CHAPTER 7
DEVELOPMENT OF INTEGRATED MSW MANAGEMENT SYSTEMS AS A SUSTAINABLE SOLUTION IN THAILAND

7.1 General Background of Integrated Waste Management

Integrated solid waste management can be defined as the selection and application of suitable techniques, technologies and management approaches to achieve specific objectives and goals (Shekdar, 2008). As the society becomes more advanced, simple expedient solutions are no longer sufficient to solve the ever-growing disposal problems. The current state-of-the-art of solid waste disposal is based on the concept of integrated management which includes the reclamation of useful material (Kathiravale and Yunus, 2008). As discussed by many authors, recycling, reuse and recovery of energy and material are essential in an integrated approach in the direction of sustainable waste management and only foresees landfill disposal for inert materials and residues from recovery and recycling (Athanassiou and Zabaniotou, 2008; Shekdar, 2008). Therefore, integrated MSW management approaches would contribute to reduce the environmental disasters, economic losses and social burdens (McDougall et al., 2001).

Furthermore, for achieving sustainable systems, it is necessary to consider the ways of improving the collection efficiency, transportation efficiency, recycling efficiency and disposal efficiency at the design phase of the intended integrated MSW management system. As seen in Sections 4.2 and 4.3, among all the phases of life cycle, treatment or disposal phase is the most important one since the major share of environmental, economic and social effects associated with treatment or the disposal practices. Thus, as pointed out by McDougall et al. (2001), biological treatment, thermal treatments, material recycling and landfilling can be combined to develop an integrated MSW management systems to maximize its environmental, social and economic performance. However, to avoid the failures that might happen during its functioning, the treatment methods envisaged need to be suitably selected for a particular location based on careful evaluation of the waste characteristics, local climatic situation, country specific policies and strategies, and other relevant such considerations.

In this section of the research, the major intention is to suggest an appropriate integrated MSW management system for Nonthaburi Municipality for improved environmental, economic and social benefits, and therefore sustainability.

7.2 Overview of the Intended Integrated MSW Management System in Nonthaburi

An integrated system was proposed for Nonthaburi Municipality by incorporating the most appropriate waste treatment technologies based on the waste characteristics. As mentioned in Chapter 4, as an initial approach to sustainable waste management, 24% of the waste generated in the municipality is recycled. However, the remaining 76% of the waste is disposed of in sanitary landfill without gas recovery. Thus, in this part of the research, appropriate technologies have been identified for the treatment of mixed waste to replace current practices of landfilling. When one considers the composition of the waste, which is disposed of at the sanitary landfill, there is a possibility to incorporate, mechanical biological treatment and thermal treatment methods. More than 65% of the waste is composed of short term biodegradables, and another 15-20% of the waste contains combustible fractions characterized by high calorific values. Thus, the intended integrated system has been designed by incorporating the most appropriate technologies such as recycling, anaerobic digestion, incineration and a landfill for residual disposal to treat different fractions of waste. The detailed explanations about the suitability of each technology to be incorporated in the integrated system are presented in Appendix C1.

7.3 Sustainability Assessment of the Intended Integrated MSW Management System

7.3.1 Defining the LCA framework for sustainability assessment

In order to evaluate the sustainability of the intended integrated MSW management system, the LCA framework was defined considering all the life cycle phases and inputs and outputs which are associated with the three pillars of sustainability, as shown in Figure 7.1. The major segments that are included within the LCA framework are collection and transportation of mix MSW, segregation of biodegradable and combustibles at the sorting facility, anaerobic digestion (AD) of organic waste, incineration of combustibles and landfilling of the residual waste. In this new MSW management system recycling follows a different process chain since recyclables are separated at household level in Nonthaburi. The recycling process chain is also incorporated within the system boundary and includes; collection and transportation of point source separated waste, preprocessing at the sorting facility, and recycling of different fractions of recyclables at the various recycling plants. In addition to the main treatment methods, all the required energy and materials production processes were also included within the system boundary. The LCA framework for the intended integrated MSW management system is shown in Figure 7.1. It includes all the inputs/outputs requirements and the mass balance analysis results.

