CHAPTER 9

EVALUATION OF THREE-DIMENSIONAL SUSTAINABILITY OF EXISTING AND INTENDED MSW MANAGEMENT SYSTEMS IN INDIA

9.1 General Background of MSW Management System in the Study Location in India

Solid waste management in urban areas all over India remains a key concern and critical problems (Ojha, 2010). Kolkata is one of India's largest metropolitan cities and like other large cities faces similar problems of poor solid waste management, thus Kolkata Municipal Cooperation (KMC) was selected as the study location. Kolkata is a metropolitan city and capital of the state of West Bengal. It is located in eastern part of India on the east bank of River Hooghly. The KMC area has a population of almost 6 million and an area of 187 km^2. MSW management is a statutory function, and KMC is responsible for the management of MSW generated in the city. The city is divided into 15 boroughs and 141 electoral wards and all MSW management operations in this area are performed under four heads viz: sweeping, collection, transportation and disposal (Hazra and Goel, 2009).

At present, Kolkata city generates approximately 2946 tonnes/day MSW and it amounts to 0.632 kg/cap/day. A mechanized compost plant with a 700 tonnes/day capacity was installed at Dhapa by KMC and the remaining waste is being open dumped (Chattopadhyay et al., 2009). The mechanized compost plant was started up in April 2000 but has not been fully functional since 2003 due to the high inert content in the un-segregated waste and the problem of marketing the compost. In Kolkata, the major disposal site of Dhapa is at the eastern fringe of the city at an average distance of 10 km from the collection points. The total area of the Dhapa disposal site is 21.47x 10^4 m^2 (Chattopadhyay et al., 2009) and the depth of the waste is 24m. The disposal site has served the City of Kolkata as an uncontrolled dumping ground since 1981. Based on site volume and waste density estimates, the site is estimated to have received approximately 7 million metric tonnes of MSW up to 2009 (KMC, 2010). Little or no soil cover has been applied throughout its history, and waste is deposited in an uncontrolled manner that has resulted in steep, unstable slopes, leachate accumulation within the waste mass, and leachate runoff into nearby water bodies (KMC, 2010). Thus, at present, Dhapa dump site has caused substantial environmental damage to the surrounding environment due to toxic and greenhouse gases emissions and contamination with highly polluted leachate. The Situation of the existing MSW management system at Dhapa is shown in Figure 9.1.

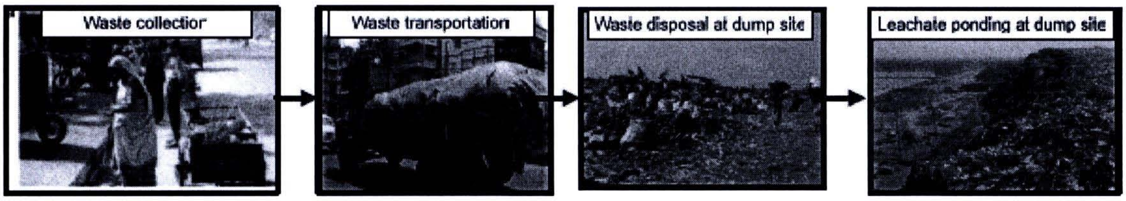


Figure 9.1: Situation of the existing waste management system in Kolkata- India

The present practice of open dumping is leading forth to substantial environmental degradation, economic losses and social burdens. Thus KMC is seeking an urgent and sustainable solution to overcome the existing burdens. Prior to developing such an improved system, a detail assessment of the existing MSW management would be useful to serve as baseline for further assessments of sustainability. Thereby, in this part of the research, a detailed environmental, economic and social assessment of the existing MSW management system in KMC is performed.

9.2 Sustainability Assessment of the Eexisting MSW Management System

9.2.1 Defining the LCA framework for sustainability assessment

As shown in Figure 9.2, the LCA framework was defined for the existing MSW management system in KMC, including all the phases of its life cycle such as street sweeping, collection, transportation and final disposal. Out of the total amount of waste generated, 24% of waste is collected and sent to a windrow composting facility at Dhapa and the remaining 76% is dumped at Dhapa dumpsite (Figure 9.2).

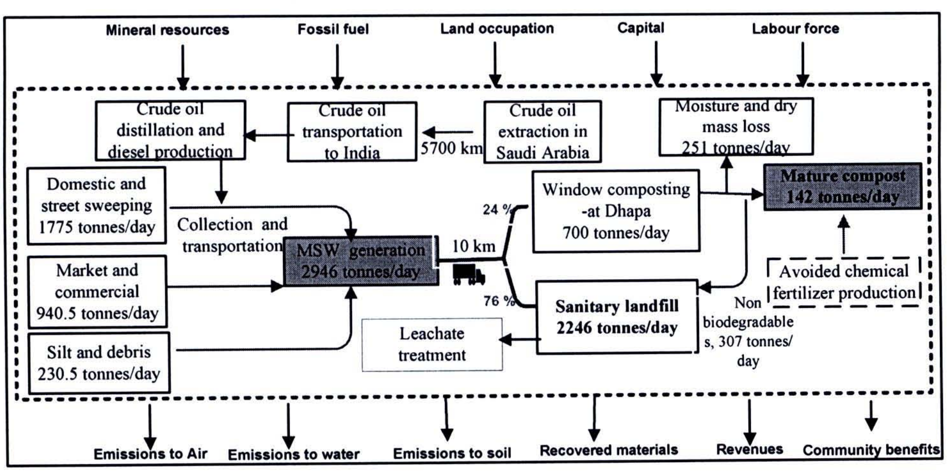


Figure 9.2: LCA framework of the existing MSW management system in Kolkata

9.2.2 Inventory analysis of the existing MSW management system

In this stage, all the inputs, and outputs related to environmental, economic and social aspects associated to the existing MSW management system were compiled within a common LCA framework (Figure 9.2). The inventory data was collected from different literature sources, and reports from KMC.

