

**Development of a Decision Support  
Tool for Planning Municipal Solid  
Waste Management Systems In  
Muzaffarnagar City (India)**

**A Collaborative Project  
Jointly Conducted by**



**Institute for Data, Systems and Society  
Massachusetts Institute of Technology,**

**USA**

**and**



**Shri Ram College  
Muzaffarnagar, India**

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# MIT (USA) - SRGC Joint Research Project on Municipal Waste Management in Muzaffarnagar City

## Memorandum of Understanding

### Memorandum of Understanding

Between

Massachusetts Institute of Technology, Cambridge, USA (The First Party)

And

Shri Ram Group of Colleges, Muzaffarnagar, (UP), INDIA (The Second Party)

This Memorandum of Understanding (MOU) sets for the terms and understanding between Massachusetts Institute of Technology (MIT), Cambridge, USA and Shri Ram Group of Colleges (SRGC), Muzaffarnagar, (UP), INDIA for Tata Waste Systems Project (2015 – 2017).

Management of waste in an environmentally sustainable manner is a challenging task. Rapid economic growth is leading to urbanization and industrialization generating waste which is adversely affecting the environment. Converting the wastes into some useful product seems to be of utmost importance for the economically, socially and environmentally sustenance.

Therefore, this MOU will be serving the following Goals:

- Enable Muzaffarnagar's transition into a model for the productive management of municipal & industrial waste.
- Create the tools to guide effective design of waste value chains for any Indian context. Demonstrate methods (technologies and operational strategies) to value addition to waste in India.
- Create a living laboratory for waste systems improvement in Muzaffarnagar city.

The above goals will be accomplished by undertaking the following Specific activities:

#### SRGC Side:

SRGC will establish a team comprising of faculty members and students from Bio Sciences, Engineering and Management. First of all, SRGC team will identify the study wards in Muzaffarnagar city and bulk generators with the discussion with MIT team. SRGC team will collect the baseline data for study wards as well as for large generators. Baseline data will be comprising of households demographic and waste audit data. School awareness program will be initiated in some of the selected schools by SRGC team with the discussion with MIT team. SRGC team will start source segregation and composting at SRGC campus. Initial bulk generator and ward level experiments will be done by SRGC team. The viability of biogas or other food waste to energy will be checked by SRGC team with the consultation of MIT team.

#### MIT Side:

MIT team will help in identifying the test wards in Muzaffarnagar city and bulk generators. The complete segregation guide along with waste audit data sheet and demographic questionnaire will be

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provided by MIT team. MIT team with the SRGC team will analyze the baseline data collected by SRGC team. MIT team then will develop an analytical model of system costs and performance. The flow of waste in the city will be analyzed. Small scale installation plan of waste to energy technology like bio gas or other food waste to energy will be provided by MIT team. Specific implementation strategies will also be explored and selected.

**Communication:**

- i. MIT and SRGC team: through Skype call in every two weeks.
- ii. MIT(USA) team shall be visiting SRGC (India) in the fall and summer every year.

**Reporting:**

MIT Principal Investigators: Prof. Randolph Kirchain and Prof. Jeremy Gregory

SRGC Principal Investigators: Dr. Ashwani Kumar and Dr. M. Asif

**Funding:**

Required Fund will be made available by TATA Centre for Technology & Design, through Massachusetts Institute of Technology, Cambridge, USA (The First Party) for purchasing the instruments, consumables/non-consumables items and manpower on demand by Shri Ram Group of Colleges, Muzaffarnagar (The Second Party). The initial budgetary allocation for the Project is \$(US) 24000 for project operation in India by SRGC.

**Duration:**

This MOU shall become effective upon signature by the authorized officials from the Massachusetts Institute of Technology, Cambridge, USA and Shri Ram Group of Colleges, Muzaffarnagar. It will remain in effect until modified or terminated by any one of the partners by mutual consent. In the absence of mutual agreement by the authorized officials from SRGC and MIT, this MOU shall end with the completion of project i.e. upto March 2017. The period may be extended further with mutual consent.

**Partners Information:**

**MIT:**

Prof. Randolph Kirchain and Prof. Jeremy Gregory  
(Principal Research Scientist, TATA Centre for Technology & Design)

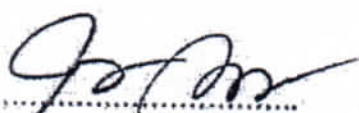
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(Affiliated to CCS University, Meerut & Approved by NCTE)

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Date: 19.01.2015

To,

Dr. Pankaj Kumar, Deptt. of Business Administration &


Dr. Ashwani Kumar, Deptt. of Biosciences

Shri Ram College, Muzaffarnagar

Dear Sir,


We are pleased to inform you that the Project Proposal entitled " **Waste Management System in Muzaffarnagar City**" submitted by you to the Management Committee, which is related to Company/Organisation Massachusetts Institute of Technology, Cambridge, USA has been approved and a amount of **\$(US) 24000** has been sanctioned for the Project in your department.

So, Please take necessary action for timely completion of the project.

  
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## Utilization Certificate

S.N.	Detail of sanction of Fund with Project name and Duration	Amount
1.	730- Day project on Tata Waste System Project, Date of Sanction of Fund- 2015 as per Sanction Letter	1588020.00/-
	<b>TOTAL</b>	<b>1588020.00/-</b>

It is Certified that out of 24000 US \$, Which is approx Rs. 1588020.00/- (Fifteen Lakhs Eighty Eight Thousands Twenty Only) in Indian Currency of grants sanctioned by MIT, USA during the year 2015-16 in favor of Shri Ram College, Muzaffarnagar, a sum of Rs. 1588020.00 has been utilized for the purpose of the project for which it was sanctioned and that the balance of Rs. Nil remaining unutilized at the end of the year has been surrendered. The Extra amount (If any) is met out by Shri Ram College.

2. Certified that we have satisfied our self that the conditions on which the grant was sanctioned have been duly fulfilled/are being fulfilled and that we have exercised the following checks to see that the money was

actually utilized for the purpose for which it was sanctioned.

### Kinds of checks exercise-

1. Checking of cash book
2. Checking of payment vouchers.
3. Checking of salary register.
4. Checking of expense bill.

For Shri Ram College

Secretary

Place: Muzaffarnagar

Date: 15.04.2017

For Goel Rakesh & Co.  
Chartered Accountants

Rakesh Kumar Goel  
Proprietor

M.No. : 071858

FRN : 003374C

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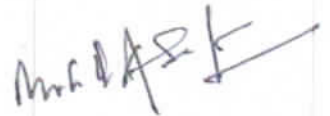
## Acknowledgements

Waste management is a significant challenge for India. The Indian waste landscape is changing rapidly as the population grows, the composition of the waste generated evolves, the extent of waste segmentation changes and the technologies available to collect and process waste improve. Many solutions have been proposed for dealing with the mixed waste but the most appropriate solution for a particular context is difficult to quantify. Thus, decisions are often made without considering the long-term economic, environmental or social consequences.

This project is of utmost important in itself as it studies a burning problem of today's era. It is quite essential to mention here those people without whose efforts it would have been very difficult to happen. First of all, we are grateful to Dr. S.C. Kulshrestha, Chairman, Shri Ram Group of Colleges, Muzaffarnagar, without whose inspiration this project would not have been possible. We are grateful to the skilled team of MIT; Prof. Rudolph Kirchain and Prof. Jermy Gregaory. We are also grateful for the cooperation of Mr. Pankaj Agrawal, Chairman, Municipality, Muzaffarnagar.




(Dr. Ashwani Kumar)



(Dr. M. Asif)

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## Development of a Decision Support Tool for Planning Municipal Solid Waste Management Systems in India

### Abstract

The present work focuses on helping Indian cities improve collection, transportation and treatment of waste by developing a GIS-based decision support tool that assesses the cost effectiveness and efficiency of collection strategies, treatment technologies and system configurations. The tool considers the unique elements of a city including the demographics, waste composition, scale, existing infrastructure for waste collection and treatment and potential for implementing new technologies. Understanding the prevailing waste management architecture of these cities is vital in designing systems which adapt to meet the needs of the growing population with changing aspirations and consumer behavior. There is a lack of bottom-up data on the composition and volumes of waste in India. Our data-driven decision-making approach combines baseline data collection through waste audits with a systems optimization modeling approach. By using the tool to evaluate the economic, environmental and social impact of different technology configurations at varying scales, we are able to quantify the expected performance associated with different architectures. The decision support tool can be used to find the minimum cost waste configuration that considers both environmental GHG emissions and employment, by constructing trade-off graphs between competing goals. A compromise solution that satisfies competing goals is obtained at the turning point of the trade-off graphs.

We also test the feasibility of improving the segregation rate in Muzaffarnagar and the impact segregation policies have on the metrics of the waste system. From the waste audits, we see that Indian households have a high composition of organic waste and waste generation increases with income level. By implementing a weekly feedback social incentive mechanism, we see that the segregation rate of organic waste by households increases to nearly twice than those households that were given no feedback. The tool shows that as the segregation rate of the city increases, the costs and GHG emissions reduce, while the employment of the waste system increases. The level of centralization of the system reduces as the level of segregation of waste increases, that is, the system moves towards smaller scale processing plants instead of large scale centralized plants.

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## Abbreviations

DSS	Decision Support System
DiD	Door to Door
GHG	Greenhouse Gas
GIS	Geographic Information System
ISWM	Integrated Solid Waste Management
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MILP	Mixed Integer Linear Programming
MoEF	Ministry of Environment, Forest and Climate Change
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NGO	Non-Governmental Organization
PAYT	Pay-As-You-Throw
PPP	Public Private Partnership
RDF	Refuse Dried Fuel
RFP	Request for Proposal
SRGC	Shri Ram Group of Colleges
SWMRT	Solid Waste Management Round Table
TPD	Tons Per Day
ULB	Urban Local Body

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# Chapter 1

## Introduction

### 1.1 Problem introduction

Municipal solid waste management (MSWM) is a significant challenge for city authorities in developing countries mainly due to the increasing generation of waste, rapid urbanization, rise in community living standards and the burden posed on the municipal budget as a result of the high costs associated with its management. It is common for municipalities in developing countries to spend 20-50% of their available municipal budget on MSWM and in spite of this expenditure, 30-60% of all urban municipal solid waste (MSW) remains uncollected and often only less than 50% of the population is served (UNEP, 2009).

The Indian waste landscape is changing rapidly as the population grows, the composition of the waste generated evolves, the extent of waste segmentation changes and the technologies available to collect and process waste improve. Municipal waste is rarely segregated at the household level. Some cities collect the mixed non-recyclable waste streams and take them to centralized dumps or incinerators, but these are becoming increasingly unpopular with Indian citizens due to the health and environmental risks for the extensive populations that live near these sites. Some cities have banned waste going to dumps or incinerators due to outcry from citizens living near the sites, even though there is no immediate alternative mechanism for handling the mixed waste.

  
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Many solutions have been proposed for dealing with the mixed waste in India, such as automated segregation and then composting or energy generation with the separate waste streams, but the most appropriate solution for a particular context is difficult to quantify. Thus, decisions are often made without considering the long-term economic or environmental consequences. The end result is a lost opportunity to transform the mixed non-recyclable waste into value in the form of energy or compostable commodities. Source segregation of waste into different streams (organic/food waste, recyclables and inorganic non-recyclable waste) creates a valuable source of input for biogas and composting technologies. However, it requires awareness and behavioral change at the household level.

## 1.2 Thesis objectives

This thesis focuses on helping Indian cities improve collection, transportation and treatment of waste by developing a GIS-based decision support tool. This will enable system designers to identify a waste management system architecture that considers the unique elements of a city including the demographics, waste composition, scale, existing infrastructure for waste collection and treatment, and potential for implementing new technologies. The tools will be generalizable enough to be applied in any city, but the emphasis will be on small to mid-sized cities. We will test the tools using the case of the city of Muzaffarnagar.

This thesis aims to answer the following questions to help Indian cities design a context-specific waste management system:

**What capacities of processing plants, technologies and system configuration make the most sense to deploy, considering multiple constraints and metrics such as cost, environmental impact, space constraints, social impact, etc.?**

In the Indian context, generally city planners and policy makers have multiple objectives when designing a waste management system. These objectives are often

competing and there are trade-offs between multiple objectives. Scenario analysis are done to decide the optimum technology and capacity of processing plants to meet competing objectives. Some of the technologies currently being used in the Indian context include biogas and composting for organic waste and pelletization for inorganic waste.


**In case of a decentralized waste system, what are the optimal locations of the processing centers within city limits?**

A centralized system reduces processing cost due to economies of scale, but transportation costs are increased due to the long travel distances from the waste generation points to the processing center or landfill, generally located at the outskirts of the city. A decentralized system minimizes transportation costs. However, capital investment and unit operation costs are higher because of the increased number of disposal sites that do not achieve economies of scale. Locating the decentralized processing centers at the optimal location in the city involves taking into account the transportation distances between the waste generation points and processing centers.

**How can source segregation of household waste be increased?**

Source segregating waste at the household level into three streams: organic/food waste, recyclables and inorganic non-recyclable waste, increases the quality of the waste going to the various processing technologies. Biogas and composting in India currently involves passing mixed waste through several filters to separate the organic waste, which is then used for processing into biogas and compost respectively. However, separating the organic waste involves extra processing cost and the compost produced from mixed waste is of poorer quality than that produced from source segregated waste. We hypothesize that source segregation of waste reduces processing cost but increases operating costs due to the extra infrastructure and collection trips required for the segregated waste. Also, costs vary depending on the percentage of the city participating in segregation.

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### 1.3 Methodology


In order to develop the tool, we will take the following steps. First, we will gather data about the current baseline performance of the existing waste management system. Then, we will build a tool to model the current and possible system architectures and evaluate the performance of the system. Next, we will test modifications to the waste system by identifying and testing strategies to improve household waste segregation. Finally, we will use the tool combined with data from the field after system modifications to identify, implement and evaluate potential solutions, policies and further modifications to the waste system.

### 1.4 Thesis overview

The structure of this thesis is as follows: Chapter 2 details the current institutional frameworks and stakeholders governing waste management in India. The baseline of waste flows of the current waste system is quantified using a bottom-up data collection approach in Chapter 3, considering Muzaffarnagar as a representative Indian city. Modifications to the current waste system are hypothesized in Chapter 4 and a behavior change mechanism to improve segregation of organic waste at the household level is tested through a pilot study. Chapter 5 focuses on the development of the decision support tool and discusses the applicability of the tool in the Indian context. A literature review of the existing decision support tools is undertaken and system optimization is identified as the modeling approach to be used in development of the decision support tool. The tool is then applied to the city of Muzaffarnagar to evaluate the economic, environmental and social impact of different technology configurations at varying scales and levels of segregation. Finally, Chapter 6 recommends policies and technology options for Muzaffarnagar and other Indian cities and discusses limitations and possible future improvements to the decision support tool.

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## Chapter 2

# Legal and policy framework for waste management in India

Though there are policies governing the handling and processing of MSW in India, there is no clear implementation and monitoring of these policies. In this chapter, we will discuss the existing policies and regulations governing waste management in India, in order to understand the institutional framework within which the decision support tool should operate.

### 2.1 Policies and regulations

The formulation of municipal waste policy and administration is done at the national level by the Ministry of Environment, Forest and Climate Change (MoEF), the Ministry of Urban Development and the Central Pollution Control Board. The Ministry of Environment, Forest and Climate Change is empowered by Environment (Protection) Act, 1986 to provide the regulatory framework for managing municipal solid waste and various other waste types in India. However, the responsibility of funding and monitoring is done at the state government and the urban local bodies (ULBs) level. According to the Indian Constitution, solid waste management is a state subject and included in the 12th Schedule of the Constitution (74th Amendment) Act of 1992. State laws governing the ULBs stipulate MSWM as an obligatory function

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of the municipal governments (Mani and Singh, 2016). ULBs are in charge of the actual service delivery either by itself or through public private partnerships. ULBs are classified into four major categories: municipal corporation, municipality, town area committee and notified area committee. The major policies governing waste management in India are detailed below.

### 2.1.1 Municipal Solid Waste Management Rules, 2000


The first set of rules governing waste management in India were the Municipal Solid Waste Management Rules, 2000. The responsibility for SWM management lies with the respective Urban Local Bodies (ULBs), consisting of municipal corporations, municipalities, nagar panchayats, etc. (collectively referred to as the 'Authorities'). The Municipal Solid Waste (Management and Handling) Rules, 2000, issued by the MoEF, Government of India, under the Environment (Protection) Act, 1986, prescribe the manner in which the Authorities have to undertake collection, segregation, storage, transportation, processing and disposal of the municipal solid waste generated within their jurisdiction under their respective governing legislation.


Compliance with the MSW Rules requires that appropriate systems and infrastructure facilities be put in place to undertake scientific collection, management, processing and disposal of MSW. However, the Authorities are often unable to implement and sustain projects to enable scientific collection, management, processing and disposal of MSW (Annepu, 2012) due to resource and expertise constraints.

### 2.1.2 National Urban Sanitation Policy

The policy was prepared by the Ministry of Urban Development in 2008. The objective of the policy is 'to transform urban India into community-driven, totally sanitized, healthy and livable cities and towns'. The policy stresses upon awareness and behavior change, open defecation free cities and integrating sanitation in all the other aspects of cities (IERI, 2015).

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### 2.1.3 Swachh Bharat Abhiyan

The Swachh Bharat Abhiyan (Mission) was launched in 2014. The main objectives of the mission include elimination of open defecation, eradication of manual scavenging, modern and scientific municipal solid waste management, to effect behavioral change regarding healthy sanitation practices, capacity building for ULBs, and to create enabling conditions for private participation in capital investment and operation and maintenance. One of the overall objectives is to achieve scientific solid waste management in 4041 cities/towns for 306 million people (TERI, 2015).


### 2.1.4 Municipal Solid Waste Rules, 2016

In 2016, the MoEF revised the Solid Waste Management Rules after sixteen years. The applicability of the new rules extended beyond municipal areas and to urban agglomerations, census towns, notified industrial townships, areas under the control of Indian Railways, airports, airbase, port and harbor, defense establishments, special economic zones, State and Central government organizations, places of pilgrims, religious and historical importance.

The Municipal Solid Waste Rules, 2016, has created a provision for making waste processing facilities mandatory in local bodies with a population of 1 million or more within two years. In the case of census towns with a population below 1 million, setting up common, or stand-alone sanitary landfills by, or for all local bodies having 0.5 million or more and for setting up common, or regional sanitary landfills by all local bodies and census towns under 0.5 million will have to be completed in three years. A sanitary landfill is a pit with a protected bottom where trash is buried in layers, compacted (pressed down to make it more solid), and covered. A sanitary landfill can reduce harm from waste that has collected, and is safer than an open dumping site.

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## 2.2 Institutional framework for MSW in India

Figure 2-1 below depicts the institutional framework of municipal solid waste management in India. The two common methods employed by the ULBs are either handling waste management operations on their own or via a private sector player (private waste management company) through a public private partnership (PPP).

