CHAPTER 6

TOWARDS THE SUSTAINABILITY - INITIATION OF SANITARY LANDFILL WITH LANDFILL GAS RECOVERY SYSTEM IN THAILAND

6.1 Potential for Sanitary Landfill with Landfill Gas Recovery System

In Chapter 5, the analysis results of the existing MSW management method in Nonthaburi have clearly shown the limitations of the present system. Even though 24% of waste recycling has contributed substantial benefits with regards to all three aspects of sustainability, the harmful impacts from the remaining 76% the waste fraction that is landfilled cannot be ignored. In Section 4.2, the environmental degradation, economic losses and social burdens associated with the existing landfill disposal system in Nonthaburi have been clearly assessed and identified.

In Thailand, a possible option for upgrading the environmental performance and financial and economic benefits of the current MSW management system could be the upgrading of the existing sanitary landfills to sanitary landfills with landfill gas (LFG) recovery for energy purposes. The major expectations from the upgraded system are the reduction of methane emissions to the atmosphere and the production of a certain amount of electricity from LFG. Application of the same approach may contribute to improve the sustainability of the MSW management system in Nonthaburi Municipality.

Compared to other MSW management technologies, sanitary landfill with gas recovery system is a low cost and easily manageable technology (COGEN Asia, 2010). In addition, as a centralized landfill, the landfill in Nonthaburi Municipality can be converted to an economically feasible LFG extraction project due to the possibility of extracting sufficient amount of LFG (Chiemchaisri et al., 2007a). Thus, initiation of LFG to energy project in Nonthaburi could be an immediate possible solution to improving the existing MSW management system.

6.2 Overview of the Intended Sanitary Llandfill with LFG Recovery System in Nonthaburi

The proposed major modification in this scenario is the upgrading of the existing sanitary landfill to facilitate recovery of LFG. It was assumed that as practiced currently, 90 tonnes of point source separated waste would be sent to recycling facilities whilst the remaining

280 tonnes of generated MSW would be collected and disposed of at the sanitary landfill. Total disposal capacity of the landfill is 900 tonnes per day, including MSW received from other municipalities and companies. Nonthaburi landfill is recognized as one of the largest landfill in Thailand; hence the capacity of the landfill would have to be enhanced in various ways after the incorporation of the LFG recovery system.

All other existing specifications of the landfill such as density of waste, depth of the landfill liner system, landfill cover, leachate collection system, etc. will meet the proposed modifications.

6.3 Sustainability Assessment of the Upgraded MSW Management System

6.3.1 Defining of LCA framework for sustainability assessment

The assessment framework was defined for the upgraded MSW management system in Nonthaburi based on life cycle considerations for both recycling and sanitary landfill with LGF recovery. The system boundary of recycling for the proposed system is similar to the existing system in that it includes collection and transportation, pre-processing at sorting facility, transportation of pre-processed recyclables to recycling facilities by heavy duty trucks and recycling processes of different types of recyclables at various recycling facilities. The system boundary of the proposed sanitary landfill with LFG recovery includes the collection and transportation of MSW by using compactor trucks, final disposal at sanitary landfill, leachate treatment and LFG recovery for electricity production. The schematic diagram of the LCA framework of the upgraded MSW management system in Nonthaburi is shown in Figure 6.1.

An inventory analysis was done with respect to environmental, economic and social aspects of both recycling and sanitary landfill with gas recovery system. A detailed description of the inventory analysis for the existing recycling activities is presented in Appendix A. For sanitary landfilling with LFG recovery, all the input resources, emissions, energy production potential etc., were taken into account in order to perform the life cycle inventory analysis. All the data related to the collection, transportation, and final disposal is similar to the existing system. Data related to electricity production from recovered LFG had to be collected. Information was obtained from various sources in the literature to quantify the electricity production potential from LFG. Detailed explanations concerning the inventory analyses related to environmental, economic and social aspects, including selection of IC engines, quantification of electricity production from LFG and all the assumptions made for calculations are presented in Appendix B 1.

