.36**	**39,825,988.26**
Chemicals, Lubricants and Oils	THB	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50	31,242,544.50
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Chemicals, Lubricants, Oils	**THB**	**34,442,927.75**	**34,780,468.44**	**35,121,317.03**	**35,465,505.94**	**35,813,067.90**	**36,164,035.96**	**36,518,443.52**	**36,876,324.28**	**37,237,712.24**	**37,602,641.82**	**37,971,147.71**
Support Services	THB	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00	7,766,400.00
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Support Services	**THB**	**8,561,964.41**	**8,645,871.66**	**8,730,601.20**	**8,816,161.10**	**8,902,559.47**	**8,989,804.55**	**9,077,904.64**	**9,166,868.11**	**9,256,703.41**	**9,347,419.11**	**9,439,023.82**
Licencing & Permits	THB	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00	3,220,000.00
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Licencing & Permits	**THB**	**3,549,848.13**	**3,584,636.63**	**3,619,764.10**	**3,655,237.78**	**3,691,059.11**	**3,727,231.49**	**3,763,763.36**	**3,800,643.19**	**3,837,889.50**	**3,875,500.81**	**3,913,480.72**
Administration	THB	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00	3,497,150.00
Cummalative Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Annualised Administration	**THB**	**3,855,338.52**	**3,893,169.30**	**3,931,322.36**	**3,969,849.32**	**4,008,753.85**	**4,048,038.63**	**4,087,710.42**	**4,127,769.98**	**4,168,222.13**	**4,209,070.71**	**4,250,318.60**
Nett Annualised Expenditure	THB	125,979,314.30	128,603,982.24	131,328,234.27	134,143,338.70	137,067,100.32	140,099,973.87	143,247,049.45	146,513,871.37	149,905,446.22	153,428,257.52	157,088,279.28

Figure 6.3: Annualised Revenue Summary Sheet (Year 3 to Year 11)

Project Revenue Summary	Note	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Annual Electricity Generation	kWh			22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00
Base Feed-In Tariff (FiTbase)	THB			2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Variable Feed-In Tariff (FiTv)	THB			3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21
FiTv Annualised Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
FiTv Price	THB			3.24	3.27	3.31	3.34	3.37	3.40	3.44	3.47	3.50
Premium Feed-In Tariff (FiTpremium)	8 Yrs			0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	-
Total FiT Rate	THB			6.55	6.58	6.62	6.65	6.68	6.71	6.75	6.78	6.11
Electricity Generation	**THB**			**146,700,247.54**	**147,411,558.27**	**148,129,839.84**	**148,855,160.58**	**149,587,589.45**	**150,327,196.13**	**151,074,050.96**	**151,828,224.96**	**136,915,389.87**
Annual Ferrous Recovery	tonnes			772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52
Spot Price	THB			1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			1,700.00	1,700.00	1,700.00	1,700.00	1,785.00	1,785.00	1,785.00	1,785.00	1,785.00
Recovery of Ferrous Metals	**THB**			**1,313,290.80**	**1,313,290.80**	**1,313,290.80**	**1,313,290.80**	**1,378,955.34**	**1,378,955.34**	**1,378,955.34**	**1,378,955.34**	**1,378,955.34**
Annual Stainless Steel Recovery	tonnes			33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59
Spot Price	THB			26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			26,000.00	26,000.00	26,000.00	26,000.00	27,300.00	27,300.00	27,300.00	27,300.00	27,300.00
Recovery of Stainless Steel	**THB**			**873,288.00**	**873,288.00**	**873,288.00**	**873,288.00**	**916,952.40**	**916,952.40**	**916,952.40**	**916,952.40**	**916,952.40**
Annual Copper Recovery	tonnes			50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38
Spot Price	THB			98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			98,000.00	98,000.00	98,000.00	98,000.00	102,900.00	102,900.00	102,900.00	102,900.00	102,900.00
Recovery of Copper Metals	**THB**			**4,937,436.00**	**4,937,436.00**	**4,937,436.00**	**4,937,436.00**	**5,184,307.80**	**5,184,307.80**	**5,184,307.80**	**5,184,307.80**	**5,184,307.80**
Annual Aluminium Recovery	tonnes			268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70
Spot Price	THB			29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			29,000.00	29,000.00	29,000.00	29,000.00	30,450.00	30,450.00	30,450.00	30,450.00	30,450.00
Recovery of Aluminium	**THB**			**7,792,416.00**	**7,792,416.00**	**7,792,416.00**	**7,792,416.00**	**8,182,036.80**	**8,182,036.80**	**8,182,036.80**	**8,182,036.80**	**8,182,036.80**
Annual Liquid Fertilizer Production	tonnes			21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00
Spot Price	THB			500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			500.00	500.00	500.00	500.00	525.00	525.00	525.00	525.00	525.00
Recovery of Liquid Fertilizer	**THB**			**10,900,000.00**	**10,900,000.00**	**10,900,000.00**	**10,900,000.00**	**11,445,000.00**	**11,445,000.00**	**11,445,000.00**	**11,445,000.00**	**11,445,000.00**
Annual Finished Compost Production	tonnes			14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00
Spot Price	THB			1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			1,000.00	1,000.00	1,000.00	1,000.00	1,050.00	1,050.00	1,050.00	1,050.00	1,050.00
Finished Compost Production	**THB**			**14,112,000.00**	**14,112,000.00**	**14,112,000.00**	**14,112,000.00**	**14,817,600.00**	**14,817,600.00**	**14,817,600.00**	**14,817,600.00**	**14,817,600.00**
Refuse-derived Fuel (RDF) Production	tonnes			95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30
Spot Price	THB			490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00
Spot Price Inflation Rate	Inflation			100.00	100.00	100.00	100.00	105.00	105.00	105.00	105.00	105.00
Accumulated Spot Price	THB			490.00	490.00	490.00	490.00	514.50	514.50	514.50	514.50	514.50
Refused-derived Fuel (RDF) Sale	**THB**			**46,605,027.00**	**46,605,027.00**	**46,605,027.00**	**46,605,027.00**	**48,935,278.35**	**48,935,278.35**	**48,935,278.35**	**48,935,278.35**	**48,935,278.35**
Annual MSW Receipt	tonnes			186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00
Pre-determined Waste Treatment Fee	THB			500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Waste Treatment Fee Inflation Rate	Inflation			100.98	101.97	102.97	103.98	105.00	106.03	107.07	108.11	109.17
Accumulated Waste Treatment Fee	THB			504.90	509.85	514.84	519.89	524.98	530.13	535.33	540.57	545.87
Waste Treatment Fee	**THB**			**94,214,340.00**	**95,137,640.53**	**96,069,989.41**	**97,011,475.31**	**97,962,187.76**	**98,922,217.20**	**99,891,654.93**	**100,870,593.15**	**101,859,124.96**
Nett Annualised Revenue	**Note 1**			**327,448,045.34**	**329,082,656.60**	**330,733,287.05**	**332,400,093.68**	**338,409,907.91**	**340,109,544.03**	**341,825,836.58**	**343,558,948.80**	**329,634,645.53**

