ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF COMPOSTING AS SELECTED MANAGEMENT TECHNIQUE OF FOOD AND GARDEN WASTE GENERATED AT MUMBAI AIRPORT

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BONAFIDE CERTIFICATE

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INTERNAL GUIDE

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ABSTRACT

The organic waste generated at Chhatrapati Shivaji International Airport, Mumbai is being disposed of without any treatment at Deonar dumping ground. Such dumping of wastes in unmanaged landfills leads to emission of greenhouse gases and contamination of soil and groundwater. To improve its environmental footprint, airport operator Mumbai International Airport Private Limited will be installing an organic waste converter for composting food and garden waste generated at the airport. Choosing an optimal diversion system for a given food and garden waste stream of a particular site involves taking into consideration factors such as amount and proportion of food and garden waste generated, electricity rate, compost market price, land availability, social acceptability, financial feasibility, technological practicality and so on. In this project, a life cycle assessment of greenhouse gas emissions, cost-benefit and cost-effectiveness analyses were undertaken for decision support in determining the converter to be installed. Composting using three different types of organic waste converters was compared with the baseline of dumping and an anaerobic digestion alternative. Both composting and anaerobic digestion offer reductions in greenhouse gas emissions, but their implementation would not result in any monetary profits to Mumbai International Airport Private Limited, as evidenced by negative net present values of all the scenarios assessed. A batch-type organic waste converter was found to have the best environmental and economic performance of all alternatives analysed. Owing to a reasonable trade-off between costs and the environmental benefits of the implementation of two treatment systems to enable management of the entire food and garden waste stream of Chhatrapati Shivaji International Airport, it was recommended that an organic waste converter and anaerobic digester be installed at the outset.

Keywords: *Food and garden waste; life cycle assessment of greenhouse gas emissions; cost-benefit and cost-effectiveness analyses etc.*

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LIST OF SYMBOLS AND ABBREVIATIONS

AAI	Airports Authority of India
ACA	Airport Carbon Accreditation
ACI	Airports Council International
AD	Anaerobic Digestion
ALM	Advanced Locality Management
ATSDR	Agency for Toxic Substances & Disease Registry
CBA	Cost Benefit Analysis
CE	Cost-Effectiveness
CEA	Cost Effectiveness Analysis
CF	Cash Flow
CH_4	Methane
CIDCO	City and Industrial Development Corporation of Maharashtra Limited
CSIA	Chhatrapati Shivaji International Airport
DEFRA	Department for Environment Food and Rural Affairs
EC	Effectiveness-Cost
GHG	Greenhouse Gas(es)
GHG-LCA	Greenhouse Gases Life Cycle Analysis
GRI	Global Reporting Initiative
IGES	Institute for Global Environmental Strategies
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation of Standardisation
LCA	Life Cycle Analysis/ Assessment
LCI	Life Cycle Inventory
LEED	Leadership in Energy and Environment Design
MCGM	Municipal Corporation of Greater Mumbai
MIAL	Mumbai International Airport Private Limited
MSW	Municipal Solid Waste
MT	Metric Tonnes
$MTCO_{2e}$	Metric Tonnes Carbon Dioxide equivalents
MTPD	Metric Tonnes Per Day
NPV	Net Present Value
OWC	Organic Waste Converter
PV	Present Value
r	discount rate
₹	Indian Rupees
SAIC	Scientific Applications International Corporation
USEPA	United States Environment Protection Agency

CHAPTER 1: INTRODUCTION

Environmental degradation, limited land availability and raw material shortages have contributed to changing the perception of wastes. Waste is increasingly being looked upon as a resource and as wealth, rather than something to be discarded. A variety of management methods exist to recover value from waste, or transform it to energy; and localised studies serve to determine the success of a given management technique in a particular area. This project is an endeavour to evaluate the environmental and economic performance of composting as the selected food and garden waste management technique of Mumbai's Chhatrapati Shivaji International Airport (CSIA).

1.1 Background

The biological degradation of waste in landfills and open dumps gives rise to emissions of the greenhouse gases (GHGs) methane and carbon dioxide, thus contributing to climate change (Intergovernmental Panel on Climate Change [IPCC], 2006). Waste decomposition also results in the formation of an acidic leachate (Agency for Toxic Substances & Disease Registry [ATSDR], 2001) which contaminates soil, groundwater and surrounding water bodies.   However, the wet nature of organic waste and its high carbon content render it suitably managed by biological treatment such as composting or anaerobic digestion as compared to thermal treatments such as incineration or conversion to refuse-derived fuel (Hill, 2010). In a biological treatment system, the natural waste decomposition process is replicated in enclosed and closely monitored conditions, due to which the degradation process is accelerated. The product of composting is a soil amendment which can replace commercial fertilisers and avoid their environmental impacts, while that of anaerobic digestion is biogas and digestate (Environment Canada, 2013). Combusting the biogas derived from organic waste leads to biogenic carbon dioxide emissions which are regarded as carbon neutral (United States Environmental Protection Agency [USEPA], 2014) and the digestate may be stabilised to obtain organic manure. Thus, subjecting organic waste to biological treatment is a means of reducing the environmental impacts of waste disposal.

Recognising this opportunity to improve the environmental performance of the Chhatrapati Shivaji International Airport (CSIA), its operating company, Mumbai International Airport Private Limited (MIAL) has planned to install an organic waste converter (OWC) of capacity 1 MT (metric tonne) per day for treating organic waste (Tapre, 2014). According to a 2013 inventory study, CSIA generates 11 MT of non-hazardous solid waste daily, of which around 30% comprises organic waste that is disposed of at Deonar dumping ground, without any treatment. The dump at Deonar, as per information on the website of the Municipal Corporation of Greater Mumbai (MCGM), occupies a land area of 132 hectares, and its proximity to slum areas and the Thane creek, further exacerbate the effects waste disposal has on the environment and health of the populace in the vicinity of the dump. The diversion of food and garden waste to composting is expected to reduce the carbon footprint of CSIA. Also, the inventory study (2013) suggested that MIAL is losing revenue which may be generated from composting. The current daily generation rate is approximately 1.8 MT of food waste and 0.2 MT of garden waste (MIAL waste disposal records; personal communication with Mr Arun Holmukhe and Mr Shailendra Joshi, January 27, 2015). Half of the daily 2 MT of food and garden waste generated at CSIA will thus be subjected to biological treatment through the composting process on installation of the OWC.

1.2 Aims and Objectives

This project has been carried out under the Environment department of MIAL and aims to conduct an environmental and economic assessment of composting as the selected management technique for food and garden waste generated at CSIA in comparison with the baseline of dumping, and anaerobic digestion as an alternative.

Objectives include:

- To quantify the GHG emissions associated with dumping of CSIA's food and garden waste using a life cycle approach
- To quantify the expected reductions in GHG emissions due to installation of a biological treatment system
- To determine the most economically feasible OWC using cost-benefit analysis
- To estimate the cost per metric tonne of reduction in GHG emissions

1.3 Project Scope

The scope of the project is limited to the food and garden waste generated at air side, terminals and land side of CSIA. Such wastes being generated from the flight kitchens and airport colony have been excluded.

1.4 Significance

The outcome of the environmental and economic assessment will be useful to decision makers at MIAL. Additionally, the GHG quantifications may serve as a baseline when the waste management system is expanded. The results of this project could also be applied to locations with similar waste streams.

1.5 About CSIA-MIAL

Figure 1.1 CSIA Terminal 1C (Photo courtesy: S. Allen, MIAL)

The following information is gleaned from MIAL's 2014 Sustainability Report which was prepared in accordance with G4 Guidelines of the Global Reporting Initiative (GRI).

MIAL is a public private partnership and joint venture between the Airports Authority of India (AAI) and a GVK-led consortium constituting of GVK Airport Holdings Private Limited, ACSA Global Limited and Bid Services Division (Mauritius) Limited. MIAL is responsible for operating, maintaining, developing and modernising, designing and constructing, upgrading, financing and managing

Chhatrapati Shivaji International Airport, Mumbai. The second busiest airport in India, CSIA currently caters to approximately 32 million passengers per year and handles over 1.5 lakh cargo flights annually.

MIAL is committed to safety and environmental stewardship. Safety measures in place include safety occurrence reporting and safety risk management systems, audits, airport emergency services and wildlife management procedures to prevent bird/animal strikes and air side incursions. Mock drills are conducted from time to time in order to test emergency preparedness and response. MIAL has in place a climate change strategy, as well as environmental and GHG policies for improving environmental footprint and reducing carbon footprint.

The Indian Green Building Council awarded the LEED India for New Construction Gold standard to the new integrated Terminal 2 of CSIA in January 2014. MIAL is compliant and certified to global standards such as ISO 14001:2001 for Environment Management System, ISO 14064-1: 2006 for GHG emissions and removals. CSIA was upgraded in March 2015 to Level 3 Optimisation of the Airport Carbon Accreditation (ACA) Program, a distinction achieved by only six other airports in the Asia-Pacific region (GVK CSIA press release, 2015, March 9).

CHAPTER 2: LITERATURE REVIEW

2.1 Waste Management at Airports

Wastes from airports are generated at terminals, air and land sides, and the waste types are depicted in Figure 2.1 below.

	Airport activity															
	Airside				Terminals					Landside				Infrastructure development		
Waste type	Airline catering	Aircraft cabin cleaning	Aircraft maintenance	Airfield operations	Administration	Staff amenities	Security processes	Retail and catering	Engineering	Vehicle maintenance	Airport landscaping	Car parking	Administration	Construction	Demolition	Maintenance
Paper		■			■			■				■	■			
Newspaper/ magazines		■			■	■		■				■	■			
Cans	■	■				■	■	■				■				
Cardboard	■	■			■			■	■				■	■		■
Metal			■				■		■	■				■	■	■
Wood				■					■					■	■	■
Glass	■	■				■	■	■	■	■				■	■	■
Plastic	■	■	■		■	■	■	■	■	■		■	■	■	■	■
Batteries			■	■	■		■	■	■	■			■			■
Oil & lubricants			■	■					■	■				■		■
Fluorescent tubes			■					■	■						■	■
Concrete														■	■	■
Fixtures, fittings & materials			■					■	■						■	■
Tyres			■						■	■						
Rags			■						■	■						
Aerosols			■	■			■		■							■
Food	■	■				■		■					■	■		
Green waste				■							■					

Figure 2.1: Airport waste types and sources (Source: Heathrow Airport Limited, 2011)

Table 2.1 characterises the types and sources of Municipal Solid Waste (MSW). On comparing Table 2.1 with Figure 2.1 depicting the type of wastes arising from different airport areas, it can be inferred that airport waste is similar in composition to MSW. In fact, airports are akin to mini-cities and the wastes generated are similarly managed (Fleuti, 2010 and Leavitt, 2010).

Table 2.1: MSW Waste Types and Sources (Adapted from World Bank, 2012)

Types	Example Sources
Organic	Food scraps, yard wastes
Plastic	Bottles, packaging
Paper	Newspapers, gift wrap, cardboard
Glass	Light bulbs, broken glassware
Metal	Foils, tins
Construction and Demolition	Rubble, concrete, masonry
Other	E-waste, textiles, rubber, leather, inert materials

However, there are certain key considerations in managing airport wastes which cannot be overlooked. These are airport security, facility space constraints, time and working with tenants; these are briefly explained as follows (USEPA, 2009). The first priority is that all elements of the waste management system must be consistent with security requirements. Terminal and land side areas often have little additional space to facilitate supplementary receptacles for source segregation, and waste at air side is a hazard that can attract wildlife, leading to bird/ animal strikes. Airline staff and cleaning service providers have limited time to spruce up aeroplanes between arrivals and departures. Finally, there are obvious challenges in dealing with a large number of tenants (food/ beverage, multiple airlines, concessionaires and others). Airport waste management can be simplified by maintaining consistent practices, providing tenants with easily accessible waste receptacles, clear instructions and training, and conducting awareness programs (USEPA, 2009). Airport waste streams tend to be high in recyclable components, and many airports have robust recycling programs for dry waste streams. A number of airports manage their food and garden wastes by composting, but a majority discard this stream by disposal in landfills or dumps.

2.2 Considerations in Management of Food and Garden Wastes

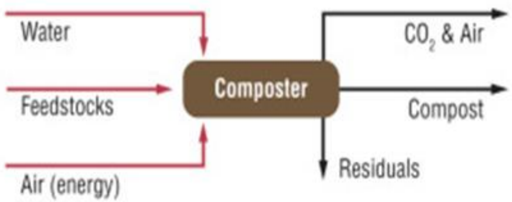
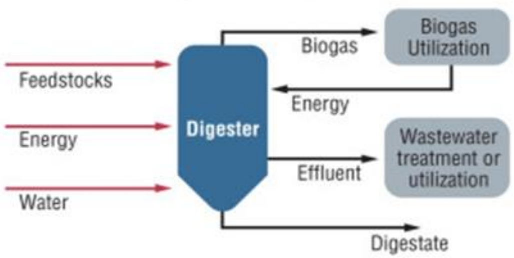
Food waste is more amenable to biological treatment using composting, vermicomposting, anaerobic digestion (AD) as compared to thermal or physical techniques such as refuse-derived fuel, biomass briquetting, pyrolysis, incineration due to its wet nature and high carbon content (Hill, 2010). The USEPA food waste hierarchy places composting and AD on the same level (USEPA, 2013) ahead of disposal but after the strategies of reduction at source; feeding hungry people; as animal feed; industrial uses i.e. oils, grease, fatty matter for biofuel production. However, research outcomes favour AD over composting for food waste and mixtures of food waste, though composting is ranked before AD in the conventional waste hierarchy (Department for Environment Food and Rural Affairs [DEFRA], 2011). Also, the waste hierarchy does not provide for combinations of management methods.