Even though, KMC is using different types of vehicles for transportation such as trucks, dumper placer vehicles, tractor trailers refuse collectors, tipper trucks, pay loaders, more than 60% of the waste is being collected by the use of tipper trucks (Chattopadhyay et al., 2009). Therefore, daya on fuel consumption efficiency of tipper trucks and emissions from fuel combustion were collected. Furthermore, the fuel production process in India was studied within the system boundary. Thus, all the processes such as crude oil extraction (Pré Consultants, 2007a), transportation from Saudi Arabia to India by ships (LIPASTO, 2009) and diesel production in India (Indian oil cooperation limited, 2010) were taken into account. Diesel distribution within the country was not considered since India is using a pipeline system for diesel distribution within the country and its environmental, economic and social burdens was assumed to be negligible when compared to the total duration of the service provided (Indian oil cooperation limited, 2010).

The Table 9.1 shows the waste composition, physical and chemical characteristics of the waste which were obtained from the literature (Hazra and Goel, 2009; Chattopadhyay et al., 2009) and reports published by KMC (KMC, 2010. According to the Hazra and Goel (2009) study, MSW in KMC consists of household waste (34.2%), street sweeping waste (22.8%), Institutional waste (6.32%) and commercial and market waste (36.37%). Similarly to other Asian developing countries, the biodegradable component represents the major fraction of the MSW (61%) and the moisture content of waste is 46% (Table 9.1) (Chattopadhyay et al., 2009).

As mentioned earlier, 24% of the generated waste is used for windrow composting production in KMC, and therefore the compost production process was incorporated within the system boundary. Moreover, the system expansion approach was used in the evaluation of useful products such as compost and to estimate the potential displacement of chemical fertilizer production from virgin resources and its emissions. According to the analysis, 250 kg of compost can be produced using one tonne of mix waste received to the facility. As stated in the literature, 1 tonne of compost is sufficient to replace 7.1 kg of N fertilizer, 4.1kg of P_2O_5 and 5.4K_2O (Patyk, 1996). The detailed inventory analysis results of both open dumping and composting is summarized in Appendix E1 (see Tables E_1 and E_2).

Table 9.1: Physical composition of MSW in KMC (Chattopadhyay et al., 2009) and chemical composition of waste (Tchobanoglous et al., 1993)

Components	MSW composition (%)	Average moisture content	Elemental composition					
			C %	H %	O %	N %	S %	Ash
Food waste	50.56	70.00	48.0	6.4	37.6	2.6	0.4	5.0
Garden Waste	4.50	40.00	47.8	6.0	38.0	3.4	0.3	4.5
Plastic	4.88	0.00	60.0	7.2	22.8	-	0.0	10.0
Paper	6.07	3.00	43.5	6.0	44.0	0.3	0.2	6.0
Glass	0.34	0.00	0.5	0.1	0.4	<.1	0.0	98.9
Metal	0.19	0.00	4.5	0.6	4.3	<.1	0.0	90.5
Inert	29.60	20.00	26.3	3.0	2.0	0.5	0.2	68.0
Other	3.86	0.00						
Total	**100.00**							

9.3 Results and Discussion

Similar to other case studies, an environmental assessment was done by using the most relevant midpoint indicators and the LCA results have been presented in Appendix E2. In this session, a comprehensive sustainability assessment was performed by using the developed endpoint composite indicators.

9.3.1 Environmental sustainability assessment of the existing MSW management system

-Quantification of "damage to ecosystems"

Dhapa dumpsite occupies a considerable area of productive land for a long period of time for dumping purpose. In addition, a significant amount of acidifying and eutrophying substances are emitted during the waste degradation process causing considerable damage to ecosystem. As far as the composting production process is concerned, productive land area has been consumed for the composting facility. Unlike other composting methods, windrow composting requires a large area of land to make composting piles, as well as for turning (approximately 21 days), curing (70 days) and storage (approximately 14 days) processes (Governo et al., 2010). Thus, considering the area of land occupied and time duration, the estimated total land occupation is 1.24 m^2yr per tonne of organic waste.

It should be noted that, with respect to the composting production process at Dhapa, damage to ecosystem would occur due to land occupation from composting production as well as from the residual waste disposal at the landfill. Land occupation for residual waste disposal would be 11.1 m^2yr per tonne of residual waste (density of residual waste is 600 kg/m^3, height of the landfill is 12 m, land occupation time for landfill is 80 years). According to KMC published information on the site description (KMC, 2010), the land use type of the presently occupied land belongs to "continuous urban" where PDF would be 1.19 (Goedkoop et al., 2008). In addition, indirect land occupation for fossil energy production requirements for both open dumping and the composting process were accounted for. Furthermore, the compost production process has been credited for avoided land occupation for chemical fertilizer production. A considerable amount of mining land can be saved, unless otherwise the fossil energy extraction for the virgin production process causes a significant damage. Therefore, the ecosystem protection ability from avoidance of energy consumption for chemical fertilizer production process is also taken into account.