Figure 6.4: Annualised Revenue Summary Sheet (Year 12 to Year 22)

Project Revenue Summary	Note	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22
Annual Electricity Generation	kWh	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00	22,392,000.00
Base Feed-In Tariff (FiTbase)	THB	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Variable Feed-In Tariff (FiTv)	THB	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21
FiTv Annualised Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
FiTv Price	THB	3.54	3.57	3.61	3.64	3.68	3.72	3.75	3.79	3.83	3.86	3.90
Premium Feed-In Tariff (FiTpremium)	First 8 Year	-	-	-	-	-	-	-	-	-	-	-
Total FiT Rate	THB	6.15	6.18	6.22	6.25	6.29	6.33	6.36	6.40	6.44	6.47	6.51
Electricity Generation	**THB**	**137,684,418.12**	**138,460,982.84**	**139,245,157.89**	**140,037,017.87**	**140,836,638.06**	**141,644,094.54**	**142,459,464.09**	**143,282,824.26**	**144,114,253.37**	**144,953,830.47**	**145,801,635.44**
Annual Ferrous Recovery	tonnes	772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52	772.52
Spot Price	THB	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00	1,700.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	1,874.25	1,874.25	1,874.25	1,874.25	1,874.25	1,967.96	1,967.96	1,967.96	1,967.96	1,967.96	2,066.36
Recovery of Ferrous Metals	**THB**	**1,447,903.11**	**1,447,903.11**	**1,447,903.11**	**1,447,903.11**	**1,447,903.11**	**1,520,298.26**	**1,520,298.26**	**1,520,298.26**	**1,520,298.26**	**1,520,298.26**	**1,596,313.18**
Annual Stainless Steel Recovery	tonnes	33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59	33.59
Spot Price	THB	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00	26,000.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	28,665.00	28,665.00	28,665.00	28,665.00	28,665.00	30,098.25	30,098.25	30,098.25	30,098.25	30,098.25	31,603.16
Recovery of Stainless Steel	**THB**	**962,800.02**	**962,800.02**	**962,800.02**	**962,800.02**	**962,800.02**	**1,010,940.02**	**1,010,940.02**	**1,010,940.02**	**1,010,940.02**	**1,010,940.02**	**1,061,487.02**
Annual Copper Recovery	tonnes	50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38	50.38
Spot Price	THB	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00	98,000.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	108,045.00	108,045.00	108,045.00	108,045.00	108,045.00	113,447.25	113,447.25	113,447.25	113,447.25	113,447.25	119,119.61
Recovery of Copper Metals	**THB**	**5,443,523.19**	**5,443,523.19**	**5,443,523.19**	**5,443,523.19**	**5,443,523.19**	**5,715,699.35**	**5,715,699.35**	**5,715,699.35**	**5,715,699.35**	**5,715,699.35**	**6,001,484.32**
Annual Aluminium Recovery	tonnes	268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70	268.70
Spot Price	THB	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00	29,000.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	31,972.50	31,972.50	31,972.50	31,972.50	31,972.50	33,571.13	33,571.13	33,571.13	33,571.13	33,571.13	35,249.68
Recovery of Aluminium	**THB**	**8,591,138.64**	**8,591,138.64**	**8,591,138.64**	**8,591,138.64**	**8,591,138.64**	**9,020,695.57**	**9,020,695.57**	**9,020,695.57**	**9,020,695.57**	**9,020,695.57**	**9,471,730.35**
Annual Liquid Fertilizer Production	tonnes	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00	21,800.00
Spot Price	THB	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	551.25	551.25	551.25	551.25	551.25	578.81	578.81	578.81	578.81	578.81	607.75
Recovery of Liquid Fertilizer	**THB**	**12,017,250.00**	**12,017,250.00**	**12,017,250.00**	**12,017,250.00**	**12,017,250.00**	**12,618,112.50**	**12,618,112.50**	**12,618,112.50**	**12,618,112.50**	**12,618,112.50**	**13,249,018.13**
Annual Finished Compost Production	tonnes	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00	14,112.00
Spot Price	THB	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	1,102.50	1,102.50	1,102.50	1,102.50	1,102.50	1,157.63	1,157.63	1,157.63	1,157.63	1,157.63	1,215.51
Finished Compost Production	**THB**	**15,558,480.00**	**15,558,480.00**	**15,558,480.00**	**15,558,480.00**	**15,558,480.00**	**16,336,404.00**	**16,336,404.00**	**16,336,404.00**	**16,336,404.00**	**16,336,404.00**	**17,153,224.20**
Refuse-derived Fuel (RDF) Production	tonnes	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30	95,112.30
Spot Price	THB	490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00	490.00
Spot Price Inflation Rate	Inflation	110.25	110.25	110.25	110.25	110.25	115.76	115.76	115.76	115.76	115.76	121.55
Accumulated Spot Price	THB	540.23	540.23	540.23	540.23	540.23	567.24	567.24	567.24	567.24	567.24	595.60
Refused-derived Fuel (RDF) Sale	**THB**	**51,382,042.27**	**51,382,042.27**	**51,382,042.27**	**51,382,042.27**	**51,382,042.27**	**53,951,144.38**	**53,951,144.38**	**53,951,144.38**	**53,951,144.38**	**53,951,144.38**	**56,648,701.60**
Annual MSW Receipt	tonnes	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00	186,600.00
Pre-determined Waste Treatment Fee	THB	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Waste Treatment Fee Inflation Rate	Inflation	110.24	111.32	112.42	113.52	114.63	115.75	116.89	118.03	119.19	120.36	121.54
Accumulated Waste Treatment Fee	THB	551.22	556.62	562.08	567.58	573.15	578.76	584.43	590.16	595.95	601.79	607.68
Waste Treatment Fee	**THB**	**102,857,344.39**	**103,865,346.36**	**104,883,226.76**	**105,911,082.38**	**106,949,010.99**	**107,997,111.29**	**109,055,482.99**	**110,124,226.72**	**111,203,444.14**	**112,293,237.89**	**113,393,711.62**
Nett Annualised Revenue	**THB**	**335,944,899.73**	**337,729,466.43**	**339,531,521.88**	**341,351,237.47**	**343,188,786.28**	**349,814,499.92**	**351,688,241.16**	**353,580,345.07**	**355,490,991.59**	**357,420,362.45**	**364,377,305.85**

Results generated from data inputted is incorporated into the simulation's balance sheet and profit-loss statement sheet to determine expected project waste treatment fees based on pre-set project internal rate-of-return (IRR).