Even within a given management option, there are many choices, which further adds to the factors that must be considered in decision making. For example, choices must be made between, or a combination of, commonly used composting types: windrow, aerated static pile and in-vessel composting. AD systems may be divided into wet and dry types, based on the moisture content of the feedstock. Characterisation of the feedstock must also be factored in – AD systems, for example, do not digest a waste stream high in garden waste very well, rendering the process inefficient. Coupled with considerations of social acceptability, economic feasibility and technical practicality, the selection of an optimal waste management method necessitates careful consideration and localised studies.

Common food and garden waste management options involve composting (microbial), AD, and vermicomposting. Land disposal is common in developing countries, and is often resorted in areas where tipping fees are cheaper than a biological treatment alternative. Although vermicompost sells for a much higher price than compost from food waste in India, vermicomposting cannot process putrescible non-vegetarian feedstock very well, takes longer time to obtain finished product, has odour problems and tends to be unviable on larger scales (various websites, OWC product information brochures), due to which only dumping, composting and AD were considered for the assessment.

A brief comparative overview of dumping, composting and anaerobic digestion from various literature sources is presented in Table 2.2.

Table 2.2: Overview of Dumping, Composting and Anaerobic Digestion

Technique	Process		Comments
Dumping - uncontrolled biological degradation	Generalised indiscriminate disposal involving vermin, rodents, microbes	• Bacterial decomposition • Volatisation • Chemical reaction	GHG & toxic emissions Soil, groundwater contamination
Composting - biological degradation under controlled conditions	**Figure 1. Composting inputs and outputs**  Source: Biocycle.net	Stages: • Mesophilic • Thermophilic • Maturation	Sample organisms: • *Bacillus* • *Streptomyces* • *Aspergillus* Compost mainly contains organic carbon; improved disease and pest-resistance of vegetation
Anaerobic Digestion - series of biological processes in absence of air under controlled conditions	**Figure 2. Anaerobic digestion inputs and outputs**  Source: Biocycle.net	Stages: • Hydrolysis • Acidogenesis • Acetogenesis • Methanogenesis	Sample organisms: • *Cellulomonas* • *Enterobacter* • *Methanobacterium* • *Methanosarcina* Stabilised digestate tends to contain higher nitrogen

2.3 LCA and CBA for Comparing Alternative Waste Management Systems

Life Cycle Analysis (LCA) is a tool which assesses the environmental performance of a system using a cradle-to-grave approach (Scientific Applications International Corporation [SAIC], 2006). An LCA is a four-step iterative process comprising goal definition and scoping, inventory analysis, impact assessment and interpretation (International Organisation of Standardisation [ISO], 2006). The boundaries, purposes and functional units of a study are defined and described in the goal definition and scoping stage, while inventory analysis involves flow diagram development, data collection and quantification of process inputs and outputs (Curran, 2012). In impact assessment, the results of the inventory analysis are used to evaluate the significance of potential environmental impacts; and finally the data from inventory analysis and impact assessment are reviewed and analysed to obtain a final conclusion in the interpretation stage (Curran, 2012). However, for evaluation of waste management systems, McDougall, White, Franke and Hindle (2001) recommend using only the goal definition and scoping and inventory analysis stages for assessment owing to uncertainties associated with impact assessment. In an LCA, climate change is evaluated under the global warming impact category on a global scale using GHG emissions inventory data characterised using global warming potentials (SAIC, 2006).

Cost-benefit analysis (CBA) is the commonest tool used for economic assessment of projects. CBA attempts to compare costs of a program to its monetised benefits. Where benefits are difficult to monetise, as in the fields of healthcare, environment; cost-effectiveness analysis (CEA) may be used as an alternative to CBA. In CEA, costs are related to specific measures of program effectiveness. A general approach to CBA and CEA involves determining the analysis framework; identifying and categorising costs and benefits over the life of the program under assessment; monetising costs; quantifying benefits in terms of effectiveness for CEA, monetising benefits for CBA; discounting to obtain present values and presenting results in terms of cost-effectiveness ratios for CEA or net present value for CBA. Recommendations may be made after conducting a sensitivity analysis. (Cellini & Kee, 2010)

Villanueva, Kristensen and Hedal (2006) outline the use of LCA and CBA for comparing alternatives for managing a waste stream. LCA and CBA translate costs and benefits of different options into measurable physical or economic units; however the economic and environmental representations provided are partial, and so these are not decision making tools but decision support tools (Villanueva *et al.*, 2006).

Food waste management LCAs vary widely in their outcome due to differences in relation to setting of system boundaries, methodological choices and variations in input data used (Bernstad and la Cour Jansen, 2012). The results of CBA, as found in various studies (*e.g.* Regenstein, Kay, Turci & Outerbridge, 1999; Faucette, Governo & Graffagnini, 2002; Zurbrügg, Drescher, Patel & Sharatchandra, 2004; Campbell & Glasser, 2009; Pandyaswargo & Premakumara, 2014), vary with scale, policy, costs of the management method and price of value-added products. In areas where the cost of landfilling is high, biological waste treatment is economically preferential and vice-versa. The choice between composting, AD or other management methods depend on the price of the value added products. For example, in the United States of America, compost from food and garden wastes sells for a higher price than conventional fertilisers and prohibitively high costs are associated with landfilling in certain states – making composting an attractive and viable option, but the converse is true for India. Subsidies on electricity and cooking gas lower the economic performance of AD in developing countries, whereas the prevalence of renewable energy credits in developed nations enhance it. Dumping is the most common method of disposal of food and garden wastes in India, largely due to it being the cheapest option. Source separation of organic wastes was found to improve LCA and CBA performance of composting and anaerobic digestion of food and garden wastes.

CHAPTER 3: METHODOLOGY

The methods used for this project were developed from literature review with inputs from the MIAL project guide. The criteria proposed by the International Environmental Technology Centre of the United Nations Environment Programme (1996) for evaluating alternatives on the basis of their environmental, economic and social feasibility formed the guidelines of the methodological framework for the assessment. Considerations include, but are not limited to, technological robustness of the alternative in light of available human and financial resources; trade-offs between costs and environmental soundness; cultural practicality and effects on society.

The methodological approach can be broadly divided into three broad phases:

1. Scenario definition for environmental and economic assessments, and to facilitate comparison between them
2. Environmental assessment involving quantification of GHG emissions associated with each scenario over the waste life cycle using a life cycle inventory (LCI) approach
3. Economic assessment involving calculation of Net Present Value (NPV) using cost-benefit analysis and Cost-effectiveness (CE) and Effectiveness-cost (EC) ratios using cost effectiveness analysis for each scenario

3.1 Scenario Definition

The three options under consideration for managing the food and garden waste generated at CSIA are dumping, composting using an OWC and anaerobic digestion with electricity production. The present practice of dumping was set as the baseline scenario S0. MIAL received several product information brochures and cost estimates from various OWC manufacturers and/or suppliers. Three types of OWCs (automatic, semi-automatic and batch, see Appendix A) can be identified, each with differing costs, labour and material requirements and different volume reduction capacities. Hence, three scenarios – S1, S2 and S3 – were set for composting, corresponding to OWC types. Anaerobic digestion with electricity production was considered as the alternate scenario S4, instead of biogas utilisation for cooking purposes, thermal uses or alternate fuel uses. This was because cooking would not be undertaken at the site, and the anaerobic digester plant utilises solar energy for heating purposes and not generated biogas. Also, use of biogas for fuel requires biogas pre-treatment, construction of pipelines, etc. whereas for electricity generation, the only basic requirement is a generator.

The same scenarios were used for life cycle analysis of GHG emissions, cost-benefit and cost-effectiveness analyses. The scenarios developed and deemed as the base case are tabulated in Table 3.1. For the sensitivity analyses, the different scenarios correspond to their respective OWC type/anaerobic digester, with the waste amount managed – transported, biologically treated, dumped – and other parameters varying as described in the corresponding sensitivity analysis.

Table 3.1: Scenarios used for Base Case and Sensitivity Analyses in Environmental and Economic Assessments

Scenario	Base Case Scenario description	Scenario description for various Sensitivity Analyses
S0	Baseline of 720 MT food and garden waste dumped annually	Baseline of 720 MT food and garden waste dumped annually
S1	Composting of 360 MT with fully automatic OWC + 360 MT food and garden waste dumped annually	Composting of food and garden waste using fully automatic OWC
S2	Composting of 360 MT with semi-automatic OWC + 360 MT food and garden waste dumped annually	Composting of food and garden waste using semi-automatic OWC
S3	Composting of 360 MT with batch-type OWC + 360 MT of food and garden waste dumped annually	Composting of food and garden waste using batch-type OWC
S4	Anaerobic digestion of 360 MT with electricity production + 360 MT food and garden waste dumped annually	Anaerobic digestion of food and garden waste with electricity production

3.2 Environmental Assessment

A bounded Greenhouse Gases Life Cycle Analysis (GHG-LCA) utilising a life cycle inventory (LCI) approach as outlined by McDougall, White, Franke and Hindle (2001) was used to facilitate comparison between dumping, composting and anaerobic digestion of food and garden waste. This technique involves the goal definition and scoping and LCI stages of a traditional LCA. After completing the goal definition and scoping stage; for inventory analysis, the different waste management systems must be described, and then the inputs and outputs to each system must be calculated. The resulting GHG emissions over the entire life cycle of waste were quantified using version II of the Institute for Global Environmental Strategies' (IGES) GHG Calculator. The calculator takes into account the regional effects of Asia as opposed to conventional calculators developed for use in Europe or North America (Menkipura and Sang-Arun, 2013).

3.2.1 Goal definition and scoping

The purpose of the environmental assessment was to quantify the GHG emissions associated with composting and anaerobic digestion as compared to CSIA's present practice of open dumping of food and garden wastes and to support CSIA's commitment to environmental sustainability. The function was management of food and garden wastes, while the functional unit was defined as the total food and garden wastes in metric tonnes (MT) generated at CSIA in one calendar year. The current annual waste stream is 720 MT, derived from an approximate daily waste generation rate of 1800 kg food waste and 200 kg garden waste i.e. a ratio of 90:10 for food waste to garden waste (MIAL waste disposal records; personal communication with Mr Arun Holmukhe and Mr Shailendra Joshi, January 27, 2015).

System boundaries were set by defining the waste life cycle and inputs and outputs to the system. For this analysis, the waste life cycle was defined as the point from which waste enters the system after being discarded to the point where waste leaves the system either on gaining value as compost or biogas, or as an emission, or the point of final disposal in the dump. Accordingly, inputs to the system are waste and energy while the outputs are compost from composting, electricity from anaerobic digestion, and emissions. The zero burden approach to waste has been followed in which generated waste has no positive or negative value assigned to it. Also, second level burdens such as those of manufacturing waste digesters/converters, bio-culture, sawdust, trucks etc. have been excluded but effects of energy consumption and waste transportation have been included. The scope of the assessment was limited to quantifying GHG emissions due to the acceptability of using carbon footprint as a measure of environmental performance.

3.2.2 Inventory analysis

The waste management systems to be compared were described by developing flow diagrams (Figures 3.1 and 3.2) for the baseline and after implementation of biological treatment system.

