CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

10.1 Conclusions

Sustainability indicator development

In this study, an attempt was made to broaden and deepen the concept of traditional LCA from environmental only to a more comprehensive three-dimensional "Life Cycle Sustainability Assessment". Then, a conceptual LCA framework was proposed for life cycle sustainability assessment as a "logical structure" for incorporating all three domains relevant to sustainable development.

As the initial step in sustainability indicator development, the most relevant midpoint indicators are identified via life cycle inventories. To quantify the impacts, mathematical formulas were developed by aggregating the effects of major emissions and resource consumption considering the effects of all the phases of life cycle. Quantification of these indicators would be really useful for the scientific decision making process. Moreover, to assess the overall sustainability of particular MSW management systems in a more tangible way, endpoint composite indicators were explored by combining various sustainability aspects based on a complex concept. Endpoint composite indicators were developed by aggregating the most crucial ultimate damages/effects of multidimensional aspects of MSW management systems, which cannot be fully captured by any individual midpoint indicators.

Developed composite indicators are closer to the actual damage and therefore easier to comprehend at the decision making stage and convince the stakeholders about the damage/effects. To measure the overall ultimate environmental damage, "damage to ecosystem" and "damage to abiotic resources" were developed as the most relevant composite indicators which measure the aggregated effects of several midpoint indicators. LCC is the major economic indicator which is useful to assess the financial feasibility of the MSW management system. "Damage to human health" and "income based community well-being" are the major social indicators which measure the most relevant social effects, which arise from MSW management issues. Thus, the set of robust composite indicators would be very useful as an appealing tool for policy makers to support policy implementation. Moreover, these indicators will be very useful for prior evaluation of three-dimensional sustainability of alternative MSW management options in any country and then for decision-making with respect to planning and implementation of sustainable MSW management projects in the near future.

To fulfill the second and third objectives of the research, the developed indicators were applied to assess the sustainability of existing MSW management systems as well as the intended integrated MSW management approaches for the selected Asian counties, namely: Thailand, Sri Lanka and India.

Overall conclusion on sustainability assessment of MSW management system in Thailand

Nonthaburi municipality was selected as the representative study location to understand the existing MSW management system in Thailand where a considerable effort has been made on working towards a sustainable solution to overcome the existing MSW management crisis. To assess the sustainability, developed midpoint and endpoint environmental, economic and social indicators were used and quantified the damages/effects of MSW management system in Nonthaburi. On the one hand, 76% of generated waste landfilling is causing considerable environmental degradation, economic losses and social burdens. On the other hand, as Nonthaburi Municipality is recycling 24% of generated waste, it has made significant impacts in improving the overall sustainability of the existing system. Recycling was found to be an extremely sustainable method in relation to three-dimensional sustainability. Thus, when one considers MSW management in Nonthaburi as a single system, 24 % waste recycling has shown the ability of compensating all the negative effects occurring from 76% waste landfilling. However, recycling cannot stand alone as an independent technology for prolonging sustainability of a waste management system. Therefore, further improvements have to be made by incorporating other waste management technologies to treat the different fractions of waste.

There is a trend towards implementing sanitary landfills with the gas collection system in Thailand as an important preliminary step for sustainable development. Thus a scenario was developed for upgrading the present system including a landfill gas recovery system. The proposed upgraded system will include a sanitary landfill with the LFG recovery system for electricity production along with the existing recycling procedure. Then the sustainability of this projected scenario was assessed by using the developed midpoint and endpoint indicators. It was revealed that incorporating of LFG recovery system could significantly influence the further reduction of ultimate damage occurrence from the existing landfill. For instance, 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 could hardly influence the improvement of the community well-being in Nonthaburi.

Still 24% of generated waste recycling in Nonthaburi has made a tremendous influence on improving the sustainability of the entire system in comparison to the effects of 76% of waste landfilling with gas recovery. For the entire MSW management system, the upgrading of 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.