6.4 Simulation Results – Projected Internal Rate of Return

On incorporation of project data into the simulation, the project's likely waste treatment fee is computed based on IRR scenarios of 8%, 10% and 12%. Each IRR scenario generates a complete set of project financials as the differing waste treatment fee changes the project's overall margin and cash flow over the project's intended life cycle.

During the computer simulation writing process, it was observed that the utilisation of the project's IRR to compute the case study's waste treatment fee had generated erroneous results due to the project's dependence of discount rate calculation for the determination of the project's IRR rate. In this regard, the computer simulation was modified to compute the project's IRR (dependent value) based on expected waste treatment fee (independent value). The results obtained within the modified computer simulation had generated comparable results as initially proposed within the research framework, hence was accepted as the pricing mechanism for this study. Utilising the sensitivity analysis method, the case study's waste treatment fee is computed for IRR rates of 8.00%, 10.00% and 12.00%.

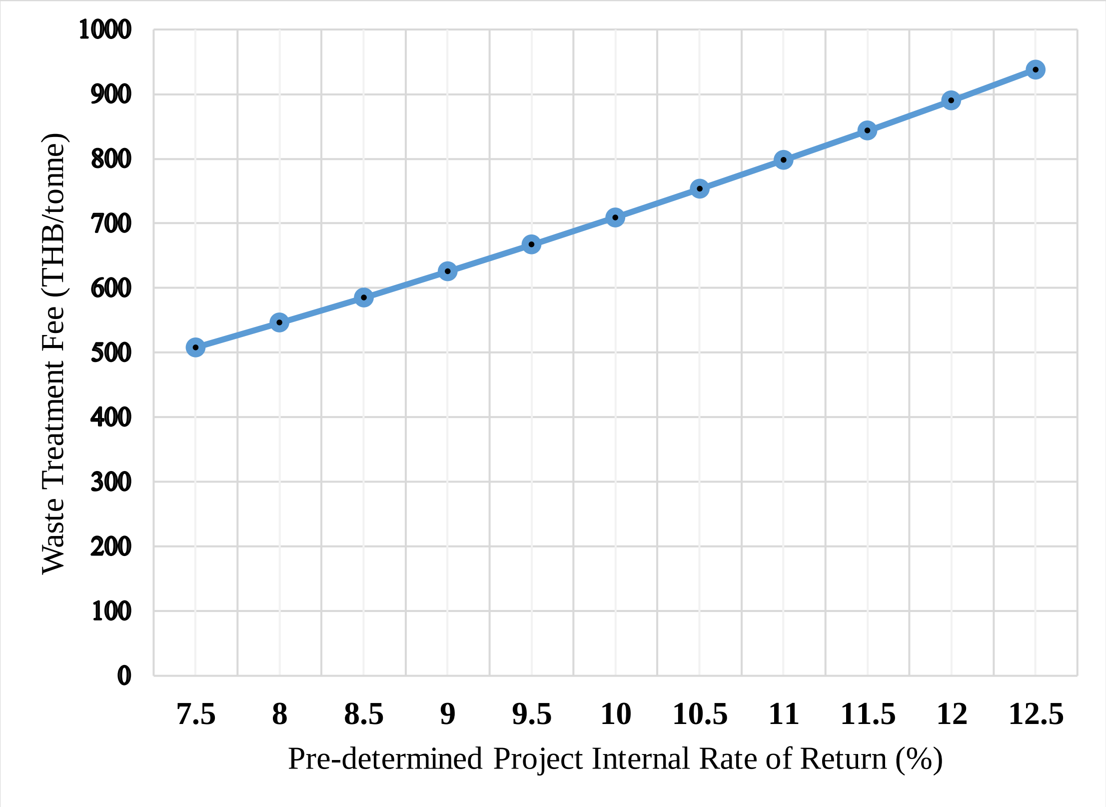
The computer simulation is further expanded to determine case study waste treatment fee (in Thai baht) at IRR intervals of 0.50%, from IRR rate of 7.50% to 12.50, rounded up to the closest 2 decimal points. This exercise is conducted to understand the waste fee growth trend in comparison to IRR growth rate. Table 6.2 presents the computer simulation waste treatment fee results based on pre-determined project IRR rates.

Table 6.2: Computer Simulation Waste Treatment Fee Results based on Project Internal Rate of Return (IRR)

Internal Rate of Return (IRR) (%)	**Waste Treatment Fee Results (THB/tonne)**
7.50	**508.00**
8.00	**546.00**
8.50	**585.00**
9.00	**625.50**
9.50	**667.00**
10.00	**709.00**
10.50	**753.00**
11.00	**798.00**
11.50	**843.50**
12.00	**890.00**
12.50	**938.00**