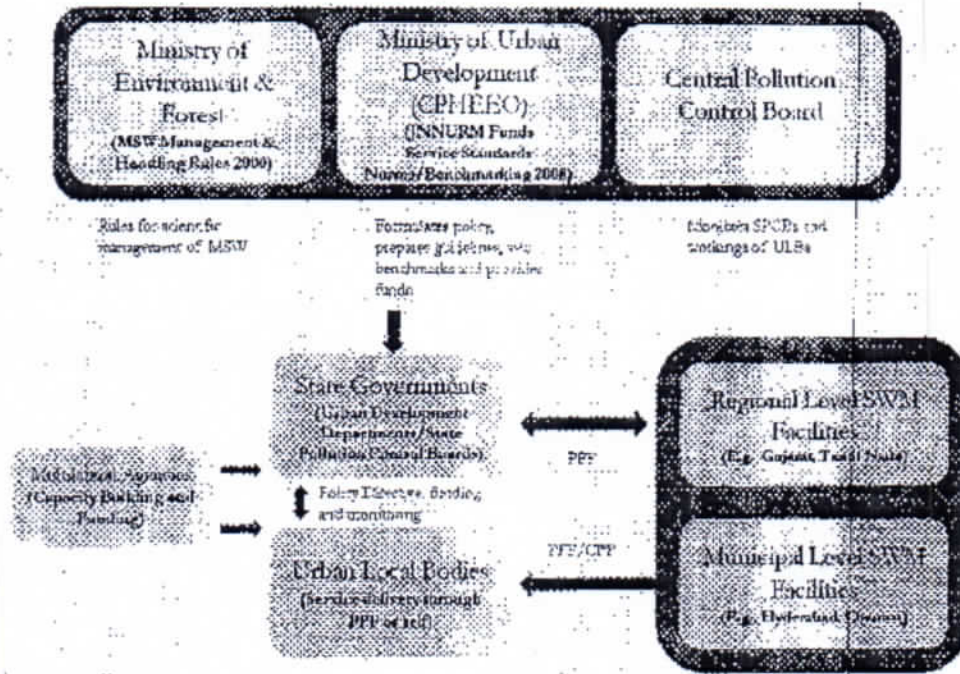


Figure 2-1: Institutional Framework for MSW Management (Athena, 2012) Legend: CPP - Community Participation Partnership, MSW - Municipal Solid Waste, PPP - Public Private Partnership, SPCB - State Pollution Control Board, SWM - Solid Waste Management, ULB - Urban Local Body

### 2.2.1 Urban local bodies

The responsibility for SWM management lies with the respective urban local bodies (ULBs), consisting of municipal corporations, municipalities, nagar panchayats, etc.

With the implementation of the SWM Rules, 2016, more emphasis has been placed by the Indian government in making sure that household waste is processed or dis-

posed of in a sanitary landfill. There are around 3000 urban local bodies in charge of waste management.

### **Limitations**

Many of the urban local bodies do not have the expertise or the resources to handle SWM as stipulated in the SWM Rules, 2016. This has resulted in many of the ULBs outsourcing their waste management operations to private waste companies.

### **2.2.2 Private waste management companies**

In India, national legislation governs the management of waste by local bodies. While the public policy is passed by the national government, it is the responsibility of the local governments to ensure compliance with the legislation. As a result of these stringency of the national legislation, many municipalities are partnering the private waste management companies via PPP. The private waste companies are hired after a competitive request for proposal (RFP) process where the companies submit blind bids for cost estimates.

There are about 20 private waste management companies in India. Some of them include: A2Z Infrastructure, Mumbai based Essel Infraprojects, Mumbai based Hanjer Biotech, Jindal group's JITF Urban Infrastructure, Ramky Enviro Engineering Limited, Switzerland based Satarem Enterprises, UAE based Trimex, Delhi based Unity Infraprojects Limited and Mumbai based UPL Environmental Engineering Limited. The market is highly fragmented with a large number of players.

### **Limitations**

The private waste companies are paid according to the tons of waste they collect daily as per their public private partnership contracts. There is a possibility that a given company may try to manipulate the amount of waste collected to garner higher revenue. Contracts need to be negotiated in a manner that creates incentives for the private waste management companies to collect waste and process it in a



scientific manner. An additional concern is that when private companies take over waste management they displace the municipal government employees whom the city was previously paying for waste collection. This could cause social unrest as the workers protest the introduction of operations by the private waste company. The private companies should be encouraged by the municipal corporations to find ways to integrate the existing waste workers into the private waste company's operations.

### 2.3 Informal sector

The formal sector in waste management in India is used to describe the activities carried by workers with wage employment of a permanent nature, either with the government or in the private waste management companies. The formal sector is governed by the various waste management rules and legislation passed by the Government of India.

The informal sector is defined as unorganized or informal workers lacking employment, work or social security. The informal sector operates outside the legal framework and is often prevalent in developing countries. Most of the recyclable waste is collected by the informal recycling sector in India before it is collected by the formal system. Some estimates indicate that the informal sector recycles 20.7% of recyclables from the formal system (Annepu, 2012). The informal sector includes wastepickers, rag pickers, kabadiwallas, itinerant waste buyers and junk-sellers. Efforts have been made by the state governments and non-governmental organizations (NGOs) to integrate the informal workers into the formal system, however there is no national policy governing the informal sector.

### 2.4 Summary

As seen from the examination of the current waste policies and the institutional framework of waste management in India, handling waste is largely the responsibility of the municipal government. It is becoming more common for the municipal government

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to outsource its waste handling to a private waste management company through a public private partnership. There is also a large informal sector that operates outside the legal framework, separate from the private waste management company. These stakeholders need to be considered while developing the decision support tool. In the next chapter, we will discuss the various stakeholders and existing policies in Muzaffarnagar, a representative Indian city, and then calculate the baseline of current waste flows in the city.

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## Chapter 3

# Muzaffarnagar as a representative Indian city

To investigate the quantitative and qualitative aspects of waste management in India, we chose the city of Muzaffarnagar. It is located in the state of Uttar Pradesh, in Northern India. In this chapter, we will investigate the current waste system in Muzaffarnagar by collecting waste generation data through waste audits and surveys. Using the data collected, we will construct the current baseline of waste flows. The baseline of waste flows will be used in Chapter 4 to test segregation policies and in Chapter 5 to develop the decision support tool.

### 3.1 Motivation for studying Muzaffarnagar

Muzaffarnagar is justified as a representative Indian city in the case study for a number of reasons. Muzaffarnagar is located about 125 kilometers north-east of the national capital, Delhi in the Indian state of Uttar Pradesh. It has a population of 392,768 and 68,975 house-holds as per the 2011 census, with a decadal growth rate of 18.42% (Office of the Registrar General and Census Commissioner, India, 2014). As per the 2011 census, there were 497 cities in India that represent 19% of India's population. A city is defined as having a population of more than 100,000 people. 90.5% of Indian cities (350 cities) have populations between 100,000 people and one

million people. 108.3 million people live within the boundaries of these 350 cities, comprising 48% of India's total urban population (Office of the Registrar General and Census Commissioner, India, 2014). While a number of studies have been conducted studying the waste generated from million-plus urban agglomerations in India, data on waste generation studies from these smaller cities is scarce.

Muzaffarnagar is an important industrial city with sugar, steel and paper being the major industries. More than 40% of the region's population is engaged in agriculture (Office of the Registrar General and Census Commissioner, India, 2014). According to the World Bank, 51% of India's population is engaged in agricultural activity, which is defined as individuals dependent on agriculture, hunting, fishing, and forestry for their livelihood (World Bank, 2010). Muzaffarnagar is an accurate representation of the labor composition of India due to the similar proportions of population engaged in agriculture.

The Tata Center and the city of Muzaffarnagar have a long relationship, as the mayor of Muzaffarnagar, Mr. Pankaj Aggarwal, has hosted projects from MIT in the past. Support extended by the local municipal government is crucial in obtaining data, conducting studies and testing policies in the city.

## 3.2 Muzaffarnagar's waste system

### 3.2.1 City-specific waste policy

Under the national Solid Waste Management (SWM) Rules, 2016, the District Magistrate or the Deputy Commissioner of the concerned district shall have the overall responsibility for the enforcement of the provisions of the SWM rules within the territorial limits of their jurisdiction (Government of India, 2016). The Muzaffarnagar municipality does not have any separate waste policy governing waste collection or waste segregation for households and large waste generators.

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### 3.2.2 Background

Until 2010, the Muzaffarnagar municipal waste workers collected waste from households and dumped the waste in a large dumping ground. None of the waste was processed or treated. In 2010, the Muzaffarnagar Municipal Corporation signed a ten year contract with A2Z Infrastructure Limited, a private Indian company, to meet Muzaffarnagar's waste needs. The contract covered collection, transportation, processing and treatment of waste as an integrated waste management system. Households were charged a new fee of Rs. 30 for door-to-door collection. As per the contract, the Muzaffarnagar municipality would pay A2Z a tipping fee per ton of waste collected.

A2Z constructed a waste processing facility at the outskirts of the city, which passes the waste through a series of filters in order to either be composted at the 120 ton capacity composting plant or made into refuse dried fuel (RDF). The remaining waste after being passed through filters and processed would be landfilled.

### 3.2.3 Logistics

Around 180 door-to-door A2Z waste workers collect waste from approximately 65,000 households in Muzaffarnagar. Though households were expected to separate their organic and inorganic waste at the household level, this was not strictly enforced and the waste was collected unsegregated. The waste workers collect the waste in cycle carts and then dump the collected waste in one of the 45 collection points located throughout the city. Then, A2Z dumpers (each of 7-8 ton capacity) collect the waste from the collection points and transport it to the waste processing facility. Municipal workers also participate in the waste system collection by street sweeping - they also dump the waste at the 45 collection points located throughout the city. A2Z also collects waste door-to-door from commercial establishments in the city. However, large generators such as restaurants and hotel primarily dump their waste directly at the collection points instead of utilizing the door-to-door collection service.

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### 3.2.4 Stakeholder analysis

The major stakeholders in the municipal solid waste management system in Muzaffarnagar include:

1. The Muzaffarnagar municipality, the local municipal government along with the mayor, Mr. Pankaj Aggarwal
2. A2Z Infrastructure Limited, the private waste collection organization, contracted by the municipality for a period of ten years (till 2021)
3. Households, who generate waste to be collected by A2Z
4. Large or bulk generators, such as hotels, malls, marriage halls, etc., which generate large amounts of municipal solid waste
5. Kabadiwalas, informal waste collectors who collect recyclables from households
6. Private sweepers, employed on an ad-hoc basis by households to sweep and clean households

The below Figure 3-1 shows how the stakeholders interact with one another:

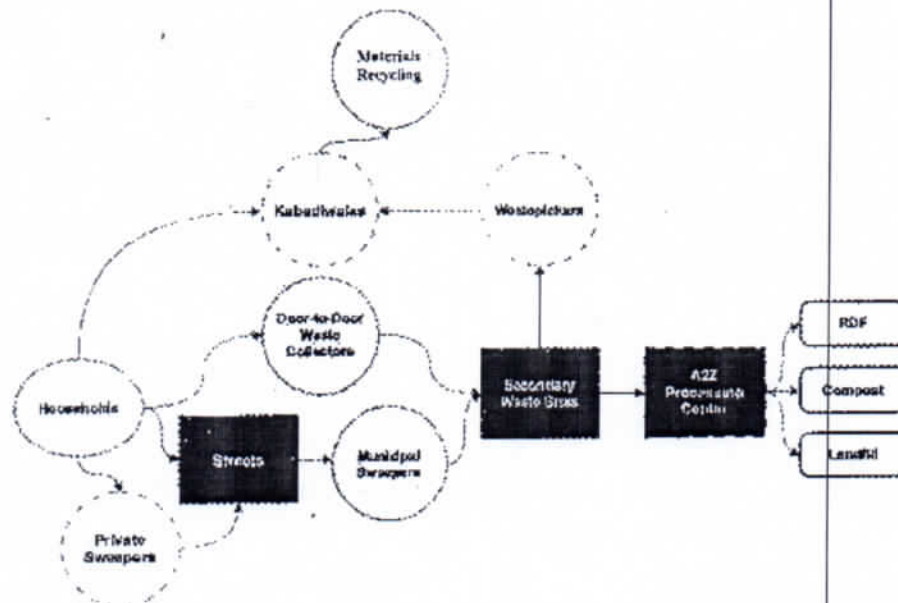


Figure 3-1: Institutional structure of the Muzaffarnagar waste system (Danck, 2015)

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## Muzaffarnagar Municipality

Currently the municipality spends 35% of its total municipal budget on the waste management system. 30% of the budget is used to pay the municipal workers involved in street sweeping while the remaining 5% of the budget covers the municipal tipping fee payment to A2Z. The municipality is responsible for waste management and it pays A2Z, the private waste company, to collect the waste. Currently, the municipality is realizing huge financial losses in supporting the existing waste management system. The municipality could enact a policy such as a waste tax or mandatory household waste separation, to reduce its financial burden. However, if the measures are too stringent, this could have political ramifications for the mayor. The local government has a high degree of influence on the waste system since interventions to improve household waste segregation and adoption of appropriate waste to energy technologies are possible only with the cooperation of the local government.

## A2Z Infrastructure Limited

A2Z Infrastructure Limited is a large Indian waste management company. As of 2014, A2Z had contracts with 24 Indian cities to develop and run their MSWM systems. A2Z is mandated by their contract to collect waste in Muzaffarnagar till 2021 and therefore has a monopoly on the control of the operations of collection, transportation and processing of waste in Muzaffarnagar. A2Z has three revenue streams: tipping fees paid by the municipal government, revenue generated from the sale of compost and revenue generated from the sale of RDF. A2Z is currently realizing a financial loss on the waste management operations in Muzaffarnagar. As per their contract, they are allowed to keep whatever profit they make from selling the waste products. However since the households do not give segregated waste, A2Z spends substantial resources separating the waste to make compost and RDF. Also, there have been disputes between A2Z and the municipality regarding payment of the tipping fees.

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## Households

The households pay a tipping fee to A2Z (\$0.50 per month) for their waste management services. However, some of the households do not use the service and dump their waste in unmarked dumping sites. All the households need to use A2Z's system for minimum revenue. Though the current waste management system is beneficial to the households as the cost of collection is relatively low, indiscriminate dumping could eventually lead to negative health conditions. Cooperation of households is required to make A2Z's operations profitable and the system efficient. Currently households do not segregate their waste but measures such as mandatory segregation of waste at the household level would allow the waste system to operate more efficiently.

## Large or bulk generators

Large or bulk generators are restaurants, hotels, malls, marriage halls, etc., which generate large amounts of municipal solid waste. Currently, the large generators are the major beneficiaries of a poor waste management system as they dump their waste without extra fees. Most of the bulk generators are not covered by A2Z and they typically dump their waste on the street. Bulk generators, if brought under A2Z's coverage, will have to pay more fees and hence would oppose any restricting regulations. The waste from the bulk generators is predominately food waste, they can play a central role in city-level composting efforts if they directly give segregated food waste to A2Z.

## Kabadiwalas

Kabadiwalas are the informal waste collectors who buy recyclables from households. The recyclables are directly collected from the household and A2Z does not receive a share of the profits since they are removed from the waste stream before reaching A2Z. Households are incentivized to segregate their recyclables as they are paid by the kabadiwalas for them. In turn, the kabadiwalas sell the households bought from the households to large wholesale recyclers.

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## Private sweepers

Private sweepers are employed on an ad-hoc basis by households to sweep and clean households. Many of the private sweepers were employed as municipal waste workers before A2Z was contracted and they opposed the introduction of A2Z in Muzaffarnagar. The private sweepers are paid to clear waste from the households but often dump the waste on the streets, instead of dumping trash in A2Z's 45 designated collection points.

### 3.2.5 Key issues in Muzaffarnagar's waste system

There are several issues in Muzaffarnagar's waste system, affecting the stakeholders involved. Not all households are being served by A2Z and collection is restricted to those households located near the 45 collection points. As a result, there is waste on the streets since some households and bulk generators dump waste instead of using A2Z's services. Lack of segregation by households forces A2Z to pass the waste through a series of filters, which increases time for processing, electricity usage and costs. The waste system as a whole is financially unsustainable. The municipality spends a substantial portion of its budget on paying fees to A2Z and the municipal waste workers. Several households do not pay collection fees and bulk generators do not pay at all as they dump waste instead of using A2Z's services. A2Z also has a limited downstream market for non-recyclable by-products such as compost and RDF. This is due to multiple reasons such as lack of education of downstream customers and also lack of consistent quality of these products. These issues, coupled with a lack of information on the waste system performance, makes improvements to the waste system a difficult challenge.

## 3.3 Baseline of the waste system flows

A2Z collects data on a daily basis on the amount of waste collected from the city. However, there is a lack of bottom-up data about the quantity and composition of

  
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waste generated by the various sources of waste in the city. There is also a lack of data on the destinations of the generated waste. Data on the composition and quantity of waste generated at the municipal level is crucial in order to plan the waste system with the appropriate collection strategies, treatment technologies and system configurations. Though the new Solid Waste Management Rules 2016 stipulate that local bodies should submit annual reports to the State Population Control Board (Government of India, 2016), currently most local bodies do not collect detailed data on the waste system. In order to collect bottom-up data on Muzaffarnagar's waste system, a variety of methods and data sources were used such as census data, waste audits and surveys.

### 3.3.1 Approach


In order to calculate the baseline of waste flows in Muzaffarnagar, we used primary and secondary sources of data to estimate the waste generation of the various waste sources and the destinations of waste. First, the waste sources and destinations were identified by interviewing the A2Z management. Then, the quantification and composition of waste from the various waste sources was completed by conducting sample waste audits and surveys. This data was then scaled up to the entire city using demographic data obtained from the 2011 census. The quantification of waste at the destinations of waste was completed using data from the A2Z management. Using the data obtained from the census, income data, waste audits, bulk generator surveys, household surveys and informal sector surveys, we are able to quantify the baseline of daily waste flows in Muzaffarnagar. This baseline can then be used as input for the development of the decision support tool.

### 3.3.2 Feasibility of the approach

Several baseline data collection and behavior change pilot implementation steps have been carried out with the help of the faculty and students of the Shri Ram College (SRC). This involvement of faculties and students was necessary due to the limited

  
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time available for field visits. The combination of field visits and study conducted allows the implementation of system-level modifications throughout the year.

### 3.3.3 Methods of data collection

#### Census data

In order to collect information about the demographics and population of Muzaffarnagar, we used data from the 2011 census. Population per ward was obtained from the census. Data from the census was also used to enumerate the number of commercial establishments, restaurants, hotels, etc. in Muzaffarnagar.

#### Income data

Since the census of India does not capture the income data of households, we used the circle rate data from the municipality as a proxy to estimate the income level of households in a region. Circle rates are a measure of the property values per square kilometer in a neighborhood.

#### Waste audits

In order to estimate the quantity and composition of waste generated by households, waste audits were conducted in select neighborhoods.


#### Bulk generator surveys


In order to estimate the quantity of waste generated by bulk generators, surveys of selected bulk generators were conducted. Bulk generator audits were not conducted due to limitations on the resources and time of the SRGC team.

#### Household surveys

Household surveys were conducted to supplement the waste audit data, in order to quantify the number of people per household and thereby calculate the per capita

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waste generation.

### **Informal sector surveys**

Surveys were conducted with the informal sector of door-to-door kabadiwalas, aggregators and wholesale recyclers, in order to quantify the recyclable waste collected outside of A2Z's operations.

### **3.3.4 Procedure**


#### **Household waste audits**

The aim of conducting waste audits was to understand the composition and quantity of household waste streams in Muzaffarnagar and compare differences based on income level.