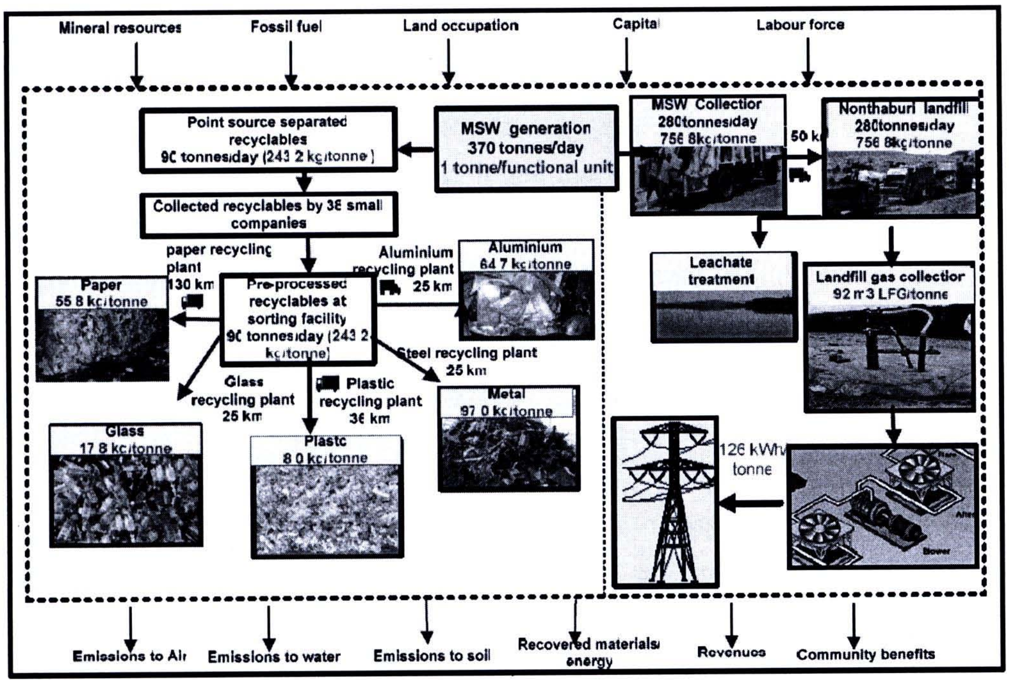


Figure 6.1: LCA framework for the proposed upgraded MSW management system

6.3.2 Inventory analysis of the upgraded MSW management system

As shown in Table 6.1, the major concern of this part of the research is to estimate the amount of methane that can be potentially produced and collected, the potential amount of electricity that can be produced out of the LFG collected, the excess amount of methane flared, and the fugitive emissions of methane per tonne of waste disposed in the landfill.

Table 6.1: LFG collection and electricity production potential per tonne of MSW

Descriptions	Amount	Unit
Methane production potential (adapted IPCC 2006 model)	61.64	m^3 per tonne
Methane collection potential using available technologies	75.00	%
Collected methane volume	46.23	m^3per tonne
Methane used for electricity production (based on capacity of IC engine and duration of engine)	34.97	m^3 per tonne
Heating value of methane	37.00	MJ / m^3
Total energy of collected methane	1293.78	MJ per tonne
Electricity efficiency of IC engine	35.00	%
Amount of energy converted to electricity	452.82	MJ per tonne
Conversion factor	3.60	MJ/kWh

Potential electricity production	**125.78**	**kWh per tonne**
Excess methane flaring		
Flared methane (collected excess methane)	11.26	m^3 per tonne
Methane oxidation through the landfill cover		
Methane oxidation potential	15.00	%
Oxidized methane	2.31	m^3per tonne
Fugitive methane		
Fugitive methane	13.10	m^3 per tonne
Density of methane	0.67	kg/m^3
Weight of the fugitive methane	**8.74**	**kg per tonne**

According to the estimations, it was found that electricity production potential from one tonne of disposed waste is 125.7 kWh. Thus, this amount of electricity production from LFG was credited since the electricity production from LFG enables the project to benefit from the avoided GHG emissions that would have otherwise occurred in the process of production of a corresponding amount of conventional electricity (Appendix B – Table B1).

6.4 Results and Discussions

For the scientific decision making purpose, one can use the midpoint indicators to assess the environmental performance of the upgraded system and such assessment has been presented in Appendix B2. In order to arrive at the right conclusions regarding the three-dimensional sustainability of the upgraded system, the developed endpoint composite indicators have been used to perform a comprehensive sustainability assessment.

6.4.1 Environmental sustainability assessment of the upgraded MSW management system

-Quantification of "damage to ecosystems"

As seen in Chapter 5, damage to ecosystem, as a result of recycling has already been quantified as reported in Table 5.1. It should be noted that materials that would be recovered from recycling were credited for the avoided virgin production of such materials. On the basis of this information, net damage to ecosystem was quantified for the recycling of one tonne of each recyclable material as well as for one tonne of the recyclable mix in Nonthaburi.