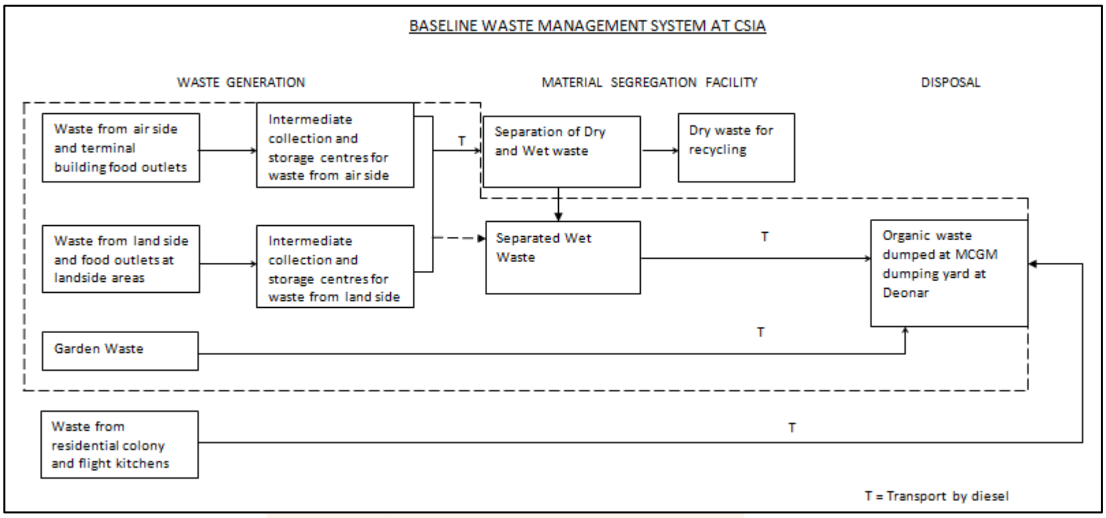


Figure 3.1: CSIA non-hazardous waste management baseline system

*Scope for GHG-LCA in dashed outline

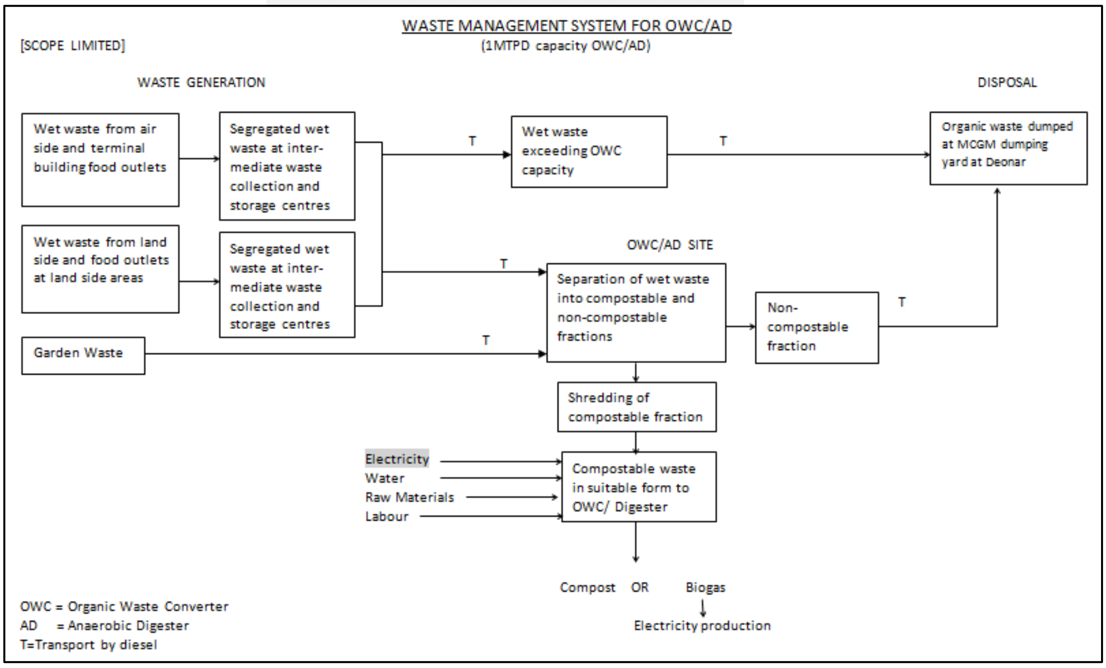


Figure 3.2: CSIA non-hazardous waste management system after implementation of biological treatment

Data collection for the inputs of the inventory analysis was carried out through personal communication with MIAL staff, and obtained from internal office documents and records, and product information brochures. Distances for waste transportation from airport reference point to Deonar dump, and from airport reference point to OWC site, and onwards to Deonar dump were obtained using Google Maps. The input data was used in the IGES calculator to obtain the output data. The input and output values in their associated categories for each scenario are tabulated in Appendix B (Tables B.1 to B.3).

Finally, sensitivity analyses were performed using the one-at-a-time approach to determine the influence of data assumptions on the LCI outcome of annual GHG emissions. Analyses were performed for determining changes in GHG emissions in the following four cases: subjecting the entire waste stream to biological treatment; reduced waste streams; varying the volume reduction achieved by OWC; and the electricity consumed by OWC/ anaerobic digester.

For the first sensitivity analysis, the annual food and garden waste stream of 720 MT was arbitrarily divided into a 660 MT fraction being biologically treated, and a 60 MT fraction non-amenable to composting or anaerobic digestion being dumped yearly. This was assumed for the situation of subjecting all the food and garden waste generated by CSIA to biological treatment, since MIAL plans to expand the system at a later phase. The fuel and distance for waste transportation were changed accordingly. The electricity used, and other required inputs were doubled to account for a second biological treatment unit to meet the total waste stream input.

The next sensitivity analysis involved a situation in which there is a hypothetical reduction in the total food and garden wastes generated at CSIA. The two waste streams chosen were those of 180 MT and 120 MT of food and garden wastes generated annually and biologically treated, as compared to the 720 MT base case stream, out of which 360 MT will be composted and the rest dumped.

The average waste volume reductions achieved are approximately 85%, 75% and 60% for the fully automatic, semi-automatic and batch type OWCs respectively, as mentioned in their product information brochures. The percentage reduction was varied by ±5% in the sensitivity analysis.

Finally, each OWC and the digester have different power ratings based on which electricity consumption was calculated for the given waste stream. The sensitivity analysis involved varying the electricity consumption by 80% and 120% of the initial value considered in the base case calculations.

3.3 Economic Assessment using CBA and CEA

The method used for cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) was consolidated and adapted from Cellini and Kee (2010) and Boardman, Greenberg, Vining and Weimer (2010). The steps involved: identifying costs and benefits of each scenario, collecting data, quantifying value-added products, monetising costs, monetising benefits for CBA and quantifying benefits in terms of units of effectiveness for CEA, building cash flows, calculating NPV for CBA and CE and EC ratios for CEA and finally, performing sensitivity analyses. It was assumed that the rate of generation of food and garden waste remains constant over the 10-year assessment period.

3.3.1 Identification of costs and benefits

The costs for the baseline scenario include only the disposal fee paid for dumping food and garden waste at the Deonar dumping ground. No benefit was associated with dumping. Set-up cost involving site preparation, building construction, electrical and plumbing works, water connection supply, etc. and costs involving purchase and set-up of the biological treatment system are common to scenarios S1 to S4. The recurring costs of composting by OWC involve operation and maintenance costs – common to S1 to S3 are costs for electricity and labour. Additional operating costs of compost culture and absorbent are required for S2 and S3. The benefit for S1 to S3 is compost. For the anaerobic digestion scenario S4, additional capital cost is required for purchase of generator and the recurring costs involve those of electricity, labour, water and generator maintenance. The benefit is renewable electricity generated from biogas. Dumping costs associated with the waste stream which exceeds system capacity are common to scenarios S1 to S4.

Certain costs and benefits have been excluded from this study. Excluded costs include those associated with waste collection and transportation, cost of personal protective equipment to workers, packaging fees and costs of quality testing for compost product. The benefits of biological waste treatment such as reduced soil and groundwater contamination of the dump vicinity and the impact of lesser quantity of toxic emissions to the population around the dump have been excluded. Also excluded is the benefit of revenue from sale of soil amendment acquired from drying the digestate obtained after anaerobic digestion of food and garden waste.

3.3.2 Data collection

Cost estimates were gained through literature review, personal communication, e-mails and telephone calls. All the costs estimates were approved by the MIAL project guide, Mr Shailendra Joshi, Deputy General Manager - Environment.

The per wet tonne disposal fee for dumping was obtained from Sharda Enterprises, the agency handling the collection, transport, segregation, recycling and recovery of all non-hazardous waste generated at CSIA. Mr Shailendra Joshi provided the total set-up cost estimate inclusive of site preparation, construction, plumbing, electrical installations, etc. for the biological treatment facility.

Capital costs of the biological treatment systems, inclusive of commissioning, were obtained from their respective manufactures and/or suppliers. For the automatic OWC associated with S1, the capital cost was obtained by e-mail from Mr Sandeep Verma of Ecoman Enviro Solutions Private Limited. The price and operating cost (labour, sawdust absorbent, compost culture) details for the semi-automatic OWC in S2 were provided by telephonic conversation with a Marketing Department representative of Earth Care Equipments Private Limited. The capital cost of the batch OWC in S3 was obtained from Mr Ajit Kude of Avni Enterprises, and absorbent and culture cost estimates used were the same as for S2. Labour cost per person, obtained from Earth Care Equipments Private Limited, was used for scenarios S1 to S4. After providing the digester capacity, an employee of Siya Instruments Private Limited, manufacturer, exporter and supplier of biogas generators and related equipment, provided the cost of the generator for converting biogas to electricity via telephonic conversation.

3.3.3 Quantification of value-added products

The value-added products for composting and anaerobic digestion for this study are compost and electricity respectively. The annual quantity of compost produced was estimated from the volume reduction percentage achieved by the respective OWC in scenarios S1 to S3. The amount of electricity generated from biogas in scenario S4 was provided in a telephonic conversation with the employee of Siya Instruments Private Limited. The value-added products were quantified as 54 MT, 90 MT and 144 MT of compost respectively for scenarios S1 to S3 and 21900 kWh of electricity for S4.

3.3.4 Monetisation of costs and benefits for CBA

The market price available from literature review was used to monetise compost. An approximate rate for electricity, inclusive of taxes and rebates, was computed by dividing the bill amount by the metered units of the February 2015 electricity bill of CSIA's Terminal 1. This obtained rate was used to monetise both operational and value-added electricity. An employee of MIAL Engineering and Maintenance department used a similar procedure and provided the approximate water charges. Summarised annual monetised costs and benefits used for CBA are attached in Table C.1 in Appendix C, while the rates used for monetisation are tabulated in Table 3.2.

Table 3.2: Rates used for Monetisation of Costs and Benefits

Parameter	Monetisation rate
Dumping	₹ 1,250 per wet MT
Electricity	₹ 9 per unit (kWh)
Labour	₹ 1, 20,000 per person per year
Operating costs for culture + absorbent (S2, S3)	₹ 2,50,000 per year
Generator maintenance (S4)	₹ 2,500 per year
Water (S4)	₹ 70 per kilolitre
Compost (S1 to S3)	₹ 5 per kg

3.3.5 Monetisation of costs and quantification of benefits in terms of units of effectiveness for CEA

The monetised costs used were same as for CBA. The unit of effectiveness chosen was reduction in GHG emissions. The GHG emissions reductions were taken from the GHG-LCA results, after subtracting the emissions associated with waste transportation.

3.3.6 Building of cash flows

It was assumed that the year of implementation i.e. 2015 of the biological treatment system would not yield any benefits, and benefits were counted from the next year onwards. Cash flows over a ten-year period were developed using Microsoft Excel and the following formula for calculating present value, adapted from Boardman *et al.* (2011) to obtain present value, using a discount rate of 10%, after accounting for inflation of the parameters, as assigned in Table 3.3. Figure C.1 in Appendix C depicts the cash flows for the base case.

$$PV = \frac{CF}{(1+r)^t}$$

Where, PV = Present Value
CF = Cash Flow
r = discount rate i.e. 10%
t = year

Table 3.3: Inflation assigned for building Cash Flows

Parameter	Inflation per Year
Dumping	2%
Electricity	5%
Labour	10%
Operating costs for culture + absorbent (S2, S3)	2%
Generator maintenance (S4)	2%
Water (S4)	2%
Compost (S1 to S3)	1%

3.3.7 Calculation of NPV and CE, EC ratios

NPV of each scenario was calculated using the formula given by Cellini and Kee (2010). The calculations are presented in Figures C.2a to C.2e in Appendix C.

$$NPV = \sum_{t-1}^{T} \frac{(B_t)}{(1+r)^{t-1}} - \sum_{t-1}^{T} \frac{(C_t)}{(1+r)^{t-1}}$$

Where, NPV = Net Present Value
B = Benefits
C = Costs
t = year from 1 to T
T = last year of analysis

The formula for calculating the standard CE ratio (Cellini & Kee, 2010) is:

$$\text{Cost Effectiveness ratio} = \frac{\text{Present Value of Costs}}{\text{Units of Effectiveness}}$$

The average CE ratio for each scenario was calculated by dividing the present value of costs for that scenario divided by the reduction in waste transportation-excluded GHG emissions achieved as compared to the baseline in metric tonnes carbon dioxide equivalents ($MTCO_{2e}$), i.e. the unit of effectiveness was the $MTCO_{2e}$ reduced. Thus, the CE ratio was obtained in terms of ₹ per $MTCO_{2e}$ reduced. The EC ratio for each scenario was calculated as the reciprocal of CE ratio and multiplied by 1, 00,000 to get results in terms of $MTCO_{2e}$ reduced per ₹ 1 lakh. The reduction in GHG emissions were calculated from the results of the GHG-LCA, after excluding emissions due to waste transportation. The calculations are shown in Appendix C, Figure C.3.

3.3.8 Sensitivity analyses

Discount rates of 5%, 8%, 12% and 15% were applied to the base case cash flows for CBA. Extreme case sensitivity analysis was used, in which select monetised parameters were varied simultaneously to obtain best case and worst case scenarios. The variation in parameters for extreme case sensitivity analysis is given in Table 3.4 below. For both CBA and CEA, sensitivity analysis considering the entire food and garden waste stream being subjected to biological treatment, was performed.

Table 3.4: Variation in Parameters for CBA Extreme Case Sensitivity Analysis

Parameter	Best Case	Base Case	Worst Case
Dumping	₹ 1,000 per wet MT	₹ 1,250 per wet MT	₹ 1,500 per wet MT
Electricity	₹ 8 per unit	₹ 9 per unit	₹ 10 per unit
Operating cost	₹ 2,02,575 per year	₹ 2,50,000 per year	₹ 2,86,525 per year
Compost	₹ 6 per kg	₹ 5 per kg	₹ 4 per kg

CHAPTER 4: RESULTS AND DISCUSSION

The findings of the environmental and economic assessments are presented separately, and then consolidated together for perspective.

