Chapter 11

Sustainable Waste Management and Waste to Energy Recovery in Thailand

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Additional information is available at the end of the chapter

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Abstract

In Thailand, the municipal solid waste (MSW) generated is currently about 71,700 tons a day. Moreover, solid waste management (SWM) is an interdisciplinary issue. The concept of WM has been embraced by Thailand through the setting of a national master plan for SWM. Several waste to energy (WTE) projects have been initiated. The anaerobic digestion WTE power plant in Rayong municipality was selected for performance evaluation. It is able to treat 70 tons of organic waste per days but its actual throughput has decreased to 20 tons per day based on limited amount of waste separation effected to isolate organic waste. In addition, a better digester design is required for the actual organic waste generated. Thermal processes such as gasification and incineration in Hatyai have been applied for mixed waste. However, they suffer from the limitation that high moisture content waste can cause fluctuating heating values. Also, the environmental impact on nearby communities is an important concern. Meanwhile, investment in WTE project has been encouraged by the introduction of the feed-in tariff (FiT) rate paid for electricity generated through sustainable processes to promote energy recovery from MSW. The keys to success for WTE technologies are waste separation at source and development of machine innovation.

Keywords: anaerobic digestion (AD), feed-in tariff (FiT), solid waste management (SWM), waste incineration, waste to energy (WTE)

1. Introduction

Thailand is located in the center of South East Asia and has a total area of about 514,000 km^2 (200,000 mile^2). The Tourism Authority of Thailand [1] noted that looking at a map of Thailand (**Figure 1**) shows a country whose borders form the rough shape of an elephant's head, the head and ears forming the mostly landlocked northern and eastern provinces and

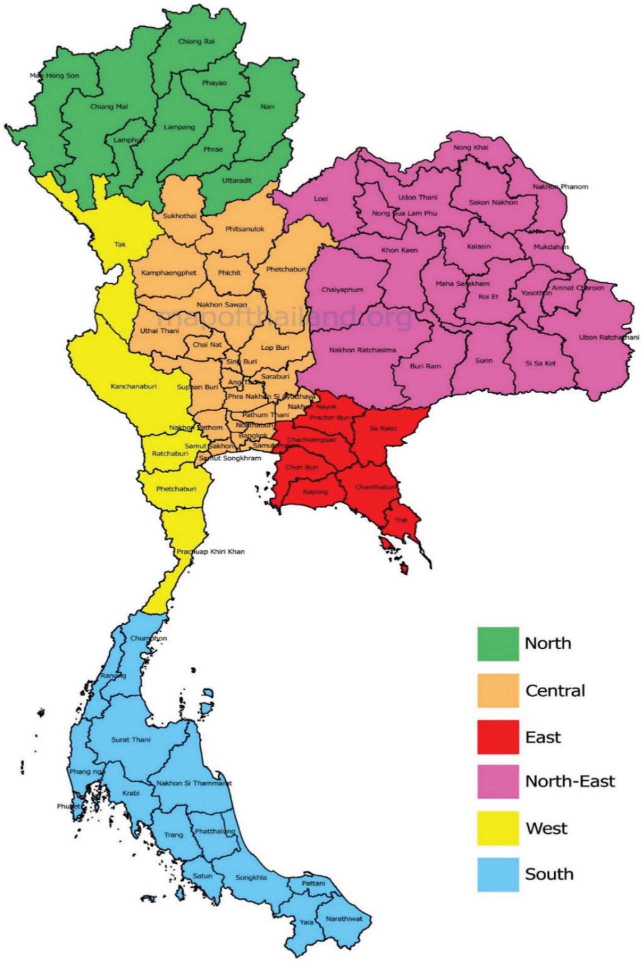

Figure 1. Provincial administration in Thailand [4].

the trunk extending down the Malaysian peninsula between the Andaman Sea and the Gulf of Thailand. Thailand had a population of approximately 66 million in 2017 [2] and the provincial administration of Thailand is divided into 77 provinces. Thailand's climate is influenced by tropical monsoons and the weather in Thailand is generally hot and humid across most of the country throughout the year. The central, northern, and northeastern Thailand, especially the landlocked provinces have three different seasons, summer, the rainy season, and a cool season, whereas the southern and the coastal regions of Thailand have only two seasons which are the hot and rainy seasons. Generally, it is relatively hot most of the year. The cool season and the summer occur from November to February and March to May respectively. Between February and May the weather is mostly hot and dry. The rainy season, lasts from May to November and is dominated by the southwest monsoon, during which time rainfall in most of Thailand is at its heaviest [3].