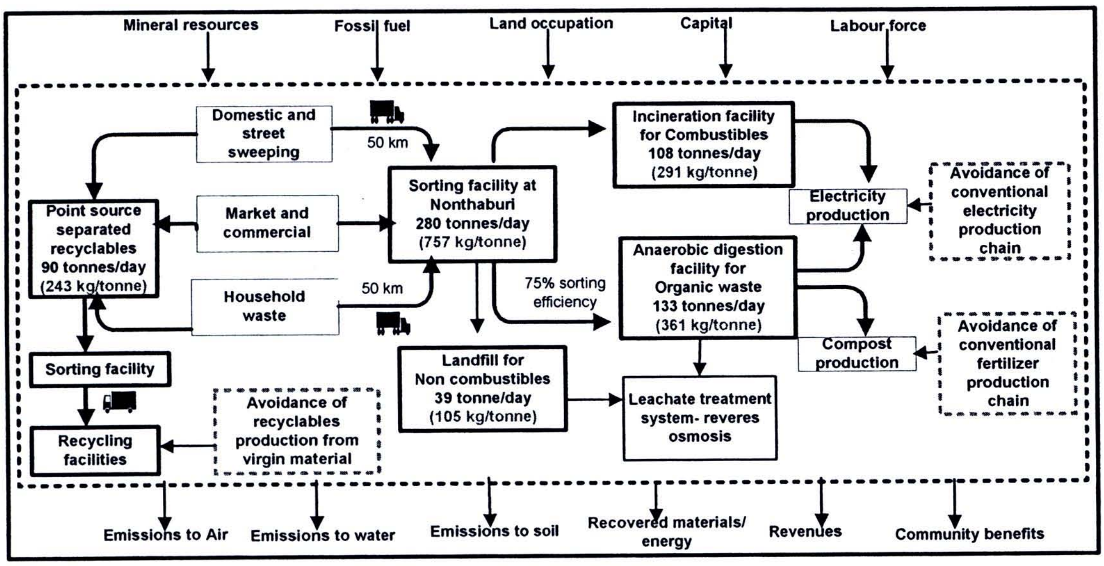

Figure 7.1: LCA framework of the intended integrated MSW management system in Nonthaburi

7.3.2 Inventory analysis of the intended integrated MSW management system

The inventory analysis was carried out following the complete chain of waste management processes in the intended integrated MSW management system. The detail explanations about the inventory data requirement for collection and transportation, sorting of waste, AD, incineration and landfilling have been presented in Appendix C2. However, production of valuable by-products from anaerobic digestion and incineration, such as appropriate technologies, would be key considerations for improving sustainability. Thus, inventory data on potential electricity production and fertilizer production and other such relevant information have been quantified as detailed below.

-Electricity production capacity from AD: To estimate the electricity production potential from AD, it was considered that the methane percentage in produced biogas is 60% and the energy efficiency of IC engine is 35% (UNFCCC. 2010). Based on these assumptions, the

estimated electricity production potential per tonne of organic waste is 192kWh and the estimation is summarized in Table 7.1. Heat production potential and heat consumption levels for onsite activities are also shown in Table 7.1.

Table 7.1: Summary of electricity production, heat production and heat consumption from AD

Description	Amount	Unit
Biogas generation potential from intended AD plant	100.00	m^3 biogas per tonne of organic waste
Methane yield	60.00	%
Potential energy production	2,220.00	MJ per tonne of organic waste
Conversion factor	3.60	MJ/kWh
Gross electricity production potential	616.67	kWh per tonne of organic waste
Efficiency of IC engine	35.00	%
Electricity production potential	215.83	kWh per tonne of organic waste
Onsite electricity consumption	24.00	kWh per tonne of organic waste
Net electricity production	**191.83**	**kWh per tonne of organic waste**
Total heat production		
As 23% cooling efficiency of engine so heat produced(kWh)	141.83	kWh per tonne of organic waste
Heat available for other activities	259.00	kWh per tonne of organic waste
Heat requirement for sterilization of food waste	22.40	kWh per tonne of organic waste
Heat requirement for heating reactors	59.15	kWh per tonne of organic waste
Net heat available for other activities at plant	**177.45**	**kWh per tonne of organic waste**

-Compost production from digestate: AD process has the potential of producing a significant amount of compost by using the wet digestate. As reported, 25% of dry matter can remain in the digestate after completion of the AD process. That amount can be converted to compost approximately after 60 days or alternatively dried with hot air supplied. If the moisture content of mature compost is 40% (Norbu et al., 2005), the compost production potential would be 0.125 tonne/tonne of organic waste. However, considerable amount of primary energy is required for digestate separation (decanter or screw-press is used for separation of liquid fraction from digestate), loading, transport and spreading on arable land. The summary of compost production process is shown in Table 7.2 including the primary energy requirement for the compost production process.

Table 7.2: Compost production potential from digestate and primary energy requirement

Summary of composting	amount	unit
Compost production potential		
Weight of wet digestate	2.28	tonne/tonne of organic waste
Remaining dry matter in digestate	25.00	% of initial DM
Remaining dry matter amount	0.08	Tonne/tonne of organic waste
Moisture content of mature compost	40.00	%
Compost production potential	**0.125**	**Tonne/tonne of organic waste**
Energy requirement for composting		
Energy requirement for separation of wet and dry	78.60	MJ/tonne of digestate
Total energy requirement 2.28 tonne of wet digestate	178.82	MJ/tonne of organic waste
Energy requirement for loading and spreading of wet sludge	29.61	MJ/tonne of slude
Total moist sludge for compost production	0.36	tonne/tonne of organic waste
Energy requirement for loading and spreading of 0.36 tonne of sludge (80% moisture)	11.10	MJ/tonne of organic waste
Energy requirement for making commercial standard compost	510.00	MJ/tonne of composting
Energy requirement for 0.13 tonne of composting	63.75	MJ/tonne of organic waste
Total primary energy requirement for composting process	253.67	MJ/tonne of organic waste
Total required diesel for primary energy	6.97	L of diesel/tonne of organic waste

Considering the mass balance, energy production and compost production potential, the overall process of anaerobic digestion per one tonne of organic waste is shown in Figure 7.2.