4.1 Outcome of Greenhouse Gases Life Cycle Analysis

The results of the GHG-LCA in terms of $MTCO_{2e}$ per year are presented in Table 4.1. Negative values of net GHG emissions imply that savings in terms of material and energy recovery and avoided emissions from dumping are higher than the direct emissions associated with that scenario.

Table 4.1: GHG Emissions of Each Scenario in $MTCO_{2e}$ per year

Scenario	Activity-based Annual GHG Emissions and Savings ($MTCO_{2e}$)			
	Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions
S0	Transportation	3.88	NIL	3.88
	Dumping	624.96	NIL	624.96
S1	Transportation	4.56	NIL	4.56
	Dumping	312.48	NIL	312.48
	Composting	113.87	428.65	- 314.78
S2	Transportation	4.56	NIL	4.56
	Dumping	312.48	NIL	312.48
	Composting	73.29	506.10	- 432.81
S3	Transportation	4.56	NIL	4.56
	Dumping	312.48	NIL	312.48
	Composting	72.07	622.27	- 550.19
S4	Transportation	4.56	NIL	4.56
	Dumping	312.48	NIL	312.48
	AD process	11.91	460.26	- 448.35

For the baseline dumping scenario, S0, GHG emissions are associated with transportation and dumping of wastes, and there are no GHG savings. For the composting scenarios S1 to S3, GHG emissions are associated with transportation of waste, dumping of the waste stream exceeding OWC capacity i.e. 360 MT annually and waste degradation and operational electricity use associated with the OWC in composting. Avoided emissions from dumping and chemical fertiliser production due to production of compost contribute to GHG savings. For scenario S4 of anaerobic digestion with electricity production, GHG emissions are due to waste transportation, waste dumping, operational electricity use and emissions due to unavoidable leakages from the AD process. Avoided emissions from electricity production and dumping contribute to GHG savings. The results of the GHG-LCA in terms of $MTCO_{2e}$ are tabulated in Table 4.1 and net GHG emissions represented graphically in Figure 4.1.

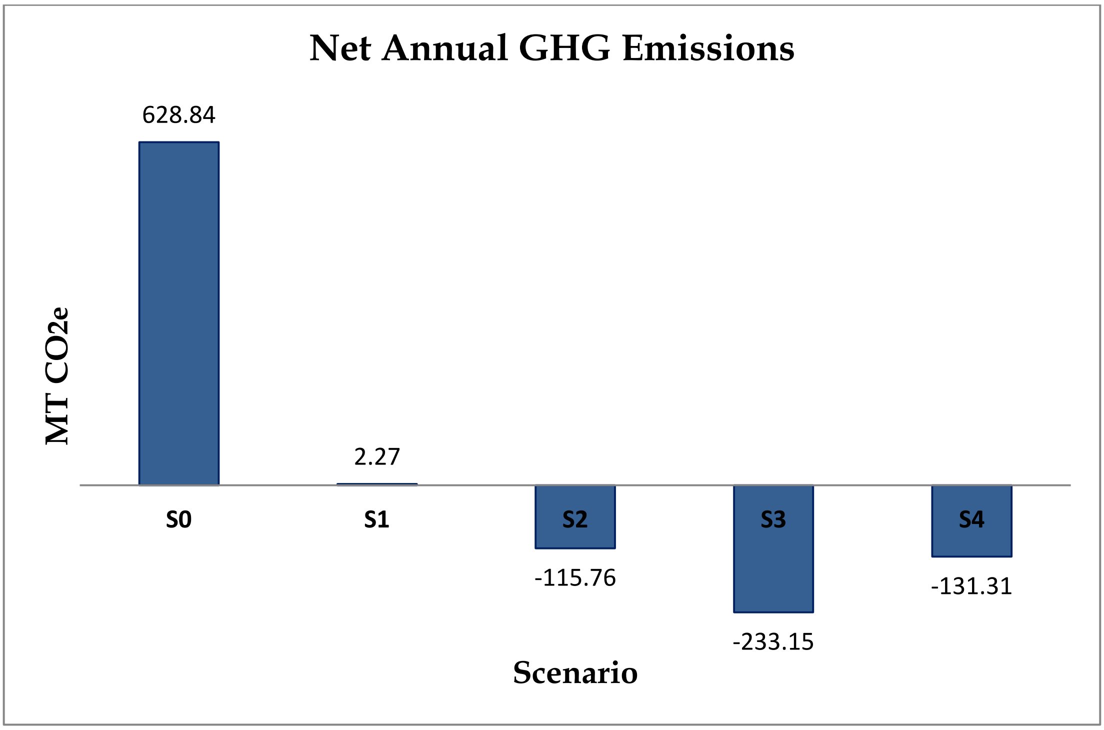


Figure 4.1: Net annual GHG emissions associated with each scenario

It is evident that implementation of either composting using OWC or anaerobic digestion with electricity production leads to significant decrease in net annual GHG emissions despite emissions from operational activities at the treatment facility and waste transportation from airport to facility site and then to the dumping ground. This decrease can be majorly attributed to avoided emissions from dumping of food and garden waste as half the waste stream is diverted to biological treatment. This is because the practices of organic waste dumping and landfilling give rise to GHG emissions of 45% to 60% methane and 40% to 60% carbon dioxide by volume (ATSDR, 2001). Over a 100-year time scale, methane contributes 21 times more to global warming than carbon dioxide, and recent research implies that mitigating climate change can be achieved more efficiently and cost-effectively by decreasing methane emissions (Smith, Reay and Van Van Amstel, 2012).

Additional decreases are attributed to production of value-added products – compost for scenarios S1 to S3, and electricity in S4. Highest GHG reductions are associated with the batch type-OWC which achieves the least volume reduction i.e. produces the greatest amount of compost. Anaerobic digestion with electricity production achieves the next highest GHG reductions followed by the semi-automatic OWC. The automatic OWC does not achieve net GHG savings due to direct emissions from relatively higher operational electricity use and lower avoided emissions owing to least amount of compost produced because of greatest waste volume reduction.

Sensitivity analysis for subjecting entire food and garden waste stream to biological treatment: It was assumed that of the annual 720 MT food and garden waste stream, 60 MT was not amenable to composting or anaerobic digestion and was dumped, and the remaining 660 MT was biologically treated. It was found that there was a percentage decrease of approximately 200% in GHG emissions over the baseline, with scenarios S1 to S4 all showing GHG savings, as evidenced in Figure 4.2. This decrease is despite the use of two like OWCs/ digesters being used with higher emissions due to operational activities. This outcome further reinforces the impact of avoided emissions from waste dumping on net GHG emissions. As in the base case above, additional decreases are due to production of value-added products.

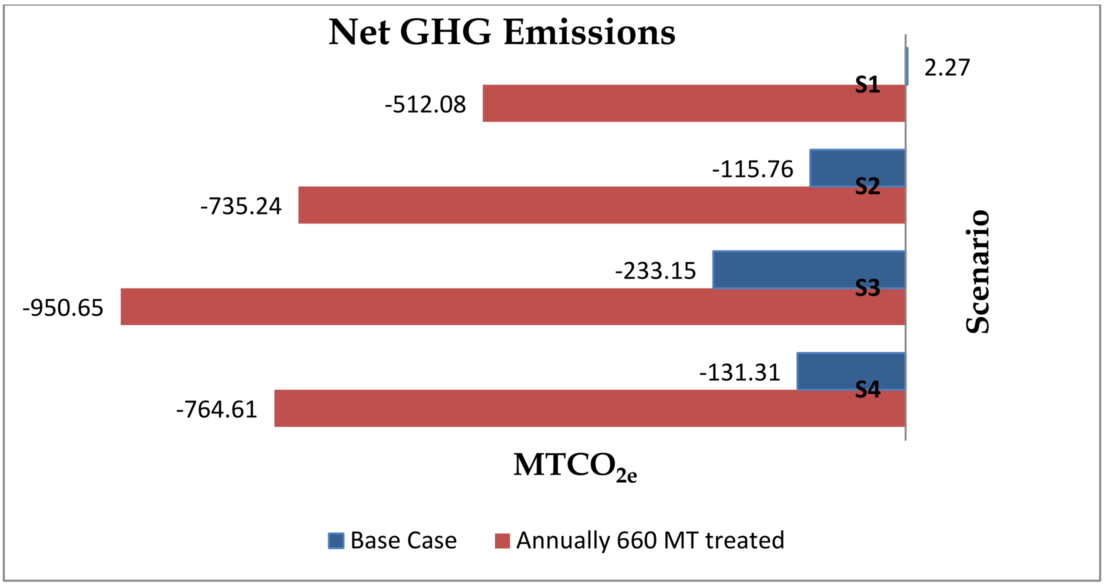


Figure 4.2: Sensitivity analysis for biological treatment of entire food and garden waste stream

The percentage decreases in net GHG emissions over the baseline of the base case and of the sensitivity analysis for biological treatment of the entire food and garden waste stream is tabulated in Table 4.2.

Table 4.2: Percentage Decrease in Net GHG Emissions over the Baseline of Dumping

Scenario	Percentage Decrease in Net GHG emissions against baseline dumping scenario S0	
	Base Case	**Annually 660 MT treated**
S1	99.64%	181.43%
S2	118.41%	216.92%
S3	137.08%	251.18%
S4	120.88%	221.59%

Sensitivity analysis for reduced waste stream: The changes in net GHG emissions due to hypothetical decrease in generation of food and garden waste at CSIA are depicted in Figure 4.3. The net GHG reductions are mainly due to avoided emissions from dumping as very less quantities of waste not amenable to composting are dumped, the rest being biologically treated. Also, since the OWC/ digester capacity is the same as in the base case, the operational electricity use is lowered due to the converter/ digester being run for fewer hours. Thus, direct emissions from the waste treatment process are also reduced. This decrease in operational electricity consumption is responsible for the further increase in GHG reductions over the base case in the annual 180 MT stream. In the case of the annual 120 MT stream the low direct emissions due to operational electricity use contributes more to GHG reductions than avoided emissions from chemical fertiliser production. The phenomenon is most evident for the batch-type OWC (S3) where the GHG reduction in the 120 MT stream are lesser than that of the base case.

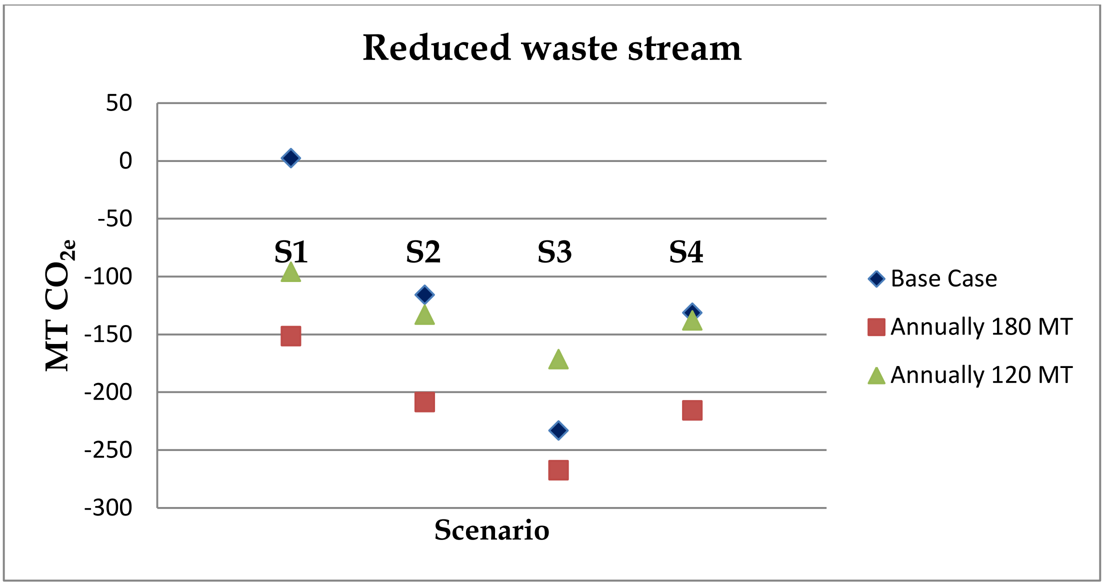


Figure 4.3: Graph showing GHG emission changes for reduced food and garden waste streams

Sensitivity analysis for different waste volume reduction achieved by OWC: The amount of compost produced by the OWC depends on its capacity for waste volume reduction. The changes in GHG emissions due to variation by ±5% of the volume reduction achieved by the OWC are represented in Figure 4.4. It is evident that more the amount of compost produced, i.e. lesser the waste volume reduced, more is the net GHG savings due to avoided emissions from chemical fertiliser production.