2. Waste situation in Thailand

Currently, the increases in the generation of municipal solid waste (hereafter MSW) caused by population growth and increasing economic development in developing countries has become one of the most serious environmental issues. Solid waste management (hereafter SWM) is difficult to implement as part of integrated management strategies and sustainable development in developing countries. A large amount of mixed waste is usually dumped in open landfills or burned outdoors. Many Asian countries have poor practical waste separation [5]. Despite the adoption of waste management strategies such as the so called 3Rs strategies (reduce, reuse, recycle), which have been widely implemented throughout the world during the last decade, a complete solution to the problems of SWM has not been found. Developing countries such as Thailand still produce large amounts of MSW which for some time have been overwhelming the available landfill sites. MSW generation has continuously increased over the years and in 2016, the total amount of MSW in the country, as reported by the Pollution Control Department (hereafter PCD), Ministry of Natural Resources and Environment (hereafter MNRE), Thailand, was 27.06 million tons which represented an increase of 0.2 million tons since 2015. As an illustration, the amount of waste generated annually is equal to a hundred times the volume of the highest building in Thailand, "Baiyoke Tower II" which is 328 metres high. Of this waste only 14.81 million tons was placed in disposal sites, with waste recovery accounting for a further 4.64 million tons with the remaining 6.91 million tons accounted for by other means [6]. The efficiency of waste collection is about 80% countrywide but only 36% of the total generated waste is disposed of using acceptable processes such as incineration, composting or landfilling [7]. However, there are only 2500 waste recovery entrepreneurs nationwide of which only one fifth use proper waste disposal methods, the remaining four fifths use illegal waste disposal methods such as open dumping, and direct burning resulting in environmental contamination through leaching, and leakage of substances. Several landfills have been burned as has been reported in newspapers [8]. Only a small fraction of the MSW collected is managed by proper treatment or disposal and there is a need for a sustainable solution to these problems as well as the implementation of public participation strategies [9]. It inevitably involves municipalities, scavengers, investors, teachers, and people.

2.1. Legislation affecting waste management

Generally, local authorities in Thailand are responsible for SWM on their administrative zones and the collection, treatment, and disposal of municipal, industrial and infectious waste is under the control of those local authorities. The MSW generated by the population of 66 million people is currently about 71,700 tons a day. The government of Gen. Prayut Chan-o-cha, the Prime Minister (hereafter PM) in power in Thailand since 24 September 2014, has recognized that the amount of waste generated and its management constitutes a serious issue and the government has adopted policies relating to SWM including the management of solid and hazardous waste. As part of this policy, the government has directed that each province should identify locations for the construction of waste facilities including proper landfill disposal sites and facilities to convert waste into renewable energy. This national strategy was incorporated into a solid and hazardous waste management roadmap which was drafted by the MNRE and represents a significant step in defining the national agenda relating to the solid waste issue.

Further regulations relating to this national agenda on SWM were announced by the office of the PM in the form of an act of parliament, published in the royal gazette, in September 2014 [10]. Under the decentralization strategy adopted, responsibility for SWM was passed to each province under the authority of the provincial governor in collaboration with the MNRE, who will provide back-up on technical and management issues to support the provincial administrations. At the beginning of the fiscal year 2015, the MNRE assigned national SWM policy to local provincial administrative and local government organizations in order to implement this policy [11]. The main concept of the national roadmap for solid and hazardous waste management is divided into four categories;

2.1.1. Residual waste

1. There will be no more open dumping and residual waste must be properly treated including urgently removing it from landfills

2. Survey and improve all illegal and improper landfills including both sites within local administrative control and private sites

To comply with the national waste management roadmap, the following steps should be applied:

- Survey and assess landfills with a view to closing or rehabilitating them.
- Renovate existing landfills to render them sanitary.
- Dispose of waste in private areas or convert it to refuse derived fuel (RDF) and promote private investment in waste treatment technologies.
- Enforce the law in relation to the operation of private illegal dumping sites.

2.1.2. Emerging waste

1. Reduce and separate waste at household sources

Reducing waste at source is a simplified methodology to save costs and natural resources. It represents a sound business concept as well as encouraging social responsibility. If the entire country adopted source reduction practices, the pressure on natural resources would be significantly decreased. Several organizations and businesses have already recognized that source reduction and waste separation and recycling will result in financial savings and will yield an enhancement of productivity as well as promoting corporate social responsibility.

2. Apply a clustering waste management system using combination technologies with the emphasis on waste to energy (WTE) and maximizing waste recovery

In order to centralize waste management systems, each province should aggregate SWM based on district and sub-district clustering taking into consideration the amount and condition of waste. The waste treatment pattern should be divided into three levels as follows:

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- Model S clusters waste disposal sites into those that receive a daily input of waste of up to 50 tons per day. The provinces in which this model was initiated were Nakorn Ratchasima, and Buriram
- Model M clusters waste disposal sites into those that receive a daily input of waste of between 50 and 300 tons per day. Model M was piloted in municipalities in Nan and Rayong provinces.
- Model L clusters waste disposal sites into those that receive a daily input of waste of more than 300 tons per day. The pilot provinces for the L model were Nonthaburi, Phuket, Songkhla (including both Songkhla and Hatyai municipalities), Chiang Rai, and Bangkok [12]

Under the M and L models waste would be processed by the following procedures:

- Promote the separation of waste at source.
- Screen hazardous waste out of MSW and gather it at a transfer station before sending it to private contractors.
- Implement a combination WMS and convert waste to electricity.
- Rehabilitate existing landfills into sanitary landfill sites for continued dumping.

Under model S the same processes would be operated as those under models M and L but a different approach to waste recovery would be adopted with composting being utilized instead of electricity generation at small scale sites and employing private contractors for hazardous waste management instead of landfill rehabilitation.