Six neighborhoods of 30 households each were selected. Two higher income neighborhoods (New Mandi and Gaushala Road), two middle income neighborhoods (Gandhi Colony and Teachers Colony) and two lower income neighborhoods (Qidwai Nagar and Kashi Ram Awas) were identified using circle rate data from the municipality and interviews with the mayor and the SRGC research team. However on further comparison of Muzaffarnagar circle rate data with circle rate data collected from Pune (99acres, 2016), we see that there is not much distinction in income levels between the middle and higher income neighborhoods in Muzaffarnagar. Hence, we removed the higher income neighborhoods from the audit and referred to the middle income neighborhoods as upper income neighborhoods.

Waste was collected from these six neighborhoods over a period of eight weeks spanning from October to December 2015. Waste was collected once a week, usually on the same day of the week, in a large gunny bag by the A2Z collector. The waste bag was then handed over to SRGC. Once the waste was handed over to SRGC, it was taken to a sorting room at SRGC campus. With the help of two trained waste pickers, the waste was sorted into 32 categories as mentioned in the waste audit sheet (Appendix A). Once the waste was sorted, it was weighed and noted down according

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to category. The waste was then averaged over the eight weeks for each category.

### **Bulk generator surveys**

Select bulk generators from each of the generation categories including hotels, restaurants, banquet halls, cinema halls and shopping malls, were selected as survey recipients. Ten representative bulk generators of varying scales were selected from each category. Surveys were conducted in order to quantify the daily customer footfall and waste generation (Appendix F). This data was then used to estimate the annual waste generation according to bulk generator category. The number of bulk generators in each category was identified from city-wide surveys as well as census data. The data was then scaled up by using the sample survey data for the entire city.


### **Household surveys**

Household surveys (Appendix B) were conducted in the six neighborhoods where the waste audits were conducted. The surveys were conducted door-to-door to collect demographic information about the number of inhabitants per household, in order to calculate the per capita waste generation from the waste audit data.

### **Informal sector surveys**

Surveys of the door-to-door kabadiwalas, aggregators and wholesale recyclers (Appendix C) were conducted in order to identify the neighborhoods in which they operate as well as the composition, value and quantity of waste collected on a monthly basis. The informal sector workers to be surveyed and their locations were identified based on interviews with the households as well as commercial establishments in the area. Fifteen informal sector workers were surveyed in total, five door-to-door kabadiwalas, five aggregators and five wholesale recyclers.

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### 3.3.5 Results

#### Household waste audit results

As shown in Figure 3-2, we see that the majority of household waste is organic and also the waste generation increases with increase in income. The lower income per capita waste generation is 132 grams/person whereas the upper income waste generation is 201 grams/person.

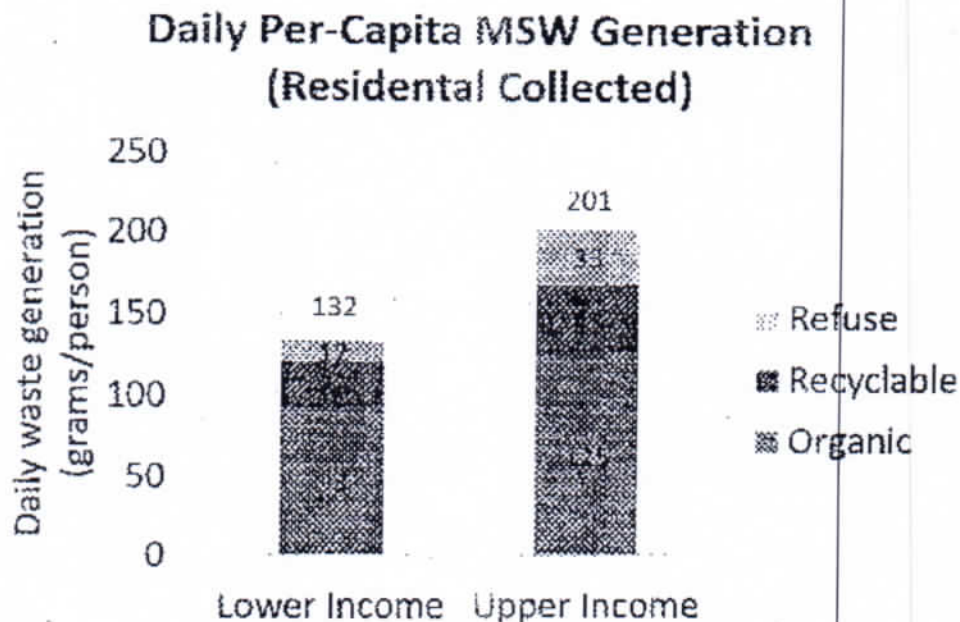


Figure 3-2: Daily per-capita generation of organic, recyclable and refuse material

Using the circle rate and census data, we can classify the percentage of the population in the lower income (41%) and higher income (59%) income groups. This data is then used to calculate the composition of waste for the entire population of Muzaffarnagar. As shown in Figure 3-3, we see that there is a high fraction of organic waste; nearly two-thirds of the total waste is organic. Also plastic forms the largest recyclable fraction at 9% of the total waste, followed by paper at 6% of the total waste. Other recyclables such as glass and metal are negligible. However, this composition represents the waste collected from households by 12%. Since households

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also give their recyclable waste directly to door-to-door kabadiwalas, the portion of recyclables in the actual household waste may be underrepresented.

### Composition of Residential Municipal Solid Waste

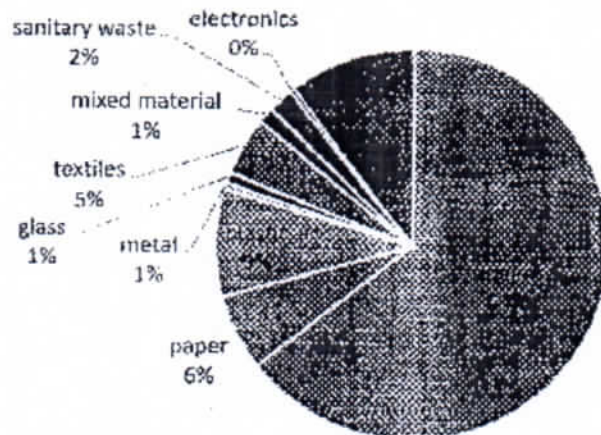



Figure 3-3: Composition of residential municipal solid waste


The higher organic fraction in municipal solid waste is similar to studies conducted in other Indian cities (Perlman, 2015). Studies on the composition of municipal solid waste in the USA show that 37% of the municipal solid waste is organic (U.S. EPA, 2014). Appropriate technologies should be considered to utilize the large percentage of organic waste in the Indian household waste stream.

#### Bulk generator survey results

The bulk generators were classified as large, medium and small based on number of daily customers. From the surveys, we estimate that large bulk generators generate 70 kg of waste per day, medium bulk generators generate 25 kg of waste per day and small bulk generators generate 10 kg of waste per day. The number of bulk generators in each category is identified from city-wide surveys as well as census data.

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### Household survey results

From the household surveys, the number of people per household in the upper and lower income neighborhoods was identified. In the upper income group, the average number of people per household was 5.6 whereas in the lower income group, the average number of people per household was 6.3. The average number of people per household was used in combination with the data of total waste generated from the waste audits, in order to calculate the per capita waste generation per neighborhood.

### Informal sector survey results

Surveys of the door-to-door kabadiwalas, aggregators and wholesale recyclers were used to obtain information about the quantity of recyclables going to the informal sector, which were not passing through A2Z's waste streams. From surveys, we see that in Muzaffarnagar, there are 500-600 door-to-door kabadiwalas, 150 aggregators and 50-60 wholesale recyclers. The door-to-door kabadiwalas collect 1-2 tons per month of recyclables. The aggregators collect around 10 tons per month of recyclables, whereas the wholesale recyclers collect around 25 ton/month of recyclables.

### 3.3.6 Quantification of waste flows

Using the data obtained from the census, income data, waste audits, bulk generator surveys, household surveys and informal sector surveys, we are able to quantify the daily waste flows in Muzaffarnagar. The sources of waste include: households (residential), commercial establishments, bulk generators, and street sweeping. The destinations of waste include the kabadiwalas and A2Z. At A2Z, the waste destinations are the two by-products: compost and RDF, landfill and moisture loss from composting. Muzaffarnagar's waste flows can be represented using a Sankey diagram, which we will describe in Figure 3-4 below.

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### Sources of waste

1. The current 2017 population of Muzaffarnagar is calculated taking the 2011 census data and using a yearly population growth rate of 1.5% based on historical growth.
2. Using the waste audit data and income data, the waste generated by households that is collected by A2Z is calculated as 69.44 ton/day.
3. Considering the informal sector and assuming that there are 550 door-to-door kabadiwalas collecting 1.5 tons of waste monthly, the amount of waste collected by the kabadiwalas daily is 27.5 ton/day.
4. Using the data gathered from the bulk generator surveys, we estimate that the bulk generators produce 2.6 ton of waste daily.
5. There were 24,114 commercial establishments in Muzaffarnagar as per the 2011 census (Office of the Registrar General and Census Commissioner, India, 2014). Assuming that the commercial establishments grow at a rate proportional to the growth in households and assuming that each establishment generates 1 kg of waste per day, the amount of waste generated is 25 tons/day.
6. Finally, as gathered from interviews with A2Z workers, 75% of the total waste is collected by the A2Z workers whereas 25% of the total waste is collected by the municipal workers. From this estimate, we calculate that waste from street sweeping is 34.02 tons/day.

### Destinations of waste

Based on data collected by A2Z on their waste processes and interviews with A2Z management, we estimate that of the total waste going to A2Z, 15% of the waste goes to the landfill, 18% is made into compost, 28% is made into RDF and 39% is lost due to moisture loss.

Muzaffarnagar's waste flows can be represented using a Sankey diagram as shown in Figure 3-4. The height of the bars corresponds to the amount of waste. The black

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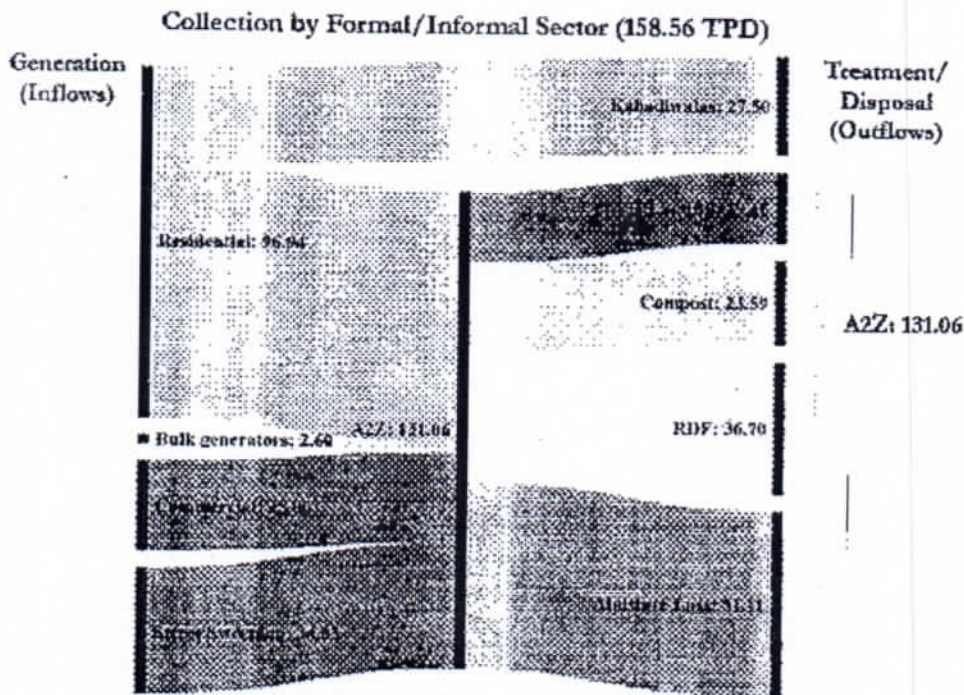


Figure 3-4: Sankey diagram representing city-wide waste quantification using surveys and census data

bars represent the nodes - the nodes on the far left represent the waste generation (inflows) and the nodes on the far right represent the waste treatment or disposal (outflows). The nodes in the center represent the collection by the informal sector or A2Z (the formal sector).

### 3.3.7 Applicability of data collection methods to other cities in India

In some cities such as Pune, the Municipal Corporation collects detailed annual data on the amount of waste generated by various sources and the waste processing destinations of the waste. However in Muzaffarnagar, we have quantified the waste flows based on data collection methods such as surveys, census and income data, which can be easily replicated in other cities in India.

  
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Now that the current baseline of waste flows has been constructed using the data collected, we will use this data in the following chapters. The baseline of waste flows will be used in Chapter 4 to test segregation policies and in Chapter 5 to develop the decision support tool.

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## Chapter 4

# Changing organic waste separation behavior


In developing countries such as India, organic waste forms a large fraction of the total waste generated by households. Sources of organic waste include food scraps, yard waste, wood and process residues. Unlike recyclables, organic waste is typically not separated by households and is mixed with other types of waste when collected.

This section lists the motivations for collecting separated organic waste, along with an overview of previous studies conducted to increase organic waste separation behavior at the source by households. Using the understanding gathered from literature, a pilot study was conducted to test household behavior change mechanisms. The results of this study and its applicability on a larger scale are also discussed.


### 4.1 Motivations for separating organic waste

#### 4.1.1 Waste composition

The composition of waste is influenced by many factors, including the level of economic development, food habits, cultural norms, geographical location, energy sources, and climate. As a country urbanizes and populations become wealthier, consumption of inorganic materials (such as plastics, paper, and aluminum) increases, while the

  
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relative organic fraction decreases (Hoorncweg and Bhada-Tata, 2012). Generally, low and middle-income countries have a high percentage of organic matter in the urban waste stream, ranging from 40 to 85% of the total. In India, the household organic waste fraction varies from 40 to 60%, with the organic fraction roughly inversely dependent on the population of the city (Kumar et al., 2009). This high proportion of organic waste is ideal for being utilized by waste processing technologies to extract valuable end products.

#### 4.1.2 Waste technologies

The available waste processing technologies used in India can be broadly divided into two categories: biological treatment and thermal treatment. Biological treatment includes aerobic composting, vermi composting and anaerobic digestion. Thermal treatment includes incineration, production of refuse dried fuel (RDF), pyrolysis and organic pelletization. In the biological treatment process, the biodegradable organic portion of waste is broken down by micro-organisms into gaseous products (carbon dioxide, methane gas, etc.) and water molecules leaving behind carbon rich byproduct called compost (CPCB, 2016). In order for biological treatment of the waste to be effective, the organic waste first needs to be separated from the mixed waste. This can be done either manually by the waste collectors or mechanically by passing the waste through a series of filters. Passing the mixed waste through filters involves additional electricity usage and costs, which is a burden at the waste processing plants due to unreliable electricity. There is a potential time and cost savings for the usage of these technologies if the waste is source separated by households.

#### 4.1.3 Waste workers

Waste workers are an alternative to separating the organic waste mechanically. During collection from households, the waste workers can manually separate the household waste in various categories. However, this poses health and safety risks to the workers exposed to unhygienic and toxic waste.

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#### 4.1.4 Waste toxicity

In unsegregated waste, the organic waste is contaminated by other fractions of the municipal waste stream. In the case of composting, the quality of the final compost is dependent on the uncontaminated quality of the input organic waste. In order to ensure sale, the compost should be safe to use as well as meet certain quality standards. Studies on heavy metal concentrations in different municipal solid waste compost demonstrate that source separated municipal waste produces a higher quality end product compared to non-source separated municipal solid waste (World Bank, 1997).

#### 4.1.5 Waste emissions


Unsegregated waste is sent to landfills if there is not a proper mechanism to process it. Organic waste in landfills undergoes anaerobic decomposition which produces methane, a harmful greenhouse gas. In some countries, regulators require landfill operators to control methane emissions by installing gas collection systems, however, this is largely absent in India. Globally, landfills are the third largest anthropogenic source of methane, accounting for approximately 11% of estimated global methane emissions in 2010 (U.S. EPA, 2011).

#### 4.1.6 Waste policy

In the Solid Waste Management Rules passed by the Government of India in 2016, waste generators should segregate and store the waste generated in three separate streams namely biodegradable, non biodegradable and domestic hazardous wastes in suitable bins and handover segregated wastes to authorized waste collectors as per the direction or notification by the local authorities from time to time (Government of India, 2016).

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## 4.2 Literature review

Several studies have investigated mechanisms and incentives to affect household waste separation behavior. Most of these studies focused on separation of recyclables, which have a market defined resale value. In England, a study was conducted to compare three behavior change based approaches, which all aimed to increase participation in the recycling collection scheme and to reduce inclusion of non-targeted materials (contamination) (Timlett and Williams, 2008). Three approaches - one doorstepping-based (door-to-door awareness), one incentives-based (reward vouchers) and one delivering personalized feedback to residents, were carried out. The findings showed that personalized incentives and feedback were highly effective at reducing contamination. Both methods resulted in a halving of the number of households setting out contaminants on collection day. The feedback approach was considerably more cost-effective than the other two approaches. In another study based in Italy, researchers examined whether combining non-monetary and monetary incentives increases municipal solid waste recyclable sorting (Buccioli et al., 2015). They investigated door to door (DiD) collection (versus drop-off), which requires users to separate their waste at home, along with pay-as-you-throw (PAYT) pricing system, that links the cost of the user to the amount of unsorted waste produced. They found that PAYT incentive increases the sorted waste ratio (SWR; i.e., the ratio of sorted to total waste) by 17 % which is additive to the effect of the DiD incentive (15.7%). However, they also found that PAYT programs induce illegal dumping: users dump their waste in adjacent towns where communal bins are available in the streets. This result suggests that decisions about the policy programs would benefit from coordination between adjacent municipalities, to avoid this undesired effect.

Some of the studies included both separation of recyclables and organic waste. In China, an incentive-based source separation model was designed and tested where households were rewarded for separating organic waste, government funds were used for waste reduction, and small recycling enterprises promoted source separation. Supermarkets signed a contract with small recycling enterprises to allow residents to

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shop with the bonus obtained for sorting organic waste and recyclables (the bonus was 0.05 CNY kg<sup>-1</sup> for organic waste and 0.1 CNY kg<sup>-1</sup> for recyclables). After one year of operation, the waste reduction rate under the incentive-based source separation model was 87.3%, whereas in the normal recycling model, where residents sold the recyclables to the rubbish collectors or small recycling stations, the waste reduction rate was 25.4% (Xu et al., 2015).

Municipalities in India have tried different schemes to encourage organic waste separation behavior. These mostly involve distributing free collection bins to households, accompanied by a door-to-door awareness campaign. In some instances, the local government conducts the awareness campaign with the help of local NGOs and social workers. In Bengaluru, citizen welfare groups Kasa Mukta Bellandur and the Solid Waste Management Round Table (SWMRT), launched a campaign called '2 bin 1 bag' in 2012.