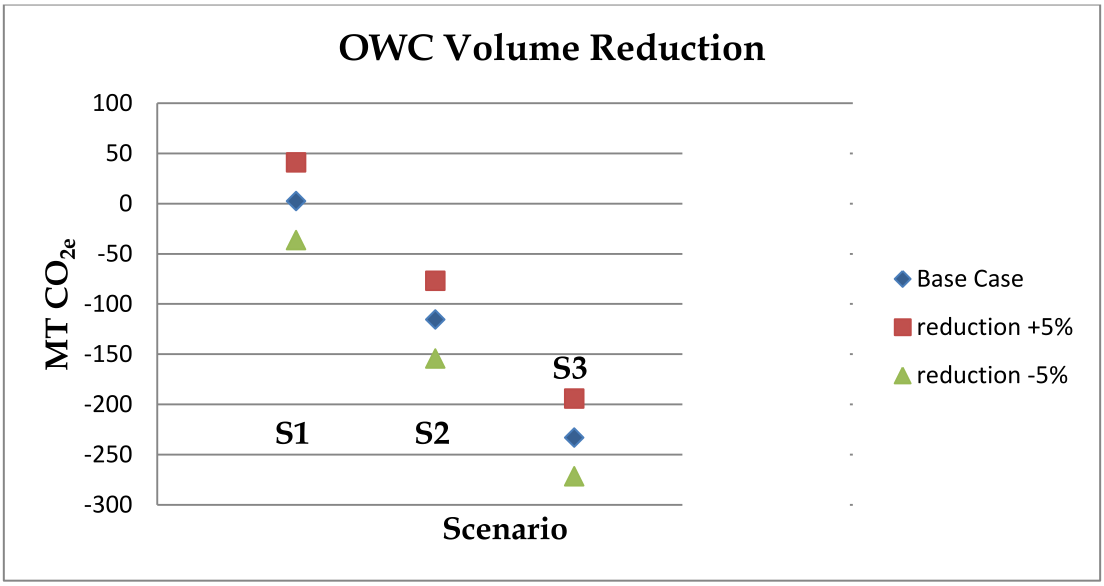


Figure 4.4: Graph showing GHG emissions for different OWC waste volume reduction capacities

Sensitivity analysis for different electricity consumption: It was found that the changes in electricity consumption by 80% and 120% of that of the base case have insignificant impact on net annual GHG emissions except in the case of the automatic OWC as seen in Figure 4.5. The automatic OWC has the highest power rating and hence the largest electricity consumption. However, if it consumes 20% or lesser electricity than that of the base case, or 30% of its rated power as claimed in its product information brochure, then net GHG savings can be expected from the automatic OWC as well.

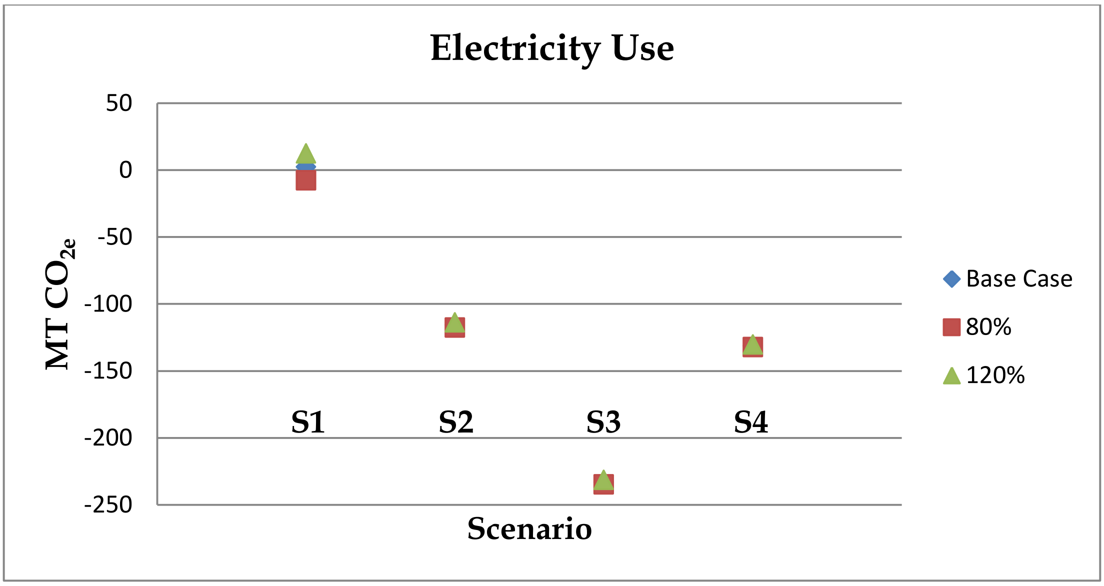


Figure 4.5: Graph showing GHG emission changes for varied electricity consumption

4.2 Outcome of Cost-Benefit Analysis

From the perspective of management of food and garden wastes generated at CSIA, none of the scenarios, including the baseline of dumping, has a positive Net Present Value, as evidenced in Table 4.3. The baseline of dumping shows the best NPV, followed by S3 (batch-type OWC). Scenario S2 using the semi-automatic OWC comes next, followed by the anaerobic digestion scenario S4. The automatic OWC scenario S1 has the least favourable NPV.

Table 4.3: NPV of Base Case Scenarios

Scenario	Net Present Value
S0	₹ - 69,82,035.52
S1	₹ - 1,39,04,491.32
S2	₹ - 91,61,278.13
S3	₹ - 79,02,006.10
S4	₹ - 1,03,38,463.09

Extreme case sensitivity analysis: By varying the costs of dumping, compost, electricity and operating costs of culture and absorbent (scenarios S2, S3) of the base case, an extreme case sensitivity analysis was performed. The NPV remains negative for all scenarios even for the best case assumptions. This is attributed to the monetised benefits having a far lower rupee value than the incurred costs. AD with electricity production shows the least variation in NPV values since the varied costs of the parameters compost, culture and absorbent do not impact it.

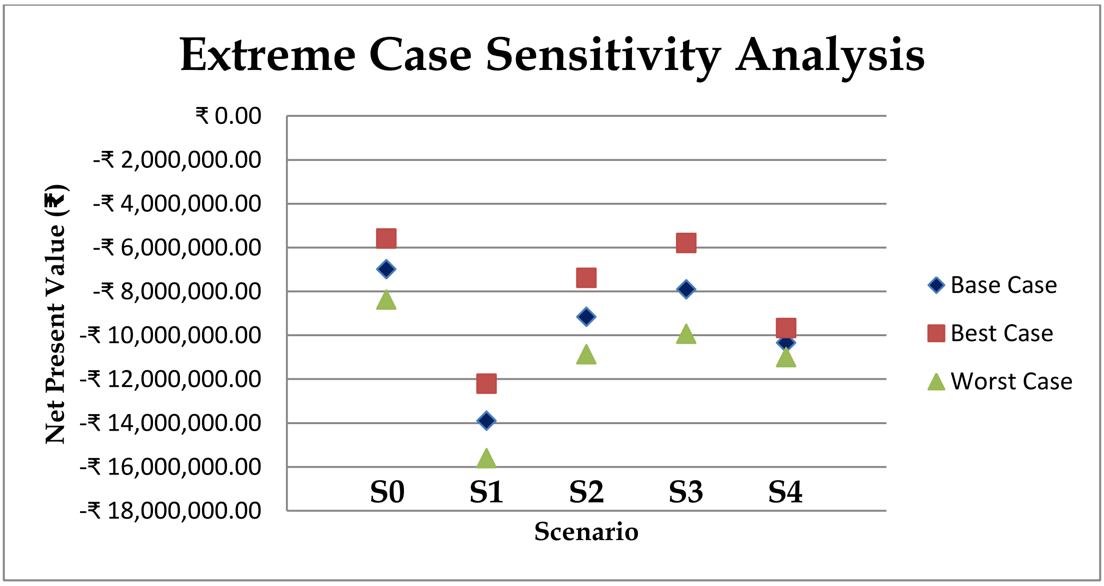


Figure 4.6: Results of CBA extreme case sensitivity analysis

Sensitivity analysis for different discount rates: Figure 4.7 describes the net present values of all scenarios of the base case over a ten-year period for varying discount rates. Although the NPV remains negative for all scenarios, it is observed that higher the discount rate, the better the NPV.

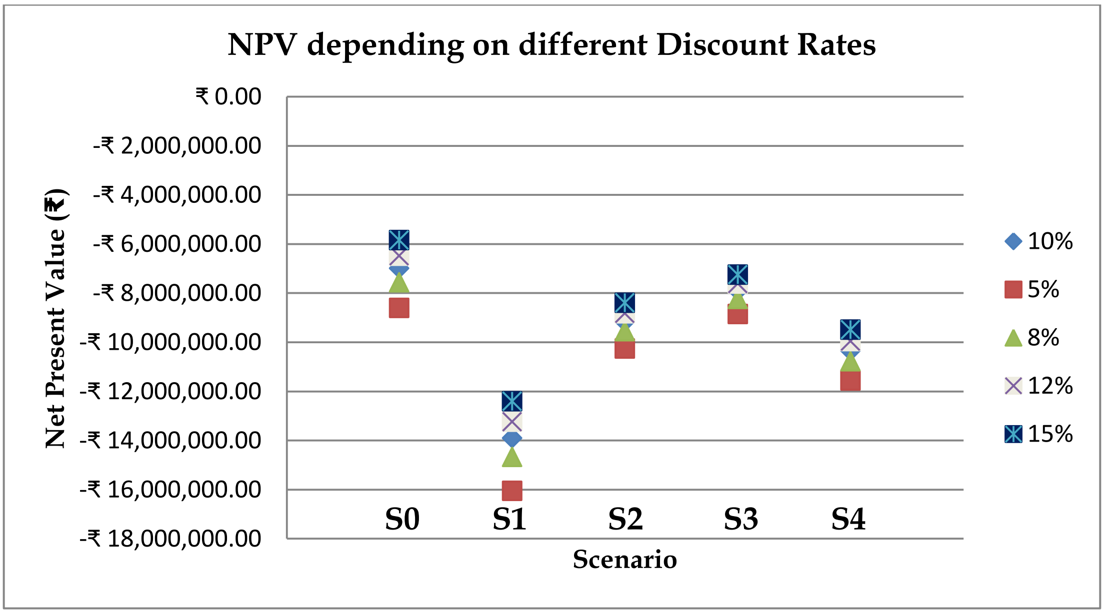


Figure 4.7: Net present values depending on different discount rates

Sensitivity analysis for subjecting the entire food and garden waste stream to biological treatment: This situation represents an increase in capital costs for an additional machine and increased operating costs, with corresponding increases in monetised benefits. For the batch OWC (S3), investing in two identical OWCs for composting food and garden waste makes its NPV better than that of the baseline of dumping. For scenarios S2 and S4, reasonable increases in investment are required for biological treatment of the entire waste stream. However, the NPV for composting the whole compostable food and garden waste fraction using the automatic OWC (S1) is much worse than that of the base case. This can be attributed to electricity costs increasing prohibitively with increase in scale despite operational conveniences of no requirements of culture and absorbent, low to no maintenance costs and less labour requirements.

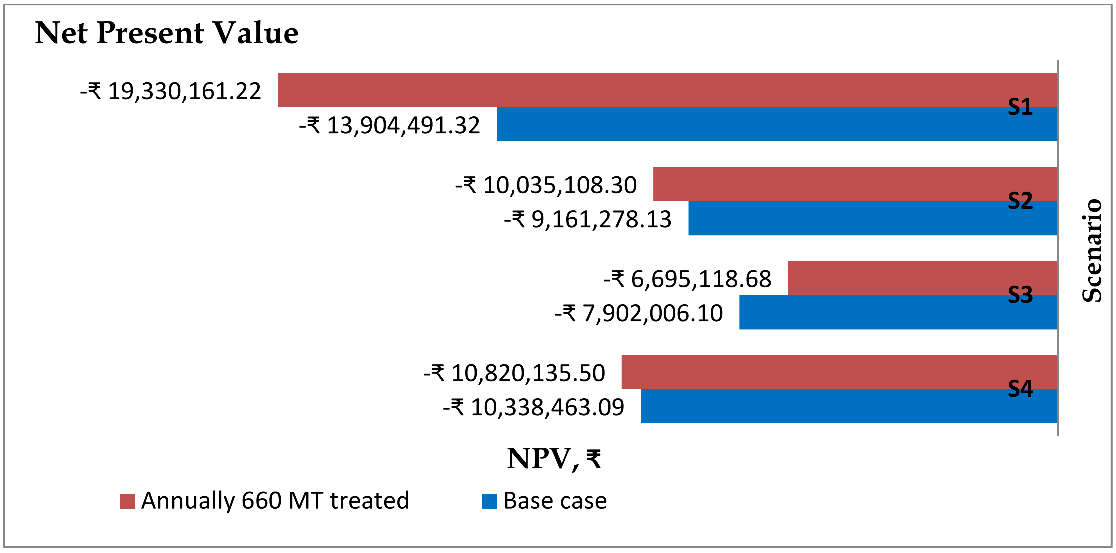


Figure 4.8: CBA sensitivity analysis for biological treatment of entire food and garden waste stream

4.3 Outcome of Cost-Effectiveness Analysis

The CEA may be considered an amalgamation of the results of the GHG-LCA and the CBA as the present value of costs obtained in CBA and the reductions in GHG emissions obtained from GHG-LCA were used to obtain the CE and EC ratios. However, it is important to note that waste transportation has been excluded from the economic assessment, so in the CEA, GHG emissions due to waste transportation have not been taken into account.

The results of the cost-effectiveness analysis is expressed in terms of ₹ per $MTCO_{2e}$ reduced for the average cost-effectiveness ratio and in terms of $MTCO_{2e}$ reduced per ₹ 1 lakh for the effectiveness-cost ratio. Similar to the results of the CBA, S3 using the batch-type OWC shows the best performance, followed by S2, S4 and S1, as shown in Table 4.4. As cost-effectiveness is analysed relative to the baseline, dumping (S0) does not feature in the CE and EC ratios. The most cost-effective option is S3, as lower the CE ratio and higher the EC ratio, the more cost-effective is the alternative under consideration.