3. Reinforce the role of the private sector in waste management and increase investment especially in waste incinerators

2.1.3. Waste management measures and policy

1. Henceforth, governors are the provincial regulatory waste management administrators

2. Legislation to introduce and standardize procedures including waste reduction, separation, collection and transportation, and, to standardize waste disposal fees for solid, hazardous and infectious waste

The roadmap focuses on policy and legislation while the practical implementation of measures on waste management have been decentralized to provincial administration organizations in three stages.

In the first stage covering a period of 6 months, governors meet with provincial waste management committees selected from related stakeholders e.g., local administration representatives, academics, NGOs and the private sector, to brainstorm and discuss SWM with a view to drafting a provincial solid and hazardous waste management model. From this an overview of the implementation of the provincial SWM model is prepared incorporating an assessment of local preparedness and how collaboration between all the stakeholders can systematically and sustainably resolve the waste problem. The provincial waste management committee also plays an important role in the selection of alternative waste technologies at a centralized waste disposal site selected depending on the size of their area and the likely inputs of waste. It is also important to deal with political issues which may arise during the bidding process for concessions and to ensure that this process is transparent and fair.

Additionally, governors have authorization to adopt a flexible approach where necessary, for example, in conducting environmental impact assessments (EIA), allowing joint ventures between private companies and government organizations under the Government Business Act (2013), the City Plan Act (1975), and the Environmental and Safety Assessment Act (ESA, 2009), as well as adopting measures to support private sector investment in solid and hazardous waste management.

In addition, provincial administration organizations have the authority to pass local regulations to set up, operate, control, and monitor waste disposal sites. These regulations may also cover waste separation (general waste, organic waste, recyclable waste, and hazardous waste) and the prohibition of the mixing of hazardous waste with general MSW.

Following this initial period, there follows an intermediate period of a year during which the policy highlights the disposal of products and packaging material which may include permitting the use of waste disposal sites and the disposal of electric appliances and electronic waste under pilot projects involving the extended producer responsibility (EPR) principle. Recycling of packaging material will be enforced in industrial sectors and measures will be taken to prevent illegal dumping of hazardous wastes. Waste treatment plants, disposal sites and recycling plants will be progressively introduced where they do not already exist and their use will be promoted. Local legislation relating to waste separation and the prohibition of the mixing of hazardous waste with MSW will also be enforced as well as other enactments to support the integrated solid and hazardous waste management program.

In the longer term beyond that year, measures will tend to focus on international directives that will make producers responsible for waste electrical and electronic equipment (WEEE) at the end of its useful life [13] based on the EPR concept and the polluter pays principle (PPP). These strategies are designed to promote the integration of environmental costs of goods throughout their life cycle into the market price. Therefore, the duty to eliminate WEEE should be allocated to producers in order to encourage them to adopt sustainable production methods [14].

2.1.4. Encouraging civil discipline, public education, and enactments for sustainability

These strategies relate to improving civic quality by both gentle and strict methods. People illegally dumping solid, hazardous, and infectious waste including industrial and radioactive waste should be traced and strictly punished. Public relations, education, and awareness-raising are necessary to ensure public participation in integrated MSW management from cradle to grave including a reduction in the use of plastics and the promotion of substitute materials. It is important that overall awareness of the issue of waste management should be raised and that the practice of waste separation should be promoted particularly among students and adolescents as this is essential to ensure sustainable MSW [15]. Awareness of

Figure 2. Handbags from coffee pouches [17].

these issues should be promoted at every school and academic institution [6] and higher educational institutions should be requested to introduce youth awareness programs for the environment and waste management. Several schools have already adopted such waste management approaches. For instance, Benjamarachutit School, a public high school in Nakorn Sri Thammarat province, applied food waste from canteen to produce effective microorganisms used in the organic hydroponic culture of Chinese mustard greens in their agricultural learning area with both economic and environmental benefits [16]. Similarly, Boonpeng [17] noted that the Director of Baan Don Kha School, a small primary school in Si Sa Ket province, initiated a waste separation campaign in which students separated waste into four types; glass bottles, plastic bottles, milk pouches, and paper. These waste products are recycled or sold to provide revenue applied to school learning activities. Similarly, this primary school also taught their students to create value-added products from waste for daily utilization such as making handbags from waste coffee pouches (**Figure 2**).

3. Modern holistic waste reduction and recovery policies

June 5, 2015, was World Environment Day, and the PM chose that day to launch a plastic-bag-free campaign to encourage Thai people to reduce the volume of trash they generate. In particular, the PM stated that the government would seek cooperation from retailers, convenience stores, department stores and shopping centers in avoiding the use of plastic bags on the 15th day of each month and instead to use cloth bags or to reuse plastic bags in order to reduce the volume of plastic waste. Meanwhile, the MNRE initiated the “Green Card” project to convince producers, suppliers and customers to produce and consume environmentally-friendly products and packaging. Card holders will gain green points whenever they purchase eco-friendly products at participating stores which will be redeemable for special vouchers or other rewards [18]. The PM also promoted strategic planning for alternative materials to substitute for polystyrene packaging with a view to banning this form of packaging which would achieve cost reductions as well as reducing waste and also announced a feasibility study into the use of biodegradable plastic bags [19].