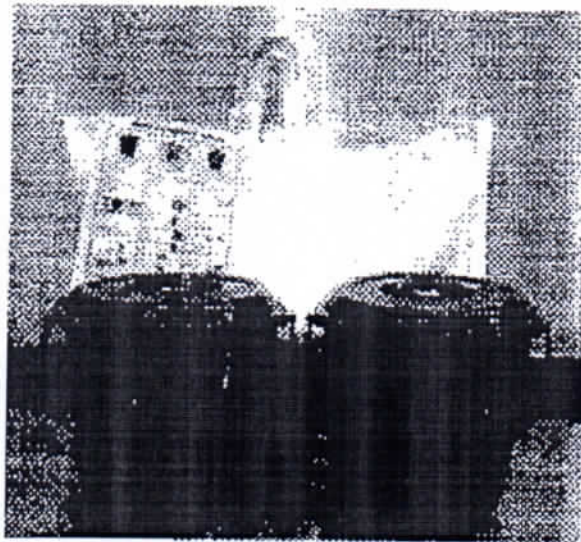


Figure 4-1: 2 bin 1 bag set (2Bin1Bag, 2017)

Households were given two bins: one red and one green, and a reusable bag, as shown in Figure 4-1 above. Organic or wet waste should be handed over to collectors in the green bin, inorganic or hazardous waste in the red bin, while the reusable bags




were to be used for recyclable or dry waste. The households were asked to separate their waste according to the appropriate bin, and the garbage collector would collect the segregated waste. In 2015, the Karnataka High Court mandated the 2 bin 1 bag system for waste collection and disposal in Bengaluru. It was mandated that all categories of waste generators - residential, non-residential and government offices - should segregate wet, dry and hazardous waste at the source. The Karnataka High Court also directed the municipality to identify violators and impose penalties (Prasad, 2015).

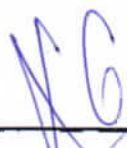
In the energy efficiency field, Opower is a US-based customer engagement platform for utilities which employs behavioral science techniques to affect customers' energy consumption (Rahim, 2010). The reports include targeted tips that seek to motivate customers to lower their energy consumption to the "normal" neighborhood rate. The reports also feature smiley-face emoticons for the most energy-efficient homes (Schmit, 2010).

As seen from the literature review, household behavior change was affected in three stages: mechanisms, awareness and incentives. Mechanisms include policy measures such as a city-wide policy notification and fines in case of non-compliance. Awareness methods include passive approaches such as advertising on collection vehicles, leaflets and newspaper articles and active approaches such as door-to-door campaigning and presentations in schools. The incentives used are broadly divided into financial and social incentives. Financial incentives include cash incentives or non-cash (in-kind) incentives such as waste for goods exchanges. Social incentives included recognition in community level meetings and feedback given on neighbors separation rate.

### 4.3 Household behavior change pilot study

Using the insights gathered from the literature review, a pilot study was designed and conducted in two neighborhoods in Muzaffarnagar, to test incentives to increase organic waste separation behavior by households. As seen from the waste audits, a high fraction of the total waste is organic waste. If this waste is separated at

  
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the household level, there is potential for the waste to be utilized in organic waste technologies.

#### 4.3.1 Approach


Two neighborhoods of similar income levels, Gandhi Colony and Teachers Colony, were chosen as the test neighborhoods for the pilot study. In one neighborhood (Gandhi Colony), no feedback was given to the households on their waste separation quantities or separation rate. This neighborhood is known as the doorstepping neighborhood. In the other neighborhood (Teachers Colony), feedback was given to the households on a weekly basis for a period of one month. This neighborhood is known as the feedback neighborhood. The steps in conducting the segregation pilot are described below. Finally, an analysis of the benefits and costs of implementing a city-wide segregation policy in the city of Muzaffarnagar is calculated.

#### 4.3.2 Procedure

1. In each neighborhood, a sample of thirty adjacent households was selected.
2. In both neighborhoods, a one day door-to-door awareness campaign was conducted by the mayor of Muzaffarnagar, Mr. Pankaj Aggarwal; Malini Parmar and Shekar Prabhakar, members of the Solid Waste Management Round Table (SWMRT), a Bengaluru-based NGO; local NGOs; and students and faculty of SRGC.
3. The participants distributed two bins (green and red) and one bag to the households free-of-charge and explained the new waste collection system. The bins were given free-of-charge to the households through a seed grant funded by the Tata Trusts. The awareness program was conducted in both Hindi and English and leaflets were handed out along with the two bins and bag kit, as shown in Figure 4-2 below.
4. The waste collector allocated one collection truck to collect the waste from the

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## कचरा प्रबन्धन की विधि

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1. जैविक कचरा	2. सूखा कचरा	3. बेकार कचरा
<p>(प्लास्टिक बैग का प्रयोग न करें)</p> <p><b>रसोई का कचरा</b> साबुत / फल के छिलके दूध/ दही का बिल्ला अंडे का पिल्ला सिक्का / अनाजी के अड़िखर्चा सड़े हुए / खोले हुए सोखन हुए पिल्ले / फुले हुए पिल्ले गुना पेट्टे पर पाक तेल / घुसके हुए तेल लवंग / अदरक</p> <p><b>बगीचे का कचरा *</b> लेबल का कचरा (सफाई में ही) मिट्टी / बालू / चूने / लकड़ी फूल के फल / अंडे पत्तों आदि</p> <p><b>प्लास्टिक</b> [कम से कम, साफ किया जाना चाहिए] प्लास्टिक के बिल्ले/बिल्ले/बिल्ले सिक्का / लकड़ी/अंडे प्लास्टिक/कागज/अनाज पुस्तकें आदि</p> <p><b>कागज</b> [कम से कम, साफ किया जाना चाहिए] खाने का कागज / कागज सूखे हुए कागज मसाले के कागज/पत्र रसोई का</p> <p><b>धातु</b> [कम से कम, साफ किया जाना चाहिए] कमरे का पेट्टे खाली के बिल्ले कमरे के बिल्ले के आदि शिला: दूध/दही/अनाज / कागज</p> <p><b>अन्य सूखा कचरा</b> गुना / खोले हुए पुस्तकें/कागज / कागज सिक्का/कागज मिट्टी / लकड़ी/अनाज साफ लकड़ी का कागज सूखे हुए कागज/पत्र/कागज/कागज</p> <p><b>अकार्यकारी कचरा - सावधानी से</b> कम से कम से कम सिक्का सूखे हुए कागज/पत्र सूखे हुए कागज/पत्र/कागज/कागज</p>	<p>(प्लास्टिक बैग का प्रयोग न करें)</p> <p><b>दैनिकी कचरा</b> [कम से कम, साफ किया जाना चाहिए] सिक्का / सड़े हुए कागज सिक्का अनाज साबुत दूध/दही/अनाज/कागज/अनाज सूखे हुए कागज/पत्र/कागज/कागज</p> <p><b>तेलपात्र जले हुए आदि **</b> [कम से कम, साफ किया जाना चाहिए] सूखे हुए कागज/पत्र/कागज/कागज सूखे हुए कागज/पत्र/कागज/कागज</p> <p><b>विशेष कार्य का कचरा/</b> <b>निष्क्रिय पदार्थ ***</b> [अलग से रखें] साबुत दूध अनाज/कागज/अनाज/कागज/कागज सूखे हुए कागज/पत्र/कागज/कागज</p>	<p>(प्लास्टिक बैग का प्रयोग न करें)</p> <p><b>दैनिकी कचरा</b> [कम से कम, साफ किया जाना चाहिए] सिक्का / सड़े हुए कागज सिक्का अनाज साबुत दूध/दही/अनाज/कागज/अनाज सूखे हुए कागज/पत्र/कागज/कागज</p> <p><b>तेलपात्र जले हुए आदि **</b> [कम से कम, साफ किया जाना चाहिए] सूखे हुए कागज/पत्र/कागज/कागज सूखे हुए कागज/पत्र/कागज/कागज</p> <p><b>विशेष कार्य का कचरा/</b> <b>निष्क्रिय पदार्थ ***</b> [अलग से रखें] साबुत दूध अनाज/कागज/अनाज/कागज/कागज सूखे हुए कागज/पत्र/कागज/कागज</p>

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<http://www.2bin1bag.in>

Figure 4-2: Door-to-door awareness leaflet (Hindi)

two neighborhoods and take the waste back to the A2Z plant. Four collection bins were placed in the collection trucks (as shown in Figure 4-3) and the waste workers were trained to place the waste in the red, green, white or black bin depending on the contents of the bins (inorganic, organic, recyclable, and unsorted waste respectively).

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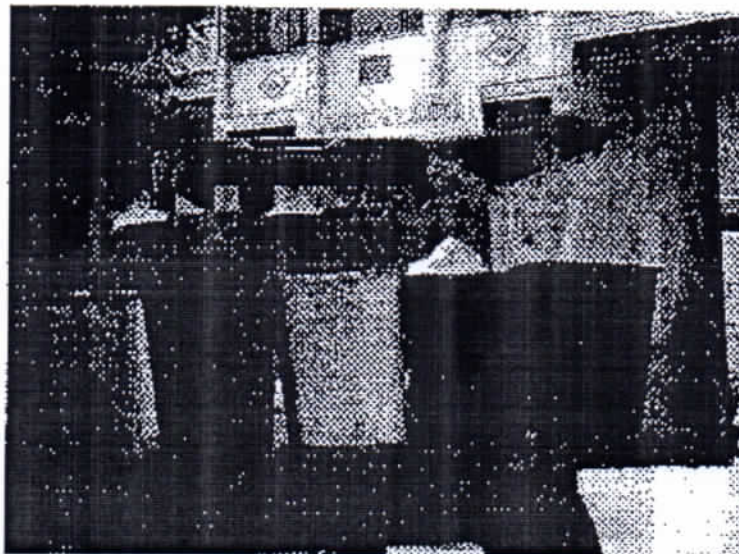


Figure 4-3: Collection bins


5. In both neighborhoods, waste was collected from the thirty households daily. The waste worker noted if each household was separating its waste into the appropriate bins. The waste collected in each category (organic, inorganic, recyclable and unsorted) per neighborhood was weighed and noted.

#### 4.3.3 Feedback

In the feedback neighborhood, households were given feedback on a weekly basis over the span of one month. The households were given feedback on three measures: how much waste their neighborhood generated in each category compared to the doorstep neighborhood, how many times per week they segregated their waste and how many times per week their neighbors segregated their waste. The feedback sheet given to the households in the feedback neighborhood is shown in Figure 4-4 below.

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# मुजफ्फरनगर पालिका परिषद्

SHRI RAM GROUP OF COLLEGES

MUNICIPAL SOLID WASTE MANAGEMENT PROJECT

PROGRESS REPORT

Household Number: 9

Head of House: Prem Singh

Period: December 12 (Monday) – December 17 (Saturday)

Waste	Weekly waste in Teachers' Colony in kg (per household)	Weekly waste in Gandhi Colony in kg (per household)
Food/wet waste (खाने/पानी/कचरा)	1.50	1.79
Dry/recyclable waste (पत्र/पत्रिका/प्लास्टिक/पेपर)	1.21	0.85
Reject waste (अपयोग्य/असहज कचरा)	0.41	0.40
Unsegregated waste (सबकुछ कचरा)	0.24	0.80
Total	3.36	3.13

Week 1 (November 21 – November 26): Your household segregated: 5 days out of 6 days (83%)

Week 2 (November 28 – December 3): Your household segregated: 5 days out of 6 days (83%)

Week 3 (December 5 – December 10): Your household segregated: 6 days out of 6 days (100%)

Week 4 (December 12 – December 17): Your household segregated: 5 days out of 6 days (83%)



In your neighborhood, 18 households out of 21 households segregated 5/6 days

Thank you for participating in making Muzaffarnagar a cleaner city!!



Figure 4-4: Feedback sheet

The feedback was done at two levels: comparison with a different neighborhood (the doorstepping neighborhood) and well as comparison within the same neighborhood. While comparing the two neighborhoods, the waste quantities generated for the thirty households on a weekly basis in kilograms were compared. While comparing within the same neighborhood, a pie chart and smiley-faces were used to indicate the

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weekly frequency of waste separation. The feedback sheet was given to the households in the feedback neighborhood weekly at the end of the collection week on Saturdays.

#### 4.3.4 Results

The weekly household separation rate, i.e., the number of households per neighborhood that separated their waste all six days of the week, were noted for each of the neighborhoods and plotted across four weeks.

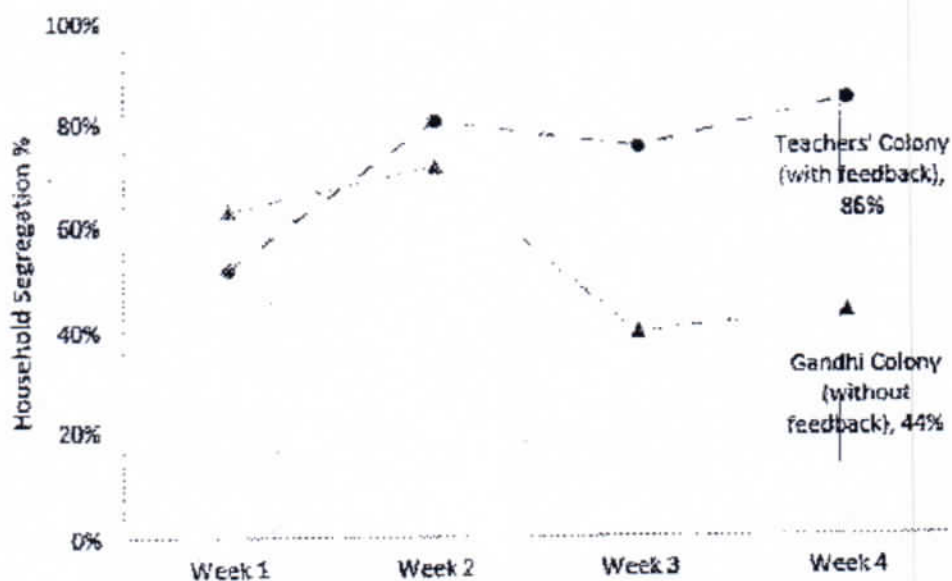


Figure 4-5: Comparison of segregation rate

From the comparison plot, we see that although both the neighborhoods started at a similar segregation rate, the feedback neighborhood had nearly twice the segregation rate than the doorstep neighborhood, at the end of four weeks.

#### 4.3.5 Cost-benefit analysis

An analysis of the benefits and costs of implementing a city-wide segregation policy in the city of Muzaffarnagar, which has a population of about 400,000 people and 65,000 households, was conducted. The cost-benefit analysis would differ depending

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on the city area and number of households.

### Relevant costs

There are costs associated with hiring waste management supervisors, who will perform multiple duties such as training the existing waste collectors, gathering data, regular inspections and local travel costs. There are also costs associated with procuring the 2 bin 1 bag set used to segregate the waste into three categories and printing the awareness material. Initially, one set will be given free to each of the 65,000 households in Muzaffarnagar. Hence this is a one-time cost. However, if the household wishes to replace the set, they will have to procure the additional set at a cost. There will be fines and policies in place to prevent households from selling the bins on the secondary market. Miscellaneous and recurring supplies costs are accounted for as well.


Table 4.1: Relevant costs

Resources	Total Annual Costs (Rs.)
Waste management supervisors (5 x 120000)	600,000
Materials and supplies (200*65000) - one-time cost	13,000,000
Recurring supplies (100*10000)	100,000
Local travel costs (10000*12)	120,000
<b>Total</b>	<b>13,820,000</b>

### Relevant benefits

Benefits from a city-wide segregation policy would accrue to both the municipality as well as the private waste collector. The municipality can negotiate contracts with the private waste collectors at more favorable conditions, guaranteeing that the collected waste from the households will be segregated. The private waste collector will likely see an overall increase in net profit. There will be an increase in revenues due to the increased quality and yield of compost and increase in tons of waste processed per hour of organic waste. There will also be an increase in costs due to the extra transportation costs for collection of segregated waste, but this will be offset by the

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increase in revenues. We assume that there will be a 20% increase in profit after implementation of the city-wide segregation policy.

Table 4.2: Relevant benefits

Resources	Total Annual Benefits (Rs.)
20% revenue increase	4,800,000
Total	4,800,000

In this scenario, the costs are incurred by the municipality whereas the benefits are obtained by the private waste collector. Assuming the costs are incurred by the private waste collector, we can determine the cost-benefit analysis of implementation.

Table 4.3: Expected benefits vs costs

Year	Expected Yearly Cost (Rs)	Expected Yearly Benefit (Rs)	Discount Factor for 7%
1	13,820,000	4,800,000	0.9346
2	820,000	4,800,000	0.8734
3	820,000	4,800,000	0.8163
4	820,000	4,800,000	0.7629
5	820,000	4,800,000	0.7130
6	820,000	4,800,000	0.6663
7	820,000	4,800,000	0.6227
8	820,000	4,800,000	0.5820
9	820,000	4,800,000	0.5439
10	820,000	4,800,000	0.5083

Table 4.4: Net present value of benefits vs costs

Year Since Initiation	Present Value of Costs (Rs.)	Present Value of Benefits (Rs.)
1	12,915,888	4,485,981
2	716,220	4,192,506
3	669,364	3,918,230
4	625,574	3,661,897
5	584,649	3,422,334
6	546,401	3,198,443
7	510,655	2,989,199
8	477,247	2,793,644
9	446,026	2,610,882
10	416,846	2,440,077
Total	17,908,870	33,713,191

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Assuming a 7% discount rate, the net present value of benefits and posts is calculated over a ten year period. The net present value of implementing the city-wide segregation policy is Rs 15,804,322 over a 10 year period. This corresponds to a payback period of four years.

#### 4.4 Conclusion

We see from the pilot study that weekly feedback given to households on their quantity of waste generated and segregation rate in comparison to their peers, increases segregation percentage by nearly twice than if no feedback were given. Implementing a city-wide segregation policy makes sense from a cost-benefit analysis perspective, though it needs to be negotiated between the municipality and the private waste collector whom should bear the costs of distributing the segregation kits and training the waste workers. The feedback mechanism can be used to make implementation of a city-wide segregation policy more effective. This policy would result in an increase in separated organic waste, which could be processed in organic waste technologies. Organic waste technologies are considered as potential technologies for processing waste in the decision support tool described in the next chapter.

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## Chapter 5


# Decision support tool development and scenario analysis

This chapter focuses on the development of the decision support tool and discusses the applicability of the tool in the Indian context. A literature review of the existing decision support tools is undertaken and system optimization is identified as the modeling approach to be used in development of the decision support tool. The tool is then applied to the city of Muzaffarnagar to evaluate the economic, environmental and social impact of different technology configurations at varying scales and levels of segregation.

### 5.1 Literature review

Complexity in SWM systems arise from siting facilities, selecting technologies and comparing different waste management options. Many different systems analysis tools have been developed to provide support for waste management decisions. These tools can be grouped into two categories: 1) descriptive tools, used for evaluation and assessment of waste management systems and 2) prescriptive tools, used for creating and designing waste management systems. In this section, we will discuss the general framework for a decision support tool, along with a review of the tools in each of the two categories.

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### 5.1.1 Decision support systems

According to Sprague and Watson (1996), conceptual models or frameworks are crucial to understanding a new and/or complex systems. They define decision support systems (DSS) broadly as an interactive computer based system that helps decision-makers use data and models to solve ill-structured, unstructured or semi-structured problems.

Figure 5-1 below describes the general flow of a decision support model, used in assisting the user in making decisions. The objective or performance criteria is specified along with system constraints. Inputs are fed into the model and the outputs are generated based on the pre-defined criteria.