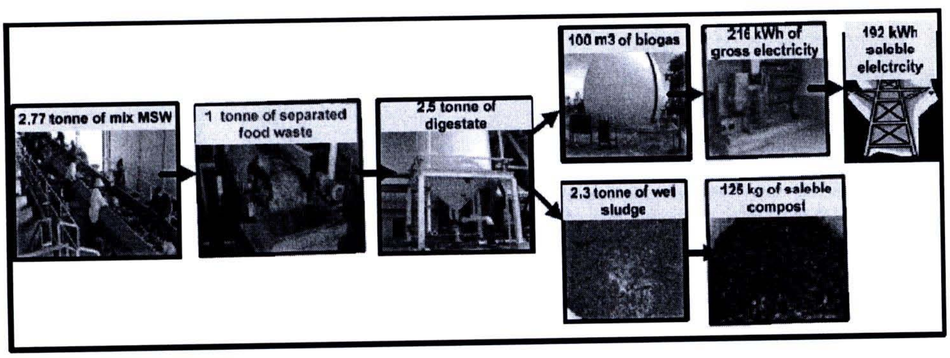

Figure 7.2: Overall anaerobic digestion process and the major outputs

-*Credited processes*: Electricity production from biogas (191.8 kWh/tonne of organic waste) and compost production (125 kg/tonne of organic waste) from digestate were credited for the corresponding amount of avoided production of conventional electricity and fertilizer. Taking into account all the inputs/outputs and credited processes for valuable by-products production, the life cycle inventory analysis was performed as detailed in Appendix C (Table C3).

-Electricity production capacity from incineration: Information regarding the life cycle inventory analysis of incineration is detailed in Appendix C2. According to the composition of combustibles in Nonthaburi, gross electricity production potential is 188 kWh/tonne of combustibles. Of this 60 kWh of electricity is needed for plant operational activities so that the net electricity production potential for selling to the grid would amount to 128kWh/tonne of combustibles, (Figure 7.3). The estimations of electricity production potential from different types of combustibles and from one tonne of mixed combustible are detailed in Appendix C (Table C4). Taking into account all the inputs and outputs, the life cycle inventory analysis was performed for the intended incineration plant in Nonthaburi. The inventory analysis results for incineration are also shown in Appendix C (Table C5). It should be noted that in the inventory analysis the 188 kWh of electricity produced per tonne of combustibles were credited for the avoided corresponding amount of conventional electricity production.

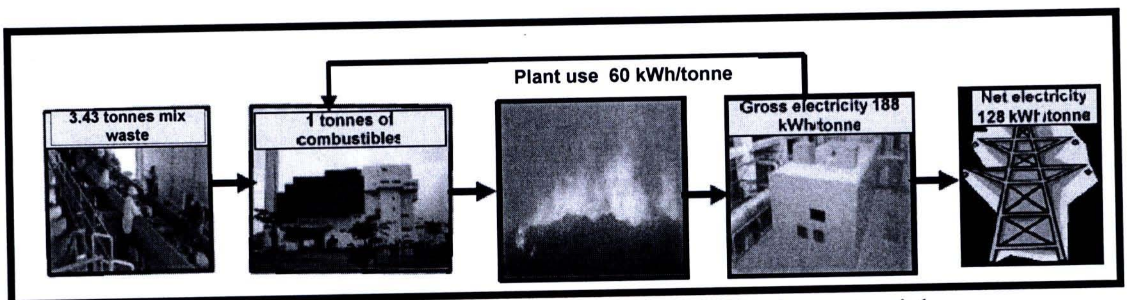

Figure 7.3: Overall incineration process and electricity production potential

-Inventory analysis of landfilling: Detailed inventory analysis for the landfill which is designed for residual waste disposal is presented in Appendix C (Table C6). For the inventory analysis, it was assumed that the construction costs of the landfill (except the landfill liner cost), operational and maintenance costs would be similar to that of the existing landfill.

7.4 Result and Discussion

Similarly to Sections 4.2 and 4.3, the life cycle assessment of individual technologies as well as the projected integrated system was performed based on the most relevant midpoint indicators identified in this research. The assessment results are detailed in Appendix C3. However, in this part of the research, the endpoint composite indicators developed were used to evaluate the three-dimensional sustainability aspects of the integrated MSW management system suggested for Nonthaburi. This assessment for the environmental, social and economic components of sustainability is presented below.

7.4.1 Environmental sustainability assessment of integrated MSW management system

-Quantification of "damage to ecosystem"

As mentioned in Sections 4.2 and 4.3, there are several aspects associated to damage to ecosystem from a particular MSW management system which include: damage occurrence potential from acidifying and eutrophying substances, direct and indirect land occupation. In contrast, the recovery of energy and materials from improved technologies contributes to reduce damage to ecosystem as a result of the credited processes. Considering all these aspects, net damage to ecosystem from different treatment methods was quantified per tonne of waste. The assessment results of damage to ecosystem as presented in Table 7.3 show the benefits that recycling, anaerobic digestion and incineration technologies bring in terms of ecosystem protection as a result of material and energy recovery. The damage to ecosystem from the integrated system is also quantified by assimilation of the effects from each technology based on the fraction of waste as shown below:

Net damage to ecosystem form the proposed integrated system ($PDF.m^2_{global}.yr$) per tonne = Net damage to ecosystem from recycling/tonne × 24/100 + Net damage to ecosystem from AD/tonne × 36/100 + Net damage to ecosystem from incineration × 29/100 + Net damage to ecosystem from landfilling × 11/100

The quantified net ecosystem damage from the intended integrated system would amount to -1.36E+04 $PDF.m^2_{global}.yr$. A negative value would be the result as the net impacts mainly due the credited impacts for recovered materials and energy. Basically, occupation of a large extend of mining land, necessary for conventional energy and materials production could be avoided, this being a reward for recovered materials and energy.