Table 9.2: Damage to ecosystem ($PDF.m^2_{global} \cdot yr$) from the existing MSW management system in KMC

Damage occurrence	Open dumping /tonne	Windrow Composting /tonne	Existing MSW management/tonne
Damage to eco system from acidifying and euthophying substances	186.07	134.46	173.81
Damage to ecosystem due to direct land occupation	27.35	22.06	26.09
Damage to ecosystem by mining of fossil fuel	67.15	118.93	79.45
Gross damage to ecosystem	**280.57**	**275.44**	**279.35**
Credited damage	0.00	135.12	32.11
Net damage to ecosystem	**280.57**	**140.32**	**247.24**

As noticed in Table 9.2, the highest share of damage to ecosystem (62.2%) from the existing MSW management is caused by the emissions of acidifying and eutrophying substances from both open dumping and the compost production process in KMC. The damage to ecosystem from direct land occupation accounts for 9.3% and the remaining 28.6% is due to the process of fossil fuel production. It is important to mention that the windrow composting process in KMC, contributes to reducing the overall damage to ecosystem. The 24% of waste composted enables to reduce the net damage to ecosystem by 12% as compared to open dumping of all the waste only.

-Quantification of "damage to abiotic resources"

Damage to ecosystem caused by fossil fuel consumption at various stages of both open dumping and composting was estimated. Diesel is the major fossil fuel that is used for both open dumping and composting. As far as open dumping is concerned, 1.46 L of diesel is consumed per tonne of waste transported and disposed. The composting process consumes diesel fuel for both transportation and the compost processing activities. As reported, 1.85 L of diesel is needed per tonne of organic waste composted for operational activities (Cadena et al., 2009). However, the compost produced (0.25 tonnes of compost per tonne of collected waste) can be credited for the avoided production of conventional fertilizer so that some amount of fossil fuel can be saved (see Appendix E, Tables E2 and E3 for credited emissions and resource consumption in avoiding conventional fertilizer production). The damage to abiotic resources from one tonne of waste open dumped, composted and for the existing MSW management (76% open dumping + 24% composting) is shown in Figure 9.3.

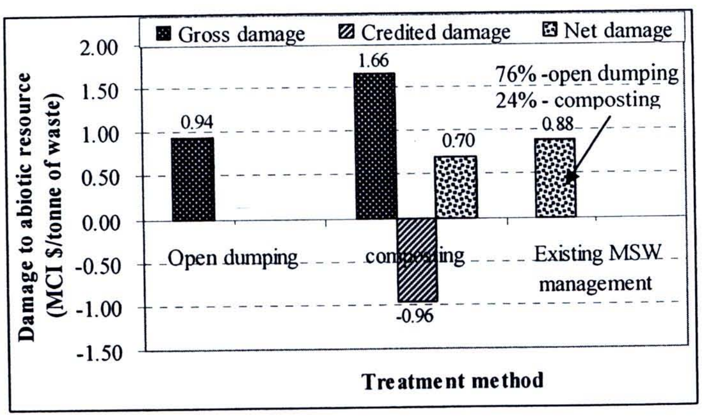


Figure 9.3: Damage to abiotic resources from the existing MSW management system in KMC

The composting of 24% of waste contributes to reducing the overall damage to abiotic resources by 6 % as compared to open dumping of all the waste only. To initiate a more sustainable MSW management system at KMC, appropriate technologies should be incorporated as part of the existing MSW management system.

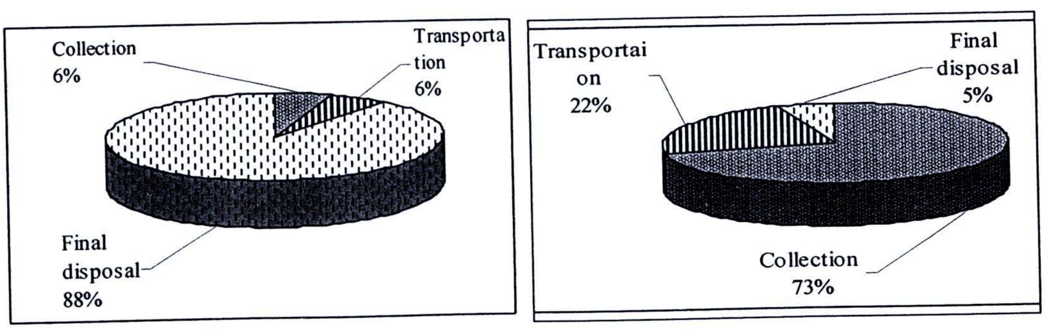
9.3.2 Economic sustainability assessment of the existing MSW management system

-Life cycle cost analysis

As in earlier case studies, in order to estimate the LCC of the existing MSW management system in KMC, all the life cycle phases of both open dumping and windrow composting were considered. Capital costs and operational and maintenance costs were calculated based on the average capital expenditure and operational and maintenance expenditures as reported by Chattopadhyay, et al (2009) for KMC over the period 2004-2007.

