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Sustainable Transition Models for Municipal Solid Waste Management: A Case Study of Saraburi Provincial Administration Organization, Thailand

Siwaree Boonthavornsatien[1], Dawan Wiwattanadate[2,*]

[1] Environment, Development and Sustainability (Interdisciplinary Program), Graduate School, Chulalongkorn University, Bangkok, Thailand
[2] Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
[*] Corresponding author: Email: dawan.w@chula.ac.th

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Abstract

Municipal solid waste (MSW) generation exceeding the capacity of mechanical biological treatment (MBT) plants is a major problem for most municipalities in Thailand. The problem is serious for the Saraburi Provincial Administration Organization (SPAO) as the high daily volumes of MSW sent to the SPAO greatly exceeds the MBT plant capacity of 20 ton d^{-1}. This results in accumulation and ultimately, open-dumping of MSW. Transition from a small (< 50 ton d^{-1}) to a medium-sized cluster (50 - 300 ton d^{-1}) is under consideration to address this problem. Therefore, this study evaluated pre-feasibility information, comparing two possible transition models. Model 1 proposes modification of the existing MBT plant to enlarge its capacity to 50 ton d^{-1}, while Model 2 would require establishing a new medium-sized MBT plant (50 - 70 ton d^{-1}). Results from field data collection as well as mass balance calculation and financial modelling indicate that without additional income from tipping or MSW management fee as well as sale of recyclable materials and scrap metals, both models exhibit negative net present value (NPV) or are not economically feasible due to high initial investment in machinery. However, sensitivity analysis based on an expected fall in future machinery prices indicates that the NPV for both models become positive if prices fall by a minimum 20 %. Due to the much higher initial investment, but the higher capacity with higher separation technology and the higher environmental benefits as well as higher ratings for sustainable development indicators, Model 2 is recommended for a long-term transition. Model 1 can still be recommended for a short - to medium-term transition. Results from in-depth interviews also confirm that Model 1, which offers additional local employment and incomes from selling recyclable materials and scrap metals would be the more feasible option owing to familiarity with the process and its lower initial investment requirement.

Keywords: MSW management; MBT plant; Sustainable models; SPAO; Mass balance calculation; Financial model

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Introduction

Rapid growth in generation of municipal solid waste (MSW) represents a major problem in most countries around the world, including Thailand, where large volumes are improperly disposed by open dumping and/or open burning. The resulting environmental and human health impacts are drastic and long-lasting, and unsustainable in the long term [1-3]. To address the problems, the National Council for Peace and Order (NCPO) approved a “Road Map on Waste and Hazardous Waste Management” and the “National Solid Waste Management Master Plan (2016-2021)” proposed by Ministry of Natural Resources and Environment (MoNRE). The latter is mandated to manage the country’s solid waste problem. There are three main principles in the master plan framework: (1) ‘3Rs Principles’ (Reduce, Reuse and Recycle); (2) ‘MSW management cluster and waste to energy’ (WtE); and ‘Stakeholder participation’ [4-5].

Saraburi province in Thailand has a high rate of solid waste generation owing to a high concentration of domestic and industrial activity. Most of the MSW generated is improperly disposed by open dumping, and some residual household wastes remain in the system. Hence, Saraburi has been included in the Road Map on Waste and Hazardous Waste Management as part of Mission 1 (Managing residual household waste in critical areas), and Mission 2 (Creating solid and hazardous waste management models). This is also relevant to the second principle of the National Solid Waste Management Master Plan (2016-2021). At present, three official MSW management clusters have been established in Saraburi under the Roadmap [6]. Nevertheless, only the Saraburi Provincial Administration Organization (SPAO) can be said to be environmentally friendly. It is jointly managed as a public-private partnership between the SPAO and SCIeco Services Co., Ltd. (SCIeco) under a Memorandum of Understanding (MOU) to apply mechanical biological treatment (MBT) to manage and utilize MSW effectively.

MBT is an integrated process combining mechanical and biological treatments to deal with MSW where the residual fraction is smaller, more stable and suitable for possible utilization [7]. The mechanical treatment process breaks down the MSW into smaller sizes by shredding and removes some recyclable materials either by hand or by mechanical sorting. The biological treatment process then digests organic materials such as food waste and vegetables, either aerobically or anaerobically. It should be noted that the MBT is not a complete or fixed process, but brings together different mechanical and biological processes according to need and characteristics of the waste stream. MBT is designed to minimize environmental impacts as well as to generate additional benefits through recovery of recyclable waste such as plastics, glass and metals, and also recoverable wastes in the form of biogas, fertilizer and Refuse Derived Fuel (RDF) [8-10].