Table 7.3: Damage to ecosystem ($PDF.m^2_{global}.yr$) from different treatment technologies and from the intended integrated system

Ways of damage occurrence/avoidance	Recycling per tonne of recyclables	Anaerobic digestion per tonne of organic waste	Incineration per tonne of combustibles	Landfillling per tonne of residual waste	Integrated system per tonne of MSW
Damage to eco system from acidifying and euthophying substances	5.46E+01	7.02E-01	5.17E+01	5.74E+00	**2.92E+01**
Damage to ecosystem from direct land occupation	0.00E+00	0.00E+00	0.00E+00	4.28E+00	**4.50E-01**
Damage to ecosystem from mining of fossil fuel	1.20E+04	6.59E+02	4.25E+02	2.81E+02	**3.32E+03**
Total damage to ecosystem	**1.21E+04**	**6.60E+02**	**4.77E+02**	**2.91E+02**	**3.35E+03**
Credited damage for recuperation of material and energy	-6.46E+04	-2.00E+03	-1.81E+03	0.00E+00	**-1.70E+04**
Net damage to ecosystem	**-5.25E+04**	**-1.34E+03**	**-1.33E+03**	**2.91E+02**	**-1.36E+04**

-Quantification of damage to abiotic resources

The effect of improved technologies and the integrated system on abiotic resources damage was assessed. Among all the appropriate technologies considered, recycling has the highest potential for contributing to the protection of abiotic resources. As described in Chapter 5, recycling process is facilitating the extraction of a considerable amount of useful materials and therefore contributing to avoid using virgin resources.

The analysis results of both AD and incinerations have shown the possibility of contributing to abiotic resources protection as a result of the energy recovered waste in the form of electricity. Although some intermediate processes like transportation, sorting, composting of sludge and initial combustion are energy intensive, the energy recovery potential from those technologies is much higher than the energy consumed by those processes. In fact, as a result of electricity production from those technologies and potential avoided resources depletion from conventional electricity production, AD would contribute to savings for society amounting to $9.36 per tonne of organic waste, as shown in Figure 7.4(a). Similarly, incineration would contribute to savings for society amounting to $9.82 per tonne of combustible waste, as shown in Figure 7.4(b).

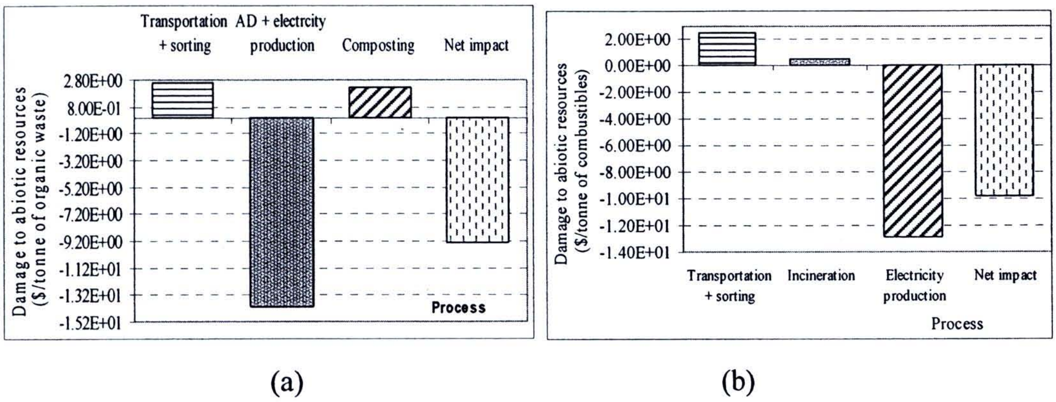

Figure 7.4: (a) Damage to abiotic resources from AD per tonne of organic waste (b) Damage to abiotic resources from incineration per tonne of combustible waste

In contrast, the designed landfill for residual waste disposal is a net energy consumer and the estimated damage to abiotic resources would amount to $2.93 per tonne of residual waste disposal.

The overall effect of the intended integrated system can be calculated by aggregating the damage occurrence/avoidance potential of different technologies as shown in Table 7.4. As a result of the combined technologies and recovery of maximum resources and energy, there is a possibility of saving $81.4 per tonne of MSW to society from the proposed integrated MSW management system. It is noteworthy to mention that, as also observed from Table 7.4, the recycling of 24% of the waste would substantially influence the final result obtained for the integrated MSW management system proposed.

Table 7.4: Damage to abiotic resources from different treatment methods and from the integrated system

Treatment methods	**Damage occurrence/avoidance ($/ per tonne each type of waste treatment)**	**% of mass for different technologies**	**Effect of each technology on final damage of integrated system**
Recycling	-3.10E+02	24	-7.54E+01
Anaerobic digestion	-9.36E+00	36	-3.38E+00
Incineration	-9.82E+00	29	-2.86E+00
Landfillling	2.93E+00	11	3.07E-01
Total damage from integrated system ($/tonne)			**-8.14E+01**

7.4.2 Economic sustainability assessment of the integrated MSW management system

As mentioned in Chapter 5 from the detailed financial analysis of recycling, the recycling of any type of recyclable is financially feasible. In fact, the recycling of one tonne of mixed recyclable has the potential of providing revenues (earnings) amounting to 11,300 baht/tonne.