4. Waste to energy (WTE) technologies

The increasing amount of mixed household waste has become a national problem in Thailand and elsewhere, the resolution of which may be to turn a crisis into an opportunity and reap benefits from garbage. The Thai government has instructed provincial authorities to find locations for constructing waste management facilities capable of using garbage to produce renewable energy. It is not only Thailand which lacks proper waste management systems and throughout the world peoples' attitudes to finding suitable sites to dump garbage have led to continuing conflicts and protests based on the "Not in my Backyard" (NIMBY) attitude. Therefore, it would be preferable to solve the problem by employing suitable waste management strategies as alternatives to disposal. The PM has declared that every province should build a WTE facility to convert waste to electricity which will support the country's efforts to reduce its dependence on natural gas and other fossil fuels. However, to-date, Thailand has just 3 WTE incinerators [19–21].

Nowadays, the use of WTE technologies is gaining momentum as a favorable waste management strategy. Unquestionably, WTE seems to be a viable option for diminishing the volume of waste as well as offering the additional benefit of producing alternative energy from waste recovery [21]. Already there has been increased recovery of recyclable materials from MSW rather than continued dependence on sanitary landfilling as the primary conventional method of solid waste disposal [22]. But the benefits of energy recovery from MSW are potentially more valuable, both as an alternative energy source and for the positive environmental implications, mainly relating to the saving of non-renewable energy derived from fossil fuels [23]. WTE or energy from waste refers to any waste treatment that transforms waste resources into electricity, steam, or heat energy. These include, for example, anaerobic digestion (hereafter AD), incineration, pyrolysis, gasification, plasma arc, and RDF. WTE technologies usually reduce the volume of original waste by as much as 90%, depending on the waste composition and the type of energy derived. A waste management hierarchy generally follows the pattern of waste avoidance or reduction, reuse, recycling, recovery treatment, followed by disposal. An integrated approach to WTE that practices waste segregation and pre-treatment of waste does not by-pass the waste hierarchy but precedes or replaces the disposal step which is a more sensible approach to WTE recovery than simply burning or converting raw unsorted waste. Nonetheless, the choice of WTE technology is important and the conversion plant itself may incorporate waste pre-treatment units to facilitate this approach.

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Thailand has a recent history of developing projects in WM in terms of sanitary landfills and managing waste through WTE facilities. Moreover, Thailand has experience of WTE projects which have been developed locally and which date back at least a decade and from these, significant lessons related to both thermal and non-thermal technologies have been learned. Thermal treatments have involved both incineration and gasification processes and under the heading of non-thermal processes, biogas has been produced from, for example, waste fermentation or AD and the following sections will examine and compare case studies relating to both these technologies.

5. Anaerobic digestion (AD) power plant: a case study of Rayong municipality

The advantages of AD systems were set out by Spuhler [24] who noted that biogas and sludge were produced, respectively, for electricity generation and the production of fertilizer. Greenhouse gas emission can be reduced through methane recovery and efficient AD treatment systems reduce excess sludge by separating out heterogeneous organic waste, leachate, and wastewater. However, AD technologies may need to be modified to be appropriate for small and medium-scale facilities in developing countries. The high sensibility of methanogenic microorganisms need to be carefully investigated. Sulphuric compounds generated during methane production can cause erosion of equipment in AD facilities, and in order to protect AD equipment, the biogas produced may need to be significantly purified. The design and construction of AD power plants on a commercial scale needs to be under the supervision of experts, and professional operational and maintenance skills are also required to deal with fluctuations in the AD process.

Bearing in mind that Thailand is located in a tropical area and that the main economic income is derived from agricultural activities, the composition of MSW in Thailand is largely from food waste (40–60%) which has a high moisture content. Therefore, organic waste in Thailand seems to have a high potential as a raw material for producing biogas which can be converted into electricity. The case study which follows is of a biogas power plant located in Rayong municipality and includes some lessons-learned from its installation in 2004 and its operation since then.

Rayong municipality, is located in the coastal industrial zone on the eastern seaboard of Thailand. Rayong province is 179 km from Bangkok, approximately 3552 km^2 in area and is separated into eight districts, 58 sub-districts called Tambons in Thai and 440 villages. The population of Rayong municipality in December 2007 was 56,085: 27,110 males and 28,975 females [25].

Rayong municipality is a largely commercial city and in the late 20th Century generated increasing volumes of MSW due to the growth of the population. Between 1995 and 1997 the volume of waste grew from 57.47 tons to 63 tons per day. In 2000, the MSW contents were noted to be composed mainly of organic waste (67.77%) [26] and the bulk density of the MSW was 220 kg per m^3, as illustrated in **Table 1**.