Table 4.4 CEA Base Case Results

Scenario	Average Cost-Effectiveness Ratio ₹ per $MTCO_{2e}$ reduced	Effectiveness-Cost Ratio $MTCO_{2e}$ reduced per ₹ 1 lakh
S1	22,167.03	4.51
S2	12,292.23	8.14
S3	9,159.94	10.92
S4	13,588.40	7.36

Sensitivity analysis for subjecting the entire food and garden waste stream to biological treatment: The result of this sensitivity analysis improves the cost-effectiveness of all the composting using OWC and anaerobic digestion scenarios, as evident in Table 4.5 below, compare with Table 4.4 above.

Table 4.5 Results of CEA Sensitivity Analysis

Scenario	Average Cost-Effectiveness Ratio ₹ per $MTCO_{2e}$ reduced	Effectiveness-Cost Ratio $MTCO_{2e}$ reduced per ₹ 1 lakh
S1	16,932.37	5.91
S2	7,353.02	13.60
S3	4,236.93	23.60
S4	7,761.21	12.88

4.4 Consolidated Results

The results of the base case scenarios of GHG-LCA, CBA and CEA are presented together in Table 4.6 for perspective. It is observed that scenario S3, which uses the batch-type OWC shows the best environmental and economic performance among all scenarios. AD with electricity production (S4) has a better environmental performance than composting using the semi-automatic OWC but its economic performance is lower.

Table 4.6: Consolidated Base Case Results for GHG-LCA, CBA and CEA

Scenario	Net GHG Emissions ($MTCO_{2e}$)	Net Present Value	Average CE Ratio (₹ per $MTCO_{2e}$ reduced)
S0	628.84	₹ -69,82,035.52	N/A
S1	2.27	₹ -1,39,04,491.32	22,167.03
S2	- 115.76	₹ -91,61,278.13	12,292.23
S3	- 233.15	₹ -79,02,006.10	9,159.94
S4	- 131.31	₹ -1,03,38,463.09	13,588.40

CHAPTER 5: CONCLUSION

This project, conducted during the time period from January 1, 2015 to March 31, 2015, focussed on comparing composting by OWC, to anaerobic digestion with electricity production as an alternative. Both options were evaluated against the current practice of dumping CSIA's food and garden waste at the Deonar dumping ground, Mumbai. The environmental and economic assessment will aid in decision support for determining the most optimal system for managing food and garden waste.

5.1 Greenhouse Gases Life Cycle Analysis

The environmental performance of dumping, composting by OWC and anaerobic digestion with electricity production was analysed by quantifying the GHG emissions over the waste life cycle. GHG emissions serve as indicators for global warming, and thus climate change. It was found that the largest contributor to reductions in GHG emissions is avoided emissions due to diversion of wastes from dumping. Thus, implementation of either composting or anaerobic digestion will result in decrease of GHG emissions.

For composting, the avoidance of emissions from chemical fertiliser production due to compost produced is the main factor for reduction in GHG emissions. However, the OWC producing the most amount of compost is the labour intensive batch-type which also requires additional space and time for completing the curing process required to obtain stable compost.

Anaerobic digestion with electricity production offers GHG reductions comparable to the semi-automatic OWC. In addition, the reductions from avoided emissions of electricity production are eligible for incorporation into CSIA's annual GHG inventories for the ACA program (Airports Council International [ACI], 2009). Also, the digestate obtained may be stabilised to yield a compost-like soil amendment. The anaerobic digestion process, however, has inherent operational disadvantages – it requires potable water equivalent to the amount of waste treated, which amounts to 1000 litres of water per day for the base case, requires skilled and intensive labour, and is prone to process upsets.

In summary, composting seems to offer immediate environmental benefits: cured compost does not require extensive drying and stabilisation as compared to digestate, and does not require as skilled labour as does the anaerobic digestion process. Nevertheless, the biogas obtained from anaerobic digestion could be used for thermal purposes or be processed to obtain renewable compressed natural gas to fuel the vehicles transporting waste. The emissions of carbon dioxide from a vehicle running on such alternate fuel are considered carbon neutral. Hence, the long-term sustainability potential of anaerobic digestion must not be ruled out during the decision-making process.

5.2 Economic Assessment

None of the management options for food and garden waste generated at CSIA had a positive NPV, including the baseline. This may be attributed to the limited scope of the project which considered the food and garden waste stream in isolation, as opposed to an integrated solid waste management approach. MIAL gains a revenue of approximately ₹ 2, 50,000 per month from management of its dry waste stream which is subjected to third-party recycling (Shailendra Joshi, personal communication). Considering a 2% annual inflation rate on rupee value of recyclables, and a discount rate of 10% over a ten-period, the NPV of dry waste management is ₹ 1, 93, 94,543.10. This may be used to finance any of the base case scenarios and scenarios in sensitivity analysis dealing with subjecting the entire food and garden waste stream to biological treatment and still obtain a positive NPV. Thus, the importance of considering waste management in totality, and not as isolated streams is apparent.

Greater monetised benefits occur in S2 and S3 (composting using semi-automatic and batch-type OWCs respectively) due to the amount of compost produced though anaerobic digestion with electricity production (S4) has low operating costs. The monetised compost in S2 and S3 outweighs the monetised electricity benefit of anaerobic digestion. The AD scenario is also not as cost-effective as the semi-automatic OWC despite comparable GHG reductions. Thus, AD with electricity production is more financially viable than only the automatic OWC option (S1).

5.3 Sustainability Implications

The better performance of the batch-type OWC (S3) among all evaluated options may be primarily credited to the relatively larger amount of compost produced. Consequently, composting using the batch-type OWC offers high GHG savings in terms of avoided emissions from chemical fertiliser production and more revenue gained from sale of compost. However, various compost market and other studies (*e.g.* Damodaran, 2011) have found that compost cannot wholly substitute chemical fertilisers in soils deficient in nitrogen, phosphorus, potassium; but does reduce the amount of fertiliser needed, since compost supplements soil organic carbon – Indian soils have low organic carbon levels due to unsustainable agricultural practices. Also, the compost generated from waste streams tends to be given away free or sold at nominal prices. It is quite possible that the actual GHG savings may be lower than those quantified in the GHG-LCA, and all the compost produced might not be sold, thus impeding environmental and economic performance. Hence, the environmental and economic benefits associated with producing the largest amount of compost may not necessarily translate as desired.

Implementation of either composting or anaerobic digestion will achieve the target of improving MIAL's environmental performance but neither alternative is financially better than the current practice of dumping. This is due to the high capital and operating costs of OWC/ digester systems, relative to the baseline of dumping by the waste handling agency. In such cases, financial considerations can override environmental concerns.

5.4 Limitations

The GHG-LCA, CBA and CEA all have inherent methodological limitations. Uncertainty in inflation trends a ten-year time period may substantially impact the results of the economic assessment; also environmental benefits were not monetised. Default values, provided by the IPCC in inventory calculations such as those used in the IGES GHG calculator for the GHG-LCA, are a potential cause of significant overestimations or underestimations of GHG emissions (UNEP, 2010). Inventory models, in any case, are at best close approximations of actual values.

The assessment results rely on careful data collection. Despite a sincere attempt to gather accurate data, most of the OWC and digester suppliers approached were reluctant to give detailed cost estimates and not forthcoming with operating information. Costs of waste collection and transportation were excluded. More refined data, inclusion of costs such as those waste collection and transportation costs, cost of shredder for pre-processing of waste before loading into OWC/ digester, costs for quality testing of compost, could influence the CBA and CEA results.

Increase in the generation rate of food and garden wastes due to airport expansion and growth were not accounted for. It was assumed that a combination of factors like implementation of waste prevention and minimisation activities at CSIA, along with passenger diversion to the upcoming airport in Panvel, Navi Mumbai expected to begin operations from 2017-2020 (City and Industrial Development Corporation of Maharashtra Limited [CIDCO], 2014), will cause food waste generation to remain at constant levels.

5.5 Recommendations

For implementation of two like machines which will handle CSIA's entire food and garden waste stream amenable to biological waste treatment, the difference in the present value of costs over the base case scenarios S2 to S4 is of the order of around ₹ 10 lakh. Given the reasonable trade-off between cost and GHG savings, it is recommended that MIAL install one OWC (batch or semi-automatic type) and one anaerobic digester from the outset, instead of the planned two-stage implementation of two like OWCs. Installation of the digester has the additional possibility of co-digesting with food waste the sludge generated from the two sewage treatment plants on airport premises, which is currently being given away for free (Smita Tapre, personal communication). This also supports MIAL's commitment to sustainability and its intention of achieving zero waste disposal from airport operations (Tapre, 2014).

Further, to improve economic performance, MIAL may study the financial feasibility of tie-ups with other commercial off-site composting facilities or residential

Advanced Locality Management (ALM) programs. The prospect of further segregation at source of food waste generated at terminal and land side food outlets into left-overs and stock surplus streams should be looked into – the surplus may then be diverted, depending on its quality, to feed poor people or used as animal feed, moving a step higher in the food waste hierarchy.

Waste inventory could be periodically conducted for better management of waste streams. Food outlets may be encouraged to use biodegradable containers. The sound waste management practices of CSIA should be publicised on social media and on advertisement screens in terminals to enhance social perception. Passengers may thus be inspired to correctly dispose waste in the proper receptacle of segregated bins already present at terminals, instead of just casually discarding in the bins as observed.

For betterment of sustainability performance, benchmarking against environmental best management practices of other airports, or for comparing the performance of MIAL's composting program once implemented, could be undertaken. Airports already undertaking food waste composting include Philadelphia, San Francisco and Denver International Airports, London Stansted Airport, Hong Kong International Airport; any of these or other airports could be used for benchmarking. Also, the scope of this project was limited to management of food and garden wastes generated at CSIA but it is suggested that the complete waste stream be considered for integrated waste management.

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Appendices

APPENDIX A

OWC/ DIGESTER INFORMATION

Selected specifications of, and allied information about the OWCs and anaerobic digester used for the assessment are presented in Table A.1 below.

Table A.1: OWC/ Digester Particulars (Source: Product information brochures and personal communication with manufacturers/ suppliers)

OWC/ digester→ **Parameter ↓**	**Automatic OWC**	**Semi-automatic OWC**	**Batch-type OWC**	**Anaerobic digester**
Associated scenario	S1	S2	S3	S4
Waste processing capacity	1250 kg/day	1000 kg/day	1000 kg/day	1000 kg/day
Power rating	43kW	8.21kW	5.97 kW	3.73 kW
Volume reduction	~85%	~75%	~60%	~90%
Capital cost	₹ 30 lakhs	₹ 20 lakhs	₹ 15 lakhs	₹ 27 lakhs (with generator)
O&M costs associated with	Labour, electricity	Labour, electricity, composting culture, sawdust absorbent	Labour, electricity, composting culture, sawdust absorbent	Labour, electricity, water, generator maintenance
Key system requirements	Drainage	Sawdust, culture	Curing, sawdust, culture	Water equivalent to waste amount

*O&M = Operation and Maintenance

APPENDIX B

INPUT DATA AND OUTPUT FROM IGES GHG CALCULATOR FOR BASE CASE SCENARIOS

Data inputs to the Version II of the IGES GHG Calculator, and the resultant outputs for base case scenarios are presented below. Table B.1 is associated with scenario S0 (dumping), data for the composting scenarios S1, S2 and S3 are presented in Table B.2, while Table B.3 represents the input and output data for the anaerobic digestion scenario S4.