Furthermore, an appropriate integrated system was developed by incorporating recycling, AD, incineration and landfill like improved technologies for recuperating maximum energy and materials. Out of all the selelcted technologies, recycling is the most promising technology as far as three-dimensional sustainability is concerned. Improved technologies like AD and incineration are not financially feasible as individual treatment methods due to the demand for high investment and operational cost. As a result of combining all the technologies, the developed integrated system has shown the maximum sustainability achievement potential 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 resource protection, 124% of revenue earning, 147% health damage avoidance and 6% community well-being improvement ability than that of the existing system. The results of the study clearly indicate the potential of sustainability development via integrated MSW management. Thus, the research findings of this study would be very useful for the decision making process on developing sustainable integrated MSW systems in the near future.

Overall conclusion on sustainability assessment of the MSW management system in Sri Lanka

At present, Sri Lanka is practicing open dumping as the main waste treatment method, and it has created severe environmental degradation, economic losses and various social problems. As an initial step towards sustainability, sanitary landfill with the LFG recovery system was designed taking into consideration the local socio-economic situations. The upgraded system was evaluated by using the developed indicators to understand the possibility of mitigating the impacts relative to the existing system. Open dumping was found to be substantially worse than a comparative system of sanitary landfill with gas recovery. Furthermore, an appropriate integrated system was proposed to replace the existing MSW management and its three-dimensional sustainability was evaluated.

As a reward for recovering a substantial amount of material and energy, the system would reach an extremely sustainable level. In fact, the results revealed that the damage avoidance potential from the intended integrated system is much higher than the sum of damage occurrence potential from the entire system. It has indicated the reduction of damage to ecosystem by 738%, damage to abiotic resources 3110%, life cycle cost by 103% and damage to human health by 94.5% relative to the existing situation. In addition, the intended integrated system will contribute to improve the community well-being by 65% in comparison to the present system.

All in all, the evaluated results of the existing system will be very useful as a baseline for understanding the severity of open dumping in a tangible way for all the stakeholders in the waste management hierarchy. The information would be useful for policy making and strategic planning on developing and implementing appropriate systems in the future. The sustainability assessment results of sanitary landfill with gas recovery and the integrated system would be very useful for planning and the development of sustainable waste management systems in Sri Lanka.

Overall conclusion on sustainability assessment of the MSW management system in India

Existing poor MSW management system in KMC- India is responsible for serious environmental damages, economic losses and social burdens. Despite 24% of waste composting, the total negative impacts from the existing system have caused a harsh situation mainly due to the severe damage caused from open dumping.

As an immediate solution for existing burdens and as an initial step towards sustainability development, sanitary landfill with the LFG recovery system was evaluated to comprehend the severity impacts relative to the existing system. The existing system was found to be substantially worse than a comparative system of sanitary landfill with gas recovery. For instance, in the ultimate damage assessment level, upgraded system with LFG recovery for electricity production has the possibility of reducing 125 % of ecosystem damage, 414% of abiotic resource damage, 59% of LCC and 58% of human health damage than that of the existing MSW management system in KMC. Furthermore, an appropriate integrated system was proposed by incorporating the most fitting technologies to KMC, considering waste characteristics and local policies and regulations.

As a result of recuperation of a significant amount of materials and energy, the system has the ability to move towards sustainability. Some of the endpoint composite indicators have shown higher damage avoidance potential than damage occurrence potential from the MSW management system. In fact, the proposed integrated system can cut down more than 100% of environmental damage and 96% of human health damage in comparison to the existing system. However, the system has not reached the financial feasibility level since life cycle cost reduction is only limited to 82% in relation to the existing cost. Thus the local authorities still have to spend some money to operate the system. Taking steps like improving the efficiencies of individual technologies, increasing the recycling activities via awareness and capacity building programmes and earning adequate revenues from tipping fee and CDM, etc. may drive the intended integrated system to the optimum economic feasible level.