The WTEF plant constructed in 2004 had the potential to treat 70 tons of organic waste per day. However, during 2004–2005, the organic waste fed to the AD system were separated in

2 main streams of about 12 and 3.3 tons per day of source sorted organic waste (SSOW) and mechanically-sorted organic fraction of MSW (OFMSW), respectively. The solid contents of the organic waste were 18% of total solids (TS) and 36% of volatile solids (VS) [27]. From 2006 to 2008, the organic waste collected and fed into the AD system was between 14.55 and 25.85 tons per day, with an average of 20.5 tons per day. However, this amount of organic waste was far less than the design capacity of the WTEF plant of 70 tons per day and represented only 29.3% of full capacity. A survey of the organic waste resources in Rayong municipality (**Table 2**) showed that marketplaces were the biggest source of organic waste representing 70% of the total. Other sources of organic waste were restaurants, hotels, and department stores. Nowadays, the organic waste treated in the AD plant is less than 20 tons a day.

The overall waste treated consisted of two waste streams (SSOW and OFMSW). The MSW collected is firstly processed in the front-end treatment (hereafter FET) unit then fed into the AD facilities to produce electricity and fertilizer [29]. There was a significant effect from the low amount of organic waste input and a lack of operation management which affected the loading capacity which has a maximum capacity of 70 tons of organic waste per day. The AD substrates were mostly, derived from food waste. The food waste treated at the WTE facility

Parameter	Unit, %
Composition	
Food waste	42.70
Paper	9.24
Rubber and leather	1.06
Clothes	2.25
Green waste (Wood and Leaves)	12.52
Plastic	17.13
Glass	0.74
Metal	4.26
Miscellaneous	10.1
Total	**100**
Chemical characteristic	
Moisture content	46.70
Carbon	18.16
Hydrogen	2.18
Nitrogen	1.20
Ash	20.62
Combustible fraction	32.68
C/N ratio	15.13/1

Table 1. MSW characteristics of Rayong municipality [26].

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was separated at its sources: communities, restaurants, hotels, marketplaces, and department stores in the Rayong municipal area. On the environmental aspect, the recovered CH_4 from the AD process that was used in electricity generation resulted in GHG reduction of about 0.34 Gg CH_4 per year, equivalent to 7.15 Gg CO_2 eq of total GHG emission per year [30].

In order to raise people's awareness of and participation in waste management, various facilities were provided and activities conducted, such as recycling banks, recycling markets, and Tung Khaw Moo which is a process in which food waste is separated and gathered before being used as animal feed. The Rayong Municipality Office approached local residents by setting up public relations teams and providing information to the community about collaborating in separating food waste from schools, households, restaurants, hotels, department stores and marketplaces. These activities need to be conducted continuously and required proper monitoring systems to be successful. However, cooperation from government departments, the administrative organization was not forthcoming and local communication was poor.

There are a number of lessons to be learned from the AD project at Rayong municipality. Firstly, the characteristics of the organic waste intended to be used should be comprehensively identified in terms of its availability, and chemical and physical characteristics. Further, the climate and also the culture, and lifestyle of the people in the area should be established and taken into consideration in assessing how much organic waste will be available. Furthermore, the small amount of organic waste produced was also a significant problem in the AD process. This might be solved by finding other sources of additional substrate such as night soil, manure, and shredded pineapple peel which could be put into the AD process to improve the biogas yield. Secondly, the facilities in the AD process should be properly designed, durable and flexible. Thirdly, AD microbial activity should be increased by means of chemicals and

Resource	**The percentage of organic wastes**	
- Marketplaces		**63.45**
Star market	41.38	
Maedaeng market	6.90	
Saroch's fresh-food market	4.83	
Middle place night market	3.45	
Clock tower night market	3.45	
Tedsabaan 1 fresh-food market	3.45	
- Restaurants		**19.31**
- Hotels		**10.34**
- Department stores		**6.90**
Lotus	3.45	
Big C	3.45	
Total		**100**

Table 2. Survey of organic waste resources in Rayong municipality (modified from [28]).

adjustment or improvement of the anaerobic microbial activity of enzymes. Finally, the feasibility of investing in this kind of project should be carefully considered taking into consideration social awareness and people's willingness to participate since both are essential for the sustainable development of such projects.

6. Waste incinerator: a case study of Hatyai municipality

Hatyai, the largest district of Songkhla province is situated near to the city of Songkhla and is the main gateway to Malaysia and Singapore. Hatyai is an attractive tourism city affording a variety of shopping centers and duty-free stores and has been identified as the major southern business center. Hatyai is located on the eastern side of Southern Thailand close to the Thai Gulf coast and it is strategically located only 60 km from the land entry port at Sadao. Hatyai has undergone significant development in the recent past and has rapidly been transformed into the commercial, transportation, communication, educational, and tourism hub of the southern part of Thailand with consequent economic growth [31]. Hatyai municipality is approximately 21 km^2 in area and is separated into 15 sub-districts, 104 communities and 4 administrative zones (**Figure 3**). Hatyai has a tropical climate, which is hot and humid, like other parts of Thailand but it has only two seasons; wet and dry. The wet season, which is influenced by the monsoon and rainstorms, extends from May to December, while the dry season extends only from January to April. Additionally, there have been occasional floods in Hatyai due to heavy rain; it is not unknown for it to rain for twenty-two days in November with more than 300 mm of precipitation (Wikipedia, 2015). The population of Hatyai municipality in 2016 was a little under 160,000 of whom around 74,000 are male and more than 85,000 are female (December 2016) [32].