The fast-growing daily volumes of MSW received by the SPAO has now exceeded the capacity of the MBT plant, resulting in an increasing amount of remaining waste being sent for open dumping, generating serious environmental impacts. SPAO is therefore considering whether to modify or enlarge the capacity of the existing MBT plant, or to establish a new medium-sized MBT plant. However, economic analysis indicates that the high cost of construction, operation and maintenance of a new plant would not generate sufficient benefit to justify the investment. Accordingly, this study aimed to compare at pre-feasibility level of the two proposed models for a sustainable transition from small to a medium-sized MSW management cluster. The two transition proposed models are as follows:

• Model 1: Modification of the existing MBT plant to enlarge capacity to 50 ton d^{-1} by constructing an additional MBT plant (20 ton d^{-1}) together with increasing separation efficiency by installing additional separating machines and/or constructing more fermentation rooms; and

• Model 2: Construction of a new medium MBT plant (50 - 70 ton d^{-1}) with facilities as recommended by the Department of Energy Development and Efficiency (DEDE), Ministry of Energy of Thailand [11].

Materials and methods

This study focuses not only on process and financial performance of the proposed models, but also analyzes income generation opportunities through recycling, as well as their relative contribution to reduction of open dumping / burning, both indicators of sustainable development developed by the United Nations Conference on Environment and Development (UNCED) [12]. Additional sustainable development indicators were also considered via a rating score. The study used mixed methods, including both quantitative (data collection and analysis) and qualitative (observation and in-depth interview) approaches, as described in the following subsections.

1) Mass balance

In order to evaluate process performance of the existing MBT plant and the two proposed models, a mass balance approach was used to investigate MSW system inputs and outputs [13]. Operational data of the existing MBT plant gathered from the SPAO's daily report covering one fiscal year (October 2016 - September 2017) was first used for calculating mass balance and MSW overall composition of the existing MBT plant. MSW composition based on a fixed MSW input of 50 ton d^{-1} were used as controlled variables for mass balance calculation of the two models. Efficiency levels used in this calculation were assumed at 70 % for manual and 80 % for mechanical sorting. It should be noted that this study did not consider RDF quality due to low requirements of RDF purchasing criteria under the MOU.

2) Financial model

Financial performance was analyzed using a financial model. Net income for each model was calculated from direct benefits minus total costs. Direct benefits refer only to incomes from selling RDF (both models) and by-products including biogas and fertilizer (only for Model 2) because income from selling recyclable materials and scrap metals currently accrues directly to workers at the MSW separation unit. In addition, no tipping or MSW management fee is charged from MSW generated household or commercial at present. Total costs are calculated from initial investment and operational costs, excluding maintenance cost because this is generally supported by the SCIeco under the MOU. In order to enhance financial performance of the transition models, four options of direct benefits gained from the models were proposed and calculated in terms of net present value (NPV) (Equation 1) to provide an economic basis for recommending the most suitable model for investment [14-15]. The four options are as follows:

Option 1: Gaining benefits from selling RDF, fertilizer and biogas ➔ (Reference case)

Option 2: Additional income from selling recyclable materials and scrap metals

Option 3: Additional income from tipping fee

Option 4: Additional incomes from selling of recyclable materials and scrap metals + tipping fee

Note: The discount rate used in this study was 2.45 %, based on government bond yields of the Bank of Thailand on 3 May, 2018, as this is a government project with low risk;

higher rates (4 %, 6 %, 8 % and 10 %) were proposed in the case of a private project [16].

$$\text{Net Present Value} = \sum_{t=0}^{n} \frac{(\text{Benefit} - \text{Cost})t}{(1+r)t} \quad \text{(Eq. 1)}$$

Sensitivity analysis was employed to identify changes in critical variables that could be pivotal to the economic justification. These factors include growth in waste generation and future reduction in machinery prices due to competition or technological breakthroughs. Changes in these variables, both positive and negative, may impact on the project's financial and/or economic performance and viability. Thereby, the analysis modelled the impact on waste volumes of projected population growth in Saraburi over four time scales (2020, 2025, 2030 and 2035). The impact of reduced machinery costs by 20 %, 40 % and 60 % were also analyzed.