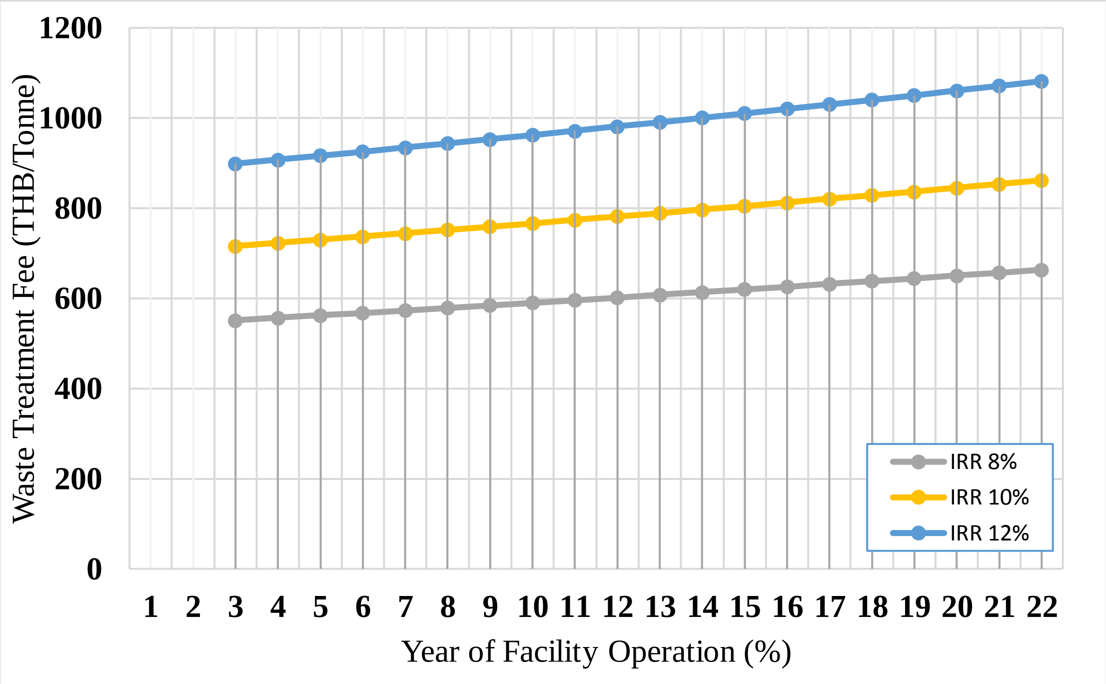
The simulation computed first-year waste treatment fees of THB 546.00, THB 709.00 and THB 890.00 based on pre-determined project internal rate of returns of 8.00%, 10.00% and 12.00% respectively. Results observe near-linear growth between the case study's pre-determined IRR and the chargeable waste treatment fee. Figure 6.5 illustrates the near-linear correlation between case study's waste treatment fee and IRR growth.

Figure 6.5: Project Waste Treatment Fee Growth based on Pre-determined Project Internal Rate-of-Return (IRR).



The case study computed waste treatment fee is subjected to annualised increases based on expected core inflation rate over the lifetime of the project. Based on modelling results, waste treatment fee/tonne ranges for the following IRR is observed at the following rates: 8% IRR (THB 546.00 – THB663.59), 10% (THB 709.00 - THB 861.69) and 12% (THB 890.00 – THB 1081.67). Figure 6.6 present annualised waste treatment fee pricing at pre-determined IRR over the facility’s operating period.

Figure 6.6: Annualised Waste Treatment Fee/Tonne based on Pre-Determined Project Internal Rate-of-Return (IRR).



6.5 Simulation Results based on Differing Scenarios

The computer simulation is utilised to analyse waste treatment fee structures based on potential plant efficiency and economic scenarios over the expected operating life of the facility. Three scenarios selected are: 1) plant availability, 2) changes in core inflation rate, and 3) effects on changes of biological treatment product sale pricing.

6.5.1 Waste Treatment Fee based on Plant Availability

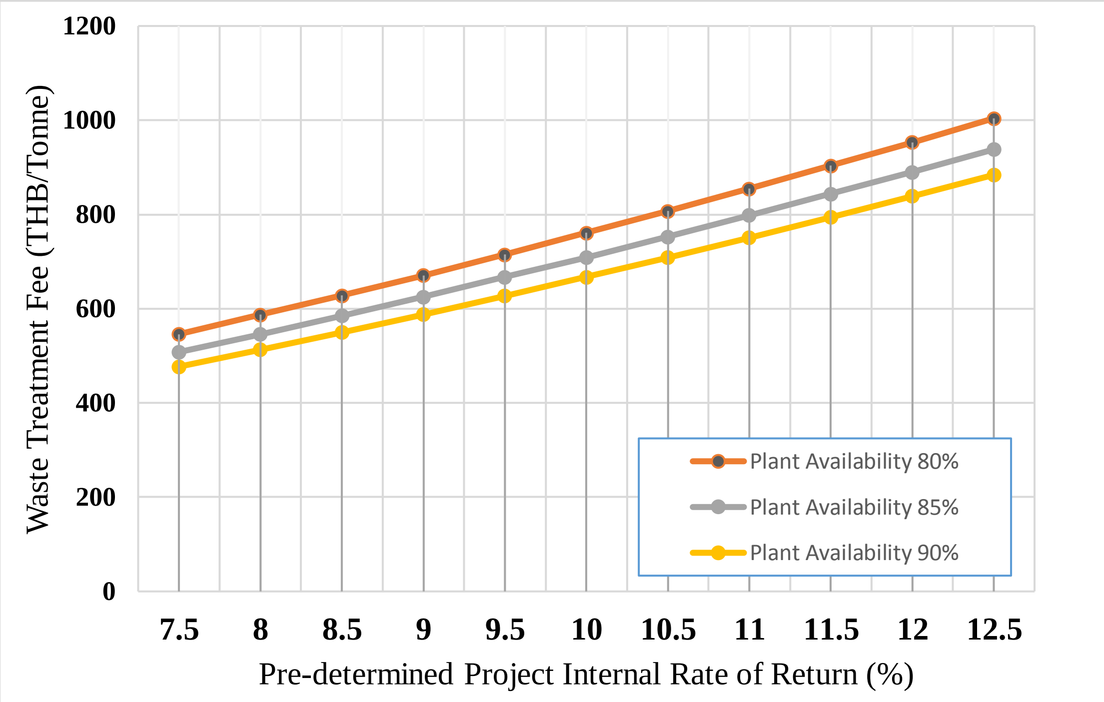
The case study's waste treatment fee is determined using differing operational availability rates to analysis the effects of changes in reduced or increased waste throughput over life of the facility. The case study term of reference (TOR) listed project availability at 85%, and the facility shall be designed to cater for daily waste receipt fluctuation rate of +/- 5%. This can be correlated is plant availability ranges of between 75% and 85% for the purposes of the simulation. Facility operating expense changes are considered negligible as the case study's fixed costs remain constant, with no or minimal changes to variable costs at differing treatment throughputs. Table 6.3 lists waste treatment fee based on pre-determined IRR rates between 7.50% and 12.50%, at case study pre-determined availability rates of 80%, 85% and 90%.