It was assumed that price of land in Kolkata in the year 1981 was 2000 INR/m^2. The present value was estimated since it represents the major share of the capital costs. In order to calculate the net present value of the land of Dapha dump site, an average interest rate (8%), inflation rate (12%) in India (CIA, 2008) and the original cost of land in Kolkata was used (Dhapa site has been used for disposing MSW since 1981). Estimated present value of the land is 109 INR/tonne of waste. In addition, KMC allocates 45 INR/tonne of waste as a yearly basis capital costs for collection, transportation and disposal services (Chattopadhyay, 2009). All together, the estimated total capital cost for open dumping at KMC amounts to 154 INR/tonne. The detailed capital cost breakdown is shown in Figure 9.4.

Despite a lot of inefficiencies in the present system, KMC is spending a lot of money for operation and maintenance activities of the existing MSW management system in the form of labour cost, fuel cost and vehicle repair costs (Chattopadhyay, 2009). Total operation and maintenance costs per tonne of waste amount to 1,447 INR/tonne. The detailed cost breakdown is shown in Figure 9.4.



(a) (b)

Figure 9.4: Detailed cost breakdown of (a) capital cost and (b) operation and maintenance costs of open dumping

In addition, environmental costs were calculated based on the Swedish EPS model (Steen, 2000). WTP values were derived, based on income elasticity of WTP for India (CIA, 2008) and the estimated default values for WTP for emissions and resources consumption is presented in Appendix A (Table A.11). The WTP values total estimated environmental costs for the emissions from open dumping amounts to 309 INR/tonne. All the cost components were added up to estimate the gross LCC of open dumping and it amounts to 1,912 INR/tonne (Figure 9.5).

The same method was followed to estimate the gross LCC of windrow composting, and the estimated gross LCC is 2,187 INR for composting per tonne of waste. In addition, the potential revenue earnings from selling the produced compost were credited for calculating the net LCC. According to the market value of compost fertilizer, it was assumed that the produced compost can be sold at the rate of 3.5 INR/kg (SNG Mercantile Pvt. Ltd, 2010). Thus by the sale of 250 kg compost (this is the amount that could be produced per tonne of waste) 887 INR/tonne income to the Municipality could be generated (Figure 9.5). Detailed cost breakdown of the composting process is also shown in Figure 9.5.

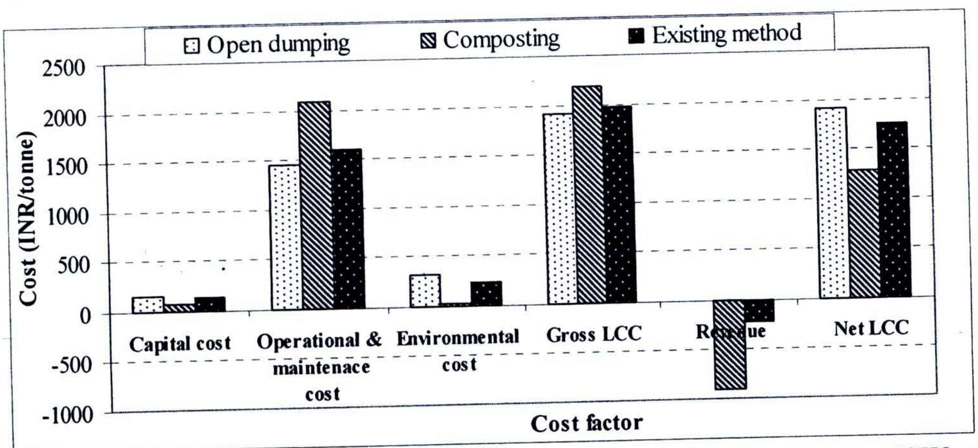


Figure 9.5: Different cost factors and gross and net LCC for existing MSW management system in KMC

The net LCC of the existing MSW management was derived (76% of open dumping, 24% of composting) based on the estimated net LCC of open dumping and composting. Thus, the net LCC cost for the existing MSW management method in KMC was found to amount to 1,761 INR/tonne of MSW (47.9 INR = US$ 1) (Figure 9.5). This result clearly indicates that, even though the present system is unable to provide an efficient waste management service to the community; the KMC is spending a considerable amount of money. Hence, application of appropriate technologies is essential to provide a better service while earning adequate revenues by producing valuable by-products.

9.3.3 Social sustainability assessment of existing MSW management system

-Quantification of "damage to human health"

As in earlier cases, damage to human health from the existing MSW management system in KMC was assessed in terms of DALYs. All the environmental emissions were estimated from both open dumping and composting methods taking into consideration all the life cycle phases such as fuel production, collection and transportation, processing of compost and final disposal at dump site (see Appendix E, Tables E1 and E2). YOLL and YLD potential from different types of emissions were estimated based on the Swedish EPS model values. (Characterization factors for DALYs calculation have been shown in Appendix A, Table A 11). Therefore, health damages were quantified as mortality; severe morbidity and morbidly that would occur through different pathways, see Figure 9.6. As discussed, the compost production process has the potential of avoiding chemical fertilizer production so that its emissions can be avoided. Therefore, 1 tonne of MSW composting has the potential of avoiding 2.16E-05 DALYs, in which 48.7% are mortalities (YOLL), 16.7% sever morbidity (YLD) and the remaining 34.6% morbidity (YLD). Therefore in order to estimate the net damage to human health from composting, the potential for avoidance of DALYs due to the compost production process was subtracted from the gross DALYs from composting. Then taking into consideration the fractions of waste which go for open dumping and composting, the potential damage to human health from the existing MSW management system was estimated, and it has shown in Figure 9.6.