3) In-depth interviews

Results from the above study were shared via in-depth interview with three key organizations: the SPAO (project owner), the Khit Khin Sub-district Administration Organization (KKSAO - as neighbour) and the SCIeco (as customer) in order to gather their opinions and recommendations. The interviews examined their perspectives on problems and barriers to implementation as well as potential solutions. Respondents' views on support needs from internal and external organizations were also elicited. The interviewers also observed and interpreted the body language and environment of the interviewees. By integrating the two approaches of in-depth interview and observation, the results would be more reliable [17-18].

In addition, income generation through recycling schemes and reduction of MSW to be open-dumped and landfilled were assessed for preliminary evaluation of sustainable development in both social and environmental aspects for both proposed models. UNCED's sustainable development indicators were used for reference. All related sustainable development indicators were evaluated by score rating in order to assess the overall sustainability of the two models.

Results and discussion

1) MSW composition

Physical composition of MSW used for mass balance calculation in this study was determined from data gathered from SPAO daily reports. As shown in Figure 1, RDF contributes the highest proportion - up to 57.24 % of the total waste stream. The main components of RDF are plastic bags, papers and wood chips contaminated with food and/or organic waste. The second major component is water, with up to 30.18 % of moisture lost during processing. This is followed with organic waste (10 %) and recyclable waste (including plastic bottles, glasses and paper boxes) accounting for 1.74 % of the waste stream. The rest are rejected waste such as stones and tile (0.59 %), hazardous waste (0.16 %) and metals (0.10 %).

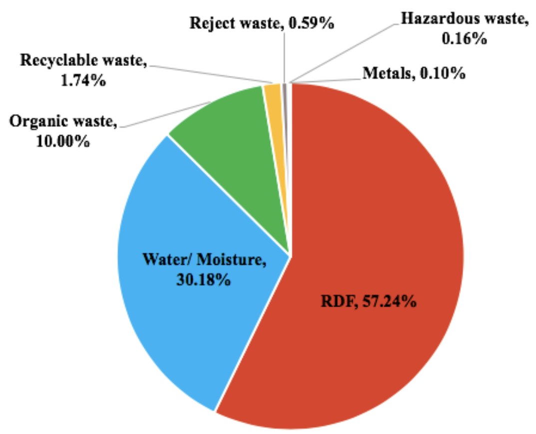

Figure 1 MSW composition received by the SPAO's MBT plant in FY2017.

2) Process performance

Mass balance was used for evaluating the process performance of the existing MBT plant and the two proposed models as illustrated in Figures 2 - 4. The MSW input was fixed at 50 ton d^{-1}, using MSW composition provided by the SPAO as controlled variables in the calculation.

Even if the volume of MSW input is fixed in the mass balance calculation of the two models, their product outputs differ in both type and volume. According to summary data of mass balance (Table 1), Model 2 can generate additional product outputs such as plant watering (6.75 tons), biogas (0.36 tons) and fertilizer (0.30 tons) from the biogas plant. Meanwhile, Model 1 can produce only RDF (contaminated with organic waste and others) that are relevant to income generation. Moreover, the volumes of product outputs of Model 2 in terms of hazardous waste, recyclable waste and reject waste are also greater than for Model 1 due to advanced and more efficient technology resulting in lower levels of contamination in RDF at the end of the process. Nevertheless, there is no significant difference between the two models in the volume of metals due to their low proportion in MSW composition. Volumes of water/ moisture loss and RDF are also similar because they rely on the same composition of MSW input and separation efficiency exclusion in the calculation.