In regard to waste management in Hatyai, the total amount of MSW in Hatyai was 164, 182, and 158 tons per day in 2012, 2013, and 2014, respectively. In the fiscal year, 2014, the highest monthly amount of waste generated was in October 2013, during the rainy season (**Table 3**).

The waste collection system has been divided into four zones, as shown in **Figure 3**, the air being to efficiently serve each individual zone. As an illustration, the waste composition in Pom-Hok, was investigated as a pilot community between 2012 and 2014 (**Table 4**) and it was found that food waste and plastic made up the largest portion of mixed waste [33]. Fees were paid to contractors with respect to waste collection amounting to between 500 and 1,000 kg of waste per day.

The waste generated is transported to a 0.22 km^2 sanitary landfill in Kuan Lang community which is separated into two parts, a landfill of about 0.13 km^2 (**Figure 4**), and a WTE plant occupying 0.02 km^2 (**Figure 5**). The MSW input is treated in the WTE facility, which is operated by a private company, by means of ash melting gasification technology. It operates on a guaranteed daily capacity of 250 tons of waste and has a maximum capacity of 400 tons per day with a generating capacity of 6.7 MW of electricity per day which is sold to the Provincial Electricity Authority (PEA) at 6.4 Bht per unit. The Hatyai Municipality Office (HMO) has to pay a waste disposal fee of 290 Bht per ton to a private company for waste treatment [33].

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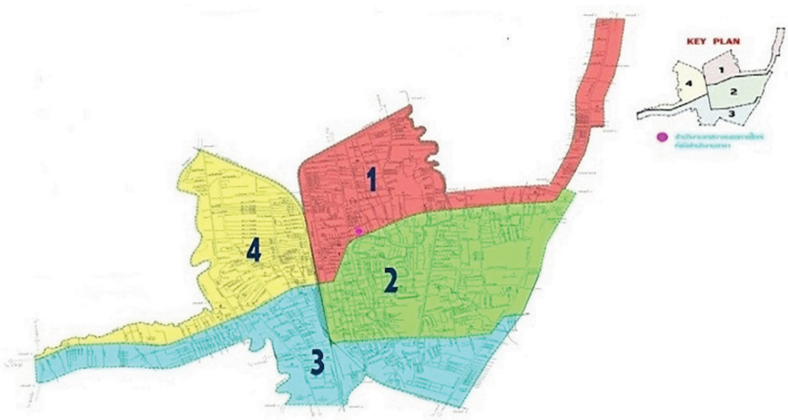

Figure 3. Waste collection zones in Hatyai municipality [32].

Since the provincial administration and regional environmental office 16 set up a collection center for hazardous waste in 2013–2014, hazardous waste in Hatyai municipality has been collected from communities prior to disposal by private companies.

The WTE facility consists of a FET facility, combustion machines, a boiler, a gas cleaning system, a controller system, an electricity generator, and a pollution control system (wastewater treatment, slag and sludge treatment, and an air pollution emission control system). Waste

Month	Generated waste
	Amount (tons)
October 2013	5,777.38
November 2013	5,253.81
December 2013	4,988.00
January 2014	4,558.15
February 2014	4,203.72
March 2014	4,610.77
April 2014	4,510.68
May 2014	4,723.88
June 2014	4,715.25
July 2014	4,292.63
August 2014	4,887.37
September 2014	4,769.37
Total	57,291.01

Table 3. Waste generated in fiscal year, 2014, Hatyai municipality [33].

Figure 4. Hatyai municipality landfill [34].

transported from the municipality is stored in an open-area in front of the FET facility. The waste is moved by a waste pusher to a conveyer through a shredder and a dryer in the FET prior to being fed into the combustion zone which is equipped with an air supply system.

Figure 5. Layout of Hatyai municipality WTE power plant [34].

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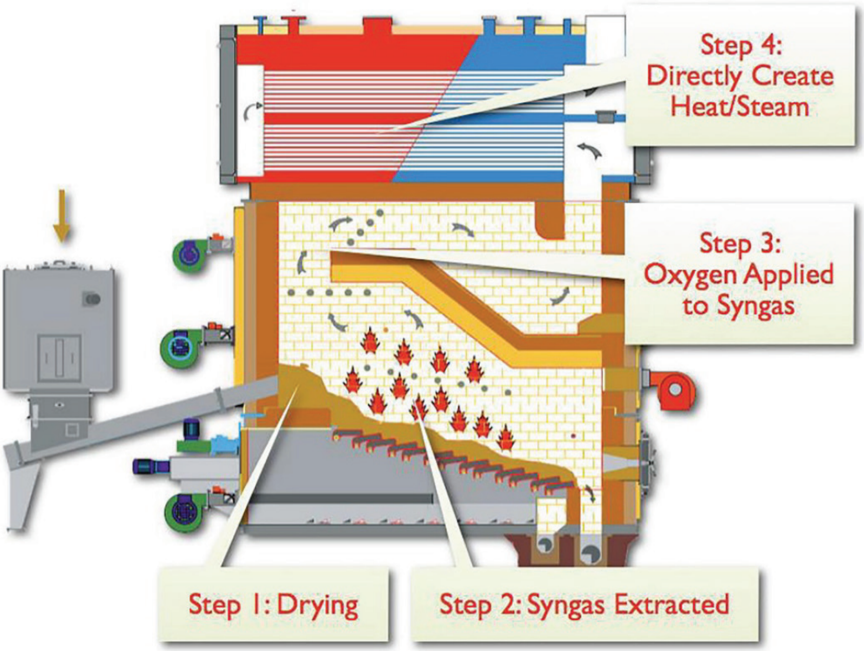

Figure 6. Gasification process [35].