Table 6.3: Waste Treatment Fee Results based on Pre-determined Project Internal Rate of Return (IRR) & Plant Operational Availability Scenarios

Project IRR (Input Data) (%)	Waste Treatment Fee Results (Output Data in THB)		
	Plant Availability 80%	Plant Availability 85%	Plant Availability 90%
7.50	**546.00**	**508.00**	**477.00**
8.00	**587.00**	**546.00**	**513.00**
8.50	**628.00**	**585.00**	**550.00**
9.00	**671.00**	**625.50**	**588.00**
9.50	**715.00**	**667.00**	**627.00**
10.00	**761.00**	**709.00**	**667.50**
10.50	**807.00**	**753.00**	**709.00**
11.00	**854.50**	**798.00**	**751.00**
11.50	**903.50**	**843.50**	**794.00**
12.00	**953.00**	**890.00**	**839.00**
12.50	**1,004.00**	**938.00**	**884.00**

Simulation results at differing plant availability rates demonstrate that the case study’s waste treatment fee rate changes by 9.30% based on annualised plant availability rate changes of 5%. Figure 6.7 illustrates waste treatment fee changes based on plant availability rates of 80%, 85% and 90%.

Figure 6.7: Project Waste Treatment Fee Growth based on Pre-determined Project Internal Rate-of-Return (IRR) at differing Plant Availability Rates



6.5.2 Waste Treatment Fee based on Changes in Core Inflation Rate

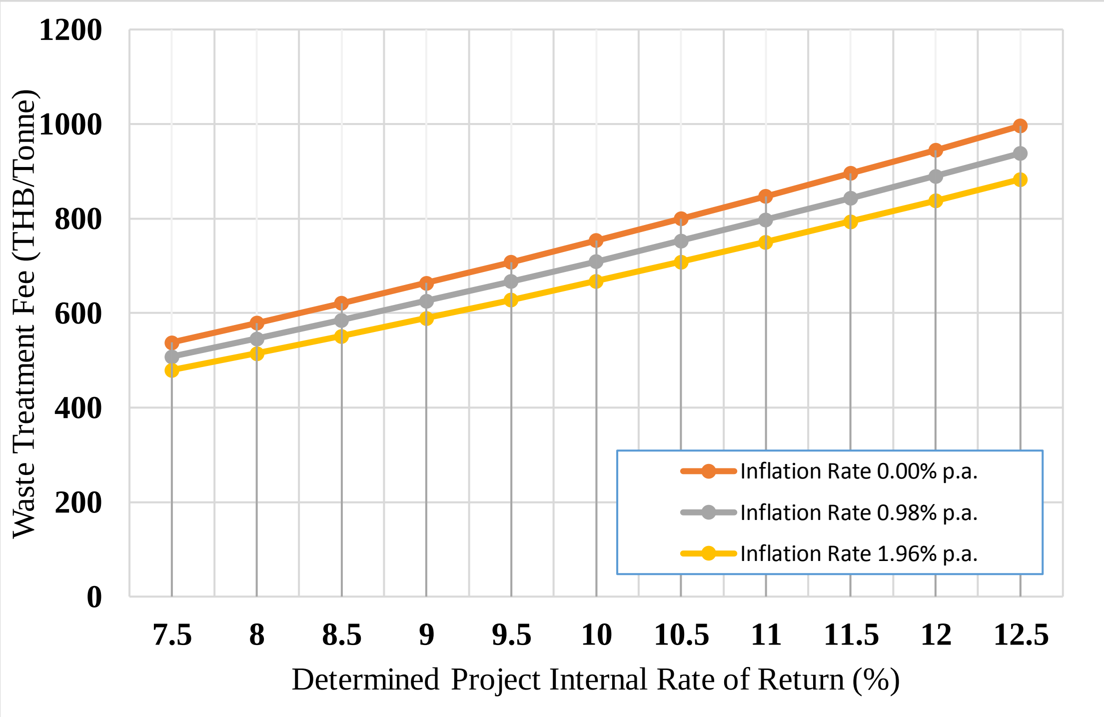
Core inflation rates play an important aspect in determining operational expenditure over the life of a waste treatment facility. While historical inflation data have presented Thailand’s average inflation rate at 0.98% with a stable, similar outlook in the long run, international socio-economic and political factors such as currency rate volatility, recession and war can affect core inflation rates, beyond originally forecasted values. In this regard, the simulation is utilised to the case study predict waste treatment fee based on reduced and increased inflation rate scenarios of 0% and 1.96%, respectively. Table 6.8 presents waste treatment rates based on pre-determined IRR rates between 7.50% and 12.50%, at case study pre-adjusted core inflation rates of 0% p.a., 0.98% p.a. and 1.96% p.a., respectively.

Table 6.8: Waste Treatment Fee Results based on Pre-determined Project Internal Rate of Return (IRR) & Core Inflation Rate Scenarios

Project IRR (Input Data) (%)	Waste Treatment Fee Results (Output Data in THB)		
	Inflation Rate 0.00% p.a	Inflation Rate 0.98% p.a	Inflation Rate 1.96% p.a
7.50	**538.00**	**508.00**	**479.50**
8.00	**579.00**	**546.00**	**515.00**
8.50	**621.00**	**585.00**	**551.50**
9.00	**664.00**	**625.50**	**589.00**
9.50	**708.00**	**667.00**	**628.00**
10.00	**754.00**	**709.00**	**667.50**
10.50	**800.00**	**753.00**	**708.50**
11.00	**847.00**	**798.00**	**750.50**
11.50	**896.00**	**843.50**	**794.00**
12.00	**945.00**	**890.00**	**838.00**
12.50	**996.00**	**938.00**	**883.00**

Results presented highlights that waste treatment fee increase as inflation rates reduced. This is caused primarily by reduction of the case study's income potential as waste treatment fee (based on TOR terms) and electricity feed-in tariff (as per power purchase agreement) are adjusted in line with annualised inflation rate changes. Waste treatment fee rates increase by approximately 5.8% to sustain pre-determined IRR within the simulation. Figure 6.8 illustrates waste treatment fee changes based on adjusted annualised core inflation rates of 0.0%, 0.96% and 1.96%.