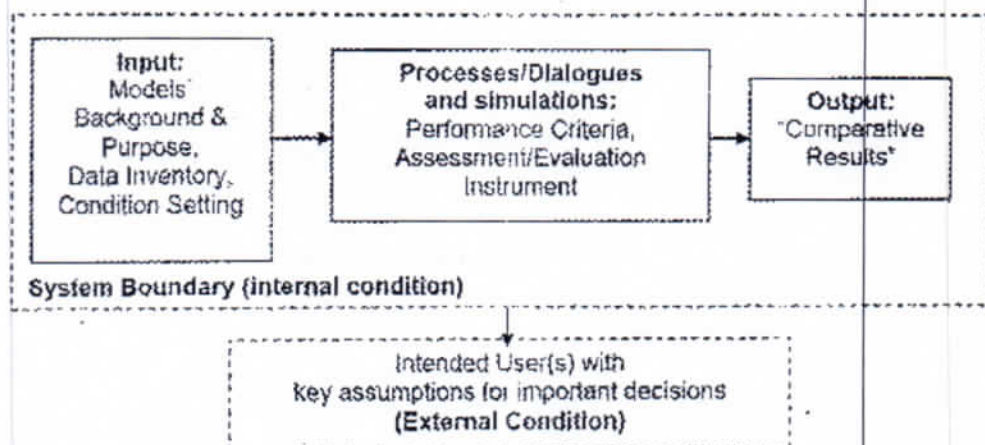

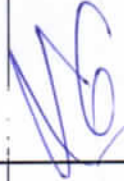


Figure 5-1: Generalized decision support model (Sprague and Watson, 1996)

Morrissey and Browne (2004) and Bani et al. (2009) conducted an overview of decision support models. The models are classified into three categories: cost-based models, environmental impact models and multi-criteria models. Environmental impact models and multi-criteria models can be classified as descriptive tools whereas cost-based models can be classified as prescriptive tools.

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### 5.1.2 Descriptive tools

#### Environmental impact models

Environmental impact models consider lowest environmental impact as their objective. These models generally employ life cycle assessment or life cycle inventory techniques. Life cycle assessment models consist of a process to evaluate environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used, wastes and emissions released to the environment, to assess impact of those energy and material uses and releases and to identify and evaluate opportunities that lead to environmental improvements (EEA, 2003). Some of the models used in this space include: RTI DST (Decision Support Tool, USA), IWM (Integrated Waste Management, UK), THE IFEU PROJECT (Germany), ORWARE (ORganic WASTE REsearch, Sweden) and EASEWASTE (Environmental Assessment of Solid Waste Systems and Technologies, Denmark). DST and IWM are life cycle inventory (LCI) models, thus not performing actual impact assessment. THE IFEU PROJECT, ORWARE and EASEWASTE are life cycle assessment (LCA) models. Local conditions and waste composition strongly influence the results of environmental assessment (Hansen et al., 2006).

#### Multi-criteria models

Multi-criteria models take several individual and often conflicting criteria into account in a multidimensional manner leading to more robust decision making rather than optimizing a single dimensional objective function. The result is a ranking of the alternatives. The type of criteria chosen in these model types depends on the objectives of the model, and therefore could include risk assessment or environmental impact assessment (Pires et al., 2011). ELECTRE III is found to be the most commonly used method for waste management decisions in the literature. The AHP method is also used in some applications (Haastrup et al., 1998). However, the allocation of weights to different alternatives is a major shortcoming of the multi-criteria technique.

### 5.1.3 Prescriptive tools


#### Cost based models


Cost-based models assign a monetary value to costs and employ methods such as cost-benefit analysis and optimization. These models have a minimum cost objective. In a cost-benefit analysis, the value of all costs and benefits involved may be expressed as an assessment metric in a case-based scenario of SWM for justification as a pure cost-benefit analysis or as an integral part of the forecasting models, simulation models and optimization models (Chang et al., 2011). Cost-based models are the most widely used in waste management modeling. However, in cost-based models, maximization of economic efficiency is the overriding factor at the expense of environmental and social criteria, which is not a sustainable approach to waste management.

#### Optimization-based DSS for waste management

Optimization tools provide decision makers with optimum ISWM policies for any region based on economic or environmental costs, mass balance, capacity limitations, operations, location and site availability (Najm and El-Fadel, 2004). The first solid waste management models were optimization models using linear programming (LP) with a single objective, so as to minimize the total or partial costs in the SWM system. These models dealt with specific aspects of the problem, for example vehicle routing and scheduling (Liebman et al., 1975) or facility site selection (Esmaili, 1972). Planners and decision makers gained beneficial use of prescriptive tools for achieving the basic short and long-term planning of SWM with respect to the cost minimization principle and technical constraints in 1970s (Chang et al., 2011). Shortcomings from models developed in 1970s were pointed out by Berger et al. (1999). They include recyclables rarely being taken into account, having only one processing option of each type and having a single generating source.

Recycling and energy recovery processes were included in later models developed by Diamadopoulos et al. (1995) and Chang and Chang (1998). Berger et al. (1999) used integrated solid waste management (ISWM) principles which extended the sys-

  
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tem boundaries of the earlier models and covered MSWM at the system level (Pires et al., 2011). Linear programming and mixed integer linear programming (MILP) is commonly used when assuming perfect foresight. Stochastic programming, fuzzy programming or interval analysis are used when considering uncertainty in relation to waste management. Waste management strategies under uncertainty with high levels of complexity and subjectivity developed prescriptive tools. Geographic information systems (GIS) and decision support systems (DSS) started being integrated with each other to help decision making with challenges on a long-term basis (Chang et al., 2011).

#### 5.1.4 DSS for waste management in India

Decision support tools are not widely used in India for planning waste management systems, though tools have been developed considering the Indian context. Solid waste transportation route planning and sanitary landfill site selection are the main focus of the DSS developed for the Indian context (Ohri and Singh, 2010). Natesan and Suresh (2002) developed a GIS based decision support system using multi-criteria evaluation models for sanitary landfill site selection. The themes identified for the purpose included land use, geology, geomorphology, drainage density, slope, soil and runoff. Ghose et al. (2006) considered allocation of available resources (man power and vehicles) and suggested an expert system based decision support tools for solid waste transportation management. Saxena et al. (2010) developed a DSS for sustainable municipal solid waste management using cost-benefit and SWOT analysis. Both environmental as well as economical sustainability of municipal solid waste management were considered. Technological aspects, institutional aspects and financial aspects were taken in the framework of integrated approach.

#### 5.1.5 Gap analysis

As seen from the literature review, optimization-based DSS used in waste management are commonly focused on economic optimization. Social aspects such as employment

  
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and health were rarely considered. In the case of developing countries such as India, waste management is more labor intensive and a large percentage of the population is employed in both the formal and informal waste management sector. As a result, sustainable waste management systems need to consider social and environmental impacts in addition to economic objectives. The unique cultural context in developing countries introduces other considerations such as open dumping, informal recycling, low rate of service coverage and insufficient supporting data (Jain et al., 2005).

Further, the technologies options and scale of processing facilities used in developing countries differ from the technology options in developed countries. Optimization models used for siting facilities such as transfer stations and landfills were used, but none of the models examined siting of different capacity processing facilities. These shortcomings make it inappropriate to apply the existing DSS directly to the Indian context.

## 5.2 Optimization model methodology

A prescriptive optimization-based DSS for the Indian context is developed using the mixed integer linear programming approach. The GIS-based model of MSW for Muzaffarnagar is developed and the assumptions, objectives, decision variables, mathematical formulation and constraints of the model are discussed below. Finally, the data sources and inputs to be used by the model are presented. The outputs generated by the model are the scales, technologies and siting of technologies that meet the defined objective function. The tool is developed to evaluate the economic, environmental and social impact of different technology configurations at varying scales and levels of segregation.

### 5.2.1 Assumptions

The assumptions used in formulating the MILP model used for modeling the MSW system for Muzaffarnagar are listed below:

1. The collection efficiency is 100%.

  
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2. It is assumed that all generated solid waste in Muzaffarnagar is collected from the households and dumped at the 45 collection points.
3. The collection centers are assumed to be located at the centroid of each ward.
4. Bulk generator, commercial and institutional wastes are transferred to the collection points at the expense of the generators.
5. The distances are measured as Euclidean measurements from the centroids of either the wards or the facilities.

### 5.2.2 Metrics

As shown in Figure 5-2 below, the DSS can consider different metrics which include economic costs, environmental costs and social benefit. The economic costs of the system include collection, treatment and transportation costs. The environmental costs are measured as greenhouse gas (GHG) emissions and the social benefit is measured in terms of people employed.

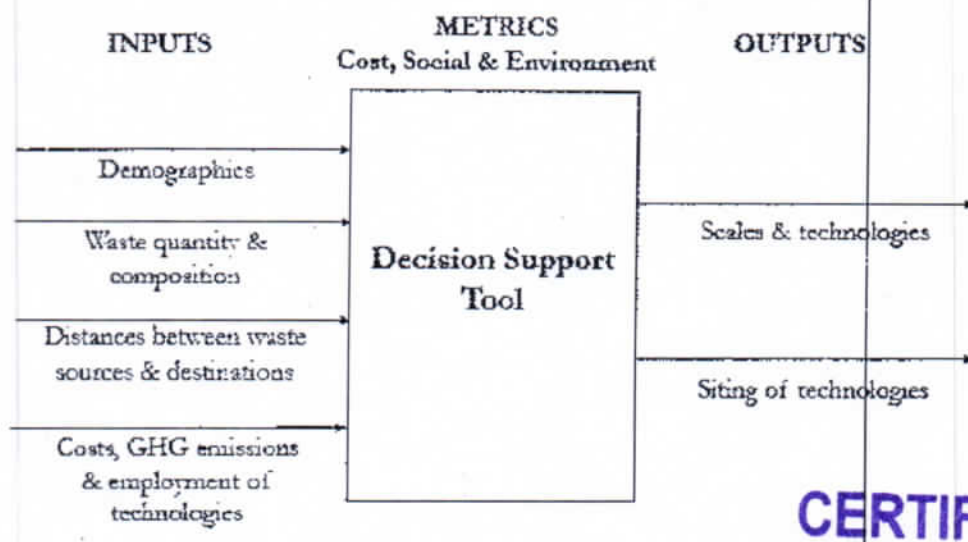


Figure 5-2: Muzaffarnagar decision support model

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### 5.2.3 Decision variables

The decision variables are the variables which can be controlled in the model. These include:

1.  $O_{s,d}$  is the mass of organic waste removed from the collection center source  $i$  to the facility destination  $j$  ( $i = 1, \dots, I; j = 1, \dots, J$ )
2.  $M_{s,d}$  is the mass of mixed waste removed from the collection center source  $i$  to the facility destination  $j$  ( $i = 1, \dots, I; j = 1, \dots, J$ )
3.  $Q_j$  is a variable that can take the value of 0 or 1. The variable is 1 if a processing facilities should be set up at the destination  $j$  and 0 if not


### 5.3 Mathematical formulation

The mathematical formulation of the MILP includes both the objective function and constraints. The objective function is to minimize the economic cost of the waste system.

#### 5.3.1 Objective function

There are two types of constraints on the function: mass balance constraints and capacity constraints. The mass balance constraints specify that the organic waste and mixed waste generated at the source should be equal to the organic waste and mixed waste at the destination. The capacity constraints specify that the organic waste processed should be equal to the total capacity of the organic waste facilities and the total waste processed should be equal to the total capacity of the processing facilities.

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$$\begin{aligned}
& \max P_O + P_M \\
& \text{s.t.} \quad \sum_{i=1}^I O_d = \sum_{i=1}^I O_s \\
& \quad \quad \sum_{i=1}^I M_d = \sum_{i=1}^I M_s \\
& \quad \quad \sum_{i=1}^I O_d \leq \sum_{i=1}^I \text{Cap}_O * p_O \\
& \quad \quad \sum_{i=1}^I (O_d + M_d) \leq \sum_{i=1}^I \text{Cap}_M * p_M
\end{aligned} \tag{5.1}$$

where  $P_O$ : net cost of organic waste,  $P_M$ : net cost of mixed waste,  $\text{Cap}_O$ : capacity of the organic waste facilities,  $\text{Cap}_M$ : capacity of the mixed waste facilities,  $p_O$ : number of organic waste facilities and  $p_M$ : number of mixed waste facilities

The costs of the waste management system can be divided into fixed and variable costs. The fixed costs consist of capital, maintenance, labor and building costs. The variable costs consist of operations and energy and transportation costs. There are also revenues associated with both the organic waste and the mixed waste due to the sale of compost and/or biogas.

$$C_F = C_C + C_M - C_L + C_B \tag{5.2}$$

$$C_V = C_O + C_T \tag{5.3}$$

where  $C_F$ : fixed costs,  $C_C$ : capital costs,  $C_M$ : maintenance costs,  $C_L$ : labor costs,  $C_B$ : building costs,  $C_V$ : variable costs,  $C_O$ : operations and energy costs and  $C_T$ : transportation costs

The cost of transportation is represented in the term  $C_T$ . The product of the mass of waste and distance traveled by the waste is calculated and multiplied by a cost per mass-distance  $C_M$  (assumed to be Rs.2) in order to calculate the transportation cost.

$$C_T = \sum_{i=1}^I \sum_{j=1}^J (D_{s,d} * (M_{s,d} + O_{s,d})) * C_M \tag{5.4}$$

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The net costs of the organic waste and the mixed waste are calculated by subtracting the costs of the waste management system from the revenues.

$$P_O = \sum_{j=1}^J ((R_O * O_{s,d}) - (C_F * p_O + C_V * O_{s,d})) \quad (5.5)$$

$$P_M = \sum_{j=1}^J (R_M * M_{s,d}) - (C_F * p_M + C_V * M_{s,d}) \quad (5.6)$$

where  $R_O$ : revenue from organic waste and  $R_M$ : revenue from mixed waste

### 5.3.2 Environmental metric

The environmental metric is used to create a trade-off graph with the minimum cost function in order to minimize the greenhouse gas (GHG) emissions of the waste system.

$$Environmental\ metric = \sum_{j=1}^J (G_O * O_d + G_M * M_d) \quad (5.7)$$

where  $G_O$ : greenhouse gases generated by the organic waste facilities and  $G_M$ : greenhouse gases generated by the mixed waste facilities

### 5.3.3 Social metric

The social metric is used to create a trade-off graph with the minimum cost function in order to maximize the employment of the waste system.

$$Social\ metric = \sum_{j=1}^J (E_O * p_O + E_M * p_M) \quad (5.8)$$


where  $E_O$ : employment created by the organic waste facilities and  $E_M$ : employment created by the mixed waste facilities

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## 5.4 Inputs to the model

The following are the inputs to the model:

  
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1. Demographic data
2. Waste quantity and composition data
3. Distances between the waste sources and destinations
4. Costs, GHG emissions and employment generated by the technologies

#### 5.4.1 Demographic data

As indicated in Chapter 3, the demographic data of Muzaffarnagar is obtained from the 2011 Census of India. Historical growth rates in population are taken in order to estimate the 2017 population, as the census is taken every ten years.

#### 5.4.2 Waste quantity and composition data

The waste quantity and composition data is calculated in Chapter 3, from the waste audits. This data, along with the demographic data, is used as an input to the model to estimate the total waste generated in Muzaffarnagar.

#### 5.4.3 Distances between the waste sources and destinations

The waste sources and destinations are assumed to be the centroids of the wards. Since there are 45 wards in Muzaffarnagar, there are 45 sources of waste and 45 potential destinations of waste. The Euclidean distances are calculated using GIS coordinates.


#### 5.4.4 Costs, greenhouse gas emissions and employment generated by the technologies

##### Types of technologies used

There are four destinations of waste considered in this model. They are: landfilling, composting, biogas and organic pelletization. These technologies are described here (Perlman, 2015).

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**Landfilling:** When organic waste is landfilled, it is dumped in a large pile either in a hole or directly on the ground. If the landfill is engineered to reduce environmental pollution, it is lined with a bottom liner to prevent liquids from seeping into the soil and groundwater, designed with cells for old and new waste, covered and equipped with a system to capture methane. If it lacks most of these features, such a site is simply an open-air dump, where waste piles up and may be regularly compacted or physically stabilized. Organic waste that is landfilled may slowly decompose anaerobically, or may remain relatively unchanged for long periods of time. Unless the landfill is generating energy from captured methane, landfilling does not generate any valuable resource from organic waste.

**Composting:** Composting accelerates the natural (aerobic) biological decomposition process by aggregated the material, often in some sort of container. In order for composting to function properly, the mixture of organic wastes must contain both nitrogen- and carbon-rich material, some moisture, oxygen, and naturally present bacteria. A diversity of materials, such as leaves, twigs, manure, food scraps, grass, wood chips, and paper can be composted. Composting significantly reduces the volume of material, as water and carbon dioxide off-gas. Shredding material before composting reduces the decomposition time and improves the quality of finished compost. After a period of maturation, which may take weeks or months, the end product of the process is compost, which is a biologically-active, nutrient rich soil-like material that can be used as a soil amendment. There are many versions of composting, such as vermi-composting (using worms), windrow-composting, pit composting, and bin composting.

**Anaerobic Digestion:** Anaerobic digestion processes organic waste in a tank digester under oxygen-free conditions. Micro-organisms biologically decompose the (often wet) material, generating biogas, which is principally composed of methane and carbon dioxide, as well as a liquid fertilizer (sludge). Anaerobic digesters can process food waste, waste oils, animal waste, and sewage, but cannot process woody materials such as twigs or coconut husks. The more putrescible the material, the higher the biogas yields of the digester will be. The biogas is filtered and the methane can be

  
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fed into an engine to generate electricity. The sludge can be applied to garden or agriculture fields as a fertilizer.

**Pelletization:** Pelletization of organic waste is a physical process in which the material is screened, shredded, dried, and densified to create fuel pellets or briquettes. These pellets can be burned as a fuel in cement kilns, power plants, boilers, or stoves. As is the case when burning any solid fuel, pellet burning systems should have scrubbers or other systems to reduce the emission of air pollutants. Pelletization is most energetically efficient if the input material is drier and has a high-calorific value.

### Scales of technologies used

The scales of technologies in tons per day (TPD) considered in the model were chosen based on their frequency of use in India and are given below.


1. Biogas: 0.1, 0.5, 2, 5 and 100
2. Composting: 0.1, 0.2, 2, 100 and 200
3. Pelletization: 0.5, 1, 2, 5 and 10


### Cost of technologies

Cost models of composting, biogas, landfilling and pelletization were created by Rachel Perlman, a graduate student studying waste systems in Pune, India. The data on the cost models has been taken from her thesis (Perlman, 2015). As some of this data was specific to Pune (such as transportation and collection costs), data from A2Z was used to calculate transportation and collection costs in Muzaffarnagar. Further, as data on composting technologies that process segregated waste was not available, the following assumptions were made to construct the cost models for segregated waste composting:

1. The fixed costs of the segregated composting facility are the same as the mixed composting facility

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2. The diesel costs are doubled due to the assumption that twice the number of collection trips are made
3. Tons processed by the composting plant per hour increase by one third
4. The yield of compost produced will increase from 7% to 18%
5. The selling price of compost will increase by one third due to increased quality of compost

The costs of the technologies are given in Appendix D.


#### 5.4.5 Greenhouse gas emissions of the technologies

Data from the greenhouse gases emitted by composting and landfilling technologies was taken from the MSW Database, developed through a cooperative agreement between RTI International and the US EPA's National Risk Management Research Laboratory (U.S. EPA, NC State University, RTI International, 2014). Data for the GHG emissions of biogas and pelletization is taken from Rachel Perlman's literature survey (Perlman, 2015) as biogas and pelletization are not technologies considered in the MSW Database. The GHG emitted by the technologies are given in Appendix D.