-LCC of anaerobic digestion

In order to perform the LCC for the AD process, information on investment costs and operation and maintenance costs were obtained from the AD facility of Rayong Municipality which is the only functioning AD facility in Thailand. In addition, capital costs related to collection and transportation were obtained from the Nonthaburi municipality. The capital cost of On-Nuch sorting plant was taken as a reference to estimate the allocated capital cost for organic waste separation.

Considering all those cost components, the capital cost of the intended AD plant in Nonthaburi was estimated which amounts to 495 baht/tonne of organic waste. A detailed capital cost breakdown is shown in Figure 7.5 (a).

Operational and maintenance costs were calculated by aggregating organic waste collection and transportation costs, operational and maintenance costs of waste sorting, and operational and maintenance costs of AD facility. The estimated total operational and maintenance costs for the AD process would amount to 1,347 baht/tonne of organic waste. The detail cost breakdown is presented in Figure 7.5 (b).

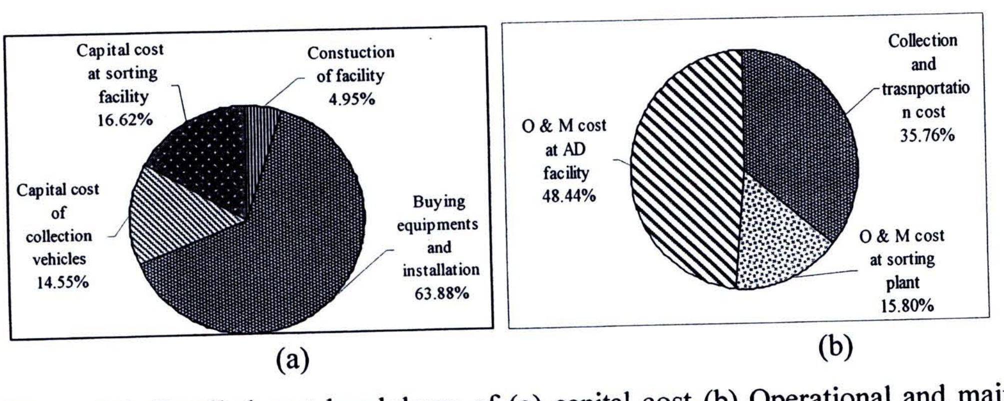

Figure 7.5: Detailed cost breakdown of (a) capital cost (b) Operational and maintenance costs of AD

Moreover, environmental costs were also calculated by estimating the monetary values of life cycle emissions which amount to 223 baht/tonne of organic waste. By adding all the cost components, the calculated gross LCC was found to amount to 2,065 baht/tonne of organic waste. In order to calculate the net LCC, direct and indirect revenues were accounted for to estimate the life cycle revenues, as shown in Table 7.5.

Table 7.5: Potential revenue earnings from AD

Ways of earning revenues	Amount of revenue	Remarks
Selling of electricity	3.5 baht/kWh × 216 kWh/tonne = 755 baht/tonne	Electricity selling price to the grid 3,500 baht/MWh (the rate from Phuket)
Selling of compost	2.0 baht/kg × 125kg/tonne = 250 baht/tonne	Compositing selling price is 2,000 baht/tonne (the rate from Rayong)
Income from households	216 baht/tonne	Collection fee
Credited environmental impacts	433 baht/tonne	Monetary value of environmental emissions
Life cycle revenue (LCR)	**1,655 baht/tonne**	

Now net LCC can be calculated as follows:

Net LCC = Gross LCC – LCR = 2,065 baht/tonne – 1,655 baht/tonne = 410 baht/tonne

It should be noted that, notwithstanding all the possible revenue earnings, still the municipality has to bear some expenses for the anaerobic digestion process. In this case, the revenue generated from the selling of produced electricity and compost alone has not been sufficient to cover the cost and make the project commercially attractive. Further increasing the efficiency of the overall process to earn more revenues, tipping fee, earning CER credits under CDM would be needed to make the project commercially attractive.

-LCC of incineration

LCC of the intended incineration plant was estimated based on the real cost information related to collection and transportation, sorting of waste and incineration of waste. Cost information related to collection and transportation and sorting of waste were obtained from Nonthaburi municipality and On-Nuch sorting plant respectively. All the investment costs (construction of facility, purchase of equipments and installation, yard improvement) operational and maintenance costs (wages of labour, consultancy fee, buying auxiliary materials, spare parts, sample testing, machinery replacement) were obtained from the Phuket incineration plant which is the biggest (250 tonnes/day) incineration facility in Thailand.

The estimated capital cost amounts to 835 baht per tonne of combustibles. The investment cost of the power plant accounts for 81% of the capital cost, another 9% is allocated for buying waste collection vehicles and the remaining 10% corresponds to the capital cost of the sorting facility.

The total estimated operational and maintenance costs for the intended incineration plant is 1,175 baht per tonne of combustibles. If the total operational and maintenance costs are allocated among the costs for collection and transportation, operation and maintenance at the sorting facility, and operation and maintenance costs at the incineration plant, they would contribute 38%, 19% and 43% respectively of the total operational and maintenance costs.

Moreover, environmental costs were calculated for the emissions from incineration which amount to 1,300 baht per tonne of combustibles. The environmental costs seem to be quite high, mainly due to the large fossil based CO_2 emissions during combustion.