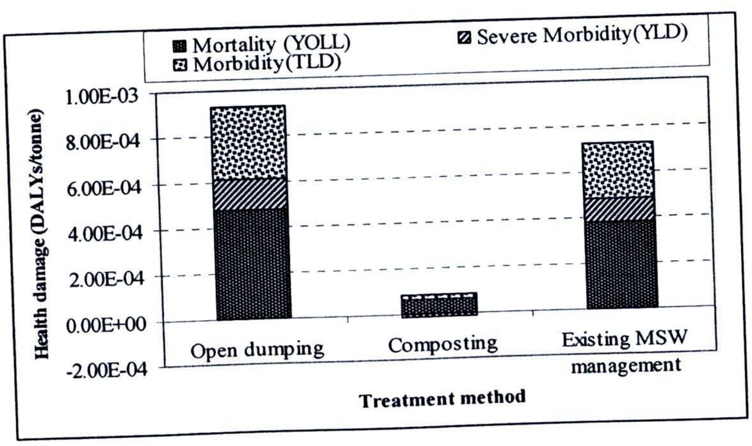


Figure 9.6: Damage to human health from open dumping, composting and the existing MSW management system in KMC

It is noteworthy to mention that 85 % of health damages from the existing system arise due to the effects of global warming, mostly from the emissions of methane from open dumping. The remaining 15% of health hazards may occur due to direct and indirect exposure to human toxicity compounds. Moreover, it should be noticed that the incorporation of composting (24% of waste) to the existing system has contributed to reduce the DALYs by 22.1 % as compared to open dumping only of all the waste generated at KMC, (Figure 9.6).

-Quantification of "Income based community well-being"

Social assessment results reveal that except for the created unskilled employment opportunities, there are no other opportunities for improving the community well-being within the present system. As reported in the literature, the existing MSW management in KMC can be introduced as a labour intensive process. As a norm of the country, handcart operators and sanitation workers are distributed within each borough on a population basis or based on commercial activities and road length (Hazra, et al., 2009). Even though, this method has created more employment opportunities, the system lacks efficiency as a result of the unskilled and untrained labour power. Most of the time manual collection and loading is being practiced, which has put the waste collectors in a serious unhygienic situation.

At present, the allocated labour force for street sweeping and MSW collection is 4.19 labour days per tonne of waste collected. Moreover, taking into consideration the labour requirement for waste transportation, the total labour requirement for MSW collection and transportation is 4.98 labour days per tonne. In addition, labour power consumption for various duties at the dumps site is 0.03 labour days per tonne of waste (KMC, 2010). Taking into consideration all the labour requirements, the estimated total labour force for open dumping process is 5.29 labour days per tonne of waste collected.

When one considers the composting process, apart from waste collection and transportation, an additional labour force is required for manual sorting of waste, handling of equipments (pay loader) for turning of compost, operational activities on processing of marketable compost. Thus, it may require additional 1.25 labour days per tonne of waste collected. Based on this, total labour force requirement for composting of waste in the present situation is 6.55 labour days per tonne of waste. Based on these values, total labour force requirement for the existing MSW management (76% open dumping + 24% composting) is 5.59 labour per tonne of waste. Even though, KMC has provided more employment opportunities, the efficiency and sanitary conditions of the workers have to be improved in order to reach better standards. The average salary of the unskilled workers hired at present is 150 INR/day (Ministry of Labour and Employment, 2010). Thus, the wages based income generation potential to the community would be 838 INR per tonne of waste. In order to improve the community well-being, skilled and trained employment opportunities have to be created via a capacity building programme. Moreover, in order to enhance the community well-being, the path leading to indirect income generation should be considered by initiating effective point source separation programmes and formal centers for buying recyclables in KMC.

9.4 Development of Sanitary Landfill with LFG Recovery System as a Sustainable Solution to the Present Problem

As the existing landfill in KMC is running at maximum capacity and it is located in the highly sensitive East Kolkata Wetlands, an internationally recognized ecological and economic resource (SNG Mercantile Pvt. Ltd, 2007), rapid solutions are needed to improve the existing MSW management system. The initiation of a sanitary landfill with LFG recovery system is a possible option and there are national and international organizations which have been engaged on activities related to feasibility analysis on initiation of such a project in KMC (KMC, 2010; SNG Mercantile Pvt. Ltd, 2007). Initiation of such LFG recovery project at KMC will improve the environment both at global and local scales through the capture and treatment of LFG. In addition revenues could potentially be earned by the municipality to cover the costs.

KMC is considering two technical options in this feasibility study such as capturing LFG, generated power by gas-engine generators or capturing LFG and treating it in a flare. However, this assessment focuses only on the electricity production option from landfill gas since it has the potential of creating economical and social benefits.

In order to assess the sustainability of the intended LFG recovery project, similar to other cases, the LCA framework was defined and a detail inventory analysis was performed taking into account all the inputs and outputs. The schematic diagram of the LCA framework and the inventory analysis results are presented in Appendix E2. To assess the sustainability of the proposed sanitary landfill in KMC, numerous assumptions were made to quantify the amount of LFG production, collection and electricity production potential. All the numerous assumptions that were made and the total methane utilization for electricity production are also summarized in Appendix E2.