Figure 6.8: Project Waste Treatment Fee Growth based on Pre-determined Project Internal Rate-of-Return (IRR) at adjusted Core Inflation Rates



6.5.3 Waste Treatment Fee based on Biological Product Sale Prices

A mechanical biological treatment (MBT) facility's revenue encompasses the facility's waste treatment fee, sale of electricity and heat, recovered and treated recyclables and biologically-treated products such as compost and liquid digestate. Among income streams, the sale price of compost and liquid fertiliser remains speculative and is dependent on the case study's ability to meet quality specification as stated within the long-term sale contract.

Research on compost and liquid fertilizer sale pricing had shown that a similar MBT facility operating in the north of Thailand retails stated products at

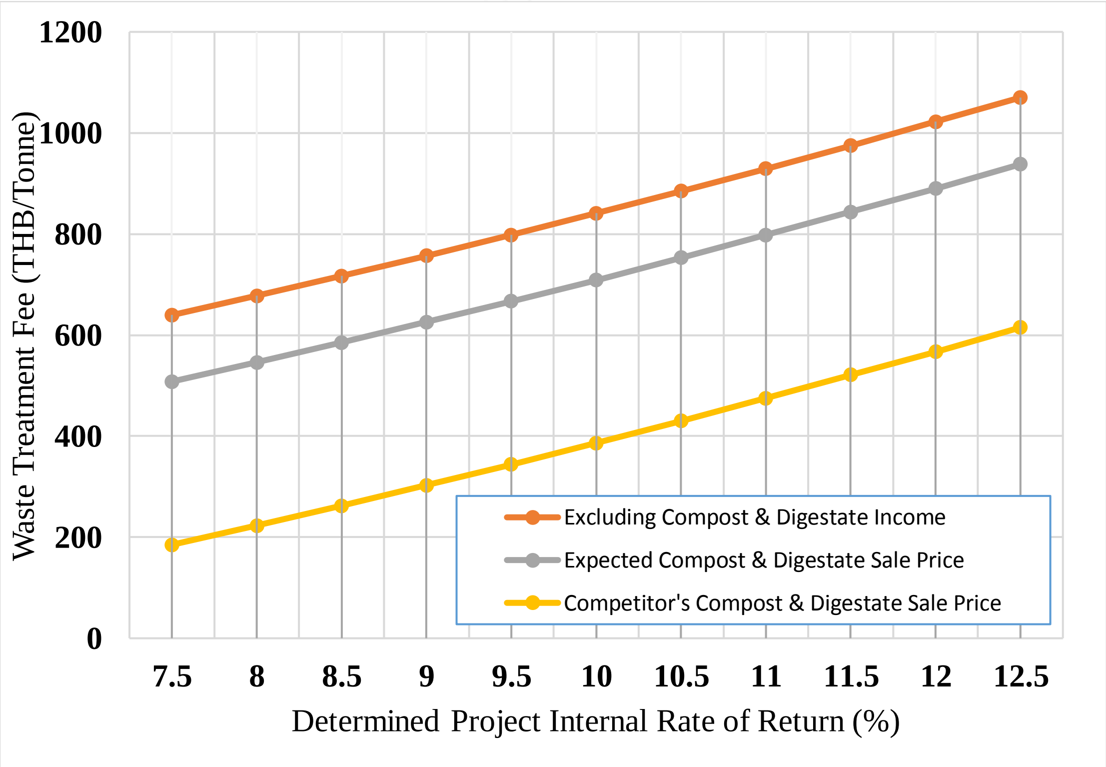
THB 3.500/tonne and THB 1,700.00/m^3 respectively. Based on market data, the simulation is utilised to determine an appropriate waste treatment fee based on 2 differing scenarios: 1) the case study is unable to monetise the sale of biologically-treated products and 2) sale price of biologically-treated products as per sale prices recorded in North Thailand. Table 6.5 lists waste treatment rates based on pre-determined IRR rates between 7.50% and 12.50%, at case study pre-adjusted biologically-treated product sale prices.

Table 6.5: Waste Treatment Fee Results based on Pre-determined Project Internal Rate of Return (IRR) & Biologically-Treated Product Sale Prices

Project IRR (Input Data) (%)	**Waste Treatment Fee Results (Output Data in THB)**		
	No Income from Digestate & Compost	**Reference Digestate & Compost Sale Rate**	**Rival Digestate & Compost Sale Rate**
7.50	**639.50**	**508.00**	**185.00**
8.00	**677.50**	**546.00**	**223.00**
8.50	**717.00**	**585.00**	**262.00**
9.00	**757.00**	**625.50**	**302.50**
9.50	**798.00**	**667.00**	**344.00**
10.00	**841.00**	**709.00**	**386.50**
10.50	**884.50**	**753.00**	**430.00**
11.00	**929.00**	**798.00**	**475.00**
11.50	**975.00**	**843.50**	**521.00**
12.00	**1,022.00**	**890.00**	**567.00**
12.50	**1,070.00**	**938.00**	**615.00**

Simulation results show that the sale price of biologically-treated products play a significant role in determining the case study's waste treatment fee, with rates increasing by as high as 20% to maintain required IRR rates in the absence of this income stream. Figure 6.9 illustrates waste treatment fee changes based on pre-determined biologically-treated product sale prices at the stated IRR.

Figure 6.9: Project Waste Treatment Fee Growth based on Pre-determined Project Internal Rate-of-Return (IRR) at adjusted Biologically-treated Product Sale Prices



Further to this, the sale price of biologically-treated products has the potential to reduce a facility's dependence on a waste treatment fee, with the facility being able to project an IRR of 8% without a need for waste treatment fee collection if compost & liquid fertiliser sale price go beyond THB 3,600/tonne respectively.

6.6 Conclusion of the Chapter

The chapter presents the outline of the computer simulation, beginning with the computer program selection (Microsoft Excel) and basis of simulation. In essence, the computer program simulates the project expected cash flow over the duration of project delivery based on input data obtained during the case study's commercial analysis to recommend the waste treatment fee based on pre-determined internal rate-of-return (IRR).

Among assumptions incorporated within the computer simulation include the inclusion of projected core inflation rate, corporate tax rate, electricity variable feed-in tariffs (FiTv) rate calculation as presented in Thailand, forecasting of revenue spot pricing and compounded personnel wage increases. Further to this, waste treatment fee pricing is determined based on projected annualised core inflation rate increases.