By summing up all the cost components, the gross LCC was estimated.
Gross LCC = Capital cost + Operational and maintenance cost + Environmental cost
Gross LCC = 835 baht/tonne + 1,175 baht/tonne + 1,300 baht/tonne = 3,310 baht/tonne
Life cycle revenue (LCR) from incineration can be estimated as follow;
LCR = Revenue from electricity selling + Fee from households for the service + Credited environmental cost
LCR = 3.5 baht/kWh × 128 kWh/tonne + 216 baht/tonne + 359 baht/tonne
= 1,020 baht/tonne
Net LCC = Gross LCC- LCR = 3,300 baht/tonne – 1,020 baht/tonne = 2,290 baht/tonne

It is noticed that the revenues earned will not be sufficient to cover all the costs. As a result the municipality would have to bear an extra 2,290 baht per tonne of combustible waste just to compensate for the loss.

It is a well-known fact that incineration is a promising solution to reduce the ever growing waste problem, since there is insufficient land area available to dispose waste. However, the analysis result clearly indicates that incineration is an expensive MSW management method. In this case, the revenue generated is not sufficient to make the project commercially attractive. Thus, adequate amount of revenue earning by increasing the efficiency of the incineration process, collecting tipping fee from local authorities and earning CDM under CER would be essential to make this kind of project commercially attractive.

-LCC of landfilling of residual waste

In order to assess the LCC of the landfill accommodating residual waste disposal, it was assumed that the capital cost and operational and maintenance costs related to collection, transportation and disposal are similar to the existing situation. Thus, the required data was obtained from the Nonthaburi municipality. The estimated capital cost, operational and maintenance costs, environmental costs, revenues, gross LCC and Net LCC are summarized in Table 7.6. The estimated net LCC would remain as 1,078 baht tonne of residual waste to be landfilled.

Table 7.6: LCC assessment of intended landfill for residual waste disposal

Cost factor	Baht/tonne	Revenue	Baht/tonne
Capital cost			
Land cost	150	Income from households	
Construction of landfill	194	for the service	216
Cost of buying waste collection vehicles	75		
Capital cost at sorting facility	82		
Total capital cost	**501**	**Total revenue**	**216**
Operational and maintenance cost			
Collection and transportation cost	452		
O & M cost at sorting plant	219		
Total O & M cost	**671**		
Environmental cost	**122**		
Gross LCC	**1,294**		
Net LCC = Gross LCC- Revenue = 1,294 – 216 = 1,078 baht/tonne			

- Overall economic sustainability assessment of the integrated MSW management system

The main objective of the detailed calculation of net LCC of different technologies is to investigate the net LCC of the intended integrated system. Thus, the net LCC of each treatment method was merged based on the fraction of waste that goes to different treatment method. As mentioned earlier, the intended integrated system has been designed for 24% of waste going to recycling, 36% to AD, 29% to incineration and 11% to landfill. Based on this, the net LCC for one tonne of MSW for the intended integrated system would amount to -1,832 baht/tonne, as shown in Figure 7.6. This indicates that, as a reward for the initiation of an integrated system, there is a possibility of earning revenue of 1,830 baht per tonne of waste, indicating that this integrated system would be economically sustainable. Despite the economical losses from AD, incineration and landfilling technologies, there is a possibility to experience "net earnings" from the integrated system as a reward for the recycling of 24% of waste. However, to earn adequate revenues from the intended integrated system, measures have to be taken, especially to reduce the cost of incineration and anaerobic digestion. In fact, the LCC can be reduced from incineration by reducing the moisture content of waste as it directly helps to increase the electricity production efficiency. As mentioned earlier, revenues from CDM and tipping fee would be needed to improve the financial feasibility of both AD and incineration.

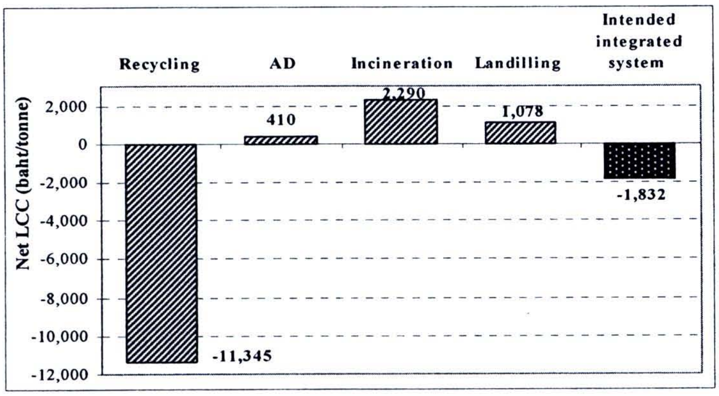

Figure 7.6: Net LCC of individual treatment methods and intended integrated system

7.4.3 Social sustainability assessment of the integrated MSW management system

-Quantification of "damage to human health"

Similar to the above cases, health hazardous potential from different technologies was added up in order to estimate the potential health damage from the intended integrated system. The Swedish EPS model was used to correlate environmental pollution and its impacts on human health through various damage occurrences pathways. Based on the life cycle inventory analysis results of recycling (see Appendix A), incineration, AD and landfilling (see Appendix C), the life cycle emissions based health damages were quantified as mortality, severe morbidity and morbidity that would occur through various diseases occurrence pathways. Then all the effects were added to estimate the total health damage expressed in terms of DALYs. As shown in Figure 7.7, contribution from recycling for avoiding damage to human health damages is substantial. AD also contributes to prevent occurrence of damage to human health from MSW management. This is mainly due to the effects of electricity production from AD resulting in avoided impact on global warming and therefore human health, which would have otherwise occurred from the production of a same amount of conventional electricity.