Composition	Unit (%)	
	Year 2012	Year 2014
Paper	12.31	4.46
Food waste	39.90	31.28
Clothes	1.89	6.70
Plastic	19.94	32.43
Napkins	0.0	4.47
Leather and rubber	1.73	0.0
Metal	10.45	0.56
Glass	11.56	5.59
Stone and ceramic	0.05	5.59
Shells	0.0	2.23
Hazardous waste	0.08	0.56
Other	2.17	6.14
Total	100.0	100.0

Table 4. Waste composition in Pom-Hok community, Hatyai municipality [33].

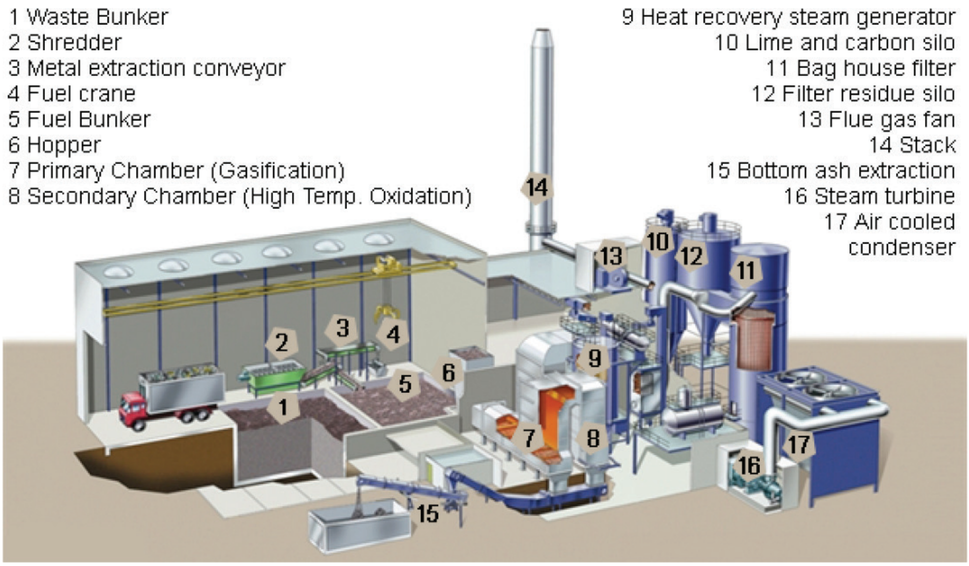

Figure 7. Structure of the WTE gasification power plant [36].

The mixed waste is ignited and burned in a gasification process (**Figure 6**). The schematic layout of the WTE gasification plant is illustrated in **Figure 7**.

The technology employed is focused on solving the problem of the increasing amount of waste generated in Thailand [37]. However, the heterogeneous composition of the waste which has a high moisture content has resulted in varying heating values especially in the

Figure 8. Wood chip mixed with residual waste before gasification.

rainy season and wood chips were mixed with the MSW before combustion to increase the heating value (**Figure 8**). Recently however, the FET has been under renovation with a view to improving its operation.

7. WTE promotion strategies and FiT incentive

The Ministry of Energy has targeted WTE production of 160 MW of electricity and 100 kilotons oil equivalent (ktoe) of thermal energy by 2021 a substantial increase from the amount of 44.324 MW reported by the Department of Alternative Energy Development and Efficiency (DEDE) in 2015. The 10-year (2012–2021) Alternative Energy Development Plan focuses on increasing the ratio of alternative energy use to one-fourth of overall use. Currently, about 22 MW electricity is produced from landfill biogas, 20 MW is generated from waste gasification and incineration, and 2 MW from AD from waste. From the total thermal energy produced of 78.6, 77.3 ktoe was derived from RDF, and the remaining small amount of 1.3 ktoe was from using methane biogas instead of fossil-fuel-based cooking gas. In addition, some cement kilns also utilize waste as a substitute fuel instead of coal [36].