The calculations revealed that electricity production potential is 97.58 kWh per tonne of waste disposed in the landfiill. When compared to Thailand and Sri Lanka, the electricity production potential is quite less in India due to the lesser amount of biodegradable waste in the MSW waste stream. In LCA perspective, the produced electricity from LFG was credited for avoidance of conventional electricity production and related emissions.

Sustainability assessment of the upgraded system using endpoint composite indicators

Midpoint indicators were used to assess the environmental sustainability and results are summarized in Appendix E3. A more comprehensive and meaningful sustainability assessment was performed for an upgraded MSW management system including landfill with LFG recovery system. Electricity and compost production processes were credited for avoidance of potential damages from the same amount of conventional electricity and fertilizer production in India. The quantified gross and net impacts for the indicators used are summarized in Table 9.3.

Table 9.3: Quantified gross and net endpoint composite indicators from the upgraded MSW management system in KMC

Impact factors	Damage to ecosystem ($PDF.m^2.yr/tonne$)	Damage to abiotic resources (MCI $/tonne)	Life Cycle Cost (INR/tonne)	Damage to human health (DALYs/tonne)	In come based community well-being (INR/tonne)
Gross impact from landfilling	286.54	1.43	1642.70	4.95E-04	
Credited impacts from electricity production	-418.06	-5.41	-783.10	-1.35E-04	
Net impact from landfilling	**-131.52**	**-3.97**	**859.60**	**3.60E-04**	**942.84**
Gross impact from composting	295.07	1.91	1195.63	1.08E-04	
Credited impacts from compost production	-135.12	-0.86	-887.74	-2.16E-05	
Net impact from composting	**159.95**	**1.05**	**307.89**	**8.69E-05**	**1064.47**
Net impact from upgraded system (76% landfilling + LFG recovery and 24% composting)	**-62.26**	**-2.78**	**728.51**	**2.95E-04**	**971.74**

Based on the evaluation results, it was found that the initiation of a LFG recovery project to replace the current practice of open dumping has the potential of providing improvements with regards to the three-dimensional aspects of sustainability. In fact, the potential avoidance of environmental damage exceeds the actual potential damage from the overall MSW management system as indicated by its net negative impact. As shown in Figure 9.7, LFG recovery for electricity production would contribute reducing damage to ecosystem by 125 %, damage to abiotic resource by 414%, LCC by 59% and damage to human health by 58% as compared to the existing MSW management system in KMC. In addition, the upgraded MSW management system may provide trained and skilled employment opportunities and would thus contribute to increase the income based community well being by 16% as compared to the existing MSW management system.

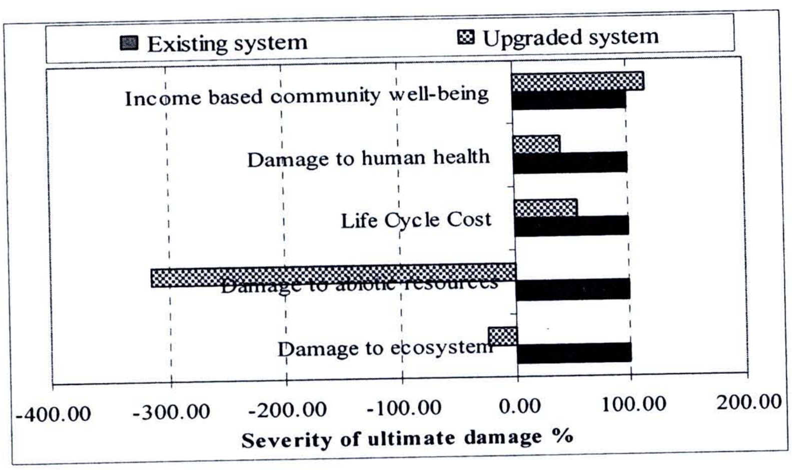


Figure 9.7: Severity of the endpoint impacts of the upgraded system in comparison to the existing MSW management system in KMC

The evaluation results clearly indicate the benefits of initiating a LFG recovery system for enhancing the three-dimensional aspects of sustainability for MSW management in KMC. Thus, the methodology and the results of this study would be useful as supporting information for switching from the current practice of open dumping to sanitary landfill with gas recovery, not only in Kolkata but also in other metropolitan cities in India.

9.5 Development of an Integrated MSW Management System as a Sustainable Solution in KMC- India

So far, the discussion was on the major drawbacks of the existing MSW management and the possible improvements that could be achieved by switching from open dumping to sanitary landfill with gas recovery. However, such intermediate improvement would not be sufficient, especially for metropolitan cities like Kolkata. Sanitary landfill with gas recovery system may not be a solution for prolonged sustainability due to the lack of available land for disposal. KMC should start considering various technologies that could be appropriate to treat different fractions of waste within an integrated system. In this part of the research, such an appropriate integrated MSW management system for KMC is considered and assessed vis-a-vis sustainability.

As an initial step towards assessing the sustainability of the intended integrated system, the LCA framework was defined taking into consideration all the life cycle phases and inputs/outputs which are associated with the three pillars of sustainability, (Appendix E- Figure E4). Then the technologies were selected taking into consideration, waste characteristics, composition and the local situation. Explanations about the proposed integrated system and criteria for technologies selection are detailed in Appendix E3.

According to the mass balance analysis of the waste for the waste treatment technologies selected as part of the proposed integrated MSW management system, it was found that 5.5% of MSW can be recovered and recycled, 30.6% of short term biodegradable waste can be used for AD, 13.8% of biodegradable waste could be used for composting, and the remaining 50.1% for landfilling (see Appendix E4 for the detailed explanations).