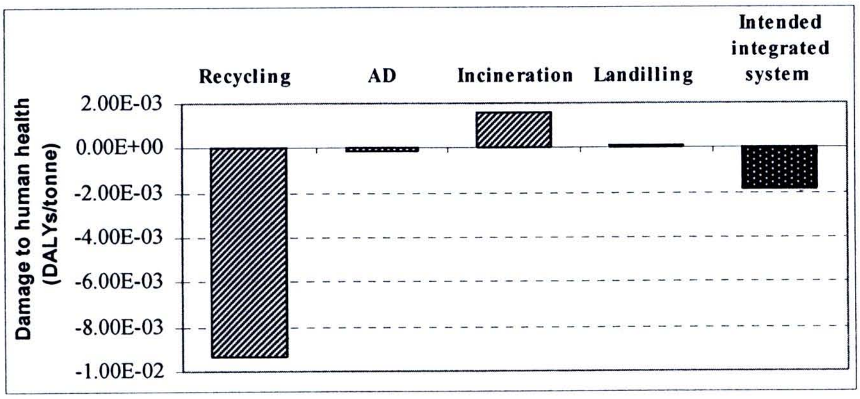

Figure 7.7: Damage to human health from individual treatment technologies and intended integrated system

In contrast, incineration contributes to damage to human health from the toxic gasses emitted (fossil CO_2, NO_x, SO_x) during the combustion process. In fact, 90% of health damages from incineration come from global warming as a result of the large fossil based CO_2 emissions occurring during the combustion. Landfilling of residual waste has also shown a possibility of minor health effects. By aggregating all health hazardous occurrences potential from different technologies, the severity of health damages from the intended integrated system were quantified. As shown in Figure 7.8, the overall health impact is shown as a negative value, indicating that the proposed integrated system has the capacity to avoid health damages. However, it should be noted that this is mainly due to the effects of recycling (24% of waste is recycled). This assessment has provided important information with respect to occurrence/avoidance of health hazards from individual technologies as well as from the intended integrated system that would be a very good indication to make decision on the sustainability.

Quntification of "income based community well-being"

As discussed in Chapters 5 and 6, public appreciation deems to be the key phenomenon for prolonged sustainability of the intended MSW management system. In order to get the public appreciation, improvement of community well-being would be the appropriate pathway. Therefore, community well-being improvements via creation of employment opportunities as well as indirect income generation were estimated for the intended integrated system.

As mentioned in Chapter 5, recycling activities contribute significantly to improving community well-being via creation of employment opportunities and indirect income generation. Thus the total income generation potential for the recycling process from direct (selling recyclables) and indirect (wages based) sources amount to 20,300 baht/tonne of recyclables, (Figure 7.8).

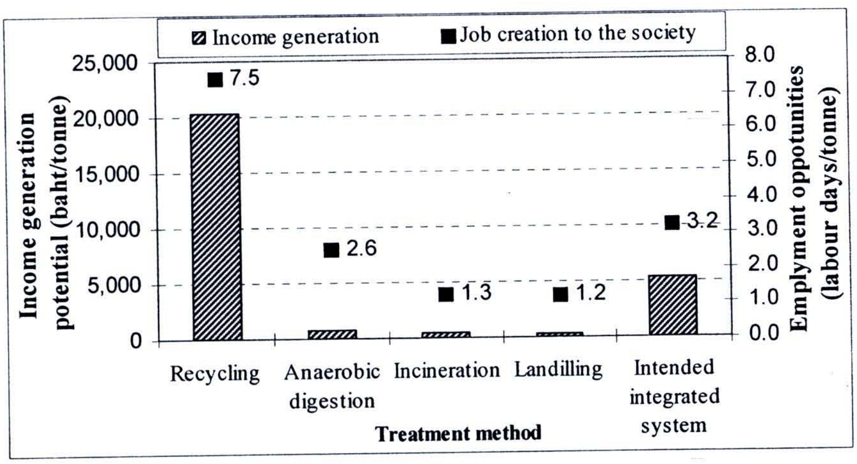

Figure 7.8: Income generation potential and creation of employment opportunities from intended integrated system

Furthermore, the possibility of improving the community well-being from other technologies such as AD, incineration and landfilling was estimated. It was noticed that, there is hardly any opportunity to earn indirect income from those technologies for the people in the community. The major way of improving the well-being would be in providing an adequate number of opportunities for skilled employment. Labour power requirement for AD, incineration and landfilling would be 2.6, 1.3 and 1.2 labours per tonne of waste respectively, (Figure 7.8). Considering the hierarchal position of the different types of jobs created, the wages based income generation potential was estimated. Wages based income generation potential for AD, incineration and landfilling would be 726, 392 and 322 baht respectively per tonne of waste. It should be noted that the improved technologies are more automated so that the labour power requirement is less.

By aggregating effects of different technologies, income based community well-being was determined for the intended integrated MSW management system. The estimated income to the community from both indirect income and wages based income amounts to 5,360 baht/tonne of waste in Nonthaburi. To provide a meaningful explanation the "per capita living expenses" of a middle class person (5,000 baht per month) was considered in Thailand. Consequently, the generated income per tonne of waste would be sufficient to at least cover the monthly expenses of one person contributing thereby to enhance quality of life.

Is the intended integrated system sustainable relative to the existing situation?