Table B.1: Inputs and Outputs for S0 Base Case

Category	Inputs		Outputs	
	Description	Value	Description	Value
Transportation	Total amount of waste transported by diesel-fuelled trucks	60 tonnes/month	GHG emissions from waste transportation by diesel-fuelled trucks	5.39 kg of CO_{2e}/tonne of waste
	Total Diesel Fuel consumption for transportation	120 L/month	Total GHG emissions from waste transportation per month	323.41 kg of CO_{2e}/ month
Mix waste land-filling	Total amount of mix waste landfilling	60 tonnes/ month	Emission of CH_4 from organic waste landfilling	41.33 kg of CH_4/tonne
	Type of landfill	Unmanaged-deep (>5m waste)	Direct GHG Emission from mixed waste landfilling/ open dumping	868.00 kg of CO_{2e}/tonne of mix waste
	Composition of landfilling waste	90% food waste 10% garden waste	Total GHG emission from landfilling per month	52080.00 kg of CO_{2e}/ month

Table B.2: Inputs and Outputs for Composting Category of S1, S2, S3 Base Case

Inputs					Outputs				
Description	Value			Unit	Description	Value			Unit
	S1	S2	S3			S1	S2	S3	
Total amount of food waste used for composting	27			Tonnes/ month	GHG emissions from operational activities	139.32	26.59	23.20	kg of CO_{2e}/ tonne of waste
Total amount of garden waste used for composting	3			Tonnes/ month	GHG emissions from waste degradation	177.00			kg of CO_{2e}/ tonne of waste
Total amount of electricity used for operational activities	6450	1230.9	1074.24	kWh/ month	Direct GHG emissions from composting	316.32	203.59	200.20	kg of CO_{2e}/ tonne of waste
Total amount of compost production	4.5	7.5	12	Tonnes/ month	Avoided GHG emissions from chemical fertiliser production	322.70	537.83	860.52	kg of CO_{2e}/ tonne of waste
Percentage of compost use for agricultural and gardening purposes	100			%	Avoided GHG emissions from organic waste landfilling	868.00			kg of CO_{2e}/ tonne of waste
					Net GHG emissions from composting (life cycle perspective)	-874.38	-1202.24	-1528.32	kg of CO_{2e} /tonne of waste
					Total GHG emission from composting per month	-26231.28	-36067.17	-45849.56	kg of CO_{2e}/ month

*Note: Input and output values for Transportation and Mix waste land-filling categories are the same as for S4 in Table B.3 on page 42

Table B.3: Inputs and Outputs for S4 Base Case

Category	Inputs		Outputs	
	Description	Value	Description	Value
Transportation	Total amount of waste transported by diesel-fuelled trucks	60 tonnes/month	GHG emissions from waste transportation by diesel-fuelled trucks	6.34 kg of CO_{2e}/tonne of waste
	Total Diesel Fuel consumption for transportation	141.2 L/month	Total GHG emissions from waste transportation per month	380.55 kg of CO_{2e}/ month
Mix waste land-filling	Total amount of mix waste landfilling	30 tonnes/ month	Emission of CH_4 from organic waste landfilling	41.33 kg of CH_4/tonne
	Type of landfill	Unmanaged-deep (>5m waste)	Direct GHG Emission from mixed waste landfilling/ open dumping	868.00 kg of CO_{2e}/tonne of mix waste
	Composition of landfilling waste	90% food waste 10% garden waste	Total GHG emission from landfilling per month	26040.00 kg of CO_{2e}/ month
Anaerobic Digestion	Total amount of food waste used for AD	27 tonnes/ month	Theoretical estimation of electricity production	633.50 kWh/ month
	Total amount of garden waste used for AD	3 tonnes/ month	GHG emissions from operational activities	12.09 kg of CO_{2e}/tonne of organic waste
	Total amount of electricity used for operational activities	559.5 kWh/ month	GHG emissions through unavoidable leakages	21.00 kg of CO_{2e}/tonne of organic waste
	Approximate water content of the influent	50%	Direct GHG emissions from AD	33.09 kg of CO_{2e}/tonne of organic waste
	The product from AD	Electricity production	Avoided GHG emissions from electricity production	410.51 kg of CO_{2e}/tonne of organic waste
			Avoided GHG emissions from organic waste landfilling	868.00 kg of CO_{2e}/tonne of organic waste
			Net GHG emissions from AD (life cycle perspective)	-1245.42 kg of CO_{2e}/tonne of organic waste
			Total GHG emission from AD per month	-37362.64 kg of CO_{2e}/month

*Note: The input and outputs values for categories Transportation and Mix waste land-filling are the same for S1, S2, S3 Base Case scenarios

APPENDIX C

DATA AND CALCULATIONS FOR CBA AND CEA

Table C.1 represents the monetised costs and benefits used for building cash flows for the economic assessment. Figure C.1 is a screenshot of the cash flows over a ten-year period computed using Microsoft Excel. Figures C.2a to C.2e depict the NPV calculations of the Base Case scenarios and Figure C.3 represents the CE and EC ratio calculations of the Base Case scenarios in Microsoft Excel.

Table C.1: Monetised Costs and Benefits used for building Cash Flows

<table>
<tr><th></th><th></th><th>Scenario →
Description ↓</th><th>S0</th><th>S1</th><th>S2</th><th>S3</th><th>S4</th></tr>
<tr><td rowspan="9">Costs (₹)</td><td rowspan="3">Year 0</td><td>Dumping</td><td colspan="5">900000</td></tr>
<tr><td>Set-up</td><td>-</td><td colspan="4">2400000</td></tr>
<tr><td>Capital</td><td>-</td><td>3000000</td><td>2000000</td><td>1500000</td><td>2700000</td></tr>
<tr><td rowspan="6">Year 1 onwards</td><td>Dumping</td><td>900000</td><td colspan="4">450000</td></tr>
<tr><td>Electricity</td><td>-</td><td>706275</td><td>134849.25</td><td>117668.70</td><td>61265.25</td></tr>
<tr><td>Labour</td><td>-</td><td>120000</td><td>120000</td><td>240000</td><td>240000</td></tr>
<tr><td>(Culture + absorbent)</td><td>-</td><td>-</td><td>250000</td><td>250000</td><td>-</td></tr>
<tr><td>Water</td><td>-</td><td>-</td><td>-</td><td>-</td><td>25550</td></tr>
<tr><td>Maintenance</td><td>-</td><td>-</td><td>-</td><td>-</td><td>2500</td></tr>
<tr><td rowspan="3">Benefits (₹)</td><td>Year 0</td><td colspan="6">-</td></tr>
<tr><td rowspan="2">Year 1 onwards</td><td>Compost</td><td>-</td><td>270000</td><td>450000</td><td>720000</td><td>-</td></tr>
<tr><td>Electricity</td><td>-</td><td>-</td><td>-</td><td>-</td><td>197100</td></tr>
</table>

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
11			Year 0	1	2	3	4	5	6	7	8	9	10		
12	S0		₹900,000.00	₹918,000.00	₹936,360.00	₹955,087.20	₹974,188.94	₹993,672.72	₹1,013,546.18	₹1,033,817.10	₹1,054,493.44	₹1,075,583.31	₹1,097,094.98		
13															
14	S1														
15		Dumping	₹900,000.00	₹450,000.00	₹459,000.00	₹468,180.00	₹477,543.60	₹487,094.47	₹496,836.36	₹506,773.09	₹516,908.55	₹527,246.72	₹537,791.66	Dumping	
16		Set-up	₹2,400,000.00	₹706,275.00	₹741,588.75	₹778,668.19	₹817,601.60	₹858,481.68	₹901,405.76	₹946,476.05	₹993,799.85	₹1,043,489.84	₹1,095,664.34	Electricity	
17		Capital	₹3,000,000.00	₹120,000.00	₹132,000.00	₹145,200.00	₹159,720.00	₹175,692.00	₹193,261.20	₹212,587.32	₹233,846.05	₹257,230.66	₹282,953.72	Labour	
18		cost sum	₹6,300,000.00	₹1,276,275.00	₹1,332,588.75	₹1,392,048.19	₹1,454,865.20	₹1,521,268.15	₹1,591,503.32	₹1,665,836.46	₹1,744,554.45	₹1,827,967.22	₹1,916,409.71	Cost sum	
19			₹0.00	₹270,000.00	₹272,700.00	₹275,427.00	₹278,181.27	₹280,963.08	₹283,772.71	₹286,610.44	₹289,476.55	₹292,371.31	₹295,295.02	Compost	
20															
21	S2														
22		Dumping	₹900,000.00	₹450,000.00	₹459,000.00	₹468,180.00	₹477,543.60	₹487,094.47	₹496,836.36	₹506,773.09	₹516,908.55	₹527,246.72	₹537,791.66	Dumping	
23		Set-up	₹2,400,000.00	₹134,849.25	₹141,591.71	₹148,671.30	₹156,104.86	₹163,910.11	₹172,105.61	₹180,710.89	₹189,746.44	₹199,233.76	₹209,195.45	Electricity	
24		Capital	₹2,000,000.00	₹120,000.00	₹132,000.00	₹145,200.00	₹159,720.00	₹175,692.00	₹193,261.20	₹212,587.32	₹233,846.05	₹257,230.66	₹282,953.72	Labour	
25				₹250,000.00	₹255,000.00	₹260,100.00	₹265,302.00	₹270,608.04	₹276,020.20	₹281,540.60	₹287,171.42	₹292,914.85	₹298,773.14	Operating	
26		cost sum	₹5,300,000.00	₹954,849.25	₹987,591.71	₹1,022,151.30	₹1,058,670.46	₹1,097,304.62	₹1,138,223.37	₹1,181,611.91	₹1,227,672.46	₹1,276,625.98	₹1,328,713.97	cost sum	
27				₹450,000.00	₹454,500.00	₹459,045.00	₹463,635.45	₹468,271.80	₹472,954.52	₹477,684.07	₹482,460.91	₹487,285.52	₹492,158.37	Compost	
28															
29	S3														
30		Dumping	₹900,000.00	₹450,000.00	₹459,000.00	₹468,180.00	₹477,543.60	₹487,094.47	₹496,836.36	₹506,773.09	₹516,908.55	₹527,246.72	₹537,791.66	Dumping	
31		Set-up	₹2,400,000.00	₹117,668.70	₹123,552.14	₹129,729.74	₹136,216.23	₹143,027.04	₹150,178.39	₹157,687.31	₹165,571.68	₹173,850.26	₹182,542.77	Electricity	
32		Capital	₹1,500,000.00	₹240,000.00	₹264,000.00	₹290,400.00	₹319,440.00	₹351,384.00	₹386,522.40	₹425,174.64	₹467,692.10	₹514,461.31	₹565,907.45	Labour	
33				₹250,000.00	₹255,000.00	₹260,100.00	₹265,302.00	₹270,608.04	₹276,020.20	₹281,540.60	₹287,171.42	₹292,914.85	₹298,773.14	Operating	
34		cost sum	₹4,800,000.00	₹1,057,668.70	₹1,101,552.14	₹1,148,409.74	₹1,198,501.83	₹1,252,113.55	₹1,309,557.35	₹1,371,175.65	₹1,437,343.75	₹1,508,473.14	₹1,585,015.02	cost sum	
35				₹720,000.00	₹727,200.00	₹734,472.00	₹741,816.72	₹749,234.89	₹756,727.24	₹764,294.51	₹771,937.45	₹779,656.83	₹787,453.40	Compost	
36															
37	S4														
38		Dumping	₹900,000.00	₹450,000.00	₹459,000.00	₹468,180.00	₹477,543.60	₹487,094.47	₹496,836.36	₹506,773.09	₹516,908.55	₹527,246.72	₹537,791.66	Dumping	
39		Set-up	₹2,400,000.00	₹61,265.25	₹64,328.51	₹67,544.94	₹70,922.19	₹74,468.29	₹78,191.71	₹82,101.29	₹86,206.36	₹90,516.68	₹95,042.51	Electricity	
40		Capital	₹2,500,000.00	₹240,000.00	₹264,000.00	₹290,400.00	₹319,440.00	₹351,384.00	₹386,522.40	₹425,174.64	₹467,692.10	₹514,461.31	₹565,907.45	Labour	
41		Generator	₹200,000.00	₹25,550.00	₹26,061.00	₹26,582.22	₹27,113.86	₹27,656.14	₹28,209.26	₹28,773.45	₹29,348.92	₹29,935.90	₹30,534.62	Water	
42				₹2,500.00	₹2,550.00	₹2,601.00	₹2,653.02	₹2,706.08	₹2,760.20	₹2,815.41	₹2,871.71	₹2,929.15	₹2,987.73	Maintenance	
43		cost sum	₹6,000,000.00	₹779,315.25	₹815,939.51	₹855,308.16	₹897,672.67	₹943,308.99	₹992,519.94	₹1,045,637.88	₹1,103,027.65	₹1,165,089.76	₹1,232,263.96	cost sum	
44				₹197,100.00	₹206,955.00	₹217,302.75	₹228,167.89	₹239,576.28	₹251,555.10	₹264,132.85	₹277,339.49	₹291,206.47	₹305,766.79	Electricity-benefit	

Figure C.1: Cash flows for base case scenarios developed in Microsoft Excel

B21 | f_x | =NPV(B18,G5:G14)+G4

	A	B	C	D	E	F	G	H	I	J
1	CBA: Dumping alternative									
2				Inflated	Inflated	Total Inflated	Total Inflated	Discount	Present Value	Present Value
3	Year	Costs	Benefits	Costs	Benefits	Costs	Benefits	Factor	Inflated Costs	Inflated Benefits
4	0	₹ 900,000.00	₹ 0.00	₹ 900,000.00	₹ 0.00	₹ 900,000.00	₹ -900,000.00	1	₹ 900,000.00	₹ -900,000.00
5	1	₹ 900,000.00	₹ 0.00	₹ 918,000.00	₹ 0.00	₹ 918,000.00	₹ -918,000.00	0.90909091	₹ 834,545.45	₹ -834,545.45
6	2	₹ 900,000.00	₹ 0.00	₹ 936,360.00	₹ 0.00	₹ 936,360.00	₹ -936,360.00	0.82644628	₹ 773,851.24	₹ -773,851.24
7	3	₹ 900,000.00	₹ 0.00	₹ 955,087.20	₹ 0.00	₹ 955,087.20	₹ -955,087.20	0.7513148	₹ 717,571.15	₹ -717,571.15
8	4	₹ 900,000.00	₹ 0.00	₹ 974,188.94	₹ 0.00	₹ 974,188.94	₹ -974,188.94	0.68301346	₹ 665,384.16	₹ -665,384.16
9	5	₹ 900,000.00	₹ 0.00	₹ 993,672.72	₹ 0.00	₹ 993,672.72	₹ -993,672.72	0.62092132	₹ 616,992.58	₹ -616,992.58
10	6	₹ 900,000.00	₹ 0.00	₹ 1,013,546.18	₹ 0.00	₹ 1,013,546.18	₹ -1,013,546.18	0.56447393	₹ 572,120.39	₹ -572,120.39
11	7	₹ 900,000.00	₹ 0.00	₹ 1,033,817.10	₹ 0.00	₹ 1,033,817.10	₹ -1,033,817.10	0.51315812	₹ 530,511.64	₹ -530,511.64
12	8	₹ 900,000.00	₹ 0.00	₹ 1,054,493.44	₹ 0.00	₹ 1,054,493.44	₹ -1,054,493.44	0.46650738	₹ 491,928.97	₹ -491,928.97
13	9	₹ 900,000.00	₹ 0.00	₹ 1,075,583.31	₹ 0.00	₹ 1,075,583.31	₹ -1,075,583.31	0.42409762	₹ 456,152.32	₹ -456,152.32
14	10	₹ 900,000.00	₹ 0.00	₹ 1,097,094.98	₹ 0.00	₹ 1,097,094.98	₹ -1,097,094.98	0.38554329	₹ 422,977.61	₹ -422,977.61
15										
16								NPV	₹ 6,982,035.52	₹ -6,982,035.52
17	Discount									
18	Rate=	10.00%								
19										
20	Shortcut:									
21	NPV=	₹ -6,982,035.52								
22	IRR=	#NUM!								