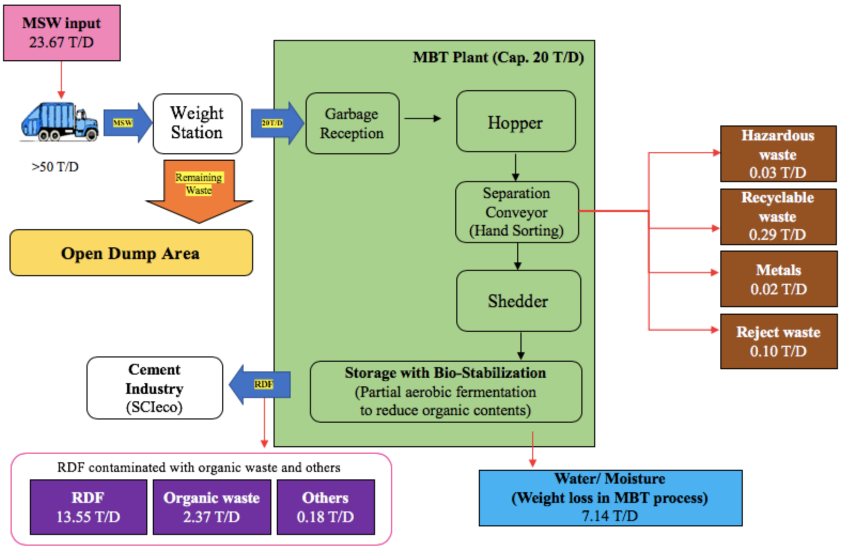

Figure 2 Mass balance of the SPAO's existing MBT plant.

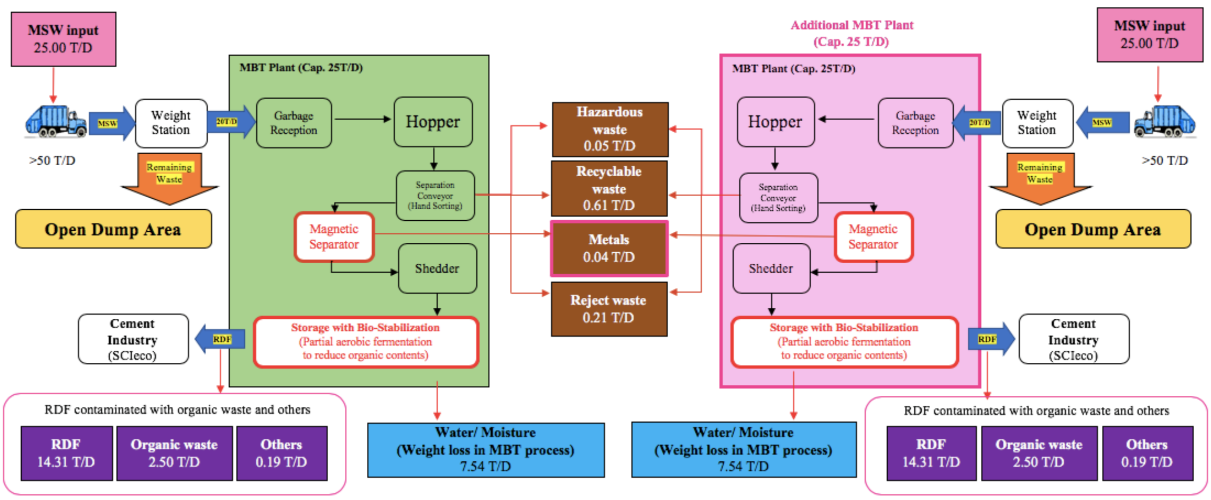

Figure 3 Diagram and mass balance of the Model 1.

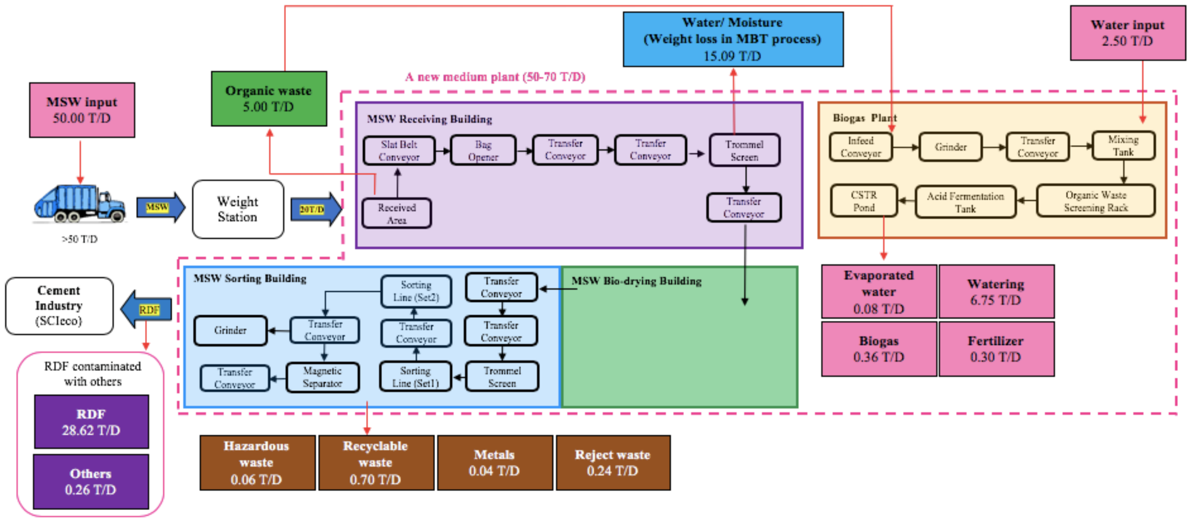

Figure 4 Diagram and mass balance of the Model 2.