On formulation of the computer simulation, case study input data is computed to determine project first-year waste treatment fee of THB 546.00, THB 709.00 and THB 890.00 based on pre-determined project internal rate-of-returns of 8.00%, 10.00% and 12.00% respectively. Project results observe near-linear growth rates between the case study's IRR rates. As waste treatment fee is subjected to annualised increases over the case study 20-year operating lifecycle, rate ranges are observed as followed; 8% IRR (THB 546.00 – THB663.59), 10% (THB 709.00 - THB 861.69) and 12% (THB 890.00 – THB 1081.67).

The computer simulation is verified utilising differing economic scenarios including plant availability, changes in core inflation rate and effects on changes of biological treatment product sale pricing. For differing plant availability rates, the computer simulation determined waste treatment fee rates as followed; 8% (THB 587.00, THB 546.00 & THB 513.00), 10% (THB 761.00, THB 709.00 and THB 667.50) and 12% (THB 953.00, THB 890.00 and THB 839.00) at availability rates of 80%, 85% and 90% respectively.

The simulation model was subjected to changes in core inflation rates, and determined waste treatment fee rates as followed; 8% (THB 579.00, THB 546.00 & THB 515.00), 10% (THB 754.00, THB 709.00 and THB 667.50) and 12% (THB 945.00, THB 890.00 and THB 838.00) at core inflation rates of 0%, 0.98% and 1.96% respectively. It is observed that reduced inflation rate increases waste treatment fee rates as a facility's cumulative revenue is reduced over the life of the facility.

On assessment of changes to biologically-treated product sale prices, the simulation computed waste treatment fee rates as followed; 8% (THB 677.50, THB 546.00 & THB 223.00), 10% (THB 841.00, THB 709.00 and THB 386.50) and 12% (THB 1,022.00, THB 890.00 and THB 567.00) at product spot rate scenarios of THB 0 (worse-case) and THB 3,500/tonne & THB 1,700/m^3 (best-case) for finished compost and liquid fertilizer, respectively. Further evaluation of biologically-treated product sale prices has the potential to reduce a facility's dependence on a waste treatment fee, with the facility projecting an IRR rate of 8% with no waste treatment fee collection if compost & liquid fertiliser sale price go beyond THB 3,600/tonne respectively.

CHAPTER 7 Conclusion

In conclusion, the fixing of a pre-set project internal rate-of-return as the basis of determining concession rates for utility projects, including proposed waste treatment facility waste treatment fees allow for better transparency in the awarding of projects, hence reducing the potential for "profiteering" and mismatched tariffs rates. The creation of a computer simulation model incorporating project deliverables, socio-economic and political assumptions throughout the operation lifecycle eases the process of determining a suitable waste treatment fee for concession authority consideration prior to awarding of long-term waste treatment contracts.

In assessing the non-treatment fee income potential of MBT facilities, literature review of the topic observe that public policy and regulation play a key role in the setting of these income streams, with implementation of source separation, combination taxation, disposal taxes and disposal-refund relief contributing significantly to income potential of MBT facilities.

Furthermore, past research has shown that fixed-term concessions may not be the optimal method for determining the profitability of infrastructure projects, rather the understanding of the complete work breakdown structure of the project is required to provide a holistic approach to the determination of concession fees and durations, with sufficient flexibility provided to incorporate internal and external factors over the project lifecycle.

While detailed procedures exist for the setting up of waste treatment facilities under the public-private partnership (PPP) model have been introduced in Thailand for over a decade, no specific details are available regarding the determination of suitable concession tariffs for similar projects. Currently, no evidence exists to show the setting of income ceilings for infrastructure project under the PPP-model within Thailand, but several nations including Singapore have adopted legislative income limits to curb profiteering.

Technical study within the research comprise quantitative and qualitative MSW sample testing within the case study's catchment area. Data collected has observed that Bangkok's MSW comprise mainly (approximately 52% content) of digestible organics such as food waste and garden waste. The second and third highest components found within Bangkok's MSW stream are mixed plastics and papers (cumulatively 31%), which form the main constituents of refuse-derived fuels. Sample organics mean moisture content is reported at 70% with wet calorific value of 2,388kJ/kg.

Sampling results conclude that MBT processing is the best suited method for treating MSW in Bangkok, due to high moisture levels and reduced calorific value for optimal efficiency through direct thermal treatment. Assessment of the case study's technical deliverables shows dry, thermophilic anaerobic digestion as the best suited AD process for treatment of sorted organic waste with high-levels of non-organic material contamination. Technology selected for the case study calculate resource recovery rate potential of 96.16%, along with net electricity generation potential of 3.00MWh.

The research covers data collection methods for determining MBT facility capital expenditure (CAPEX) and operational expenditure (OPEX) categories, utilising the case study's life cycle as example for this research. Data collected cover the expected 22-year lifecycle of the facility. In addition to CAPEX and OPEX analysis, the study identifies possible revenue routes and facility income streams such as electricity generation, waste treatment fee and income from sale of process products.

Project capital investment for a Mechanical Biological Treatment (MBT) facility is divided into 8 categories. On assessment of the case study's technical requirements and equipment selection, the case study's base cost estimate is determined at THB 1,548,249,933.77. Additionally, 10% and 5% of project base cost estimate is set as project contingency and construction financing buffers respectively, bring the case study's overall project capital expenditure to THB 1,780,487,423.84.

Project operational expenditure throughout the lifetime of a MBT facility is divided into 8 categories, with operational categories subject to external economic influences such as core inflation adjustment over the facility's operating lifecycle. These adjustments are incorporated within the computer simulation for determining annual changes in waste treatment fee rates over the operating lifetime. Project revenue potential of a MBT facility is dependent on specific project deliverables and can be divided into 5 general categories – waste treatment fee; mechanically recovered products; biological treatment products, market-prepared products and project incentives.

The final component within the research strategy is the formulation of computer simulation to determine the intended facility waste treatment fee based on pre-determined project internal rate-of-return (IRR). These formulas are computed into a Microsoft Excel spreadsheet which was selected as the program of choice for the research due to widespread utilisation and availability and its ease-of-use design for easy manipulation of formulas to meet custom plant requirements.

During the formulation of computer simulation, it was observed that computer simulation was unable to directly utilise IRR rates to determine waste treatment fee due to the formula's dependence of discount rate calculation. Due to this consideration, the computer simulation was modified to compute the project's IRR (dependent value) based on expected waste treatment fee (independent value). This had provided comparable waste treatment fee results as per the originally proposed research framework, hence was incorporated as pricing mechanism for the study.