The inventory analysis was done for individual technologies. Recovered materials from recycling and recovered energy from AD and landfilling were credited for avoided conventional materials and energy production. The individual treatment technologies as well as proposed integrated system were assessed using the midpoint indicators as detailed in Appendix E4.

To assess the sustainability of the proposed integrated MSW management system in KMC, the endpoint composite indicators developed for this purpose in this research were used.

Table 9.4, summarizes results of the obtained ultimate environmental, economic and social damages. Effects of the individual treatment technologies were aggregated based on the fractions of waste undergoing those treatments within the integrated system in order to estimate the overall damage/effects for the proposed system.

As noticed in Table 9.4, net negative impacts for "damage to ecosystem" and "damage to abiotic resources" were obtained. It indicates that the intended integrated system provides benefits with regards to both aspects.

Table 9.4: Quantified endpoint composite indicators from the intended integrated MSW management system in KMC

Treatment method	% of mass	Damage to ecosystem $PDF.m^2_{global}.yr$ /tonne	Damage to abiotic resources (MCI $/tonne)	Life Cycle Cost (INR/tonne)	Damage to human health (DALYs/tonne)	Income based community well-being (INR/tonne)
Recycling mix	5.51	-1.95E+04	-1.35E+02	-7.03E+03	2.03E-04	1.95E+03
AD	30.63	-1.09E+03	-7.80E+00	4.21E+02	-1.81E-04	1.23E+03
Composting	13.80	5.63E+01	3.34E-01	1.78E+02	3.44E-05	1.06E+03
Landilling	50.06	-3.60E+02	-3.35E+00	1.12E+03	1.45E-04	9.44E+02
Integrated system	**100.00**	**-1.58E+03**	**-1.14E+01**	**3.27E+02**	**3.29E-05**	**1.10E+03**

To get a clear understanding, the ultimate impacts of the intended integrated system were compared with those of the existing MSW management system in KMC, (Figure. 4.36). The intended integrated system would contribute to reducing damage to ecosystem by 740%, damage to abiotic resources by 1390%, LCC by 82% and damage to human health by 96% as compared to the existing MSW management system. In addition, as illustrated in Figure 9.8, there is a possibility of improving the income based community well-being by 32% by means of creating skilled employment opportunities.

According to the evaluation results, the intended integrated system would contribute to improve environmental and social sustainability. It shows the possibility of reducing environmental damage by more than 100% and damage to human health by 96% as compared to the existing system. However, the integrated system would not contribute to reach economic sustainability. Even though local authorities may experience a significant cost reduction as compared to the existing MSW management, still there is no possibility for "net earnings" for the integrated system proposed. The fraction of waste being recycled should be increased to be able reach some level of economic sustainability as it is a waste management option that can contribute to bringing revenues to the local authority as observed with the Thailand case for instance. Moreover, earning an adequate amount of money as "tipping" fee from local authorities and earning CDM under CER might be needed to make this kind of project economically feasible and commercially attractive.

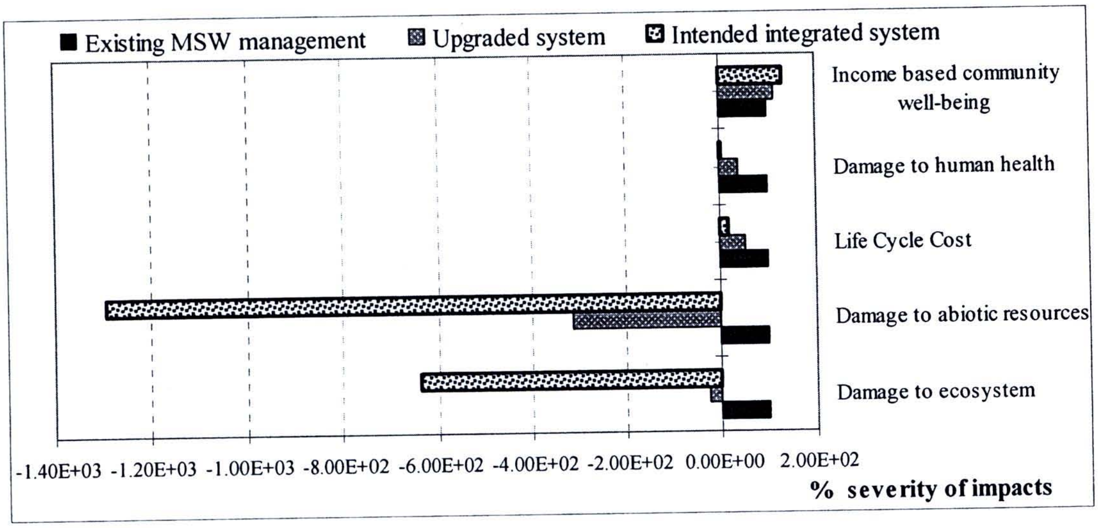


Figure 9.8: Severity of the endpoint impacts of intended integrated system in comparison to the existing MSW in KMC

9.6 Sustainability Improvements of Intended Integrated Systems – a Sensitivity Analysis for Future Scenarios

Similar to other cases, a sensitivity analysis was performed to assess the sustainability of the potential integrated systems in KMC. As noticed, recycling is the most promising technology to drive the entire integrated system towards sustainability. According to the composition of waste in KMC, total recyclable materials in the mix waste stream are 11.5%. For the integrated system designed, it was assumed that the recovery rate of plastics and paper is 50% and recovery rate of metal and glass is 75% from the mix waste stream. Similar to other countries, there is a potential to increase the recovery rate of recyclables with an appropriate awareness program for promoting point source separation. If KMC can increase the waste recycling rate, simultaneously the percentage of waste landfilling can be reduced. Taking into account all these aspects, a sensitivity analysis was performed to predict the sustainability of the future scenarios with the enhanced recycling rates. As shown in Figure 9.9, the level of sustainability improvement of future scenarios was compared in relation to the designed integrated system in KMC (5.5 % of waste recycling).