#### 5.4.6 Employment generated by the technologies

The employment generated by the technologies is taken from data collected by Rachel Perlman and discussion with A2Z management. The employment generated by the technologies are given in Appendix D.

Once all the inputs have been entered into the model, different scenarios can be analyzed by considering varying objectives of the waste system planner.

  
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## 5.5 Scenario analysis

A waste planner has to consider multiple metrics and balance competing goals when planning a sustainable waste management system. The tool is used to determine the minimum cost scenario in Muzaffarnagar and examine the trade offs between the competing goals of minimum cost, minimum GHG emissions and maximum social impact. We also consider two scenarios: when there is 0% segregation versus when there is 100% segregation in the city.

### 5.5.1 Map-based representation of Muzaffarnagar


The map below represents the current waste infrastructure of Muzaffarnagar. There are 45 wards, numbered in Figure 5-3 below. The current A2Z composting plant is located on the outskirts of the city, to the west of the city boundaries. The darker shading of the wards represent the waste generated by the ward - the darker the shade, the more waste generated by the ward. The legend refers to three potential technologies which are represented by three colors: red for composting, green for biogas and blue for pelletization. This representation is used throughout this chapter. As shown in Figure 5-3, there are no biogas or pelletization plants currently being used in Muzaffarnagar. The potential location of the processing facilities are assumed to be located at the centroid of the ward.

### 5.5.2 Waste planner metrics

The tool considers three metrics in addition to the cost, environment and social impact metrics. They are:

1. Space occupied
2. Level of centralization
3. Capacity utilization

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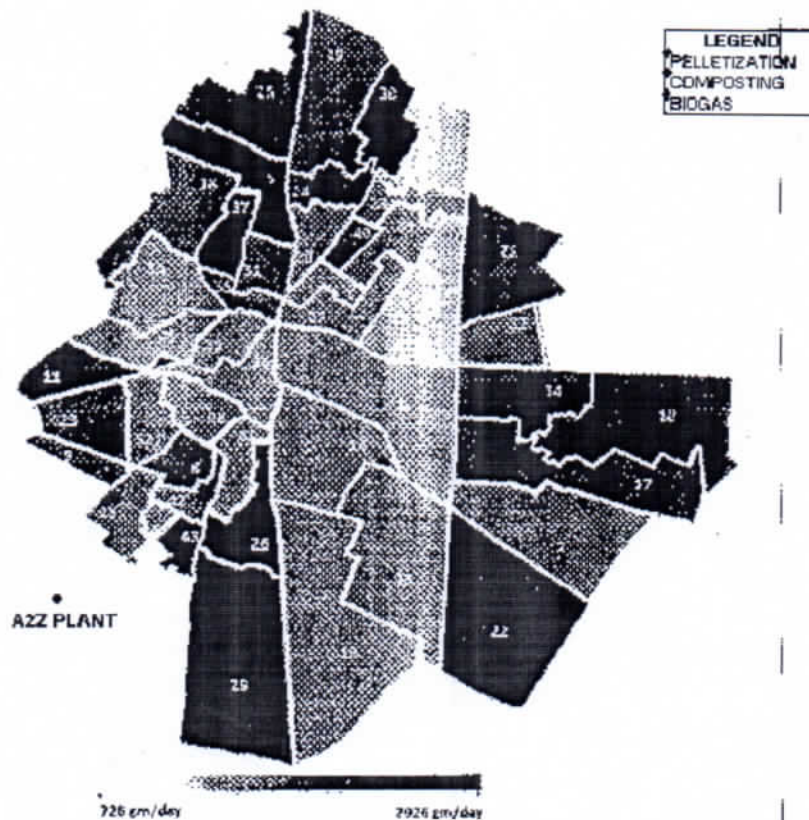


Figure 5-3: Current A2Z waste infrastructure

**Space occupied**

The space occupied by the waste processing facilities is measured in  $m^2$  and detailed in Appendix D. Typically, the larger capacity of the waste facility in terms of tons processed per day, the greater space it occupies.

**Level of centralization**

The level of centralization of the waste system is measured in terms of average tons of waste processed per facility. The greater the average tons of waste processed per facility, the more centralized the waste system is.

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## Capacity utilization

The capacity utilization of the waste system is measured as a percentage, with the numerator as the amount of waste processed by the system and the denominator the total capacity of the waste system.

As calculated in Chapter 3, there is 130.54 tons of waste generated in Muzaffarnagar daily which is collected by A2Z. We will consider the minimum cost objective and examine the trade offs between these competing goals of minimum cost, minimum GHG emissions and maximum social impact. We also consider two scenarios: when there is 0% segregation versus when there is 100% segregation in the city.

### 5.5.3 Segregation scenarios

#### 0% segregation

When there is 0% segregation in the city, none of the waste goes to the organic waste processing facilities. As shown in Figure 5-4, the model satisfies the minimum cost objective by constructing another 100 tons per day (TPD) composting plant in Ward 1. The metrics associated with this waste configuration are detailed in Table 5.1.

#### 100% segregation

When there is 100% segregation in the city, there is 50.80 TPD of organic waste generated and available for processing in the city. As shown in Figure 5-5, the model satisfies the minimum cost objective by constructing 45 small scale composting plants of 0.1 TPD capacity each (represented by the red dots) and nine 5 TPD biogas plants (represented by the green dots). The metrics associated with this waste configuration are detailed in Table 5.1.

Table 5.1 below represents the various metrics associated with the minimum cost scenario with both 0% and 100% segregation. We see from the table that as the segregation rate of the city increases, the costs and GHG emissions reduce, while the employment of the waste system increases. The optimization function maximizes net

  
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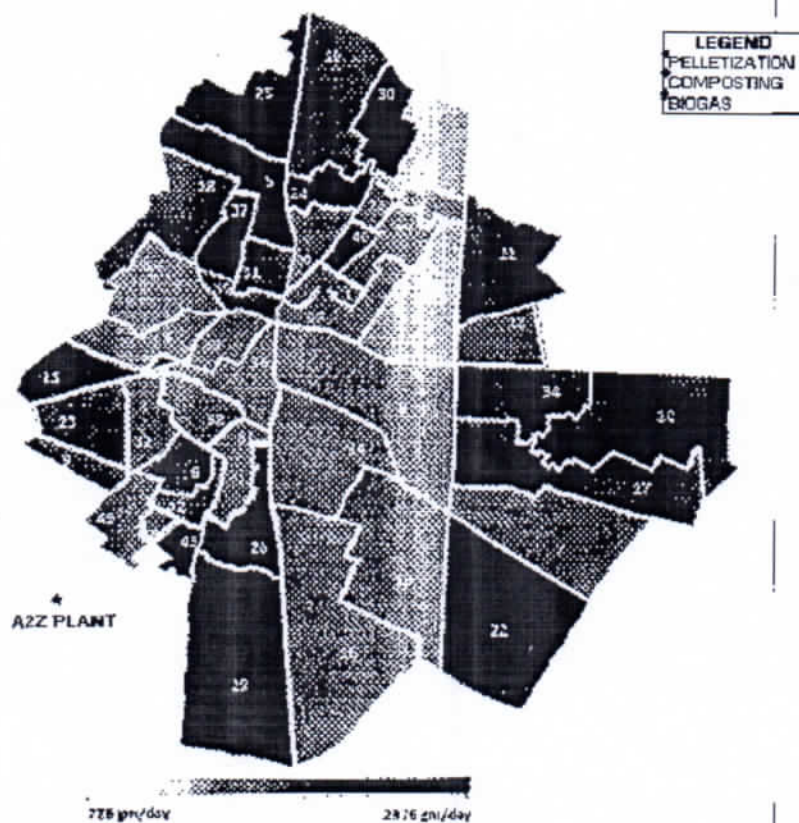


Figure 5-4: Minimum cost scenario - 0% segregation

profit, but since all results in Muzaffarnagar are negative profit, we refer to the net costs.

Table 5.1: Segregation scenarios - summary metrics

Segregation	Net Costs (Rs.)	GHG Emissions (ton-PP <sub>2</sub> -eq)	Labor (people)	Space (²)	Centralization (tons/facility)	Capacity Utilization
0%	34,013,250	71,672	35	640,000	63,203	63.20%
100%	23,830,362	41,419	80	329,000	2,298	84.55%

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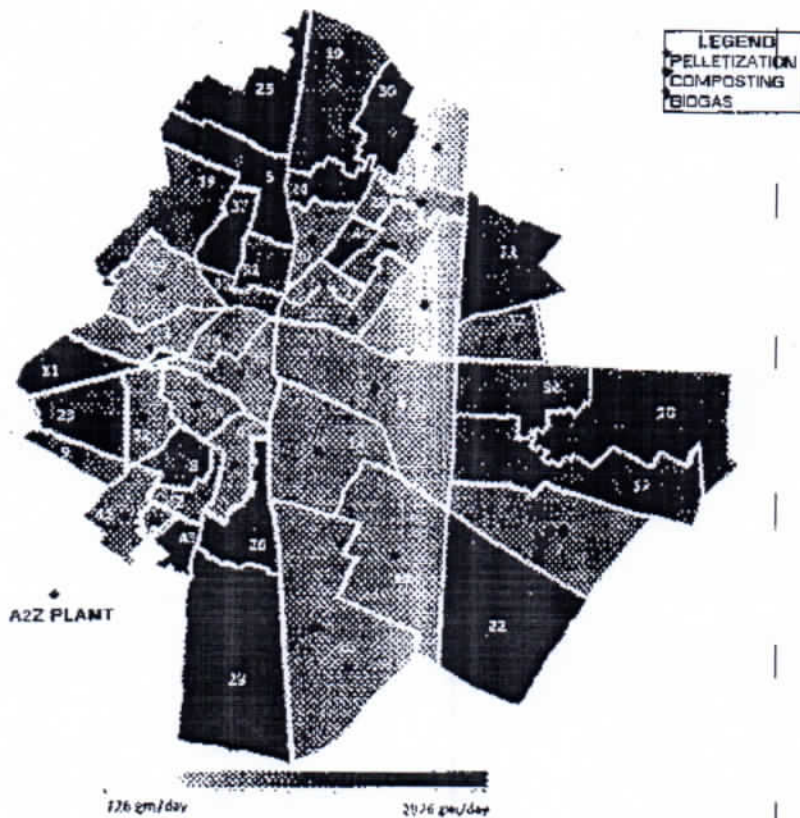


Figure 5-5: Minimum cost scenario - 100% segregation

#### 5.5.4 Trade-off curves

There are trade-offs between the competing goals of the waste system: minimum cost, minimum GHG emissions and maximum employment. Trade-off graphs are used to obtain the optimum system configuration that satisfies competing goals.

#### Cost vs. GHG

The minimum cost and minimum GHG emissions for the 0% segregation scenario are the same waste system configuration. We consider here the trade-off between cost and GHG emissions in the case of 100% segregation.

As shown in Figure 5-6 below, a trade-off curve between cost and GHG emissions can be constructed by keeping minimum cost as the objective function and increasing

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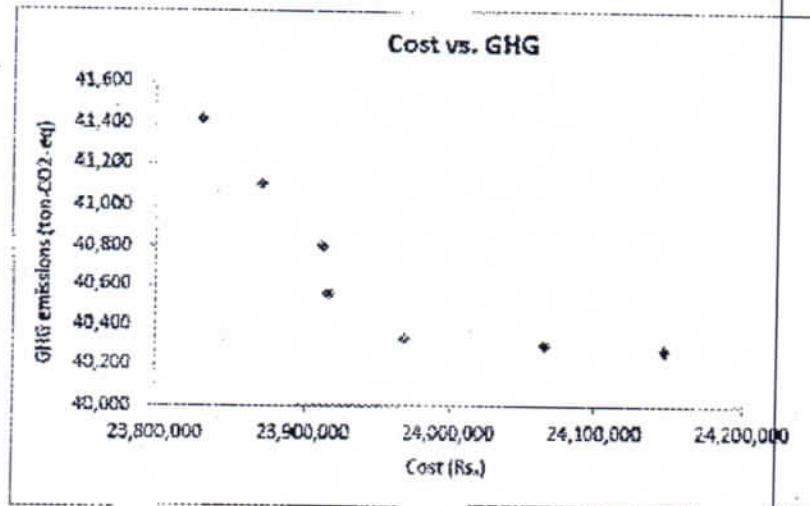


Figure 5-6: Cost vs. GHG emissions trade-off (100% segregation)

the constraint on GHG emissions. A compromise solution is around the turning point, which is at the coordinates (Rs.23,916,769, 40,563 ton-CO<sub>2</sub>-eq).

### GHG vs. Labor

Using the metrics obtained from the cost vs. GHG emissions trade-off curve, we can construct the GHG emissions vs. labor trade-off curve.

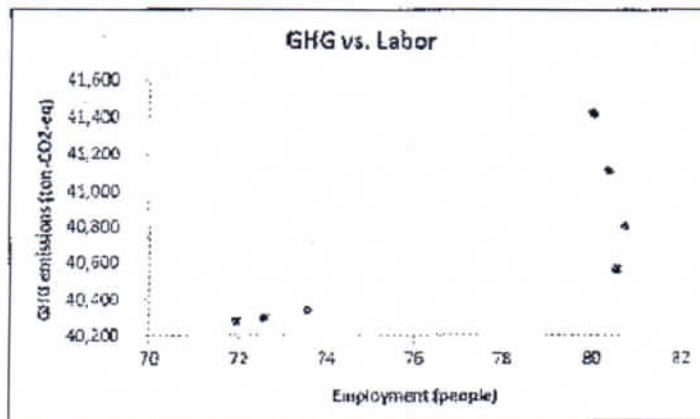


Figure 5-7: GHG emissions vs. labor trade-off (100% segregation)

As shown in the trade-off curve in Figure 5-7 above, there is a large increase in

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employment indicated by the gap in the curve. A compromise solution is at the coordinates (81 people, 40,563 ton-□□<sub>2</sub>-eq). It is at this configuration where the waste system shifts from having 45 small scale 0.1 TPD composting plants to more biogas plants of 2 and 5 TPD capacity. The biogas plants increase employment by 7 people for an increase in 225 ton-□□<sub>2</sub>-eq.

### Cost vs. Labor

As shown in Figure 5-8 below, a trade-off curve between cost and labor/employment can be constructed by keeping minimum cost as the objective function and increasing the constraint on people employed. A compromise solution is around the turning point, which is at the coordinates (Rs.30,946,155, 125 people). At this point, the system configuration changes from predominately small scale composting and biogas plants to an addition of pelletization plants which require more labor, to handle the organic waste in the system.

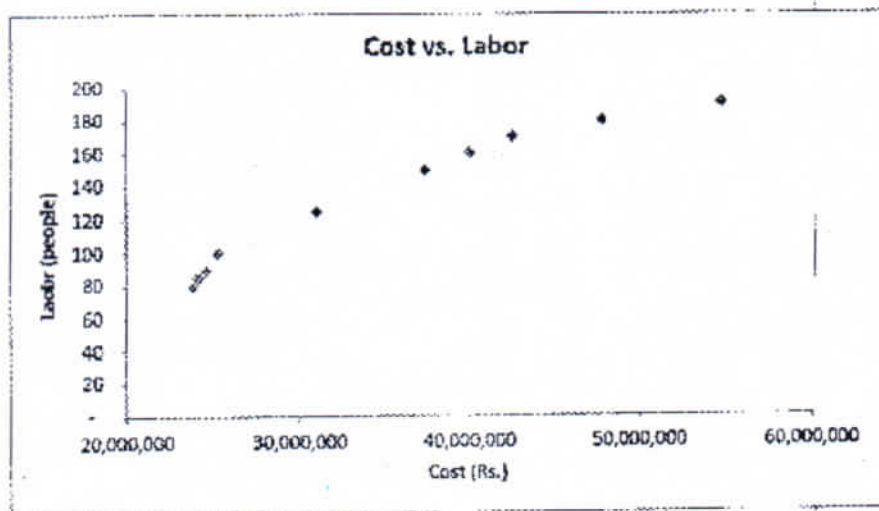


Figure 5-8: Cost vs. labor trade-off (100% segregation)

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### Cost vs. GHG isoquants

The cost vs. GHG emissions can be examined for different labor constraint ranges. The isoquants have been examined for four labor ranges: 75-80 people, 80-85 people, 85-90 people and 90-95 people. As seen in Figure 5-9 below, as the labor constraint range increases, the costs increase as well, though the GHG emissions are the same.

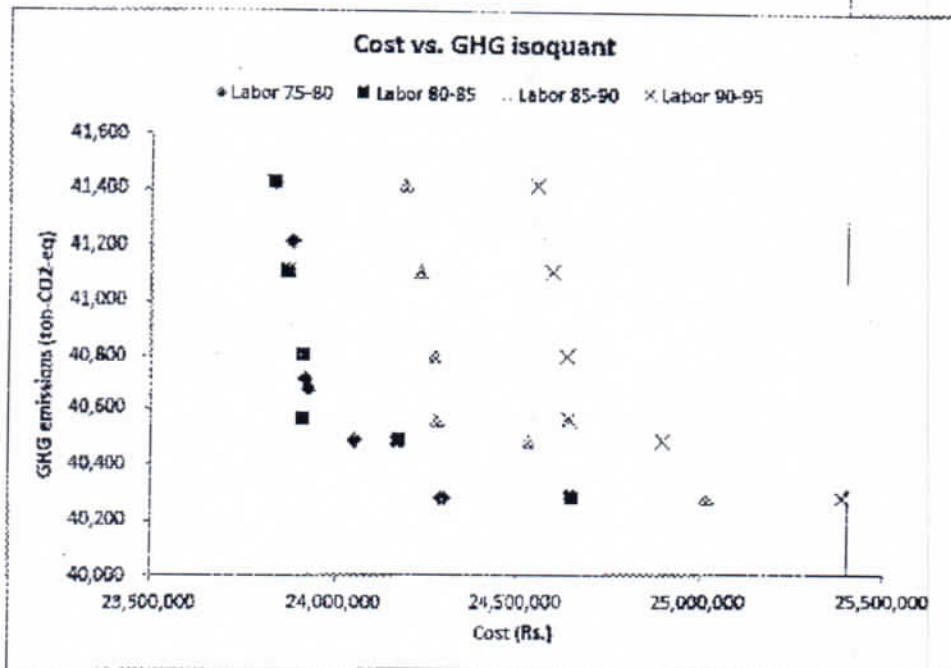


Figure 5-9: Cost vs. GHG isoquants

We can see from the trade-off curves that the labor curves for 75-80 people (represented by blue diamonds) and 80-85 people (represented by red squares) overlap. The difference in costs between the two labor scenarios is negligible with increased employment and at a similar level of GHG emissions. In case of the 85-90 people labor curve and 90-95 people labor curve, we see that costs increase as employment increases, with the same level of GHG emissions.

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### 5.5.5 Level of segregation scenario

As mentioned earlier in Chapter 3, there is no segregation of waste at the source in Muzaffarnagar. The waste is collected unsegregated and separation is done mechanically through a series of filters at the composting plant. If a city-wide segregation policy mandating separation of organic waste at the source for households, bulk generators and commercial establishments, the cost of the waste system would differ. In Figure 5-10 below, we examine how the cost of the waste system differs depending on the level of segregation in the city. The level of segregation is defined as the percentage of organic waste that is sorted separately out of the total available organic waste. The assumptions while calculating the costs of segregating waste is mentioned previously in section 5.4.4.