To quantify the overall damage potential from sanitary landfill with LFG recovery, the same concept was followed, as described in Session 4.2.3.1. The novelty in this scenario is the electricity production process from the recovered LFG which has been credited for avoidance of damage to ecosystem as a result of conventional electricity production. As shown in Table 6.2, the credited ecosystem damage for electricity production from LFG amounts to 539 $PDF.m^2_{global}.yr$ per tonne of landfilled waste. In comparison to the net ecosystem damage caused from the existing landfill, the incorporation of the LFG recovery system would progressively contribute to reducing the damage by 67 %.

As a whole, the net damage to ecosystem from the proposed upgraded system can be calculated as:

Net damage to ecosystem from upgraded MSW management system (per tonne of waste) = Net damage to ecosystem from landfilling with LFG recovery per tonne × 76/100 + Net damage to ecosystem from recycling per tonne × 24/100 = -1.23E+04 $PDF.m^2_{global}.yr$ per tonne.

Table 6.2: Quantified damage to ecosystem ($PDF.m^2_{global}.yr$ per tonne) from the upgraded MSW management system in Nonthaburi

Factors of damage to ecosystems	Landfill +LFG recovery per tonne	Damage from recycling (per tonne of recyclables)					
		Paper	Plastic	Glass	Aluminium	Metal	Recyclable mix
Damage to eco system from acidifying and euthophying substances	5.80E+02	7.12E+01	1.73E+02	6.21E+01	1.55E+01	6.00E+01	5.46E+01
Damage to ecosystem due to direct land occupation	1.06E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Damage to ecosystem by mining of fossil fuel	2.96E+02	1.58E+04	3.84E+04	1.20E+04	5.47E+03	1.21E+04	1.20E+04
Total damage to eco-system	**8.86E+02**	**1.58E+04**	**3.85E+04**	**1.21E+04**	**5.49E+03**	**1.21E+04**	**1.21E+04**
Credited damage for valuable by-products	5.39E+02	1.45E+04	7.29E+04	1.68E+04	1.67E+05	3.33E+04	6.46E+04
Net damage to eco - system	**3.47E+02**	**1.38E+03**	**-3.44E+04**	**-4.74E+03**	**-1.61E+05**	**-2.12E+04**	**-5.25E+04**

It was found in the initial assessment of the existing MSW management system of Nonthaburi, that only a 24% fraction of waste recycling contributed substantial benefits with regards to ecosystem protection. As far as ecosystem damage is concerned, further benefits can be achieved from LFG recovery and electricity production from it. The incorporation of LFG recovery system enables to reduce by an additional 3.3% the damage to ecosystem of the existing system. The incorporation of a LFG recovery system would enable therefore to enhance the environmental sustainability of the existing MSW management system.

-Quantification of "damage to abiotic resources"

Potential damage to abiotic resources that may result from upgraded MSW management system in Nonthaburi was assessed based on the concept detailed in Chapter 4. As seen in Chapter 5, there is a potential of saving $310 per tonne of mix recyclables in the recycling process in Nonthaburi, see Figure 6.2.

Sanitary landfilling with LFG recovery system will bring in a significant potential for abiotic resources conservation as a result of the electricity produced from the recovered LFG as opposed to the existing system. Potential saving to the society in the form of avoided of abiotic resources depletion from conventional electricity production amounts to $5.82 per tonne of waste landfilled, as shown in Figure 6.2. In other words, electricity production from LFG offers the possibility of avoiding damage which exceeds by far the damages from landfilling. Damage from landfilling is mainly due to fuel consumption for transportation and HDPE liner production.

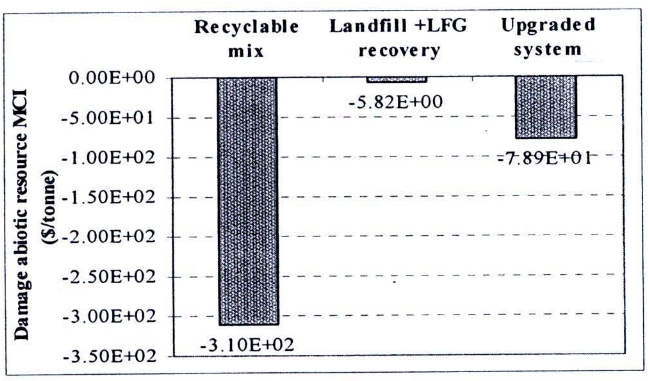


Figure 6.2: Damage to abiotic resources from recycling and landfill with LFG recovery system