To support WTE productivity, the government has promoted campaigns to encourage public participation in waste separation and WTE conversion, as well as providing information and conducting meetings with local administrative organizations, communities, municipalities, academic institutes, and students to enhance awareness and understanding about municipal waste management for a sustainable environment and energy security. It has also initiated measures to promote WTE production beginning with a 3.50 Bht per kWh subsidy for power generated from waste incineration and gasification, and a 2.50 Bht per kWh subsidy for landfill gas converted to electricity and AD from waste fermentation. The Energy Service Companies (ESCO) revolving fund for the energy support project from Thai government was also established to support energy conservation and investment in renewable energy, with investments in facilities and equipment being eligible for financial support from the Board of Investment (BOI) and the machinery import tariff being waived. Moreover, an exemption from corporation tax for 8 years with a further 5-years at a 50% reduction will apply to alternative energy projects. To motivate energy-from-waste production in 2014, a 4.54 million Bht budget has been allocated to study and enhance the efficiency of potential WTE projects [36]. Latterly, the National Energy Policy Commission (NEPC) has replaced its policy of applying additional rate payment structures with a "feed-in tariff" (FiT) system based on actual cost. For renewable energy from MSW, the FiT rate will be varied based on the annual cost of fuel. In particular, very small power producers (VSPPs, i.e., power producers generating less than 10 MW per year) have now been converted from the additional rate to FiT in power purchase agreements (PPAs) for 20-year project lifetimes. The new VSPP PPAs will apply a competitive bidding model instead of a first-come first-served process. Besides, an FiT premium for all project lifetimes privilege will be provided at a rate of 0.50 Bht per unit extra above the regular FiT in order to provide an incentive in the Southern border provinces to support energy security in those areas. WTE projects located in southern border provinces are eligible for a higher FiT incentive with regards to logistic and location. Details of these schemes are shown in **Table 5** [36].

Capacity (MW)	FiT (Bht/kWhr)			Support duration (Years)	FiT premium (Bht/kWhr)	
	FiT_F	$FiT_{V,}$ 2017	FiT[(1)]		Bio-fuel projects (First 8 years)	Projects in border area[(2)] (Entire project lifetime)
1. Waste (Integrated waste management)						
Installed capacity >1 MW	3.13	3.21	6.34	20	0.70	0.50
Installed capacity >1–3 MW	2.61	3.21	5.82	20	0.70	0.50
Installed capacity >3 MW	2.39	2.69	5.08	20	0.70	0.50
2. Waste (Landfill)	5.60	—	5.60	10	—	0.50
3. Biomass						
Installed capacity >1 MW	3.13	2.21	5.34	20	0.50	0.50
Installed capacity >1–3 MW	2.61	2.21	4.82	20	0.40	0.50
Installed capacity >3 MW	2.39	1.85	4.24	20	0.30	0.50
4. Biogas (Wastewater/Manure/Solid waste)	3.76	—	3.76	20	0.50	0.50
5. Biogas (Energy crop)	2.79	2.55	5.34	20	0.50	0.50
6. Hydropower						
Installed capacity >200 kW	4.90	—	4.90	20	—	0.50
7. Wind	6.06	—	6.06	20	—	0.50

(1)Remark: This FiT rate applies to projects that supply power into the grid system in the year 2017. After 2017, FiT_V will be continually increased depending on the core inflation rate. This rate applies to waste fuel (integrated waste management), biomass, and biogas (energy crop) projects only [36].

(2)Projects located in Southern Border Provinces i.e. Yala, Pattani, Narathiwat provinces, and only 4 districts in Songkla province (Chana, Tepha, Sabayoi, and Natawee) [36].

Table 5. Feed-in tariff (FiT) rate of renewable energy for very small power producers (VSPP) [36].

8. Conclusion

The current rapid growth in the generation of MSW due to population growth and increasing economic development in developing countries has become one of the most serious environmental issues. In 2016, the total amount of MSW in Thailand increased to 27.06 million tons. The efficiency of waste collection is about 80% countrywide but only 36% of the total generated waste is disposed of through acceptable processes such as incineration, composting and landfilling. Moreover, SWM is an interdisciplinary issue. It inevitably involves municipalities, scavengers, investors, teachers, and people. The concept of WM has been embraced by Thailand through the setting of a national master plan for SWM, waste separation at source, clustering waste disposal sites, terminating open dumping, rehabilitating landfills, promoting investment in waste businesses, and building up civil discipline to support sustainable SWM. The increasing amounts of household mixed waste has created a national problem, the resolution of which is to turn a crisis into an opportunity and to reap benefits from garbage. The Thai government has directed provincial authorities to discover new locations for constructing waste management facilities in order to manage the increasing amounts of garbage and to produce renewable energy. WTE is primarily aimed at waste treatment, with the additional benefit of recovering energy and materials from the process. Nowadays, WTE technologies are gaining momentum as a favorable means of managing waste. AD is the most favorable technology for organic waste separated at source. To enhance the AD performance, the retrofitting AD unit to minimize biogas leakage and increasing microbial activities by improving tank mixing is recommended [38]. Thermal processes such as incineration can also be used to treat mixed waste with a low moisture content but this technology has limitations when dealing with high moisture content waste which may cause fluctuated heating values.

However, the environmental impact on nearby communities is an important concern. Nevertheless, motivation for investment in WTE projects has been provided by the FiT rate paid for electricity generated with the aim of promoting energy recovery from MSW. Furthermore, a FiT premium rate for all project lifetimes of 0.50 Bht per unit above the regular FiT is now applicable as an incentive in the southern border provinces. In conclusion however, sustainable SWM can only succeed through the improvement of WTE technology and with public participation.

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