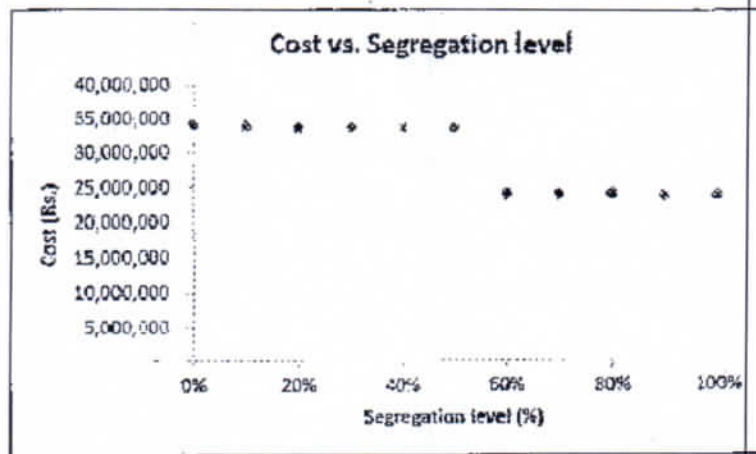


Figure 5-10: Cost vs. level of segregation

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At a city-wide level of segregation of 60%, the costs of the waste system reduce by nearly Rs. 9.5 million. This is because when the system has a segregation level of less than 60%, the minimum cost configuration occurs with a 100 TPD large scale composting plant, as shown in Figure 5-11.

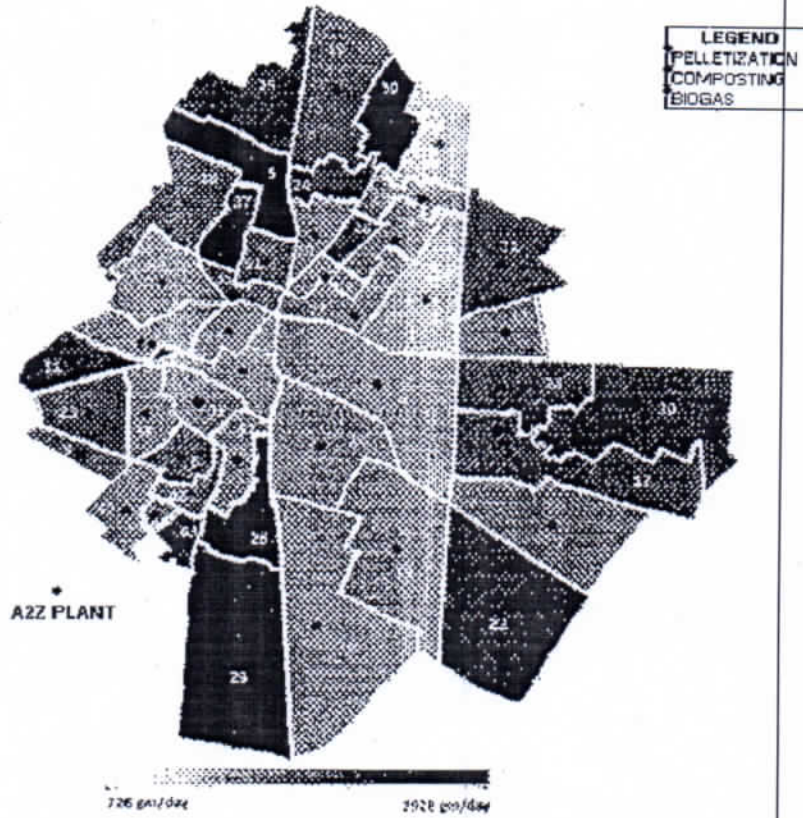


Figure 5-11: Waste configuration at 50% segregation level

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Once the level of segregation reaches 60%, the minimum cost configuration shifts to a system with distributed small scale composting plants, as shown in Figure 5-12 below.

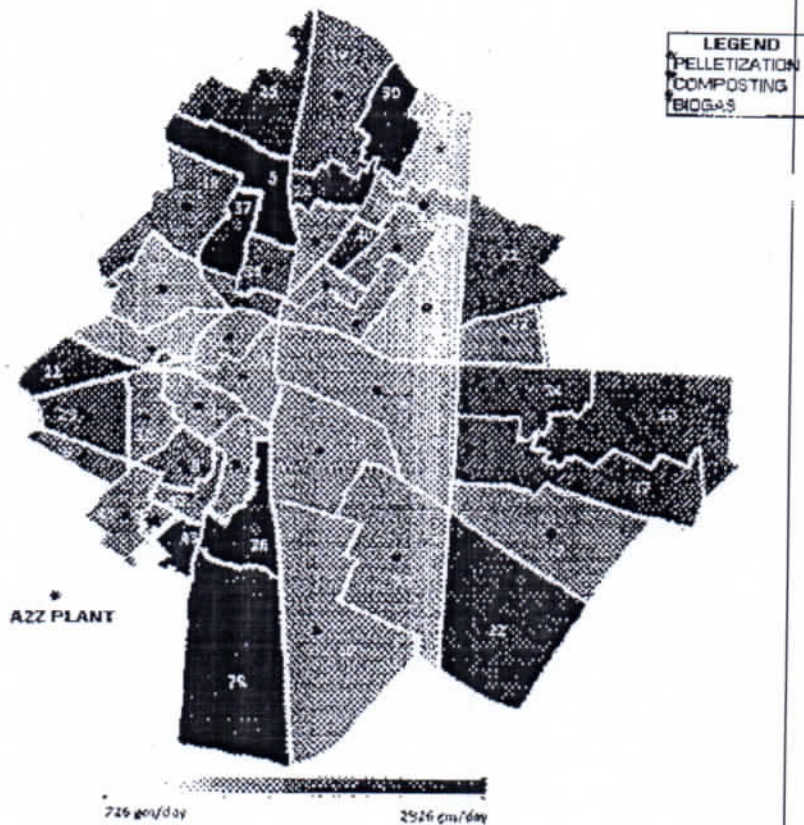


Figure 5-12: Waste configuration at 60% segregation level

### 5.5.6 Future change in population scenario

Currently the population of Muzaffarnagar is 401,443 people, with a historical annual growth rate of 1.5%. The waste system needs to meet the needs of the growing population. We have considered how the change in population relative to the 2017 population affects the waste generated and configuration of the waste system in Muzaffarnagar. The population year corresponding to the population change in percentage is given in Table 5.2 below.

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Table 5.2: Change in waste generation with population


Population change relative to 2017 (%)	Population (people)	Year	Waste Generated (TPD)
100%	401,443	2017	126.41
110%	441,588	2024	139.05
120%	481,732	2029	151.69
130%	521,877	2035	164.33
140%	562,021	2040	176.97
150%	602,165	2045	189.61
160%	642,310	2049	202.25
170%	682,454	2053	214.89
180%	722,598	2057	227.53
190%	762,743	2061	240.17
200%	802,887	2065	252.81

In Figure 5-13, we have examined how the cost/person and capacity utilization of the waste system change when the population level changes relative to the 2017 population. The cost/person is represented by the blue line and the capacity utilization of the waste system is represented by the red line. The number of facilities employed in the system is represented by the number and letter F above the capacity utilization line. At the 130% population relative to 2017 population (corresponding to year 2035), the capacity utilization of the waste system reaches 100%. The configuration of the system at the 130% population level is given in Figure 5-14 below. At the 130% population level, the system consists of 45 small scale 0.1 TPD composting plants and twelve 5 TPD biogas plants.

At the 140% population level (corresponding to year 2040), the waste system drops to 59% capacity utilization and the configuration of the system is shown in Figure 5-15 below. At the 140% population level, the system consists of two 100 TPD composting plants and one 100 TPD biogas plant and the system moves towards a more centralized waste configuration.

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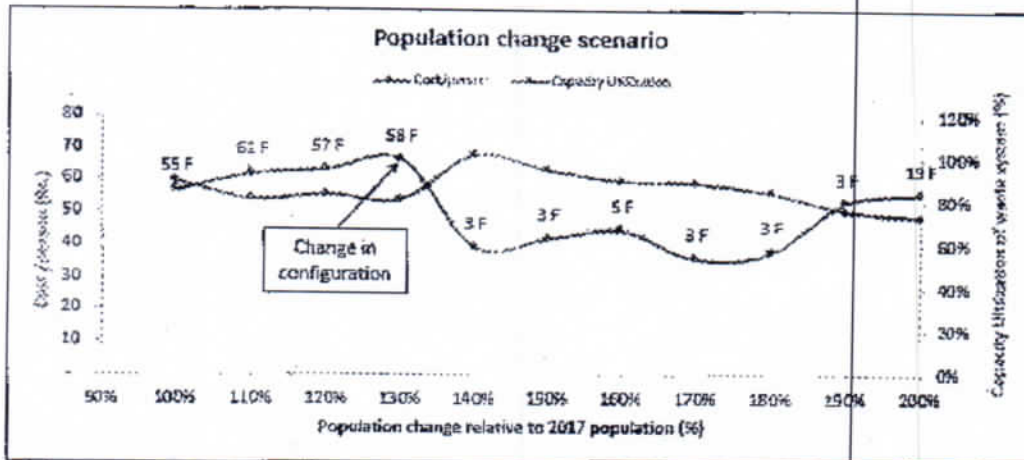


Figure 5-13: Population change scenario

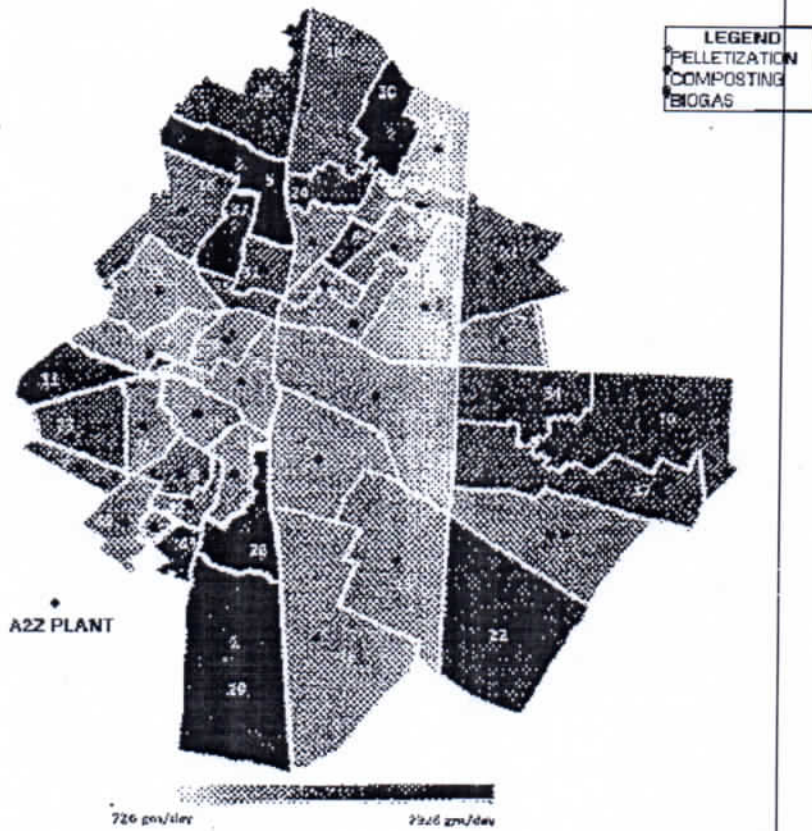


Figure 5-14: Waste system configuration at 130% population level

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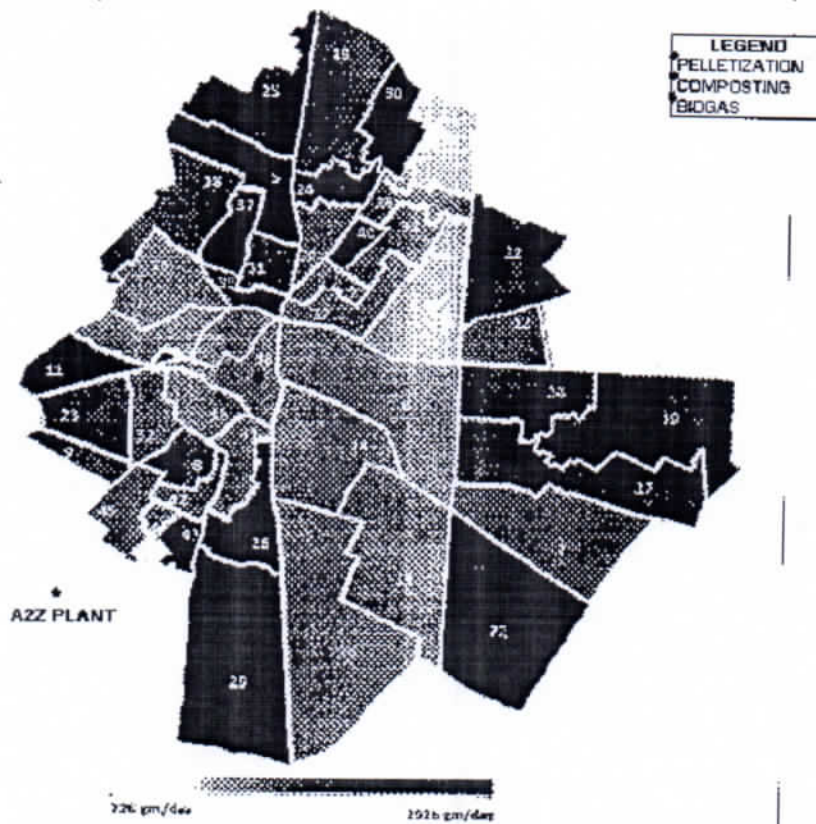


Figure 5-15: Waste system configuration at 140% population level

### 5.5.7 Future change in income level scenario

As indicated in Chapter 3, 59% of the population of Muzaffarnagar is classified as upper income and 41% of the population is classified as lower income. The per capita waste generation of the lower income group is 132 grams/person and the upper income group is 201 grams/person, as calculated from the waste audits. The World Bank estimates that over the five year period of 2004-05 and 2009-10, 11% of the poor and vulnerable population moved into the middle class (World Bank Group, 2015). As the income groups are not clearly defined in Muzaffarnagar, we will assume that over a 5 year period, there is an 11% shift from the lower income group to the upper income group. We will consider two future scenarios, one with a ten year time horizon (2027) and the other with a twenty-five year time horizon (2042).

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### Ten year time horizon scenario

Assuming an annual growth rate of 1.5% and a 11% shift in income level (we will assume that 11% stays constant as the shift in income level, instead of linearly increasing over time), the waste generation increases to 164.07 TPD instead of 157.28 TPD without any income level shift. The configuration, as shown in Figure 5-16 below, consists of two 100 TPD composting plants, forty-three 0.1 TPD composting plants and ten 5 TPD biogas plants. There is no change in configuration from the no income level shift scenario.

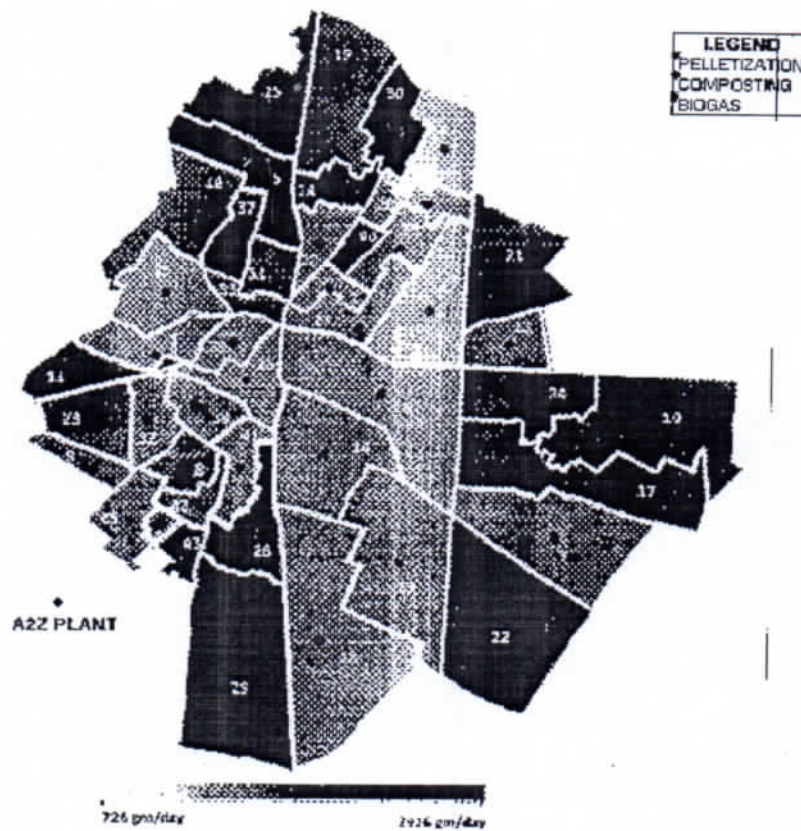


Figure 5-16: Waste system configuration in 2027

Table 5.3 shows the comparison between the two scenarios for a 1.5% yearly growth in population; when there is no income shift versus when there is an overall 11% income shift over the ten year time horizon. There is no significant difference in

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employment, space or capacity utilization between the two scenarios. There is an increase in costs and GHG emissions in the 11% income shift scenario.

Table 5.3: Income shift scenarios - Ten year time horizon

Income Shift	Net Costs (Rs.)	GHG Emissions (ton- $\square$ $\square$ $\square$ -eq)	Labor (people)	Space ( $\square$ )	Centralization (tons/facility)	Capacity Utilization
None	36,821,145	55,941	92	649,300	2,860	61.85%
11%	37,598,697	59,686	94	649,500	2,878	64.47%

#### Twenty-five year time horizon scenario

Assuming an annual growth rate of 1.5% and a 11% shift in income level (we will assume that 11% stays constant as the shift in income level, instead of linearly increasing over time), the waste generation increases to 205.13 TPD instead of 196.63 TPD without any income level shift. The configuration, as shown in Figure 5-17 below, consists of two 100 TPD composting plants and one 100 TPD biogas plant. There is no change in configuration from the no income level shift scenario.

Table 5.4 shows the comparison between the two scenarios for a 1.5% yearly growth in population: when there is no income shift versus when there is an overall 11% income shift over the twenty five year time horizon. There is no significant difference in employment, space or capacity utilization between the two scenarios. There is an increase in costs and GHG emissions in the 11% income shift scenario.