Looking further at the net impacts of the whole system (24% recycling + 76% landfilling with gas recovery), it should be noted that the total abiotic resources depletion potential amounts to -$78.9 per tonne of MSW in Nonthaburi, as shown in Figure 6.2. The society would benefit from the avoided net damage of -$78.9 per tonne of waste as a result of the avoided extraction of fossil fuel and mineral resources due to recycling and incorporation of LFG recovery system for electricity production. Thus the upgraded system would drive the existing system towards improved environmental sustainability with the saving of an additional $6.4 per tonne of MSW in comparison to the existing system.

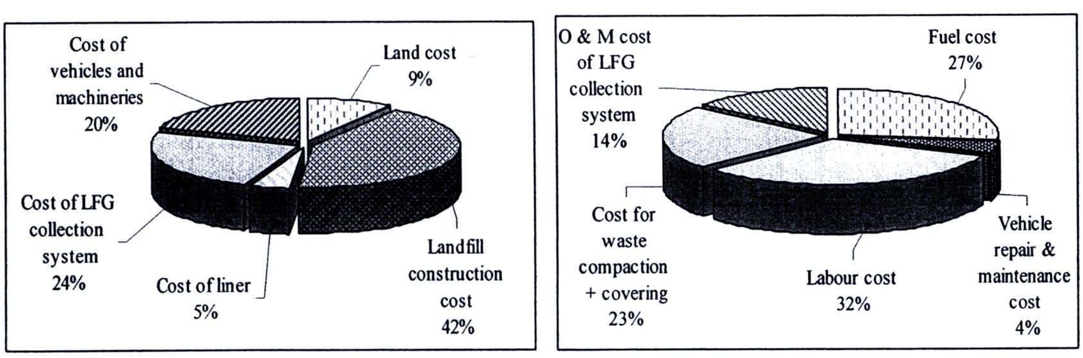
6.4.2 Economic sustainability assessment of the upgraded MSW management system

LCC was used to assess the financial feasibility of upgraded MSW management system in Nonthaburi after the incorporation of the LFG recovery system. As seen in Chapter 5, according to the financial analysis, it was revealed that recycling of one tonne of mix recyclables has the potential to generate "net earnings" amounting to 11,300 baht per tonne.

-LCC for sanitary landfill with LFG recovery

LCC analysis results of the existing sanitary landfill were described in Chapter 5. Besides the LCC evaluation information of the existing system, upgraded MSW management system requires additional information related to costs like capital cost for energy extraction (gas collection and flaring systems, electricity generation), annual operational and maintenance cost, potential revenues from selling of electricity, etc. Capital costs and operational and maintenance costs for IC engine generator and gas flaring system are summarized in Appendix B (Table B4).

According to this analysis, the total capital cost requirement for the sanitary landfill with LFG recovery system is 748 baht per tonne of waste. Breakdown of the capital cost among the different cost items is shown in Figure 6.3(a). Estimated total operational and maintenance costs of the landfill would be 724 baht per tonne of waste. A detailed cost breakdown is shown in Figure 6.3(b).



(a) (b)

Figure 6.3: Detailed cost brake down of (a) capital cost (b) Operational and maintenance costs of sanitary landfill with LFG recovery

The quantified environmental costs associated with emissions and resources consumption for the entire life cycle of sanitary landfill with LFG recovery amounts to 659 baht per tonne of waste as also shown in Figure 6.4. Then by accumulating all the capital costs, operational and maintenance costs and environmental costs, the gross LCC was estimated to amount to 2,131 baht per tonne.

In order to calculate the net LCC, the probable direct and indirect revenues were accounted for. The direct revenues could be earned in the form of the fee that is being collected from the households (20 baht/household/month), and the possible revenue from the sale of the electricity produced from LFG. Indirect revenues can be earned by the avoidance of emissions as a result of electricity production from LFG. By adding all the direct and indirect revenues, the calculated life cycle revenue for the upgraded landfill is 858 baht per tonne of MSW. Out this amount, 25% of revenue is from the fee that is collected from the households, 48% from the selling to the grid of electricity produced from LFG and the remaining 28% as credited environmental costs.