Table 1 Summary data of mass balance

Inputs and outputs	The existing MBT plant (ton d^{-1})	Model 1 (ton d^{-1})	Model 2 (ton d^{-1})
Inputs			
- Waste Input	23.67	50.00	50.00
- Water Input	0.00	0.00	2.50
Outputs			
- Hazardous Waste	0.03	0.05	0.06
- Recyclable Waste	0.29	0.61	0.70
- Metals	0.02	0.04	0.04
- Reject Waste	0.10	0.21	0.24
- Water/moisture loss	7.14	15.09	15.09
- Evaporated Water	-	-	0.08
- Watering	-	-	6.75
- Biogas	-	-	0.36
- Fertilizer	-	-	0.30
- RDF	13.55	28.62	28.62
- Organic Waste	2.37	5.00	-
- Others*	0.18	0.38	0.26
- Total amount of RDF selling to the SCIeco**	16.10	34.00	28.88

Note: * 'Others' in this calculation refers to remaining waste that cannot be sorted by the separation processes. It generally accounts for 20 % and 30 % of the waste stream when separated by machines and manually, respectively.

- The efficiency of separation processes (both manual and machine) were assessed by interviews of the responsible operators during May 2018.

** Total amount of RDF selling to the SCIeco is mixed with organic waste and other waste. It cannot be sorted by waste type owing to the low amount of organic waste and others, and unviable for separation.

3) Financial model

This study applied financial modelling to analyze the financial performance of the two models [15-16]. Model 1 requires lower initial investment because it covers only an additional MBT plant (20 ton d^{-1}), magnetic separator installation, and more fermentation room construction. However, its operational cost would be double that of Model 2 (see Table 2) due to its outdated technology and higher labour and energy requirement.

Four options of benefits gaining from the models were proposed for financial performance enhancement. NPVs were calculated for various assumptions of discount rate (2.45 %, 4 %, 6 %, 8 % and 10 %) and machinery price lowering (20 %, 40 % and 60 %) for a 20-year plant lifetime, as illustrated in Figures 5 - 6. As indicated in Figure 5, without additional incomes (Option 1), both models exhibit negative NPV or are not economically feasible for all discount rate assumptions. Nonetheless, Model 1 becomes feasible under Option 3 (with additional income from tipping fees) at a discount rate below 6 % and Option 4 (with additional incomes from both selling of recyclable materials and scrap metals, and tipping fees) at a discount rate below 8 %. This implies that investment in Model 1 is infeasible if the discount rate is higher than 8 %. Meanwhile, Model 2 becomes feasible under Option 3 at a discount rate below 2.45 %, and Option 4 at a discount rate below 3 %.

In addition, all four options for both models, at a 2.45 % discount rate, start becoming feasible if machinery prices fall by at least 20 %, as shown in Figure 6.

Table 2 Costs and benefits of the two models

Cost-benefit	Model 1	Model 2
Costs (THB a^{-1})		
- Initial investment	38,167,819	129,072,796
- Operational cost	10,968,000	5,192,931
Benefits (THB a^{-1})		
- RDF selling	13,087,580	9,952,800
- Recyclable waste & metals selling	417,846	473,366
- MSW management fee	1,300,000	1,300,000
- Biogas	-	2,060,604
- Fertilizer	-	187,200

Note: - RDF and fertilizer selling prices are 1,000 and 2,000 THB ton^{-1} respectively under the MOU.

- Selling prices of recyclable waste and metals cited from Wongpanit website in 19th May 2018, which were 1,950 THB ton^{-1} for lowest rate of recyclable waste and 4,000 THB ton^{-1} for lowest rate of metals [19].

- MSW management fee referred from the Act on the Maintenance of the Cleanliness and Orderliness of the Country (NO. 2), B.E. 2560 is 1,000 THB ton^{-1} [20].