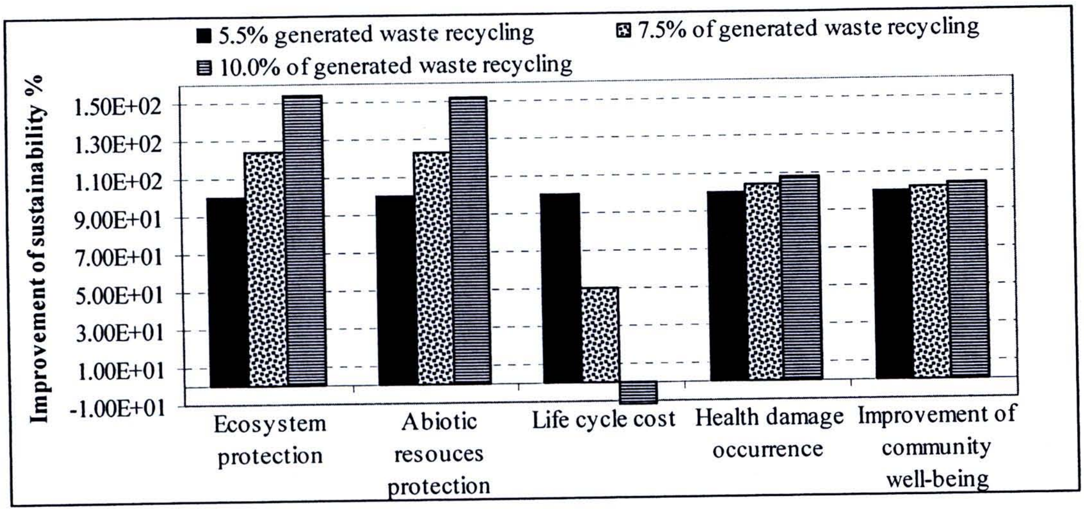


Figure 9.9: Future perspectives of sustainability improvement of the intended integrated systems by improving the waste recycling rate in KMC

If KMC can initiate an effective recycling program for recycling 7.5% of generated waste, the intended integrated system would have the potential for further improvement by 24% of ecosystem protection, 23% of abiotic resource protection, 50% of life cycle cost reduction and 2% of improvement of community well-being (see Figure 9.9). However, occurrence of damage to human health has been slightly amplified with increasing recycling rate. Paper and plastics are the main recyclable items in KMC and such recycling processes would emit a significant amount of human toxicity compounds. Figure 8.7 also shows a further sustainability improvement potential by increasing the waste recycling up to 10% of generated waste. Overall sustainability of the waste management system in KMC is highly sensitive to the recycling rate, especially for reducing the life cycle cost and then to reach the financial feasibility level.

9.7 Conclusion

According to the evaluation results, despite a 24% of waste being composted, the overall impacts from the existing waste management system are of concern mainly as a result of damages from open dumping. The results obtained from the existing MSW management system should be used to convince all relevant stakeholders about the severity of those impacts.

As an intermediate solution and as an initial step towards sustainability development, sanitary landfill with the LFG recovery system was designed and evaluated to better assess the severity of the impacts relative to the existing system. The existing system was found to perform substantially worse than the upgraded system for all the sustainability aspect assessed. For instance, in the ultimate damage assessment level, the upgraded system would enable to reducing damage to ecosystem by 125%, damage to abiotic resources by 414%, LCC by 59% and damage to human health by 58% as compared to the existing MSW management system in KMC. These results clearly indicate that even the appropriate application of one particular technology can substantially contribute to reducing existing environmental, economic and social damages. However, application of landfill with a gas recovery system would not be a solution for prolonged sustainability due to lack of land availability.

Therefore, an appropriate integrated system was proposed by incorporating the most appropriate technologies for KMC. As a benefit from the recovery of a significant amount of materials and energy, the system enables to move towards achieving sustainability vis-a-vis its three-dimensional aspects. In fact, the proposed integrated system would enable to cut down damage to environment by more than 100% and damage to human health by 96% as compared to the existing system. However, the LCC reduction is only limited to 82% relative to the existing cost. By improving the efficiencies of individual technologies, increasing the recycling activities and earning adequate revenues from tipping fee and CDM, the proposed integrated system could reach economic sustainability. Moreover, the sensitivety analysis showed that the overall sustainability improvement of the intended integrated systems is highly sensitive to the recycling rate. In fact, 50% LCC of designed integrated system can be reduced by increasing waste recycling rate to 7.5% instead of 5.5% of designed rate of waste recycling.

The research findings related to intended sanitary landfill with gas recovery and integrated MSW management system would be very useful at the decision making level for the development of a sustainable MSW system in KMC.