The net LCC of the upgraded landfill was calculated by subtracting the above revenues from the gross LCC. It was found to amount to 1,273 baht per tonne (Figure 6.4). As a result of the revenues earned from the selling of electricity to the grid and avoided emissions from conventional electricity production, 49% of the net LCC can been reduced for the upgraded landfill with gas recovery system as compared to the existing landfill in Nonthaburi.

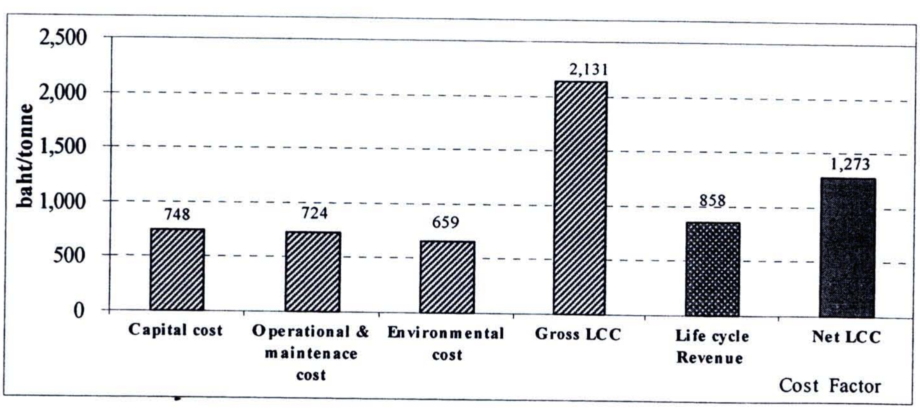


Figure 6.4: Gross and net LCC associated to the landfill with LFG recovery

In order to estimate the overall net LCC for the upgraded system in Nonthaburi, the net LCC of both recycling and landfilling with gas recovery was considered, as shown in Table 6.3.

Table 6.3: Net LCC of the upgraded MSW management system in Nonthaburi

Description	Net LCC (baht)
Net LCC of recycling of 24% per tonne of waste	-11,344 /tonne x 24/100 = -2,723
Net LCC of landfilling + gas recovery, 76% per tonne of waste	1,273/tonne x 76/100 = 968
Net LCC of upgraded system per tonne generated waste	**-1,755 baht per tonne**

The resulting net LCC of the upgraded MSW system is found to amount to -1,755 baht per tonne of waste. This indicates that there is a potential for a "net earning" of 1,755 baht for each tonne waste generated in Nonthaburi municipality. Hence, the MSW management system suggested is financially attractive leading towards improved economic sustainability with a potential revenue twice that of the existing MSW management system.

6.4.3 Social sustainability assessment of the upgraded MSW management system

-Quantification of "damage to human health"

In Chapter 5, health damage occurrence potential was quantified from both recycling and virgin production in the form of mortality, severe morbidity and morbidity. When all the effects were added up, potential health damages from one tonne of mix recyclable waste were quantified in the form of DALYs and found to amount to -9.32E-03 DALYs. Such negative impact indicated the positive effects with regards to human health protection resulting from recycling.

In this scenario, the main focus is on assessing the potential health damage occurrence/avoidance from the sanitary landfill with LFG recovery. The potential damage occurrence from various emissions from landfill as well as potential avoidance of health damages as a result of electricity production from LFG was taken into account in order to estimate the net damage to health, as shown in Figure 6.5. Gross health damage occurrence potential was found to amount to 8.02E-04 DALYs per tonne of waste. Of this amount, 54% is due to the effects of emissions contributing to global warming particularly from fugitive methane emissions and the remaining 46% due to direct and indirect exposure to human toxicity compounds.

However, LFG recovery enables to contribute reducing health damages from the avoided fraction of methane emitted to the air and the corresponding amount of electricity produced from the LFG collected (which is replacing conventional electricity production). As indicated in Figure 6.5, the net health impacts from the sanitary landfill with LFG recovery amounts to 6.26E-04 DALYs per tonne of waste. It should be noted that the incorporation of the proposed LGF recovery system has a substantial influence in reducing damages to human health since it is found to be lowered by 68% as compared to the existing landfill.

Considering the fractions of waste that is being treated using both recycling and landfilling with LFG recovery, the total estimated health damage per tonne of MSW for the upgraded MSW management system in Nonthaburi amounts to -1.76E-03 DALYs. The upgraded system would therefore contribute reducing damage to human health leading towards improved social sustainability.