Figure C.2a: NPV calculation in Microsoft Excel for base case S0 (screenshot)

	A	B	C	D	E	F	G	H	I	J
1	CBA- Automatic OWC alternative									
2				Inflated	Inflated	Total Inflated	Total Inflated	Discount	Present Value	Present Value
3	Year	Costs	Benefits	Costs	Benefits	Costs	Benefits	Factor	Inflated Costs	Inflated Benefits
4	0	₹ 6,300,000.00	₹ 0.00	₹ 6,300,000.00	₹ 0.00	₹ 6,300,000.00	₹ -6,300,000.00	1	₹ 6,300,000.00	₹ -6,300,000.00
5	1	₹ 1,276,275.00	₹ 270,000.00	₹ 1,276,275.00	₹ 270,000.00	₹ 1,006,275.00	₹ -1,006,275.00	0.9090909	₹ 914,795.45	₹ -914,795.45
6	2	₹ 1,276,275.00	₹ 270,000.00	₹ 1,332,588.75	₹ 272,700.00	₹ 1,059,888.75	₹ -1,059,888.75	0.8264463	₹ 875,941.12	₹ -875,941.12
7	3	₹ 1,276,275.00	₹ 270,000.00	₹ 1,392,048.19	₹ 275,427.00	₹ 1,116,621.19	₹ -1,116,621.19	0.7513148	₹ 838,934.03	₹ -838,934.03
8	4	₹ 1,276,275.00	₹ 270,000.00	₹ 1,454,865.20	₹ 278,181.27	₹ 1,176,683.93	₹ -1,176,683.93	0.6830135	₹ 803,690.95	₹ -803,690.95
9	5	₹ 1,276,275.00	₹ 270,000.00	₹ 1,521,268.15	₹ 280,963.08	₹ 1,240,305.07	₹ -1,240,305.07	0.6209213	₹ 770,131.86	₹ -770,131.86
10	6	₹ 1,276,275.00	₹ 270,000.00	₹ 1,591,503.32	₹ 283,772.71	₹ 1,307,730.61	₹ -1,307,730.61	0.5644739	₹ 738,179.84	₹ -738,179.84
11	7	₹ 1,276,275.00	₹ 270,000.00	₹ 1,665,836.46	₹ 286,610.44	₹ 1,379,226.02	₹ -1,379,226.02	0.5131581	₹ 707,761.03	₹ -707,761.03
12	8	₹ 1,276,275.00	₹ 270,000.00	₹ 1,744,554.45	₹ 289,476.55	₹ 1,455,077.91	₹ -1,455,077.91	0.4665074	₹ 678,804.58	₹ -678,804.58
13	9	₹ 1,276,275.00	₹ 270,000.00	₹ 1,827,967.22	₹ 292,371.31	₹ 1,535,595.91	₹ -1,535,595.91	0.4240976	₹ 651,242.57	₹ -651,242.57
14	10	₹ 1,276,275.00	₹ 270,000.00	₹ 1,916,409.71	₹ 295,295.02	₹ 1,621,114.69	₹ -1,621,114.69	0.3855433	₹ 625,009.89	₹ -625,009.89
15										
16								NPV	₹ 13,904,491.32	₹ -13,904,491.32
17	Discount									
18	Rate=	10.00%								

Figure C.2b: NPV calculation in Microsoft Excel for base case S1 (screenshot)

	A	B	C	D	E	F	G	H	I	J
1	CBA: Semiautomatic OWC alternative									
2				Inflated	Inflated	Total Inflated	Total Inflated	Discount	Present Value	Present Value
3	Year	Costs	Benefits	Costs	Benefits	Costs	Benefits	Factor	Inflated Costs	Inflated Benefits
4	0	₹ 5,300,000.00	₹ 0.00	₹ 5,300,000.00	₹ 0.00	₹ 5,300,000.00	₹ -5,300,000.00	1	₹ 5,300,000.00	₹ -5,300,000.00
5	1	₹ 954,849.25	₹ 450,000.00	₹ 954,849.25	₹ 450,000.00	₹ 504,849.25	₹ -504,849.25	0.9090909	₹ 458,953.86	₹ -458,953.86
6	2	₹ 954,849.25	₹ 450,000.00	₹ 987,591.71	₹ 454,500.00	₹ 533,091.71	₹ -533,091.71	0.8264463	₹ 440,571.66	₹ -440,571.66
7	3	₹ 954,849.25	₹ 450,000.00	₹ 1,022,151.30	₹ 459,045.00	₹ 563,106.30	₹ -563,106.30	0.7513148	₹ 423,070.10	₹ -423,070.10
8	4	₹ 954,849.25	₹ 450,000.00	₹ 1,058,670.46	₹ 463,635.45	₹ 595,035.01	₹ -595,035.01	0.6830135	₹ 406,416.92	₹ -406,416.92
9	5	₹ 954,849.25	₹ 450,000.00	₹ 1,097,304.62	₹ 468,271.80	₹ 629,032.81	₹ -629,032.81	0.6209213	₹ 390,579.89	₹ -390,579.89
10	6	₹ 954,849.25	₹ 450,000.00	₹ 1,138,223.37	₹ 472,954.52	₹ 665,268.85	₹ -665,268.85	0.5644739	₹ 375,526.92	₹ -375,526.92
11	7	₹ 954,849.25	₹ 450,000.00	₹ 1,181,611.91	₹ 477,684.07	₹ 703,927.84	₹ -703,927.84	0.5131581	₹ 361,226.28	₹ -361,226.28
12	8	₹ 954,849.25	₹ 450,000.00	₹ 1,227,672.46	₹ 482,460.91	₹ 745,211.55	₹ -745,211.55	0.4665074	₹ 347,646.69	₹ -347,646.69
13	9	₹ 954,849.25	₹ 450,000.00	₹ 1,276,625.98	₹ 487,285.52	₹ 789,340.46	₹ -789,340.46	0.4240976	₹ 334,757.41	₹ -334,757.41
14	10	₹ 954,849.25	₹ 450,000.00	₹ 1,328,713.97	₹ 492,158.37	₹ 836,555.59	₹ -836,555.59	0.3855433	₹ 322,528.40	₹ -322,528.40
15										
16								NPV	₹ 9,161,278.13	₹ -9,161,278.13
17	Discount									
18	Rate=	10.00%								

Figure C.2c: NPV calculation in Microsoft Excel for base case S2 (screenshot)

CBA: Batch OWC alternative

Year	Costs	Benefits	Inflated Costs	Inflated Benefits	Total Inflated Costs	Total Inflated Benefits	Discount Factor	Present Value Inflated Costs	Present Value Inflated Benefits
0	₹4,800,000.00	₹0.00	₹4,800,000.00	₹0.00	₹4,800,000.00	₹-4,800,000.00	1	₹4,800,000.00	₹-4,800,000.00
1	₹1,057,668.70	₹720,000.00	₹1,057,668.70	₹720,000.00	₹337,668.70	₹-337,668.70	0.9090909	₹306,971.55	₹-306,971.55
2	₹1,057,668.70	₹720,000.00	₹1,101,552.14	₹727,200.00	₹374,352.14	₹-374,352.14	0.8264463	₹309,381.93	₹-309,381.93
3	₹1,057,668.70	₹720,000.00	₹1,148,409.74	₹734,472.00	₹413,937.74	₹-413,937.74	0.7513148	₹310,997.55	₹-310,997.55
4	₹1,057,668.70	₹720,000.00	₹1,198,501.83	₹741,816.72	₹456,685.11	₹-456,685.11	0.6830135	₹311,922.07	₹-311,922.07
5	₹1,057,668.70	₹720,000.00	₹1,252,113.55	₹749,234.89	₹502,878.67	₹-502,878.67	0.6209213	₹312,248.09	₹-312,248.09
6	₹1,057,668.70	₹720,000.00	₹1,309,557.35	₹756,727.24	₹552,830.12	₹-552,830.12	0.5644739	₹312,058.19	₹-312,058.19
7	₹1,057,668.70	₹720,000.00	₹1,371,175.65	₹764,294.51	₹606,881.14	₹-606,881.14	0.5131581	₹311,425.98	₹-311,425.98
8	₹1,057,668.70	₹720,000.00	₹1,437,343.75	₹771,937.45	₹665,406.30	₹-665,406.30	0.4665074	₹310,416.95	₹-310,416.95
9	₹1,057,668.70	₹720,000.00	₹1,508,473.14	₹779,656.83	₹728,816.31	₹-728,816.31	0.4240976	₹309,089.26	₹-309,089.26
10	₹1,057,668.70	₹720,000.00	₹1,585,015.02	₹787,453.40	₹797,561.62	₹-797,561.62	0.3855433	₹307,494.53	₹-307,494.53
							NPV	₹7,902,006.10	₹-7,902,006.10

Discount Rate= 10.00%

Figure C.2d: NPV calculation in Microsoft Excel for base case S3 (screenshot)

CBA: Anaerobic digester alternative

Year	Costs	Benefits	Inflated Costs	Inflated Benefits	Total Inflated Costs	Total Inflated Benefits	Discount Factor	Present Value Inflated Costs	Present Value Inflated Benefits
0	₹6,000,000.00	₹0.00	₹6,000,000.00	₹0.00	₹6,000,000.00	₹-6,000,000.00	1	₹6,000,000.00	₹-6,000,000.00
1	₹779,315.25	₹208,050.00	₹779,315.25	₹197,100.00	₹582,215.25	₹-582,215.25	0.909091	₹529,286.59	₹-529,286.59
2	₹779,315.25	₹208,050.00	₹815,939.51	₹206,955.00	₹608,984.51	₹-608,984.51	0.826446	₹503,292.99	₹-503,292.99
3	₹779,315.25	₹208,050.00	₹855,308.16	₹217,302.75	₹638,005.41	₹-638,005.41	0.751315	₹479,342.91	₹-479,342.91
4	₹779,315.25	₹208,050.00	₹897,672.67	₹228,167.89	₹669,504.78	₹-669,504.78	0.683013	₹457,280.77	₹-457,280.77
5	₹779,315.25	₹208,050.00	₹943,308.99	₹239,576.28	₹703,732.71	₹-703,732.71	0.620921	₹436,962.64	₹-436,962.64
6	₹779,315.25	₹208,050.00	₹992,519.94	₹251,555.10	₹740,964.84	₹-740,964.84	0.564474	₹418,255.34	₹-418,255.34
7	₹779,315.25	₹208,050.00	₹1,045,637.88	₹264,132.85	₹781,505.03	₹-781,505.03	0.513158	₹401,035.65	₹-401,035.65
8	₹779,315.25	₹208,050.00	₹1,103,027.65	₹277,339.49	₹825,688.15	₹-825,688.15	0.466507	₹385,189.62	₹-385,189.62
9	₹779,315.25	₹208,050.00	₹1,165,089.76	₹291,206.47	₹873,883.29	₹-873,883.29	0.424098	₹370,611.82	₹-370,611.82
10	₹779,315.25	₹208,050.00	₹1,232,263.96	₹305,766.79	₹926,497.17	₹-926,497.17	0.385543	₹357,204.77	₹-357,204.77
							NPV	₹10,338,463.09	₹-10,338,463.09

Discount Rate= 10.00%

Figure C.2e: NPV calculation in Microsoft Excel for base case S4 (screenshot)

Scenario	Transport excluded Net GHG Emissions $MTCO_{2e}$	Present Value of Inflated Costs ₹	Reduction in GHG emission $MTCO_{2e}$	Average Cost-effectiveness ratio ₹ per $MTCO_{2e}$ reduced	Incremental Cost-effectiveness ratio ₹ per $MTCO_{2e}$ reduced	Present Value of Inflated Costs 100000 ₹	EC ratio $MTCO_{2e}$ reduced per 1 lakh ₹
S0	624.96	₹6,982,035.52	0				
S1	-2.3	₹13,904,491.32	627.26	₹22,167.03	11,036.02	₹139.04	4.51
S2	-120.33	₹9,161,278.13	745.29	₹12,292.23	2,924.02	₹91.61	8.14
S3	-237.71	₹7,902,006.10	862.67	₹9,159.94	1,066.42	₹79.02	10.92
S4	-135.87	₹10,338,463.09	760.83	₹13,588.40	4,411.53	₹103.38	7.36

Figure C.3: Base case average CE and EC ratios calculation in Microsoft Excel (screenshot)