Case study input data is computed to determine project first-year waste treatment fee of THB 546.00, THB 709.00 and THB 890.00 based on pre-determined project internal rate-of-returns of 8.00%, 10.00% and 12.00% respectively. Project results observe near-linear growth rates between the case study's IRR rates. As waste treatment fee is subjected to annualised increases over the case study 20-year operating lifecycle, rate ranges are observed as followed; 8% IRR (THB 546.00 – THB663.59), 10% (THB 709.00 - THB 861.69) and 12% (THB 890.00 – THB 1081.67).

The computer simulation is further verified utilising differing economic scenarios including plant availability, changes in core inflation rate and effects on changes of biological treatment product sale pricing. For differing plant availability rates, the computer simulation determined waste treatment fee rates as followed; 8% (THB 587.00, THB 546.00 & THB 513.00), 10% (THB 761.00, THB 709.00 and THB 667.50) and 12% (THB 953.00, THB 890.00 and THB 839.00) at availability rates of 80%, 85% and 90% respectively.

The simulation model was subjected to changes in core inflation rates, and determined waste treatment fee rates as followed; 8% (THB 579.00, THB 546.00 & THB 515.00), 10% (THB 754.00, THB 709.00 and THB 667.50) and 12% (THB 945.00, THB 890.00 and THB 838.00) at core inflation rates of 0%, 0.98% and 1.96% respectively. The research has shown that reduced inflation rate increases waste treatment fee rates due to reduced facility cumulative revenue over the lifetime of plant operation.

Changes to sale pricing of biologically-treated products compute waste treatment fee rates as followed; 8% (THB 677.50, THB 546.00 & THB 223.00), 10% (THB 841.00, THB 709.00 and THB 386.50) and 12% (THB 1,022.00, THB 890.00 and THB 567.00) at product sale spot rate scenarios of THB 0 (worse-case) and THB 3,500/tonne & THB 1,700/m^3 (best-case) for finished compost and liquid fertilizer, respectively. Utilising the computer simulation, the facility projects an IRR rate of 8% with no waste treatment fee collection if compost & liquid fertiliser sale price go beyond THB 3,600/tonne respectively.

In conclusion, this study is designed as a table-top analysis to determine potential waste treatment project tariffs by utilising real-life case study information as the basis of research. While all waste treatment options are designed with the objective to treat MSW economically and safely, no two facility processes are identical in nature. In this regard, each project shall be evaluated separately based on project-specific objectives, with detailed understanding of each project's technical and commercial requirements. While the study's pricing mechanism can be exported for use in other projects, the data for evaluation of each project shall be project-specific.

Currently, infrastructure concession agreements under the PPP-model within Thailand fall within the Trade Secret Act. B.E.2545 (2002) that limit information gathering activities. As accuracy of the waste treatment pricing mechanism is dependent on input data presented, the issuance of standardised economic forecasting information shall reduce the potential of erroneous (deliberate or otherwise) misrepresentation of data presented.

Long-term forecasting of an infrastructure project's concession fee increases stakeholder risk exposure in the event of significant changes to process and economic parameters during project execution. Further studies may assess economic patterns, such as reviewing alternative pricing mechanism options such as a base + variable waste tipping fee mechanism which may potentially reduce risk exposure over longer periods.

7.1 Study Limitation

The waste treatment fee pricing mechanism is developed based on several long-term process and macroeconomic assumptions that are beyond the project developer's direct control. The validation of the computer simulation results is highly dependent on economic conditions over the operating life of the facility. Further to this, the simulation model is designed based on the assumed municipal solid waste (MSW) disposal composition over the lifetime of the facility.

It must be highlighted that consumer disposal patterns influence MSW characteristics over time. While historical data provided by the Bangkok Metropolitan Authority (BMA) can be utilised to predict MSW composition trends in the short or medium term, potential changes in government regulation and policy may alter consumer MSW disposal patterns, which directly affect the project's process flow and mass balance.

While several countries have set IRR ceilings for infrastructure projects under the public-private partnership (PPP) model, Thailand has yet to implement such measures. As such, current IRR selected as basis of study is based on prevailing rates in neighbouring countries, with the possibility of Thailand's investors requesting for higher IRR rates than the assumed within this study.

7.2 Future Suggestion

Several out-of-study-scope suggestions are recommended for further research that may contribute to increasing the accuracy and efficiency in determining suitable tariff rates for infrastructure projects under the PPP-model, particularly for waste treatment facilities. Among suggestions include:-

1. Determination of project internal rate-of-return (IRR) ceiling limit for implementation of infrastructure project under the Public-Private Partnership (PPP) model as basis of Thailand's regulatory policy
2. Detailed technical, environmental and commercial feasibility study of municipal solid waste (MSW) treatment technologies for utilisation within Thailand
3. Feasibility study on denationalisation of waste treatment services and implementation of direct charging mechanism for waste disposal and treatment services based on unit-based waste treatment pricing mechanism.

7.3 Academic Contribution

This thesis is written to explore and put forward a standardised approach of pre-set IRR rates for the determination of treatment fees for privately funded MSW treatment facilities within Thailand, in line with the growing practice of setting project commercial terms based on pre-set project profit ceilings.

Literature review for this study has highlighted significant funding deficiencies for the implementation of government-funded sustainable waste treatment options within developing nations due to limited and/inefficient tax and tariff collection systems. The public-private partnership (PPP) model allows for accelerated implementation of infrastructure projects, but in many cases are based on prejudicial terms that may benefit a single party. Several countries, including neighbouring Malaysia and Singapore have implemented IRR ceilings to dispel this concern.

On the engineering aspect, the study covers comprehensive MSW quantitative and qualitative sampling and technical evaluation of different mechanical recovery and biological treatment methods to determine the optimal technology suite for treatment of Bangkok's waste. This research includes detailed mass balance and energy balance assessment studies to project resource recovery and electricity generation potential, which can be utilised as the basis of plant design and commercial evaluation for future projects.

While many assumptions within this study involve macroeconomic data which project stakeholders may not have control, the pricing mechanism presented within this study may be used to evaluate project financials at pre-determined intervals in order to gauge a project's financial health and adjust payments in line with committed IRR rates, as a form of investment protectionism.

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