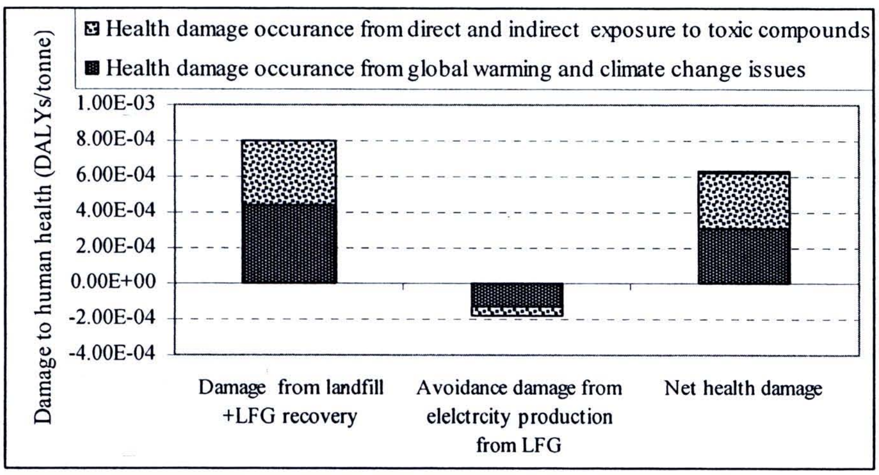


Figure 6.5: Occurrence, avoidance and net damage to human health from the sanitary landfill with LFG recovery.

-Quantification of "Income based community well-being"

The quantification of the improvement of community well-being as a result of the suggested MSW management system is another important social aspect for decision making. In Section 5.4.3, it has been shown how direct and indirect income generation from recycling activities influence the uplifting of living standards. According to the evaluation, it was found that the total income generation potential from direct (selling recyclables) and indirect (wages based income from 7.5 labour days) revenues would amount to 20,300 baht per tonne of mix recyclable.

Wages based income generation is a major factor contributing to the uplifting of community well-being with regard to landfilling. As described in Section 5.4.3, 332 employment opportunities have been created from the existing landfill. As a sanitary landfill, it has employed the maximum number of labours that is required to ensure the operational activities so that it would not be possible to provide more employment opportunities at the landfill site. However, there may be a possibility of enhancement of employment opportunities due to the electricity production process from collected LFG. According to the study done by Lunda et al. (2003), employment opportunities from electricity production process at a power plant are 0.4 man-days/MWh in Thailand. Therefore, electricity production from LFG may provide an additional 0.04 labour days per tonne of MSW management. However, this is not a significant increment and overall employment opportunities would remain the same as the existing situation. Thus the wages based income generation potential was assumed to be 330 baht per tonne of MSW landfilled for the case of landfill with LFG recovery system.

As shown in Section 5.4.3, the quantified social benefits due to both recycling and landfilling would amount to 5,130 baht per tonne. Although this is a substantial benefit that would contribute enhancing the community's life style, there are no additional benefits to the community expected in terms of financial earnings as a result of the LFG to energy recovery system.

6.5 Conclusion

There is currently a trend in Thailand towards the introduction of sanitary landfills with gas collection system to replace open dumps and to upgrade the existing sanitary landfills. The promotion of LFG recovery projects is an important preliminary step towards sustainable development. To this end, the upgrading of the existing sanitary landfill to a landfill with LFG recovery system for electricity production was assessed using the newly developed endpoint composite indicators.

It was revealed that incorporation of LFG recovery system can significantly influence the reduction of ultimate damages from the existing landfill and could drive the entire system towards sustainability. As noticed, per tonne of MSW disposed, LFG recovery for electricity production would enable to reducing damage to ecosystem by 67 %, damage to abiotic resources by 181%, LCC by 49%, and damage to human health by 68% as compared to the existing landfill. However, the upgraded landfill with LFG recovery has hardly any influence on the improvement of the community's well-being in Nonthaburi.

For the entire MSW management system, the upgrading of existing landfill to landfill with LFG recovery contributes to enhance the protection of the ecosystem by 3.3%, to reduce damage to abiotic resources by 14.4 %, increase earning in terms of net revenue by 114% and reduce damage to human health by 134% as compared to the existing waste management system in Nonthaburi. These results clearly indicate the beneficial effects that would result from the upgrading of landfill to landfill with LFG recovery system with regards to the three-dimensional aspects of sustainability.