- Biogas selling price retrieved from LPG price for low income household of Department of Internal Trade in 2016 that is 18,130 THB ton^{-1} [21].

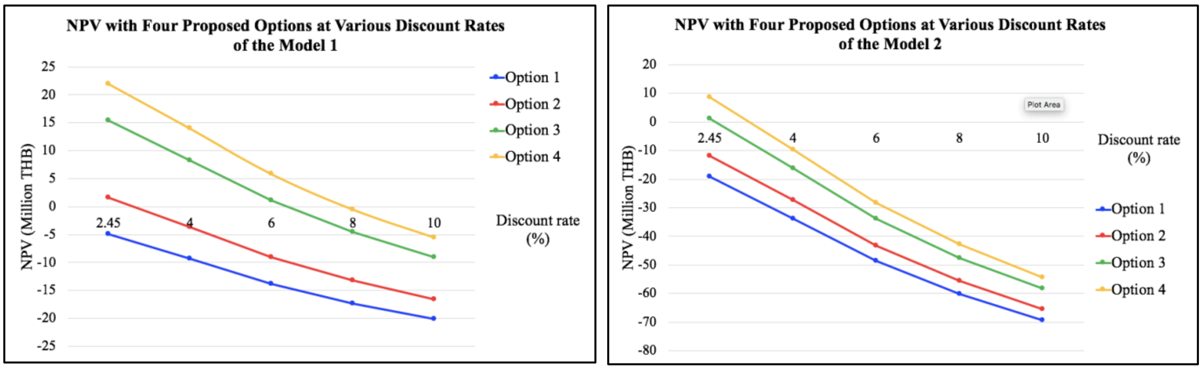

Figure 5 NPV with four proposed options for financial performance enhancement at various discount rates.

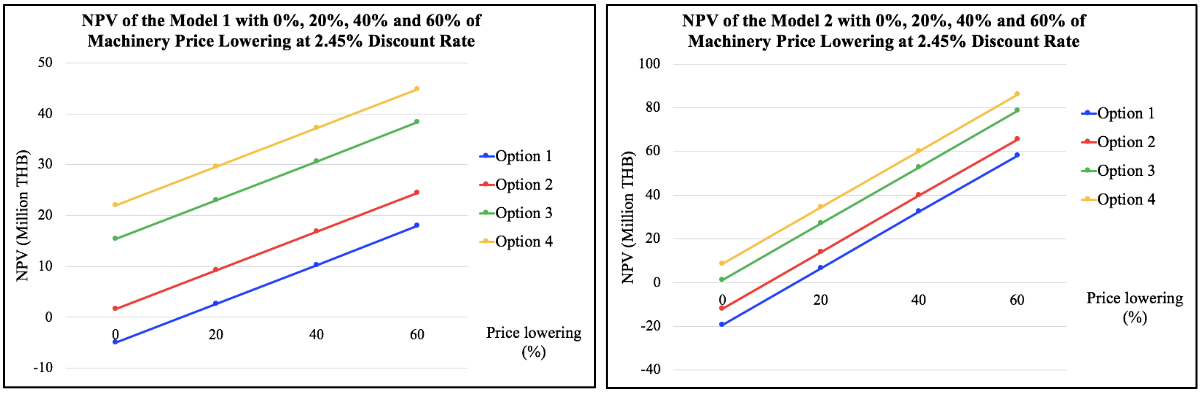

Figure 6 NPV of four proposed options for financial performance enhancement at 2.45 % discount rate with different assumptions of machinery price lowing.

The uncertainty associated with projections of MSW generation which is directly related to population growth was also considered. According to the population projection for Thailand from 2010 - 2040, Saraburi's population growth will fall from 698,000 people in 2020 to 648,300 people by 2035. However, these numbers exclude the latent population that commonly influence Saraburi's population [22] and thus its waste volumes. Waste volumes were estimated by multiplying waste volumes per person of Saraburi (1.09 ton d^{-1}) by projected population growth for Saraburi during 2008 - 2016 [1]. On this basis, waste generation in the province will decrease from 760,820 tons in 2020 to 648,300 tons in 2035. Hence, both models could comfortably accommodate all MSW input with a capacity of 50 ton d^{-1} from now (2018) to 2035, based on these projections.