10.2 Recommendation for Further Studies

Based on the findings of this study, the following future research areas are recommended.

1. Composite indicator -Damage to ecosystem: This is a very useful composite indicator to measure the overall ultimate damage/effects of the MSW management system on ecosystem. For comparison purpose, the damage has to be measured as a global bio productive area considering the effects of acidification, eutrophication, land occupation

and land conversion. In this study, literature documented approximate values have been used since one was unable to find the more reliable country specific information. To do a more accurate estimation on ecosystem damage, country specific PDF, and equivalency factors and yield factors are needed for different types of land use. Thus further studies are needed to find out the country specific PDF, equivalency factors and yield factors of different types of land use.

2. Environmental cost calculation in LCC: Even though, local authorities are not concerned about the environmental cost yet, it is necessary that this factor should be taken into account in LCC estimation. The people in the community may have to bear this cost in the form of health costs due to the environmental pollution. However, there is no available information or a developed model to estimate the monetary value of environmental pollutants considering the country specific economic, social backgrounds. Thus in this study EPS developed "willingness to pay" model (Steen, 2000) was correlated to selected countries assuming that the health cost would be proportionate to the country's GDP-PPP values. But, this is a rough estimation and there should be an appropriate way to estimate the environmental cost considering country's socio-economic and cultural situation. If the WTP values are calculated using a model, those values should be field tested for validation. As this is a critical issue in cost calculation, an understandable and a real way of estimating the monetary value of the pollutants is essential and further research is required.

3. Improvement of social sustainability assessment: In this study two major critical area such as "damage to human health" and "income based community well-being" have been investigated with respect to social sustainability of waste management systems. However, further studies are needed to develop indicators and to quntify the other critical social aspects of MSW management activities in a tangible way which are related to poverty alleviation and social capital building, contribution to real GDP growth etc.

4. Development of a baseline to sustainability assessment and decision making: The developed endpoint composite indicators would be useful to quantify and compare the ultimate damages/effects with respect to environmental, economic and social aspects of different MSW management options which will be useful for selecting the most promising approach. In fact, it was clearly observed that the three-dimensional sustainability

development via the integrated approach relative to the existing system is the best. In this study, existing MSW management systems in each country were considered as baselines for comparison purposes to assess the improvements that integrated waste management systems may provide as compared to those baselines. For the three countries selected the existing waste management situation is different so that a country specific baseline is used for comparative sustainability assessment.

If someone is interested to compare the results between different countries, a common baseline would be needed. In this regards, the situation of sanitary landfill with gas recovery can be taken as a common baseline since it is a technology likely to be implemented as a first step towards improved SWM in Asian developing countries. Thus, comparisons can be made relative to a common baseline for better interpretation of results based on the country's situation. In addition, a baseline should help decision-makers and policy-makers to find a clear answer about sustainability performances and also to find the exact answer to the question of "is this MSW management system sustainable? Therefore, development of such a baseline including critical threshold value of sustainability status is still a challenging issue and further research is needed.

5. Quantification of the sensitivity of each pillar on overall sustainability: The composite indicators developed would be useful to quantify each aspect of sustainability. However, when it comes to decision and policy making stage, one may be interested to know the most sensitive aspect for improved sustainability. When each sustainability aspect is treated independently (with different units) it is difficult to come up with adequate suggestions for policy making. Hence all 3 aspects of sustainability should be incorporated into a common unit. Furthermore, converting all the three pillars into one common unit creates an opportunity to aggregate sustainability indicators to one single index. Therefore, weighting and further aggregation of the developed composite indicators would seem to facilitate the decision making process. The one feasible approach would be to convert all the end results of composite indicators to monetary values. However, there are some limitations of such approaches including introducing additional uncertainty in the calculations. Some information would invariably be lost as is the case whenever data is aggregated. Taking into account all these considerations, weighting and aggregation of all the three pillars have to be done in an appropriate way and further research is required.