An analysis of the potential for sustainability improvement of the proposed integrated MSW management system as compared to the existing system would be an interesting point to support decision making on the technologies to be adopted, (Figure 7.9). As Nonthaburi municipality is already recycling 24% its waste, they have already achieved a certain environmental, economic and social sustainability as shown from the results of the assessment performed with the endpoint composite indicators developed in this research. As shown in Figure 7.9, the upgrading of the existing system to landfill with landfill gas recovery was found to improve the overall sustainability of the MSW management system in Nonthaburi.

The incorporation and combination of additional treatment technologies for the proposed integrated MSW management system showed improvement for all the impact categories assessed with regards to sustainability. The intended integrated system was found to offer the potential of optimizing ecosystem protection by 14%, abiotic resources protection by 18%, revenue earnings by 124%, avoidance of damage to human health by 147% and community well-being by 6% ability as compared to the existing system.

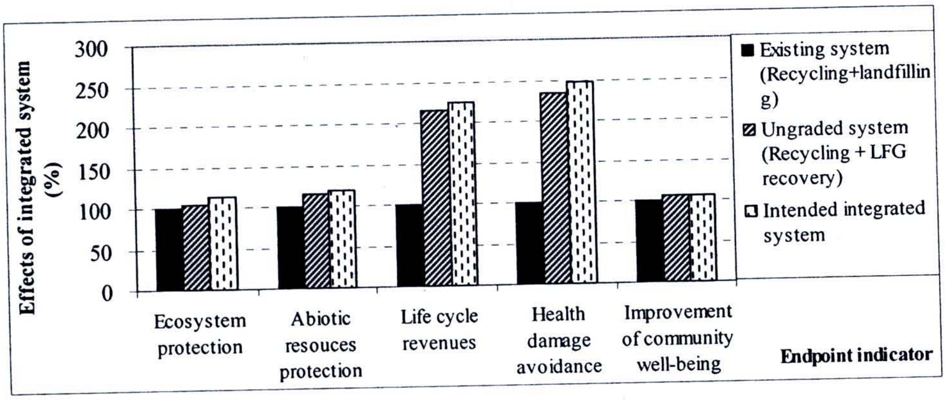

Figure 7.9: Sustainability improvement of the intended integrated systems relative to the existing MSW management system in Nonthaburi

7.4.4 Further improvement of sustainability of integrated system – a sensitivity analysis

According to the analysis results, it was clearly observed that overall sustainability of an integrated waste management system in Nonthaburi is highly sensitive to the recycling rate and the effects of recycling has been significantly contributed to drive the entire integrated system towards sustainability. In contrast, incineration is identified as a technology which caused some health hazardous and also it is an expensive waste treatment method. Therefore, a sensitivity analysis was performed to predict the future perspectives on improvement of three-dimensional sustainability of such integrated system with an increasing recycling rate while reducing the waste incineration rate proportionately. If Nonthaburi Municipality initiate an integrated system in the future, with 30% of waste recycling, instead of existing 24%, the MSW management system would have the potential of further improving the all the sustainability aspects more than 20% (Figure 7.10).

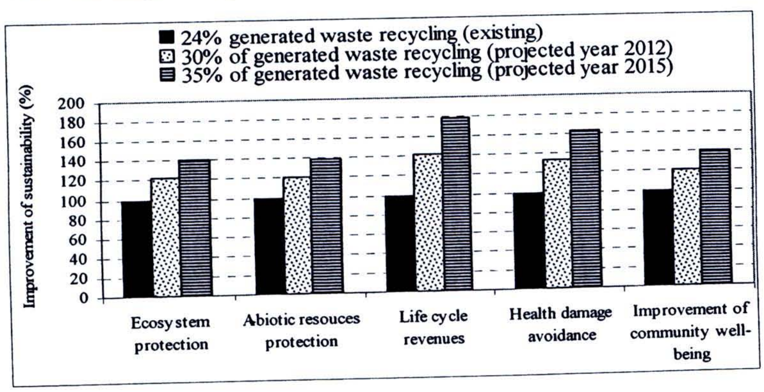

Figure 7.10: Future perspectives of sustainability improvement of the integrated system by improving the waste recycling rate in Nonthaburi

Figure 7.10 also shows the possibilities of further improvements with an increasing recycling rate.

7.5 Conclusion

Developed endpoint indicators were used for comprehensive sustainability assessment of the intended integrated MSW management system in Nonthaburi. Recycling, AD, incineration and landfill technologies were incorporated to develop an appropriate integrated system, aiming to maximise energy and materials recovery. Out of all the technologies considered and assessed, recycling was found to be the most promising technology with regards to its potential for driving the entire system towards improved sustainability. AD and incineration were found to contribute to environmental and social sustainability. However, still each of those technologies was found to be not economically sustainable due to high investment and operational costs. Adequate amount money as tipping fee from local authorities, earning CDM under CER and improvement of the efficiency of the technology would be essential to make this kind of treatment technologies economically attractive.

As a result of combining all the technologies, the developed integrated system has shown the maximum sustainability relative to the existing and upgraded MSW management systems. For instance, the intended integrated system has the potential of 14% ecosystem protection, 18% of abiotic resources protection, 124% of revenue earning, 147% health damage avoidance and 6% community well-being improvement ability than that of the existing system. The outcomes of this study will be very useful for the decision making process on developing sustainable integrated MSW systems in near future.