Table 5.4: Income shift scenarios - Twenty five year time horizon

Income Shift	Net Costs (Rs.)	GHG Emissions (ton- $\square$ $\square$ $\square$ -eq)	Labor (people)	Space ( $\square$ )	Centralization (tons/facility)	Capacity Utilization
None	41,197,757	69,527	52	641,000	65,544	65.54%
11%	41,929,441	73,795	54	641,000	68,376	68.38%

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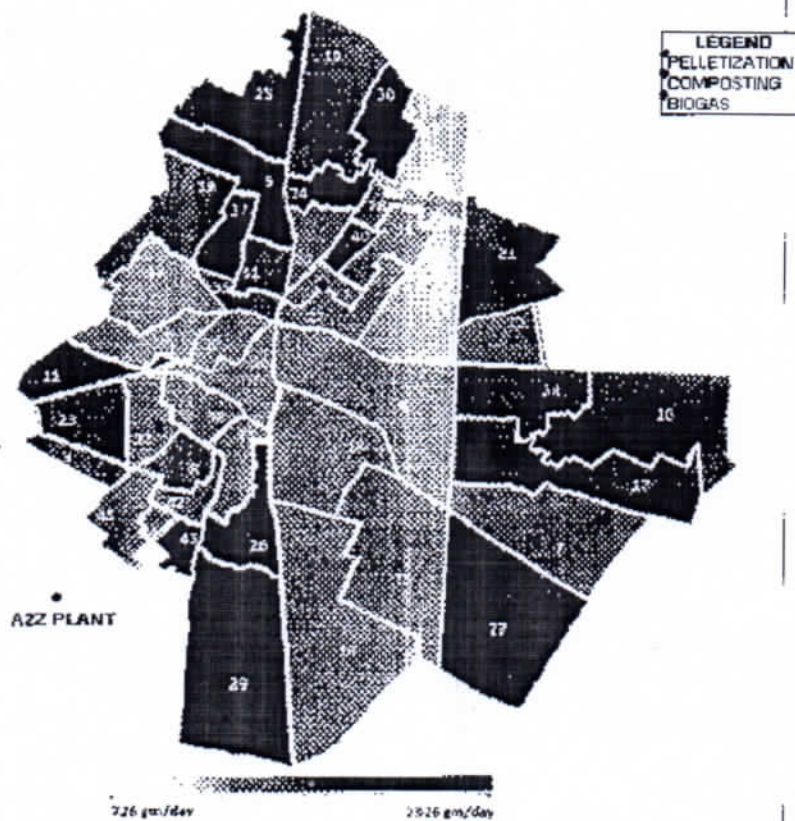


Figure 5-17: Waste system configuration in 2042

## 5.6 Summary

The decision support tool is applied to the city of Muzaffarnagar to evaluate the economic, environmental and social impact of different technology configurations at varying scales and levels of segregation. The tool is used to find the minimum cost waste configuration that considers both GHG emissions and employment, by constructing trade-off graphs between competing goals. A compromise solution that satisfies competing goals is obtained at the turning point of the trade-off curves.

As seen from the decision support tool, as the segregation rate of the city increases the costs and GHG emissions reduce, while the employment of the waste system increases. The level of centralization of the system reduces as the level of segregation of waste increases. The waste system needs to build capacity as the waste generation

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of the city increases due to future population growth and upward income mobility. As the segregation rate increases, distributed waste systems should be constructed in order to meet the growing waste generation.

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## Chapter 6

### Conclusions and recommendations

This thesis aimed to help Indian cities plan their waste management systems by answering the following research questions:

1. What capacities of processing plants, technologies and system configuration make the most sense to deploy, considering multiple constraints and metrics such as cost, environmental impact, space constraints, social impact, etc.?
2. In case of a decentralized waste system, what are the optimal locations of the processing centers within city limits?
3. How can source segregation of household waste be increased?

We considered the city of Muzaffarnagar in order to characterize, model and test our DSS and segregation policies. We considered Muzaffarnagar as a representative Indian city and the results obtained in Muzaffarnagar are applicable to other mid-sized cities in India. We will discuss our recommendations for policy and technologies in Muzaffarnagar. Finally, we will conclude with recommendations for future work.

#### 6.1 Methodological contributions

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1. **Decision support tool considers cost, environmental emissions and employment of the waste system:** The decision support tool can be used

  
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to find the minimum cost waste configuration that considers both environmental GHG emissions and employment, by constructing trade-off graphs between competing goals. A compromise solution that satisfies competing goals is obtained at the turning point of the trade-off curves.

2. **Methodology to increase organic waste segregation rate:** Our segregation pilot shows that the social incentive mechanism of giving weekly feedback to households on their waste generation and separation relative to their peers increases their segregation rate.

## 6.2 Conclusions

Below are the key findings that are presented in this thesis.

1. **Indian households have high organic waste composition:** The waste audits showed that household waste consisted of 64% organic waste. The high organic content of household waste can be utilized effectively in organic waste processing technologies, if the organic waste is separated from the general waste stream.
2. **Waste generation increases with income level:** The per capita waste generation in Muzaffarnagar is 132 grams/person for the lower income group and 201 grams/person for the upper income group. The upper income group generates 1.5 times the lower income group. The waste system has to build capacity in order to process future increase in waste volumes due to growth in population as well as upward income mobility.
3. **Social incentives increase segregation rate:** Households can be encouraged to segregate their organic waste by using social incentives and reinforcement. Households that were given weekly feedback on their waste generation and segregation rate compared to their neighbors, increased their segregation rate by nearly twice than those households that were given no feedback.

  
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4. **Increase in segregation rate reduces costs:** We see from the decision support tool that as the segregation rate of the city increases the costs and GHG emissions reduce, while the employment of the waste system increases.
5. **Increase in segregation rate reduces the level of centralization of the waste system:** The level of centralization of the system reduces as the level of segregation of waste increases, that is, the system moves towards smaller scale processing plants instead of large scale centralized plants.
6. **Future growth scenarios can be met by distributed waste systems:** The waste system needs to build capacity as the waste generation of the city increases due to future population growth and upward income mobility. As the segregation rate increases, distributed waste systems should be constructed in order to meet the growing waste generation.


### 6.3 Recommendations for Muzaffarnagar

The following are the recommendations for changes to be made to the waste system in Muzaffarnagar:

1. **Increase segregation through policy implementation:** In order to minimize the costs of the waste system with lower GHG emissions and increased employment, the level of segregation in the city should increase from the current 0% level of segregation. This can be implemented in two ways:
  - (a) A bulk generator segregation policy should be implemented in order to mandate that the large amount of waste generated by the bulk generators is segregation and processed efficiently. This policy was drafted by the Mayor of Muzaffarnagar at our recommendation and the text of the policy is included in Appendix E.
  - (b) A city-wide household segregation policy should be enacted in order to encourage households to separate their organic waste. The 2 bin 1 bag

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mechanism should be extended to the rest of the city and A27 should ensure that adequate infrastructure is in place to collect the segregated waste. The social incentive model should be used by providing weekly feedback to increase the segregation rate.


2. **Build distributed waste systems:** Currently the system in Muzaffarnagar is highly centralized with a single 100 TPD composting plant. If the segregation policies are implemented, the separated organic waste will increase making it economically feasible to use smaller scale organic waste technologies. Our recommendation is to build smaller scale composting and biogas plants throughout the city to process the organic waste as the segregation level increases. Since distributed waste systems provide economic, environmental and social benefits, they should be built to meet the future increase in waste generation. The distributed small scale waste systems also provide the advantage of staggering capacity build out in contrast to the large scale processing plants.


## 6.4 Recommendations for future work

There is scope for further work on the development of the decision support tool. Some of the future work recommendations include:

1. The current tool constructed for Muzaffarnagar specifies the locations of the processing plants in order to construct the optimum system configuration. The tool can be made more applicable to other cities in India by modifying the architecture in order to accommodate jurisdictions of arbitrary size.
2. The tool also needs to be able to solve problems that explicitly consider future (uncertain) growth within the jurisdiction, while remaining fast to solve. To realize that, other solution approaches can be tested, most likely involving some two stage approach to limit the solution space.
3. The tool currently considers Euclidean distances while calculating the distances between the sources and destinations of waste. The tool can be made more

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accurate by considering the exact routing distances and traffic conditions by road.


4. The government of India under the Prime Minister Narendra Modi has a vision of developing 100 smart cities under the Smart Cities Mission. These cities would employ ICT (Information and Communication Technology) to monitor the use of electricity, gas, waste, harvesting, oil, transport, water etc, and utilize analytics to give efficient solutions.

(a) The tool could be useful in planning the waste management systems in these cities by catering the tool to different archetypes of jurisdictions in India (for example, high density or low density, higher fraction of middle income or higher fraction of lower income, located near agriculture or away, located near recycling markets or away, etc.).

(b) Discussions with the leadership of the Smart Cities Mission could result in the possibility of the tool being used on a wider scale.

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## Appendices

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## Appendix A: Waste audit worksheet

1. Date
2. Day of the week
3. Area/district being covered
4. Estimated population of the area
5. Did it rain (circle all that apply)?  
Yesterday | Earlier today | Now
6. How wet is the waste?  
Wet | Not wet | A little wet
7. Name of the auditor
8. Names of the waste picker(s)

Item No.	Categories	Weight (Kg)	
<b>ORGANICS</b>			
1	Food scraps		
2	Yard waste		
3	Other biodegradable material		
<b>PAPER</b>			
4	White paper		
5	Newspaper		
6	Other paper		
7	Cardboard		
<b>PLASTIC</b>			
8	Films and sheets		
9	Plastic bags		
10	Styrofoam		

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11	Thick PET bottles		
12	HDPE containers		
13	Other plastic		
<b>MIXED MATERIALS</b>			
14	Tetra Pak		
15	Chip bags and packets		
<b>METAL</b>			
16	Aluminum		
17	Steel		
18	Other metal		
<b>GLASS</b>			
19	Clear		
20	Brown		
21	Green		
22	Broken pieces of glass		
<b>TEXTILES</b>			
23	Textiles		
<b>SANITARY WASTE</b>			
24	Diapers		
25	Sanitary napkins and tampons		
<b>ELECTRONICS</b>			
26	Batteries		

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27	Large non-portable appliances			
28	Computer electronics (cell phones etc.)			
29	Wood			
30	Carpet			
31	Inert material (rocks, sand)			
32	Other Items (broken ceramics, paint)			

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## Appendix B: Demographic questionnaire

### General Information

#### 1. Location & Area Information

- (a) Ward No
- (b) Mohalla
- (c) Address

#### 2. Land Area of House

- (a) 300 – 600 Sq. Ft. (LJG)
- (b) 600 – 1200 Sq. Ft. (MIG)
- (c) 1200 – 2400 Sq. Ft. (HIG)
- (d) Above 2400 Sq. Ft.

### Family Information

#### 1. Family Size

- (a) Below 15 Yrs. of Age
- (b) Between 15 – 25 Yrs. of Age
- (c) Between 25 – 60 Yrs. of Age
- (d) Above 60

#### 2. Earning Members

##### a. Earning Member 1

Profession:

- i. Agriculture
- ii. Service
- iii. Business
- iv. Labor Work
- v. Other (specify)


##### b. Earning Member 2

Profession:

- i. Agriculture

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- ii. Service
- iii. Business
- iv. Labor Work
- v. Other (specify)

c. Family Income

- i. Lower Income Group (up to 1.5 Lakh)
- ii. Lower Middle Income Group (between 1.5 to 3.5 Lakh)
- iii. Upper Middle Income Group (between 3.5 to 8 Lakh)
- iv. Higher Income Group (above 8 Lakh)

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## Appendix C: Kabadiwala questionnaire

### Demographic questions

1. Name
2. Age
3. Do you own a phone/smart phone?

### Business questions

1. Where do you work/which neighborhoods do you collect from?
2. What are your timings?
3. How many households do you collect from daily?
4. Is any overlap with other D2D collectors in the neighborhoods you collect?
5. Do some households not give waste to you? Why?

### Waste profile

1. On average, how much material do you collect during one day?
2. On average, how much value material do you collect daily?
3. Do you know other waste pickers in the city? How many?
4. Who do you sell your material to? Where are they located?
5. How often do you sell your material?

Material	Buy Price (Rs/kg)	Sell Price (Rs/kg)	Kg collected per month
Newspaper			
Cardboard			
Glass/Glass Bottles			
Plastic Bottles			
Aluminum			
PET			
Tin			
Rubber			
Electronics			
Hair			
Metal			
Polythene			

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Paper			
Carpet			
Shoes			
Other			

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## Appendix D: Cost, GHG and employment of technologies

LANDFILL		
	Fixed cost (Rs.)	
Mixed	Variable cost/ton (Rs.)	205,415
Mixed	Revenue/ton (Rs.)	
Segregated	Variable cost/ton (Rs.)	205,415
Segregated	Revenue/ton (Rs.)	0
	GHG (CO <sub>2</sub> -eq/ton)	2172
Mixed	Labor/ton	0.32
Segregated	Labor/ton	0.32
	Space (m <sup>2</sup> )	220,000


BIOGAS						
		0.1b	0.5b	2b	5b	100b
	Fixed cost (Rs.)	74,722	201,811	691,342	1,296,329	17,199,633
Segregated	Variable cost/ton (Rs.)	20,303	20,303	20,303	69,803	69,803
Segregated	Revenue/ton (Rs.)	227,078	227,078	227,078	227,078	227,078
	GHG (CO <sub>2</sub> -eq/ton)	-51	-51	-51	-51	-51
Segregated	Labor/ton	3.00	1.00	1.50	1.00	0.23
	Space (m <sup>2</sup> )	9	50	160	500	1,000


COMPOSTING						
		0.1c	0.2c	2c	100c	200c
	Fixed cost (Rs.)	30,117	134,954	556,255	9,675,603	11,295,603
Mixed	Variable cost/ton (Rs.)	-	-	-	131,629	141,302
Mixed	Revenue/ton (Rs.)	-	-	-	69,300	69,300
Segregated	Variable cost/ton (Rs.)	0	76,022	101,363	164,027	171,353
Segregated	Revenue/ton (Rs.)	237,600	237,600	237,600	237,600	237,600
	GHG (CO <sub>2</sub> -eq/ton)	24	24	24	24	24
Mixed	Labor/ton	-	-	-	0.20	0.15
Segregated	Labor/ton	3.00	2.50	1.05	0.20	0.15
	Space (m <sup>2</sup> )	100	200	2,000	100,000	200,000

PELLETIZATION						
		0.5p	1p	2p	5p	10p
	Fixed cost (Rs.)	478,292	696,082	1,079,185	1,934,048	2,881,035
Segregated	Variable cost/ton (Rs.)	184,800	161,700	297,248	285,698	262,598
Segregated	Revenue/ton (Rs.)	330,000	330,000	330,000	330,000	330,000
	GHG (CO <sub>2</sub> -eq/ton)	-42	-42	-42	-42	-42
Segregated	Labor/ton	4.00	3.00	2.00	1.20	1.00
	Space (m <sup>2</sup> )	47	84	140	279	372

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## Appendix E: Muzaffarnagar bulk generator policy

It is to be informed about user charges in health department of Municipal Corporation, Muzaffarnagar that a company named A2Z has been working for Solid Waste Management. According to an agreement between the Company & the Corporation there was a contract of increase of 5% after 3 years & 5% annually increase each year. According to a demand of tipping fees increase by A2Z company which are accepted by the Government gazette U.P. on 7<sup>th</sup> May, 2011. The user charges have been modified as follows, which approval are expected by the board.

The detail description is as following:


According to the UP Govt., Urban Development Section-7 Govt. Order no. 3680(1)/9-7-2004-129L/02 Lucknow, Dated 12 Oct., 2004, a new guideline has been issued under the block (B) of sub section (2)H(f) of section no. 296, 297 & 298 of Municipal Corporation Act, 1916 has been given-

### Modified By-laws

1. Municipal Corporation means the Municipal Corporation area of Muzaffarnagar.
2. User Charges area stands for the all areas under the Municipal Corporation, Muzaffarnagar & in future all the areas which are included in it will be considered under it.
3. Executive Officer means Executive Officer of Municipal Corporation, Muzaffarnagar.
4. Authorized Officers stands for the Officers of Municipal Corporation, Muzaffarnagar who are authorized for this by the Executive Officer from time to time..
5. User Charges fee is that which will be charged by A2Z door to door trash collection under the area of Municipal Corporation, Muzaffarnagar.
6. User Charges fee will be charged every month according to rule 12 of the Fee By-laws.
7. The user charge will be collected by the authorized agencies. No charges will be taken without receipt. This is Payer's duty to keep the receipt carefully and to be presented on demand of the authorized officers of Municipal Corporation, Muzaffarnagar or authorized agency. The collection will be deposited in the Municipal Corporation Fund the very next day by the collector. It will be checked by the Executive Officer/Authorized Officer or Account Officer from time to time.
8. The user charges will be taken for the collection of trash from the campus of residential/non-residential buildings.
9. After applicable of this By-laws nobody will throw the waste materials on roads/gutters/public places or open spaces.
10. If the user charge is no paid, the Executive Officer or Authorized Officer/ Agency have right to collect the 20 times more charge of payable amount according to this By-laws.
11. According to rule 12 the rates of user charges for living and non living premises will be increased 10 % in two years, the rates can be changed by government from time to time.
12. User charges for the use of Municipal Corporation services (door to door collection)

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Residential	Description	Rate per month (Rs.)
Category A	BPL families and the campus free from house tax	30.00
Category B	The residential units up to 200 meters area	40.00
Category C	The residential units over 200 meters area	50.00
Category D	Housing Societies and multi floor buildings flats	
	Up to 3 BHK	40.00
	More than 3 BHK	50.00
<b>Non Residential</b>		
Category A	Shops up to 200 fit area	50.00
Category B	Shops & Commercial installation more than 200 fit area (Differ from Shopping Complex)	100.00
Category C	Public Schools and Professional Coaching up to 100 students	200.00
	Public Schools and Professional Coaching up to 500 students	300.00
	Public Schools and Professional Coaching more than 500 students	500.00
Category D	Engineering College, Medical College, Management College & Private UG/PG college, Center, Shopping cum Office Complex, Hostels of Private Educational Institutes	500.00
Category E	Central Govt. Offices, UP Govt. Offices, Power Corporations, Telephone Exchanges, PWD, Bank offices, LIC offices etc, Lodges and Guest Houses & Hotel up to 10 rooms, Govt./Semi Govt./Private Hospitals, Cooperative Societies	500.00
Category F	Marriage Home, Malls, Banquet Halls, Clubs, Cinema Halls, Restaurants', Hotel/Guest House more than 10 rooms	1000.00

By using the power given in section 299(1) of Municipalities Act, 1916, the Municipal Corporation orders that it is punishable to disobey any rule of this By-laws, which is 1000.00 conviction for first time and if found regularly to be fined extra Rs. 25 per day from the date of first conviction or from the next day of notice, issued by Executive Officer or Authorized officer of Corporation.

The Chairman had ordered on dated 23.06.2016 to produce the proposal of increasing the user charges in Municipal Corporation area according to the above description before the board for approval.

On the proposal submitted, Sh. Ombir Singh, Hon'ble Member proposed that it should be notified under. Later on it was proposed by Sh. Vivek Garg Hon'ble Member that the details of restaurants under non-residential category F should be described because some restaurants are very big and some are small. So the restaurants of 20 yards covered area should be charged Rs. 200, 40 yards covered area Rs. 400 and more than 40 yards area 1000 rupees will be charged as user charge, which was supported by the present members of House and letter on it was decided unanimously that the proposal is accepted with the above changes.

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## Appendix F: Bulk generator questionnaire

### HOTELS

1. Name and address of the facility
2. Category (Small/Medium/Large)
3. Number of rooms available
4. Number of guests per week
5. Number of guests per annum
6. Waste generated per day

### RESTAURANTS & DHABAS

1. Name and address of the facility
2. Category (Small/Medium/Large)
3. Number of seats available
4. Number of guests per day
5. Number of guests per week
6. Number of functions per week
7. Waste generated per day

### BANQUET HALLS

1. Name and address of the facility
2. Category (Small/Medium/Large)
3. Hall capacity
4. Functions per month
5. Average function strength
6. Average waste generated per function

### CINEMA HALLS

1. Name and address of the facility
2. Category (Small/Medium/Large)
3. Number of seats available
4. Shows per day
5. Number of tickets per day
6. Number of tickets per week
7. Waste generated per day

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