4) Income generation through recycling schemes

Since recyclable waste can reduce demand for virgin raw materials and increase income generation for local communities, it is identified by UNCED as a significant indicator of sustainable development. As summarized in Table 3, the volumes of recyclable waste and metals sorted by the models are twice as high as the existing MBT plant due to increasing MSW input volumes. Also, the advanced technology used in Model 2 can more effectively separate recyclable wastes from the waste stream, which increased the amount of recyclable waste sorted by Model 2 compared with Model 1 (around 0.09 ton d^{-1}). However, there is no significant difference in the amount of metals sorted owing to low volumes in the waste stream. Finally, Model 2 would generate much more income from recycling schemes compared with the existing MBT plant, and slightly more than Model 1, on a daily, monthly and annual basis.

5) Reduction of MSW to be open-dumped and landfilled

UNCED (2007) specifies the percentage of landfilled waste as one of the most important indicators of sustainable development because it can serve as an overarching measure of environmental impacts resulting from waste management. Increasing the MSW capacity via either of the two models will reduce open-dumping and landfill and conserve these open-dumping and landfill spaces. Both proposed models can receive 25 ton d^{-1} more than the existing MBT plant, saving approximately 31,200 m^3 of MSW, equivalent to 12.48 Olympic-size swimming pools, from open-dumping or landfill [23].

6) Involved organization interviews

In this study, in-depth interviews were scheduled to gather opinions and recommendations from the MBT plant's three key stakeholder organizations: SPAO, KKSAO and SCIeco, was planned to be conducted. Unfortunately, SCIeco declined to participate; thus, the interview results reflect the findings relating only to SPAO and the KKSAO.

SPAO is the local administrative organization with direct responsibility for management of the existing MBT plant. In SPAO's opinion, both proposed models would be applicable. Model 1 is preferred because of familiarity with the process and arrangements with the same groups of customers. Although Model 1 incurs high operational cost due to labour and energy costs for its outdated technology, its low capital investment and high income potential from sale of RDF under the MOU renders it preferable to Model 2, particularly as a short-term management solution.

Table 3 Income generation through recycling schemes

	Recycling schemes	Generation rate (ton d^{-1})	Selling price (THB ton^{-1})	Total (THB d^{-1})	Total (THB $month^{-1}$)	Total (THB a^{-1})
The existing MBT plant	Recyclable waste	0.29	1,950.00	561.32	14,594.27	175,131.21
	Metals	0.02	4,000.00	63.62	1,654.12	19,849.39
	Total	0.31		624.94	16,248.38	194,980.60
Model 1	Recyclable waste	0.61	1,950.00	1,185.67	30,827.37	369,928.42
	Metals	0.04	4,000.00	153.58	3,993.12	47,917.40
	Total	0.65		1,339.25	34,820.49	417,845.82
Model 2	Recyclable waste	0.70	1,950.00	1,357.20	35,287.20	423,446.40
	Metals	0.04	4,000.00	160.00	4,160.00	49,920.00
	Total	0.74		1,517.20	39,447.20	473,366.40

Note: Selling prices of recyclable waste and metals cited from Wongpanit website in 19th May 2018, which were 1,950 THB ton^{-1} for lowest rate of recyclable waste and 4,000 THB ton^{-1} for lowest rate of metals [19].

SPAO also believes that Model 1 would face fewer practical problems in actual implementation compared with Model 2, again because operational challenges with the existing MBT are well understood and readily managed. SPAO needs support from private sector actors such as SCIeco in technology, construction design and operational knowledge, as well as from educational institutes in terms of research. The current study provides an objective basis to facilitate decision-making by the SPAO, and can moreover serve as a reference for other administrative organizations facing similar challenges, who are interested in adopting MBT technology for MSW management.

Meanwhile, the KKSAO, the local administrative organization responsible for Khit Khin sub-district, in which an open dumping area is located nearby the existing MBT plant, believes that SPAO should increase the capacity of the existing MBT plant to 50 - 60 ton d^{-1} in order to reduce pressure on the KKSAO open dumping area. KKSAO also prefers Model 1; as there would be continuity with the existing process, operational issues will be readily anticipated and addressed, and it will be possible to synchronize working processes. However, the future projection for annual MSW volumes is key to this choice. Model 1 might not offer adequate capacity if MSW generation in Saraburi continues to increase every year. To encourage the SPAO to apply Model 1, private sector support for technology advancement, materials and budget are needed due to the limited capacity of local administrative organizations in these areas.

The advantages and disadvantages of the two models can be linked to the three dimensions of sustainability and assigned a score rating (see Table 4). Higher income generation through selling recyclable waste and RDF would generate economic benefits for both models. Although Model 2 generates biogas and fertilizer as additional economic outputs; sales of RDF will be less than for Model 1 due to reduced contamination. Hence, both models obtain the same score of 3 points due to the high income from product sales for Model 1 and the higher quality of RDF produced by Model 2 (which might be expected to drive higher prices for RDF in the future). Importantly, operational costs for Model 2 are lower than for Model 1 due to a reduced labour requirement for the separation process; therefore, Model 2 obtains 2 points while Model 1 gains only 1 point on this criterion.

In terms of environmental performance, Model 2 also scores higher with 3 points. Due to the higher efficiency of its separation process, levels of hazardous waste contamination in RDF are reduced, herby reducing environmental threats from disposal in a sanitary landfill. Moreover, Model 2 can receive up to 70 tons MSW d^{-1}, providing adequate capacity for long-term management. From a social perspective, these reduced environmental impact translate into enhanced health and quality of life for residents. Hence, Model 2 scores 3 points by this parameter, compared with 2 points for Model 1.

In regard to employment generation, Model 1 scores 3 points as a result of labour required for manual separation processes, while the more highly automated process in Model 2 results in a score of 2 points. Nevertheless, manual separation is undesirable as it can result in human health impacts from garbage exposure. For this reason, Model 2 scores 3 points while Model 1 obtains only 1 point in terms of human health impact. The aggregate rating scores for sustainable development indicates greater sustainability for Model 2 (16 points) than Model 1 (12 points).

Table 4 Sustainable development indicators rating of the two models.

Indicators of sustainable development	Model 1 (points)	Model 2 (points)
Economic		
- Increased income generation though sales of product outputs	3	3
- Reduced operational cost	1	2
Environment		
- Reduction of MSW sent for open-dumping or landfill	2	3
Social		
- Local employment	3	2
- Human health impacts from garbage exposure	1	3
- Quality of people's lives though reduction of environmental impacts	2	3
Total	12	16

Note: Rating score: 3 = Good, 2 = Fair, 1 = Poor

Conclusion

In this study, the two sustainable transition models (modification of the existing MBT plant, or Model 1, and establishing a new medium MBT plant, Model 2) were proposed to the SPAO to expand the capacity of the existing MBT plant to 50 ton d^{-1}. Following collection of information and stakeholder interviews, the two options were compared using the UNCED sustainable development indicators, covering the three dimensions of sustainability. Using mass balance approach and financial modelling, the process and financial performance of the two models was analyzed, while sensitivity analysis was employed to identify the impact of changes in critical variables on the feasibility of either option. Moreover, the potential of both options for income generation through recycling schemes and reduction of MSW sent for open-dumping and landfill were assessed from a sustainable development perspective. In-depth interviews were conducted with two of the three key stakeholder organizations to gather their opinions and recommendations on the results of the study, and the UCEDD sustainable development indicators used to provide an overall appraisal of the sustainability of the two models.

The results indicate that although Model 2 exhibits high volume and type of product outputs due to advanced separation technology, these product outputs do not generate much income due to the reduced production of total RDF for sale to SCIeco. However, Model 2 is preferable as a long-term management solution, thanks to its higher capacity of 70 ton d^{-1}, higher quality of RDF production, reduced contamination and reduced environmental impact. However, economic modelling revealed negative NPVs for both models due to high investment costs and limited income potential.

Sensitivity analysis explored the impact of changes in key variables on NPV, using a range of assumptions for discount rate to evaluate financial performance. The results indicate that without additional income streams from either recycling and/or tipping fees, both models exhibit negative NPVs at all discount rate assumptions. However, Model 1 starts becoming feasible with additional income from tipping fees at a discount rate 6 % or with additional incomes from both selling of recyclable materials and scrap metals, and tipping fees at a discount rate of 8 %. Meanwhile, Model 2 starts becoming feasible only for the option with additional incomes from sales of recyclable materials and scrap metals, and tipping fees, at a discount rate below 3 %. In addition, for both models, all four options at 2.45 % discount rate, start becoming feasible if machinery costs fall by at least 20 %.

In summary, the financial modelling as well as in-depth interviews indicate that Model 1 is preferable and recommended for a short- to medium-term transition, while Model 2 is recommended as a long-term solution.

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